MODULE 1

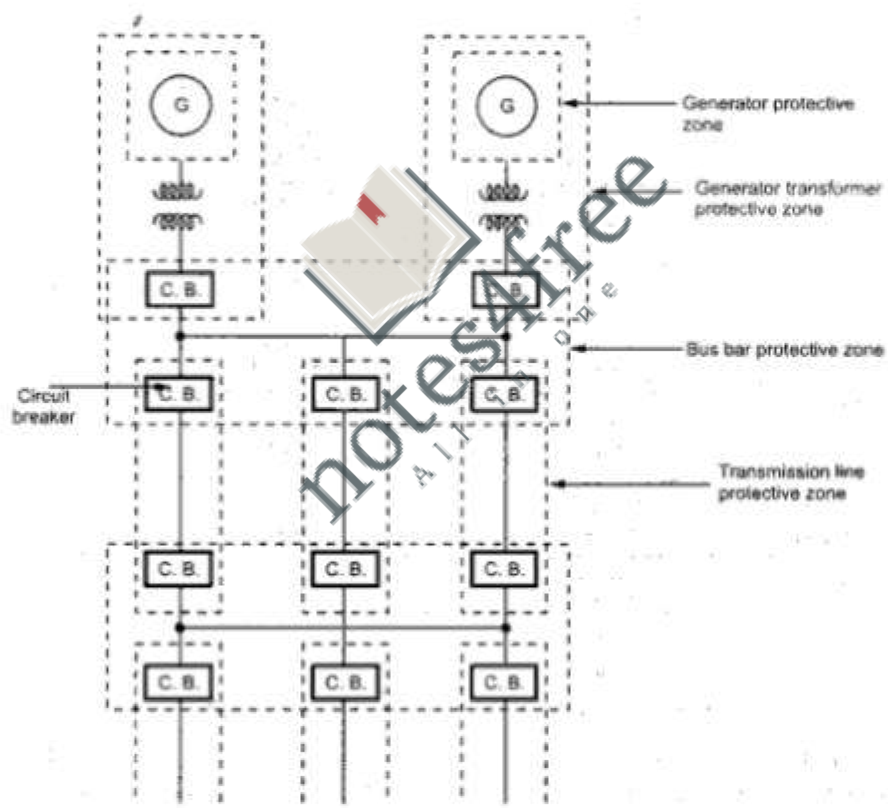
PROTECTIVE RELAYING

- Requirement of Protective Relaying
- Zones of protection, primary and backup protection
- Essential qualities of Protective Relaying
- Classification of Protective Relays

Introduction Protective Relaying is one of the several features of the power system design. Every part of the power system is protected. The factors affecting the choice of protection are type and rating of equipment, location of the equipment, types of funks, abnormal conditions and cost. The protective relaying is used to give an alarm or to cause prompt removal of any element of power system from service when that element behaves abnormally. The abnormal behavior of an element might cause damage or interference within effective operation of rest of the system. The protective relaying minimizes the damage to the equipment and interruptions to the service when electrical failure occurs. Along with some other equipment's the relays help to minimize damage and improve the service.

The relays are compact and self-contained devices which can sense the abnormal conditions. Whenever an abnormal condition exists the relay contacts get closed. This in tum closes the hip circuit of a circuit breaker. The circuit breakers are capable of disconnecting a fatty element, when they are called upon to do so by the relays. Thus entire process includes the operations like fault, operation of relay, opening of a circuit breaker and removal of faulty element. This entire process is automatic and fast, which is possible due to effective protector relaying scheme. The protective relaying scheme includes protective current transformers, voltage transformers, protective relays, time delay relays, auxiliary relays, secondary circuits, top circuits etc. Each component plays its own role, which is very important in the overall operation of the scheme the protective relaying is the team work of all these components. The protective relaying also provides the indication of location and type of the fault.

Protective Zones in a protective relaying scheme, the circuit breakers are placed at the appropriate points such that any element of the entire power system can be disconnected for repairing work, usual operation and maintenance requirements and also under abnormal conditions like short circuits. Thus a protective covering is provided around rich element of the system. A protective zone is the separate zone which Es established around each system element. The significance of such a protective zone I B that any fault occurring within cause the tripping of relays which causes opening of all the circuit breakers within that zone. The various components which are provided with the protective zone are generators, transformers, transmission lines, bus bars, cables, capacitors etc. No part of the system is left unprotected The Fig. shows the various protective zones used in a system



The boundaries of protective zones are decided by the locations of the current transformer. In practice, various protective zones are overlapped. The overlapping of protective zones is done to ensure complete safety of each and every element of the system. The zone which is unprotected is called dead spot. The zones are overlapped and hence there is no chance of existence of a dead spot in a system. For the failures within the region where two adjacent protective zones are overlapped, more circuit breakers get tripped than minimum necessary to disconnect the faulty element If there are no overlaps, then dead spot may exist, means the circuit breakers lying within the zone may not trip even though the fault occurs. This may cause damage to the healthy system. The extent of overlapping of protective zones is relatively small. The probability of the failures in the overlapped regions is very low; consequently the tripping of the too many circuit breakers will be frequent. The figure shows the overlapping of protective zones in primary relaying.

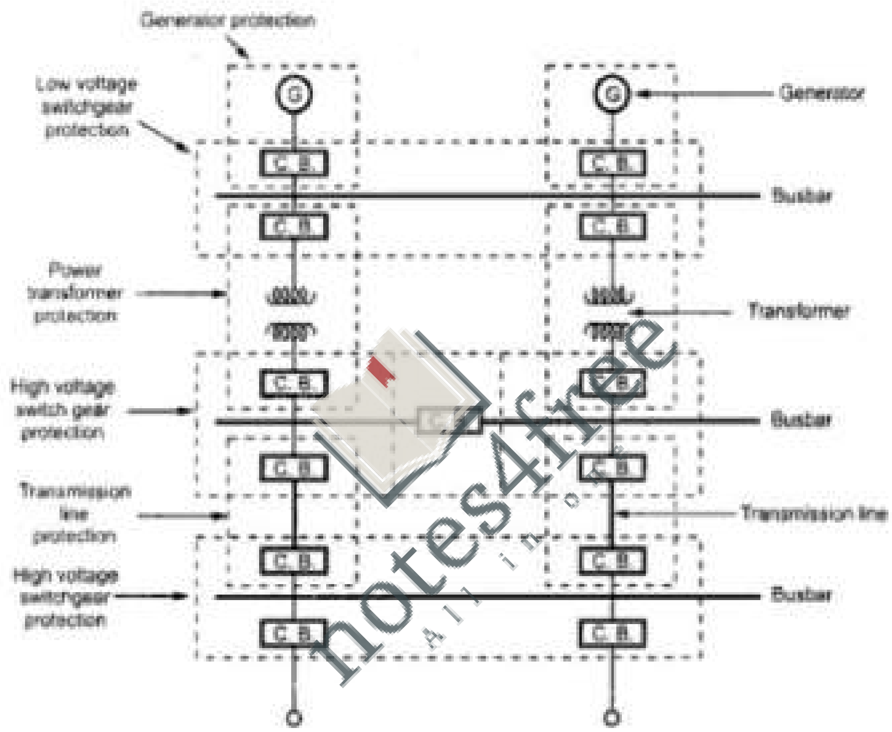


Fig. shows Overlapping zones in primary relaying It can be seen from the Fig. that the circuit breakers are located in the connections to each power system element. This provision makes it possible to disconnect only the faulty element from the system. Occasionally for economy in the number of circuit breakers, a breaker between the two adjacent sections may be omitted but in that Case both the power system are required to be disconnected for the failure in either of the two. Each protective zone has certain protective scheme and each scheme has number of protective systems.

Primary and Backup Protection: The protection provided by the protective relaying equipment can be categorized with two types as 1. Primary protection 2. Backup protection

The primary protection is the first line of defense and is responsible to protect all the power system elements from all the types of faults. The backup protection comes into play only when the primary protection fails.

The backup protection is provided as the main protection can fail due to many reasons like,

1. Failure in circuit breaker

2. Failure in protective relay

3. Failure in tripping circuit

4. Failure in d.c tripping voltage

5. Leas of voltage or current supply to the relay. Thus it the backup protection is absent and the main protection tails then there is a possibility of severe damage to the system. When the primary protection is made inoperative for the maintenance purpose, the backup protection acts like a main protection .The arrangement of back up protective scheme should be such that the failure in main protection should not the failure in bark up protection as well This is satisfied if back up relaying and primary relaying do not have anything common. Hence generally backup protection is located at different stations from the primary protection. Front the cast and economy point of sew. The backup protection is employed only for the protection against short circuit and not for any other abnormal conditions.

Essential Qualities of Protective Relaying:

Essential Qualities of Protective Relaying A protective relaying scheme should has certain important qualities Such an essential qualities of protective relaying are,

1. Reliability

2. Selectivity and Discrimination

3. Speed and Time

4. Sensitivity

5. Stability

6. Adequateness

7. Simplicity and Economy

Reliability A protective relaying should be reliable is its basic quality. It indicates the ability of the relay system to operate under the predetermined conditions. There are various components which go into the operation before a relay operates. Therefore every component and circuit which is involved in the operation of a relay plays an important role. The reliability of a protection system depends on the reliability of various components like circuit breakers, relays, current transformers potential transformers (P.T.si, cables, trip circuits etc. The proper maintenance also plans an important role in improving the reliable operation of the system. The reliability can not be expressed in the mathematical expressions but can be judged from the statistical data. The statically survey and records give good idea about the of the protective system.

Classification of Protective Relays

All the relays consist of one or more elements which gets energized and actuated by the electrical quantities of the circuit. Most of the relays used now a days are On-no-mechanical type which work on the principles of electromagnetic attraction and electromagnetic induction

Electromagnetic Attraction Type Relays The electromagnetic attraction type relays operate on the principle of attraction of an armature by the magnetic force produced by undesirable current or movement of plunger in a solenoid. These relays can be actuated ay a.c. or d.c. quantities. The various types of these relays are,

1 **Solenoid Type:** In this relay, the plunger or iron core moves into a solenoid and the operation of the relay depends on the movement of the plunger.

2. **Attracted Armature Type:** This relay operates on the current setting. When current in the circuit exceeds beyond the limit, the armature gets attracted low the magnetic force produced by the undesirable current the current rating of the circuit in which relay is connected plays an important role in the operation of the relay.

3. Balanced Beam Type: In this relay, the armature is fastened to a balanced beam for normal current, the beam remains horizontal hut when current exceeds, the armature gets attracted and beam gets tilted causing the required operation.

Induction Type Relays These relays work on the principle of an electromagnetic induction. The use of these relays is limited to a.c quantities. The various types of these relays are,

1.Induction Disc Type: In this relay, a metal disc is allowed to rotate between the two electromagnets. The electromagnets are energized by alternating currents. 11w two types of constructions used for this type are shaded pole type and watt-hour meter type.

2 .**Induction Cup Type**: In this relay electromagnets act as a stator and energized by relay coils.

Directional Type Relays These relays work on the direction of current or power in the circuit The various types of these relays are,

1. **Reverse Current Type:** The relay is actuated when the direction of the current is reversed or the phase of the current becomes more than the predetermined value.

2. **Reverse Power Type:** The relay is actuated when the phase displacement between applied voltage and current attains a specified value.

Relays Based on Timing In relays the time between instant of relay operation and instant at which tripping takes place can be controlled. This time is called operation time. Based on this, the time relays are classified as,

Instantaneous Type: In this type no time is lust between operation of Max-and tripping of contacts. No intentional time delay is provided.

Definite Time tag Type: In this type intentionally a definite time lag is provided between operation of relay and tripping of contact.

Inverse Time Lag Type: In this type, the operating time is approximately inversely proportional to the magnitude of the actuating quantity.

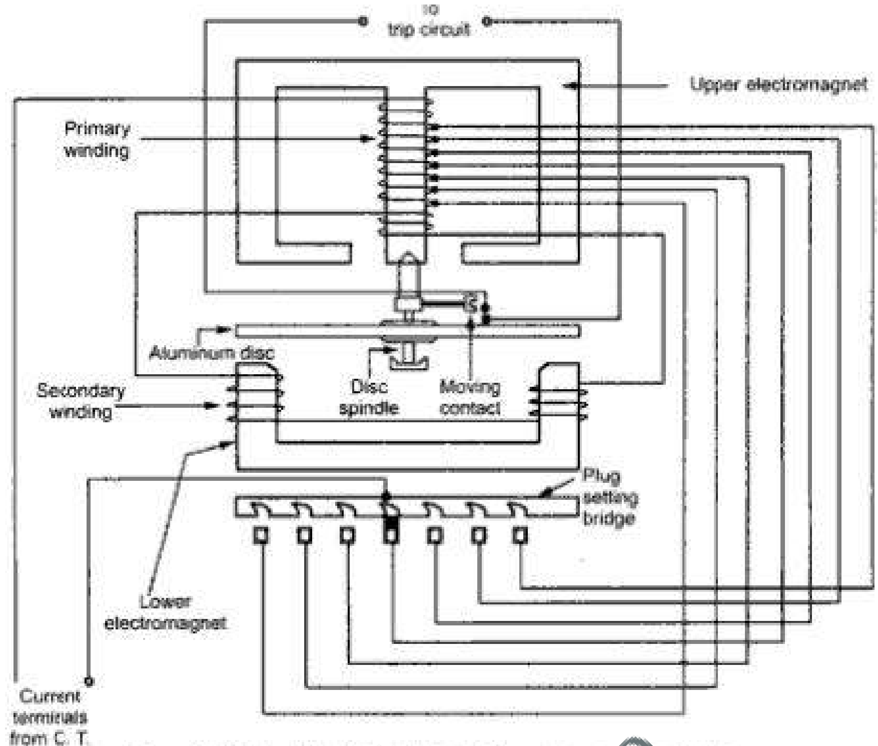
MODULE II

INDUCTION TYPE RELAY

- **Induction type relay:** Non-directional and directional over current relays
- IDMT and Directional characteristics.
- Differential relay – Principle of operation, percentage differential relay
- Bias characteristics, and distance relay – Three stepped distance protection
- Impedance relay, Reactance relay, Mho relay, Buchholz relay
- Negative Sequence relay
- Microprocessor based over current relay – block diagram approach

Non-directional

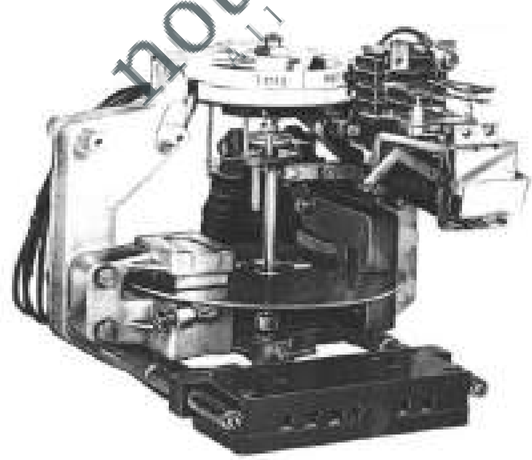
This relay is also called earth leakage induction type relay .The overcurrent relay operates when the current in the circuit exceeds a certain preset value. The induction type non directional overcurrent relay has a construction similar to a watt-hour meter, with slight modification .The fig shows the constructional details of non directional induction type over current relay.

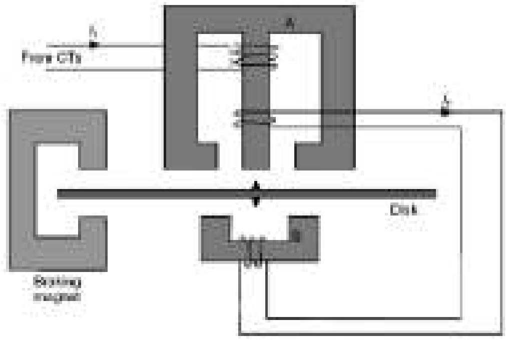


It consists of two electromagnets. The upper is E shaped while the lower is shaped the aluminium disc is free to rotate between the two magnets. The spindle of the disc carries moving contacts and when the disc rotates the moving contacts come in contact with fixed contacts which are the terminals of a trip circuit. The upper magnet has two windings. Primary and secondary. The primary connected to the secondary of C. I. on the be protected. This winding is tapped at intervals. The tapping's are connected to plug setting. With the help of this bridge, number of turns of primary winching can be adjusted. Thus the desired current setting for the relay can be obtained. There are usually seven sections of tapping's to have he overcurrent range from 50% to 20%, in steps of 25%. These values are percentages of the current rating of the relay. Thus a relay current may be MA i.e it car be connected to C.T. with secondary current rating of WA but with 50% setting the relay will start operating at SA. So adjustment of the current setting is made by inserting a pin between spring loaded jaw of the bridge socket. at he proper tap value required. When the pin is withdrawn for the purpose of changing the setting while relay is in service then relay automatically adopts a higher current setting thus secondary of C.T. is not open circuited. So relay remains operative for the fault occurring during the pant-of changing the setting. The secondary winding on the central limb of upper magnet is connected in series with winching on the lower magnet. This winding is energi7ed by the induction from primary By this arrangement: of secondary winding, the leakage duxes of upper and lower magnets are sufficiently displaced in space and time to produce a rotational torque on the aluminium disc. The control torque is provided by the spiral spring. When current exceeds its preset value, disc rotates and moving contacts on spindle make connection with trip circuit terminals. Angle through which the disc rotates is between 0' to 360". The travel of the moving contacts can be adjusted by adjusting angle of rotation of disc. This gives the relay any desired setting which o indicated by a pointer on a time setting dial. The dial is calibrated from 0 to I. This does not give direct operating time but it gives multiplier which can be used along with the time-plug setting multiplier curve to obtain actual operating time of the relay. The time-plug setting multiplier curve is provided by the manufacturer.

Principle of the construction and operation of the electromechanical IDMTL relay

As the name implies, it is a relay monitoring the current, and has inverse characteristics with respect to the currents being monitored. This (electromechanical) relay is without doubt one of the most popular relays used on medium- and low-voltage systems for many years, and modern digital relays' characteristics are still mainly based on the torque characteristic of this type of relay. Hence, it is worthwhile studying the operation of this relay in detail to understand the characteristics adopted in the digital relays.





The above relay can be schematically represented as shown in Figure

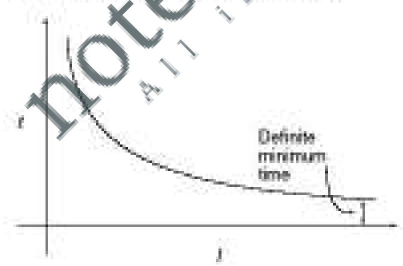
In the secondary winding which in turn sets up a flux in B. Fluxes A and B are out of phase thus producing a torque in the disk causing it to rotate. Now, speed is proportional to braking torque, and is proportional to driving torque. Therefore, speed is proportional to I^2.

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

Hence,

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}} \propto \frac{1}{t}$$

This therefore gives an inverse characteristic (see Figure 9.3).



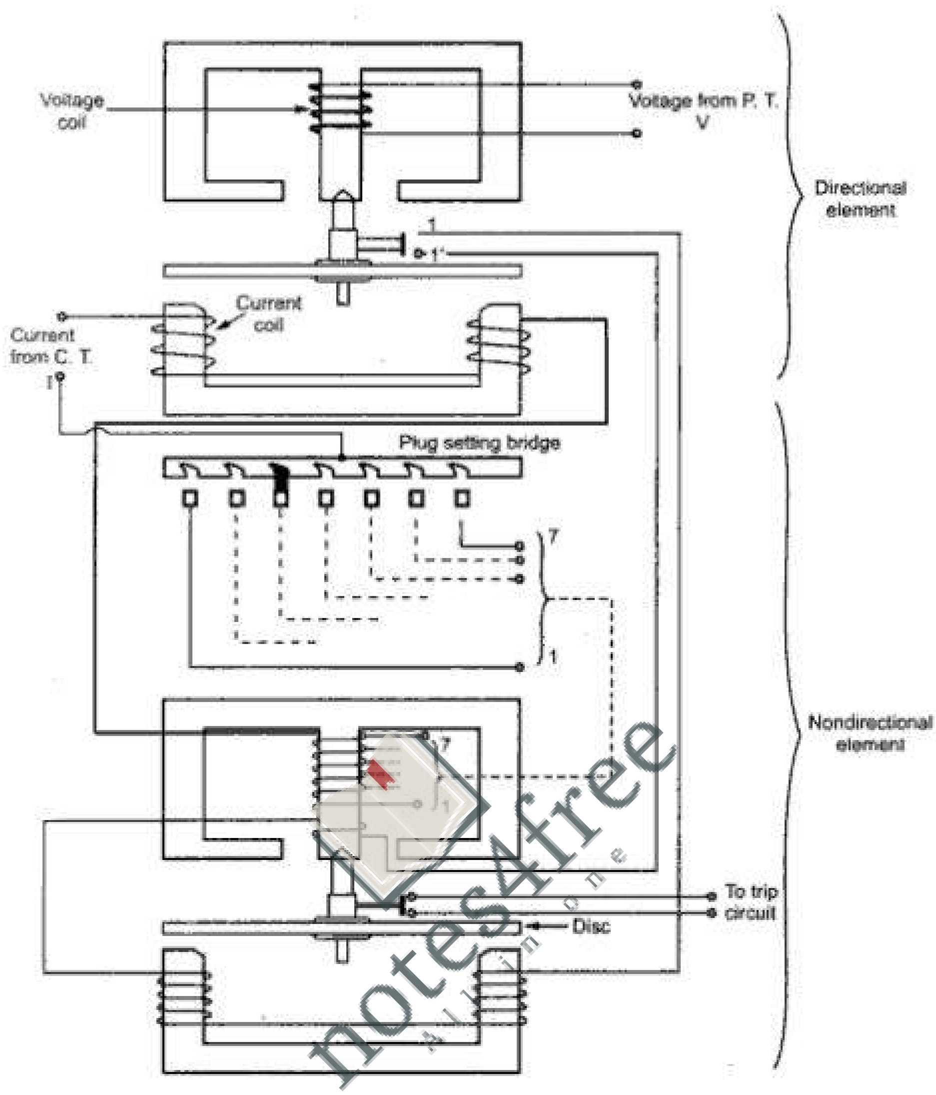
It can be seen that the operating time of an IDMTL relay is inversely proportional to a function of current, i.e. it has a long operating time at low multiples of setting current and a relatively short operating time at high multiples of setting current. The characteristic curve is defined by BS 142 and is shown in below figure. Two adjustments are possible on the relay, namely:

1. **The current pick-up or plug setting:** This adjusts the setting current by means of a plug bridge, which varies the effective turns on the upper electromagnet.

2. **The time multiplier setting:** This adjusts the operating time at a given multiple of setting current, by altering by means of the torsion head, the distance that the disk has to travel before contact is made.

Directional over current relays

Directional Induction Type Overcurrent Relay The directional power relay is not suitable to use as a protective relay under short circuit conditions. This is because under short circuit conditions the voltage frills drastically and such a reduced voltage may not be sufficient to produce the driving torque required for the relay operation. Hence in practice, directional induction type orer current relay is used. This relay operates almost independent of system voltage and power factor. low, directional induction type overcurrent relay uses two relay elements mounted. They elements are I Directional element which is directional power relay 2. Non directional element which is non directional over current relay The schematic arrangement of such a directional relay is shown in the fig:



Directional element: The directional element is nothing but a directional power relay which operates when power in the circuit flows in all particular direction the voltage coil of this element is energized by a system voltage through a potential transformer. The current coil on the lower magnet is energized by the system current through a current transformer .The trip contacts of this relay (1 - V) are connected in series. With the second's y winding of non directional element Non directional element: The current coil of the directional element is connected in series with the primary winding of non directional element. The plug setting bridge is provided in this element to adjust current setting as per the requirement. The trip contacts (I - I') are in series with winding on lower magnet of non directional element. So unless and until trip contacts (1 - V) are closed two the movement of the dice of directional element, the non directional element tannin (the movement of the non directional element is neutralized by the directional element.

Operation Under normal conditions, power flows in the proper direction and hence directional element of the relay is inoperative. Thus the secondary winding on lower magnet of non directional element is open and hence non directional element is also inoperative. When the fault takes place, the current or power in the circuit has a tendency to flow in reverse direction. The current flows through current aid of directional element which produces the flux. The current in the voltage coil produces another flux. The two fluxes interact to produce the torque due to which the disc rotates. As disc rotates, the trip contacts (1 - V) get closed. Note that the design of directional element is such that it is very sensitive and though voltage falls under short circuit, the current coil is responsible to produce sufficient torque to have disc rotation It is so sensitive that it can operate even at 2 % of power flow in reverse direction The current also flows through the primary winding on the upper magnet of non directional element. Thus energizes the winding to produce the flux. This flux induces the e.m.f. in the secondary winding of the non directional element according to induction principle. As the contacts (1 - V) are closed, the secondary winding has a closed path. Hence the induced e.m.f. drives the current though it, producing the flux. The two fluxes interact to product. The driving torque which rotates the disc. Thus the contacts of trip circuit get closed and it opens the circuit breaker to isolate the faulty section. So directional element must operate first to have the operation of the non directional element.

Differential relay – Principle of operation, percentage differential relay

In the overcurrent relays, a current is sensed but such relays are not very sensitive as these relays cannot distinguish between heavy loads and minor fault conditions. In such cases, differential relays can be used A differential relay is defined as the relay that operates when the phasor difference of two or more similar electrical quantities exceeds a predetermined value. Thus a current differential relay operates on the result of comparison between the phase angle and magnitudes of the currents entering and leaving the system to be protected. Under normal conditions, the two currents are equal in phase and magnitude hence relay is inoperative. But under fault conditions, this condition no longer exists. The relay is connected in such a manner that the difference between current entering and curial leaving flows through the operating coil. If this difference current exceeds a preset vane then the relay operates and opens the circuit breaker. Almost any type of relay connected in a certain way can be made to operate as a differential relay

Types of Differential Relays: Types of differential relays are.

I. Current differential relay
II. Biased beam relay o: percentage differential relay
III. Voltage balance differential relay

Current Differential Relay of the differential relays is of current differential type. Consider an over current relay connected in the circuit seas to operate as the current differential relay. This is shown in the Fig 3.1. Two current transformers are used having same ratio are connected on the either side of the section to be protected. The secondaries of current transformers are connected in series, so they carry induced currents in the same direction.

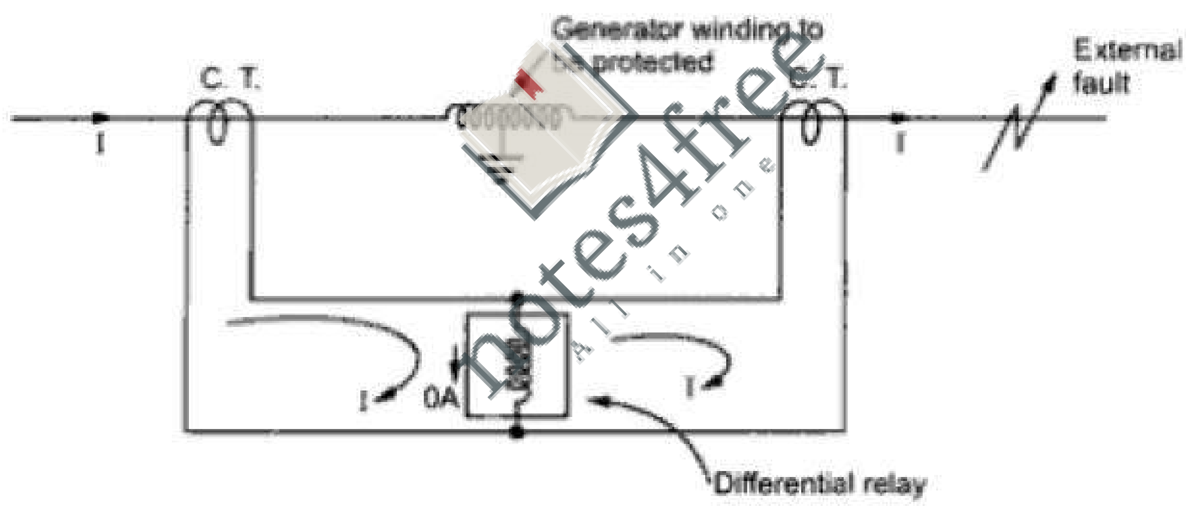


Fig. Current differential relay

This relay suffers front the following disadvantages, I. The current transformers are connected through tables called pilot cables. The impedance of such pilot cables generally CAM'S slight difference between the currents at the ends of the section to be protected A sensitive relay can operate to a very small difference IT the two currents, though there is no fault existing.

Percentage differential relay: As the name suggests, this relay is designed to operate to the differential current In terms of its fractional relation with the actual current flowing through the protected circuit. The Fig. shows the arrangement of a biased beam relay.

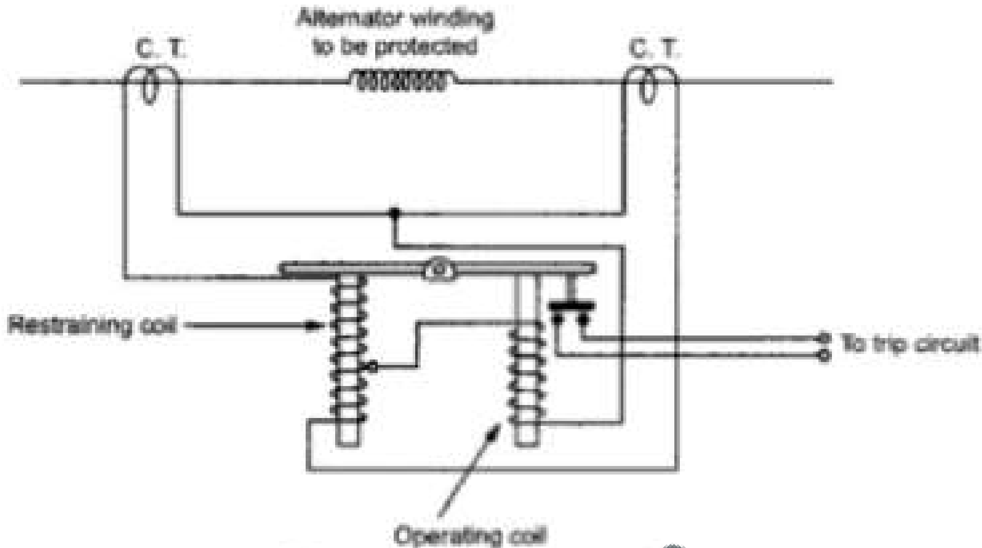


Fig. Biased beam relay

The simple circuit connection of this type of relay is shown in the Fig.

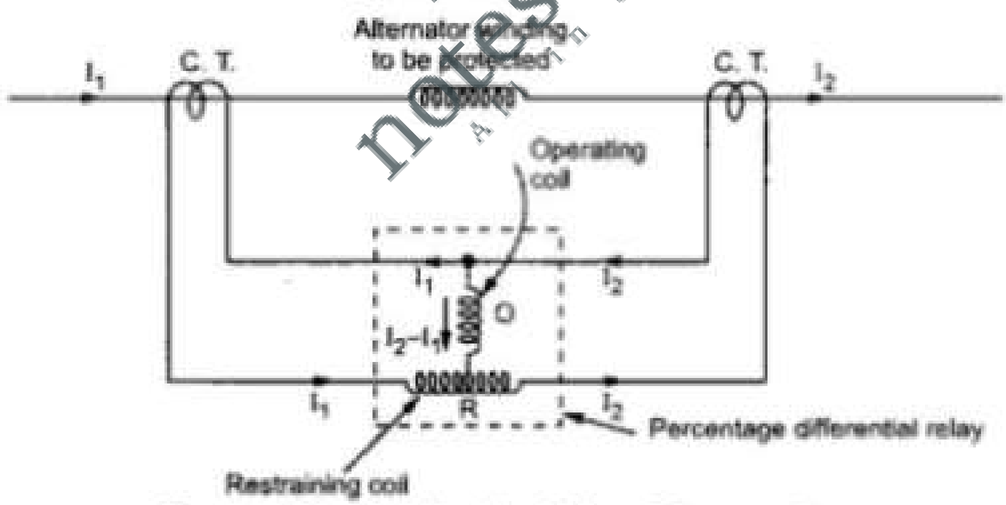


Fig. Simple circuit of biased beam relay

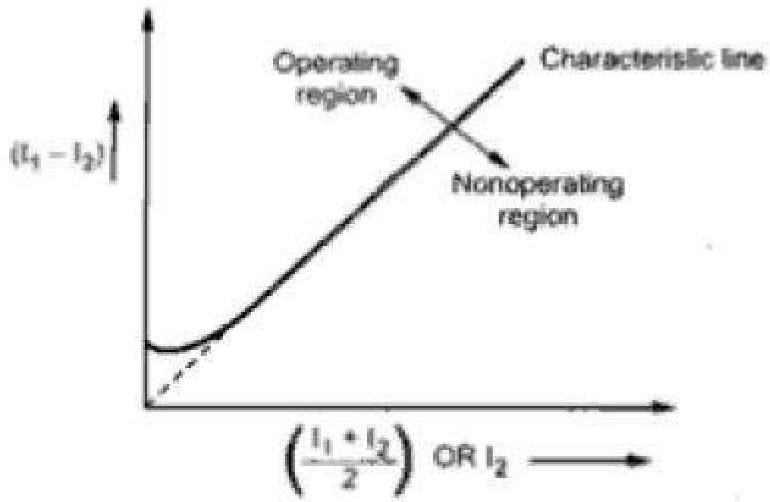


Fig. Operating characteristics

Under normal and through load conditions, the bias force produced due to the restraining coil is greater than the operating force produced by operating coil hence relay is inoperative. When internal fault occurs, the operating force becomes more than the bias force beam moves and the trip contacts are closed to oven then circuit breaker. The operating characteristics of this type of relay are shown in the Fig. It can be seen that except at low currents, the characteristics is. a straight line. Thus the ratio of the differential operating current to the average restraining current is a fixed percentage relay, Hence the relay name is percentage current differential relay relays are called constant slope percentage differential relays: In some relays, the slope of the characteristics increases as the short circuit current increases. Such characteristics are shown in the above graph.

Distance relay

Distance Relays in the relays discussed up till now; the operation of the relays is dependent on the magnitude of the current or voltage of the circuit to be protected. In distance relays the operation k dependent on the ratio of the voltage and current, which is expressed in terms of impedance. Hence basically distance relays are called impedance relays. The impedance is nothing but an electrical measure of distance along a transmission line. The relay operates when the ratio V/I i.e impedance is less than a predetermined value. As the ratio WI affects the performance of these relays, the relays are also called ratio relays. Dependent on the ratio of V and I there are three types of distance relays which are,

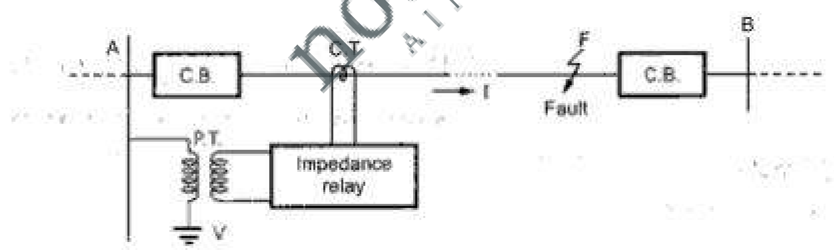
I. Impedance relay which is based on measurement of impedance

2. Reactance relay which is based on measurement of reactance X.

3. Admittance or Mho relay which is based on measurement of component of admittance Y. In short, a distance relay is one whose performance is based on the measurement of impedance, reactance or admittance of lire between the location of relay and the point where fault occurs.

Impedance Relay

The impedance relay works corresponding to the ratio of voltage V and current I of the circuit to be protected. There are two elements in this relay; the one produces a torque proportional to current while the other produces a torque proportional to voltage. The torque produced by the current element is balanced against torque produced by the voltage element. Thus the current element produces operating torque, pickup torque which can be said to the positive torque. The voltage element produces restraining torque, reset torque which can be said to be negative torque. So this relay is voltage restrained overcurrent relay.

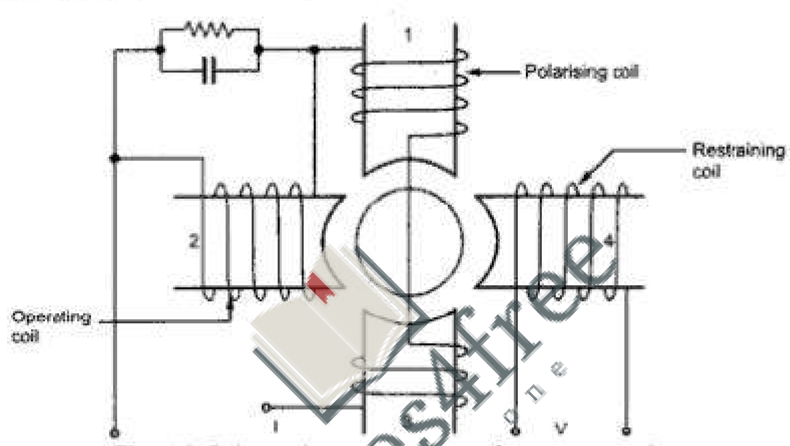


The current element is energized by current though CT while voltage element is energized by voltage through PT* The section Ali of the line n protected under normal conditions, the ratio of voltage V and current I is denoted as which is impedance of line. The relay is inoperative under this condition. When the fault occurs at point F in the protected when then the voltage drops while current increases. Thus the ratio Vin i.e. the impedance reduces drastically. This is the impedance of line between the points at which relay is connected and the point F at which tend so when the impedance reduces than it predetermined value A. it trips and makes the circuit breaker open.

Reactance relay

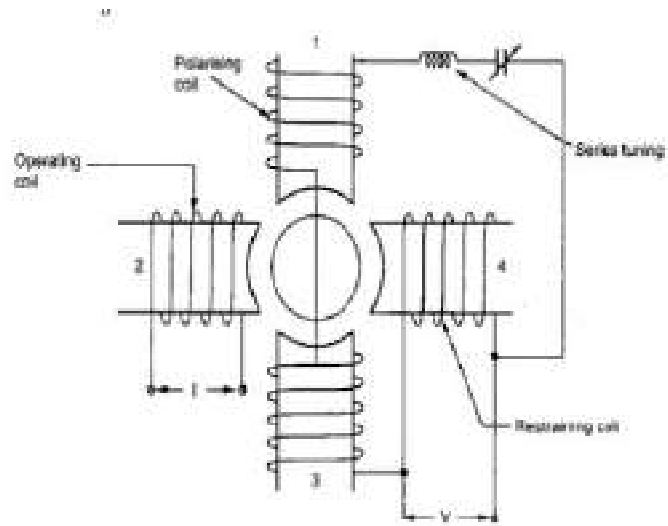
Relay the operating torque b obtained by current while the restraining torque due to a current-voltage directional relay. The overcurrent element develops the positive torque and directional unit produces negative torque. Thus the reactance relay is an overcurrent relay with the directional restraint. The directional element is so designed that the maximum torque angle

Construction



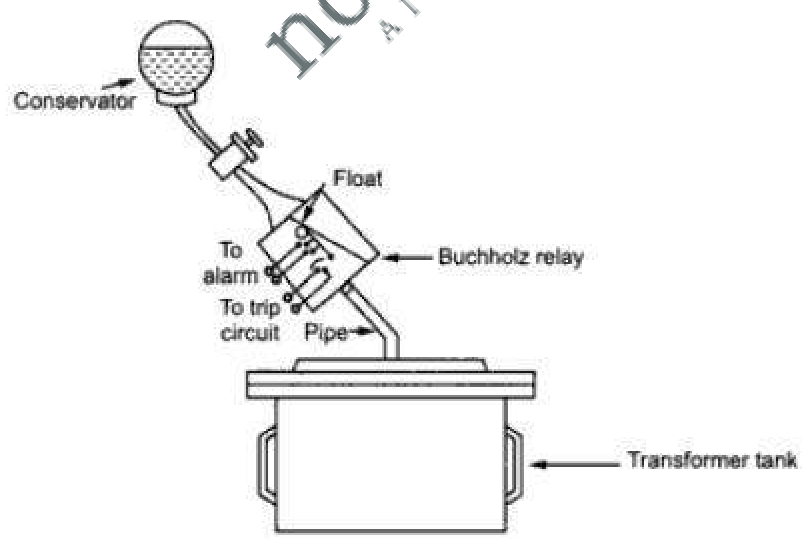
The structure used tor the reactance relay can be of induction cup type. It is a four pole structure. It has operating coil, polarizing coil and a restraining coil. The schematic arrangement of coils for the reactance relay is shown in the Fig. The current I flows from pole 1, through iron core stacking to lower pole 3. The winding on pole 4 is fed from voltage V. 1ow operating torque is produced by interaction of fluxes due to the windings drawing current coils of (produced by poles I. 2 and 3. While the restraining torque is developed due to interaction of fluxes due to the poles 1, 3 and 4). Hence the operating torque is proportional to the square of the current while the restraining torque is proportional to the product of V and I (VI) The desired maximum torque angle is obtained with the help of RC circuit.

Mho relay: In the impedance relay a separate unit is required to make it directional while the same unit can not be used to make a reactance relay with directional feature. The mho relay is made inherently directional by adding a voltage winding called polarizing winding. This relay works on the measurement of admittance Y z 0. This relay is also called angle impedance relay.

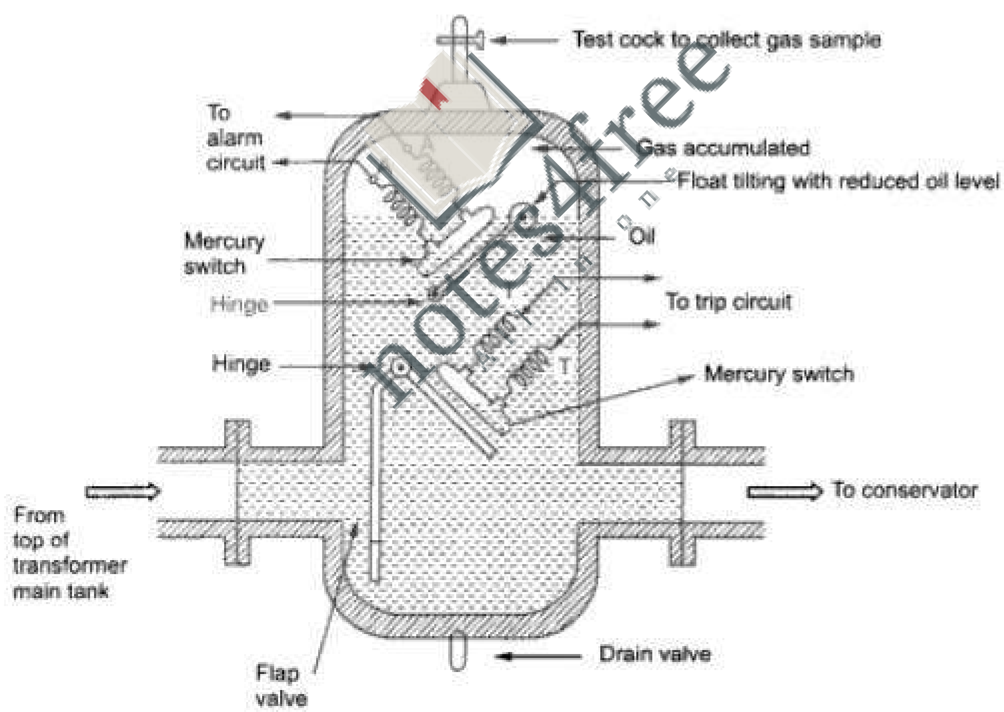


In this relay the operating torque is obtained by V and I element while the restraining torque is obtained by a voltage element. Thus an admittance relay is a voltage restrained directional relay. Thy operating torque is produced by the interaction of the fluxes duo to the windings carried by the poles I, 2 and 3. While the restraining torque is produced by the interaction of the fluxes due to the windings carried by the poles I. 3 and 4. Thus the restraining torque is proportional to the square of the voltage (V2) while the operating torque is proportional to the product of voltage and current (VI). The torque angle is adjusted using series tuning circuit.

Buchholz relay



Operation: There are many types of internal faults such as insulation fault, core heating, bad switch contacts, faulty joints etc. which can occur. When the fault occurs the decomposition of oil in the main tank starts due to which the gases are generated. As mentioned earlier, major component of such gases is hydrogen. The hydrogen tries to rise up towards conservator hut in its path it gets accumulated in the upper part of the Buchholz relay. Through passage of the gas is prevented by the flap valve. When gas gets accumulated in the upper part of housing, the oil level inside the housing falls. Due to which the hollow float tilts and close the contacts of the mercury switch attached to it, this completes the alarm circuit to sound an alarm. Due to this operator knows that there is some incipient fault in the transformer. The transformer is disconnected and the gas sample is tested. The testing results give the indication, what type of fault is started developing in the transformer. Hence transformer can he disconnected before fault grows into a serious one. The alarm circuit does not immediately disconnect the transformer but gives only indication to the operator. This is because some times bubbles in the oil circulating system may operate the alarm



Construction of Buchholz relay

UNIT - 7 & 8

PROTECTION SCHEMES: GENERATOR PROTECTION

- **Protection Schemes: Generator Protection** - Merz price protection, prime mover faults
- Stator and rotor faults,
- Protection against abnormal conditions – unbalanced loading
- Loss of excitation, over speeding.
- **Transformer Protection** - Differential protection
- Differential relay with harmonic restraint, Inter turn faults
- **Induction motor protection** - protection against electrical faults such as phase fault
- ground fault, and abnormal operating conditions such as single phasing
- Phase reversal, over load.

Introduction

The generators used in the power system are the alternators which produce very high a.c voltages the protection of generators is very much complex due to the following reasons:

The generators are very large machines producing, very high voltages and are connected to buabars. Various other equipment's are always associated with the generators. Such equipment's are prime movers, excitation systems, voltage regulators, cooling systems etc. Thus protection of generators must consider the presence of these higher equipment's also.

The generators are very costly, expensive and important factor in a power system. The protection scheme must be such that it should not shut oft the generators as far as possible. The shut oil generators result in a power shortage. All these factors make the design of protection scheme for the generator very much complex.

Generator Faults

The various faults which can occur associated with a generator can be classified as,

1. Stator faults: The faults associated with the stator of the generator

2. Rotor faults: The faults associated with the rotor of the generator.

3. Abnormal running conditions: This includes number of abnormal conditions which may occur in practice, from which the generator must be protected.

Stator Faults

The stator faults mean faults associated with the three phase armature windings of the generator. These faults are mainly due to the insulation failure of the armature windings. The main types of stator faults are.

1. Phase to earth faults

2. Phase to phase faults

3. Inter-turn (involving turns of same phase winding). The most important and common fault is phase to earth fault. The other two are not very common while inter-turn fault is very difficult to detect.

Phase to Earth Faults:

The faults mainly occur in the armature slots. The faults are dangerous and can severe damage to the expensive machine. The fault currents less than 20 A cause negligible burning of core if machine is tripped quickly. But if the fault currents are high, severe burning of stator core can take place. This may lead to the requirement of replacing the laminations which Is very costly and time consuming. So to avoid the damage due to phase to earth faults, a separate, and sensitive earth fault protection is necessary for the generators along with the earthing resistance.

Phase to Phase Faults: The phase to phase faults means short circuit between two phase windings. Such faults are uncommon because the insulation used between the coils of different phases in a slot is large. But once phase to earth fault occurs, due to the over heating phase to phase fault also may occur. This hull is likely to occur at the end connections of the armature windings which are overheating parts outside the slots. Such a fault causes severe arcing with very high temperatures. This may lead to melting of copper and lire if the insulation is not fire resistant.

Stator Inter-Turn Faults: The cols used in the alternators are generally multi tum coils. So short circuit between the turns of One Coil may occur which Is called an inter-turn fault. This fault occurs due to current surges with high value of (L di/do voltage across the turns. But if the coils used are single turn then this fault can not occur. Hence for the large machines of the order of 50 kVA and more, it is a normal practice to use single turn coils. But in some countries, multi tum coils are very commonly used where protection against inter-turn faults is must.

Rotor Faults: The construction of an alternator is generally a field winding as most of the alternators arc of rotating field type. The field winding is made up of number of turns. So the conductor to earth faults and short circuit between the turns of the field winding, are the commonly occurring faults with respect to a rotor. These severe mechanical and thermal stresses, acting on the field winding insulation. The field winding is generally not grounded and hence single line to ground fault does not give any fault current. A second fault to earth will bring circuit the part of the field winding and may there by produce an unsymmetrical field system. Such an unsymmetrical system gives rise to the unbalanced forces on the rotor and results in pressure on the hearings and the shaft distortion, if stub a fault is not cleared vet, early. So it is very much necessary to know the existence of the lust occurrence of the earth fault so that corrective measures can be taken before second pull occurs. The unbalanced loading on the generator is responsible to produce the negative sequence currents. Thee currents produce a rotating magnetic field which rotates in opposite direction to that of rotor magnetic field to this field, there is induced e. m f. in the rotor winding. This causes overheating of the rotor .Rotor earth fault protection and rotor temperature indicators are the essential and arc provided to large rating generators.

Abnormal Running Conditions In practice there are number of situations in which generator is subjected to some abnormal running conditions. The protection must be provided against the abnormal conditions. These abnormal conditions include, I. Overloading 2. Over speeding 3.

Unbalanced loading 4. Over voltage 5. Failure of prime mover (Arc of excitation (Field failure) 7. Cooling system failure

Overloading: Due to the continuous overloading, the overheating of the stator results. This may increase the winding temperature. If this temperature rise exceeds certain limit, the insulation of the winding may get damaged .The degree of overloading decides the effects and temperature the. The protection is generally very high value hence continuous overloads of less value than the setting cannot be sensed by overcurrent protection

Over speeding: In caw of hydraulic generators a sudden loss of load results in over speeding of the generator. This is because the water flow to the turbine cannot be stopped or reduced instantly. Generally a governor is provided to present the over speeding. But it there is any fault in the turbine governor then the dangerous over speeding may take place. Hence it is necessary to supervise the working of turbine governor and rake some corrective measures if there is some fault in the governor.

Unbalanced Loading: The unbalanced loading of the generator results in the circulation of negative sequence currents. These currents produce the rotating magnetic field. This rotating magnetic field rotates at the synchronous speed with respect to rotor. The direction of rotation of this magnetic field is opposite to that of rotor. Hence effectively the relative speed between the two is double the synchronous speed. Thus the e.m.f. gets induced, having double the normal frequency; in the rotor winding .The circulating currents due to the induced e.m.f. are response to overheat the rotor winding as. Rotor stampings. Continuous unbalanced load mote than 10% of the rated load causes tremendous heating which is dominant incase of cylindrical rotor of turbo alternators. The reasons for the unbalanced load conditions arc,

Occurrence of unsymmetrical faults near the generating station. The failure of circuit breaker near the generating station in clearing all the three phony, Negative sequence protection is important to prevent dangerous situations due to negative sequence currents which are because of unbalanced load conditions.

Over voltage: The over voltages ore basically due to the over speeding of generators. Another reason for this the faulty operation of voltage regulators. Not only the internal over voltages are dangerous but atmospheric surge voltages can also reach to the generators. Such atmospheric surge voltages are generated by direct lighting strokes to the aerial lines of high voltage system. Inductively and capacitive, these surges can get transferred to the generator. To protect the generators from surge voltages, the surge arresters and surge capacitors are often used. At the time of re striking across the contacts of circuit breakers, the transient over voltages get generated such surges are called switching surges and can be limited by the uses of modem circuit breakers RC surge suppressors also help in reducing switching surges. Another situation, when the transient over voltages are generated, is when the arcs are pounded. During arcing grounds, the transient voltages having amplitudes five times more than the normal line to neutral peak amplitude are generated Such transient voltages are dangerous and can be reduced by using resistance earthing.

Failure of Prime Mover: The failure of prime mover results in motoring operation of synchronous generator. The generator draws active power from the network and continues to run at synchronous speed as a synchronous motor. This may lead to dangerous mechanical conditions if allowed to persist for more than thirty seconds. The serious overheating of the steam turbine blades may result to prevent this reverse power protection achieved by directional power relays is used.

Loss of Excitation: The loss of excitation or reduced excitation is possible due to the field failure i.e. opening of field winding or due to short circuit in field or due to some fault in exciter system. Such loss of excitation results in loss of synchronism within a second and the. Causes the increase in speed of the generator. Since power input to the machine remains same, the generator starts working as an induction generator, drawing the reactive power from the bus. The machine starts drawing an exciting current from the system. Which is equal to the full load rated value? This leads to the overheating of the stator winding and the rotor body due to induced current' The loss of excitation may also lead to the pole slipping condition which results in the voltage reduction for the output above hail the rated load Loss of excitation should not persist for long and corrective measures disconnection of alternator should be taken immediately. For this a tripping scheme can be used which can trip the generator circuit breaker immediately when there is a field failure.

Cooling System Failure: failure of cooling system also causes severe overheating to rise the temperature above safe limit. This may lead to insulation failure, causing some other faults to occur. The thermocouples or resistance thermometers are used in large machines to sensor the temperature. The corrective measures are taken whenever the temperature exceeds the limit Apart from the above dominant abnormal conditions, some conditions may exist which are fare m practice.

Merz price protection

This is most commonly used protection scheme for the alternator stator windings. The scheme is also called biased differential protection and percentage differential protection. In this method, the currents at the two ends of the protected section are sensed using current transformers. The wires connecting relay coils to the current transformer secondary's arc called pilot wires. Under normal conditions, when there is no fault in the windings, the currents in the pilot wires fed (mm

C.T. secondary's are equal. The differential current is - through the operating cods of the relay as zero. Hence the relay is inoperative and system is said to be balanced. When fault occurs inside the protected section ot the stator windings, the differential current i, - 12 flows through the operating coils of the relay. Due to this current, the relay operates.. This trips the generator circuit breaker to isolate the faulty section. The field is also disconnected and is discharged through suitable impedance.

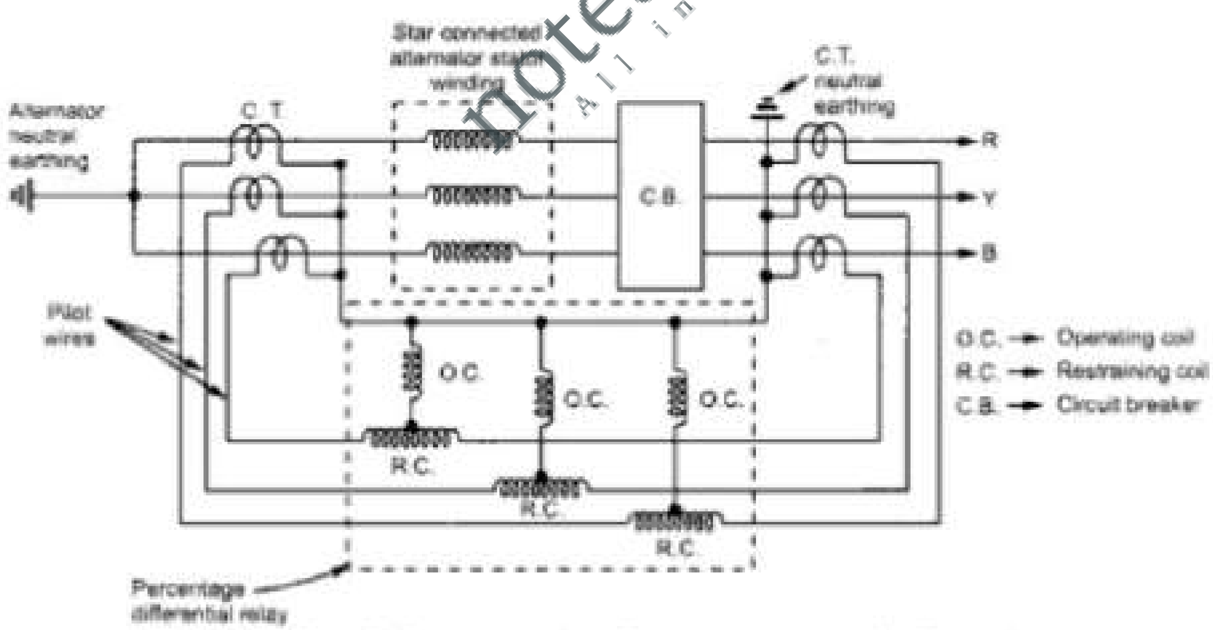


Fig. Merz-Price protection for star connected alternator

Transformer Protection

Percentage Differential Protection for Transformers: percentage differential protection or Wu-Price protection based on the circulating current principle can also be used for the transformers. This system gives protection against phase to phase faults and phase to ground faults to the power transformers. The principle of such a protection scheme is the comparison of the currents entering and leaving the ends of a transformer. The vector difference of currents will passes through the operating coil while the average current will passes through the restraining coil. In normal conditions, the two currents at the two ends of the transformer are equal and balance is maintained. So no current flows through the operating coil of the relay and relay is inoperative. But when there is phase to phase fault or phase to ground fault, this balance gets disturbed. The difference current flows through the operating coil due to which relay operates, tripping the circuit breaker. Compared to the differential protection used in generators, there are certain important points which must be taken care of while using such protection for the power transformers. These points are,

I. In a power transformer, the voltage rating of the two windings is different. 11w high voltage winding is low current winding while low voltage winding is high current winding. Thus there always exists difference in current on the primary and secondary sides of the power transformer. Hence if C.T.s of same ratio are used on two sides, then relay may get operated through there is no Fault existing. To compensate for this difficulty, the current ratios of C.T.s on each side are different. These ratios depend on the line currents of the power transformer and the connection of

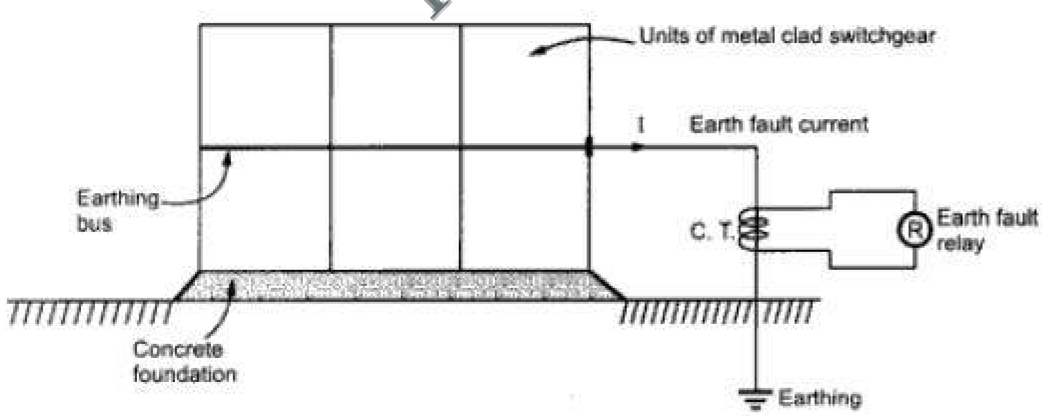
Due to the different turn's ratio; the currents led into the pilot wires from each end are same under normal conditions so that the relay remains inoperative. For example if K is the turns ratio of a power transformer then the ratio of C.T.s on low voltage side is made K times greater thin that of C.T.s on high voltage side.

2. In case of power transformers, there is an inherent phase difference between the Voltages induced in high voltage winding and low voltage winding. Due to this, there exists a phase difference between the line currents on primary and secondary sides of a power transformer. This introduces the phase difference between the CT. secondary currents, on the two sides of a power transformer. Though the turns ratio of C.T.s are selected to compensate for turns ratio of transformer, a differential current may result due to the phase difference between the currents on

two sides. Such a differential current may operate the relay though there is no fault; hence it is necessary to correct the phase difference. To compensate for this, the CT. connections should be such that the resultant currents fed into the pilot wires from either side are displaced in phase by an angle equal to the phase shift between the primary and secondary currents. To achieve this, secondary's of C.T.s on star connected side of a power transformer are connected in delta while the secondary's of C.T.s on delta connected side of a power transformer are connected in star.

Differential relay with harmonic restraint, Inter turn faults

This protection is nothing but the method of providing earth fault protection to the transformer. This protection can be provided to the metal clad switchgear. The arrangement is shown in the Fig. The metal clad switchgear is lightly insulated from the earth. The frame of the switchgear i.e. enclosure is grounded. This is done through a primary of current transformer in between. The concrete foundation of switchgear and the other equipment's are lightly insulated from the ground. The resistance of these equipment's with earth is about 12 ohms. When there is an earth fault, then fault current leaks from the frame and passes through the earth connection provided. Thus the primary of C.T. senses the current due to which current passes through the sensitive earth fault relay. This operates the relay. Such a protection is provided only for small transformers. For the large transformers, the differential protection is enough to sense and operate for the earth faults.



Induction motor protection

Introduction

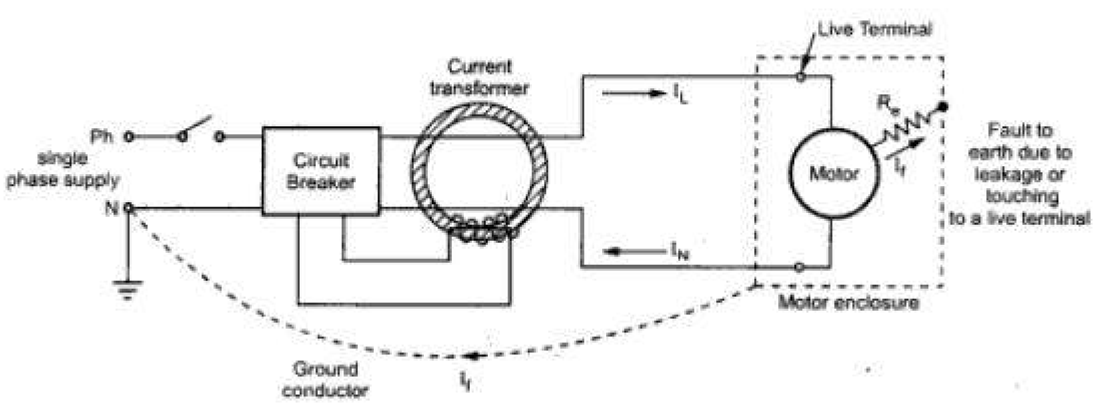
Based on the control action i.e. starting, stopping or reversal, controlling elements known in electrical terms as switchgear are employed for the protection of induction motor. Generally two basic protections viz short circuit protection and overload protection are provided for each motor. The switchgear used for protection includes contactors with H.R.0 fuse and thermal overload relays along with circuit breakers. If the rating of the motor is up to 150 kW then contactors and fuses can be used while for motors having rating beyond 150 kW, circuit breakers are used. The contactor is a kind of switch through which supply can be given to the motor when its coil is energized. If the current to be interrupted is six times the rated current of the motor then contactors can be used.

Abnormal Conditions and Failure in Case of Induction Motor: The three phase induction motors are used in numerous industrial applications. Hence before studying the protection circuit we have to consider the abnormal conditions and failure that may occur in case of induction motor. If the motor is heavily loaded beyond its capacity then it will be overload condition of motor in which case motor draws heavy current from the supply and there will be simultaneous rise in temperature of winding and deterioration of the insulation resulting in damage of winding. Hence the motor must be protected against tins mechanical overloading with overload protection circuits. Normally thermal overload relays, over current relays or miniature circuit breaker with built in trip coils may be used. It might be possible that the rotor is locked or starting lasts for longer duration or rotor does not move because of excessive load (stalling) at start. In all these cases motor draws heavy current from the supply and results in damage to the winding due to overheating as stated above. In this case thermal relays or instantaneous overcurrent relays are used.

If the supply conditions are abnormal such as loss of supply voltage, unbalanced supply voltage, phase sequence reversal of supply voltage, over voltage, under voltage or under frequency then also the performance of the motor is affected. With unbalanced supply voltage there will be excessive heating while with under voltage the motor draws more current for the same load. For under voltage protection, under voltage relays are used. With correct phase sequence, the motor runs in one direction. With change in phase sequence of supply it runs in other direction which is dangerous in some of the applications such as cranes, hoists or elevators. In such cases phase reversal relay may be provided which will disconnect the supply to the motor through the circuit breaker. Due to excessive temperature rise, the insulation may get damaged which may lead to stator earth fault or stator phase to phase fault which are rare in nature. For low rating motors, HRC fuses provide sufficient protection against these faults while for large motors, differential protection may be used. Due to blowing of fuse in any phase or open circuit in one of the three phases results in single phasing. In such case motor continues to run and if it is loaded to its rated value then it will draw excessive current which will damage the rotor and eventually the motor will be damaged due to excessive overheating. Normally thermal overload relays are used against single phasing. Sometimes special single phase preventer may be provided.

Ground fault protection

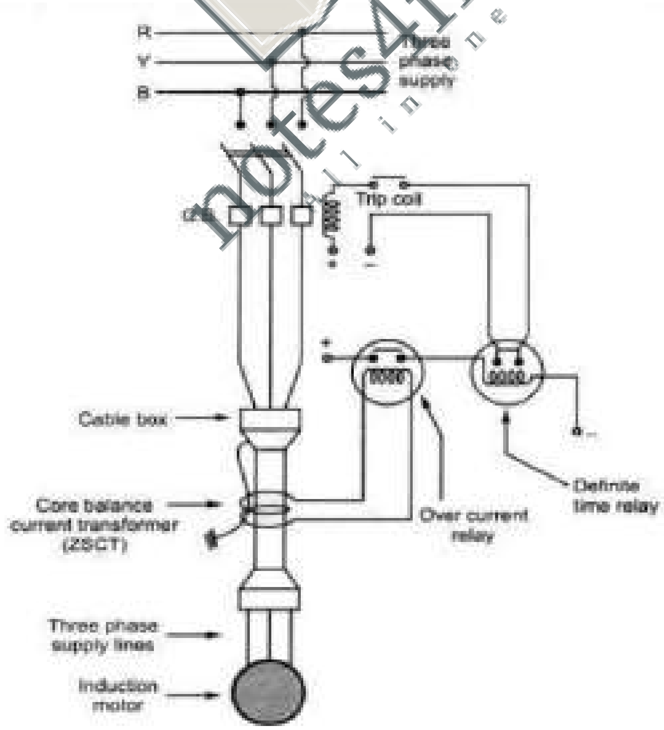
The ground fault protection is achieved using earth leakage circuit breaker (ELCB). When the fault current or leakage current flows through earth return path then it forms the earth fault. These faults are relatively frequent and hence protection is required against these which is provided with the help of Earth leakage circuit breaker. Consider an example of a person whose finger sticks into the socket. Even though the metal enclosure is securely earthed, the person will receive a severe shock. Under such case there must be certain device that will cut the supply. This can he done with the help of ELCB which will typically trip in around 25 cms if current exceeds its preset value. The schematic of ELCB is shown in Fig.



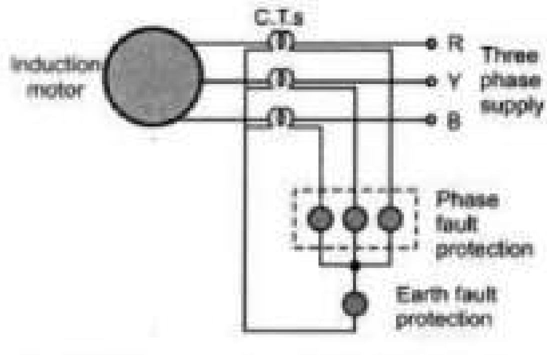
As shown in the Fig ELCB consists of a small current transformer surrounding live and neutral wire. The secondary winding of current transformer is connected to relay circuit which can trip the circuit breaker which is connected in the circuit. Under normal conditions, the current in line and neutral conductor is same so the net current (IL -IN) flowing through the core is zero. Eventually there will not be any production of flux in the core and no induced emf. So the breaker does not trip. If there is a fault due to leakage from live wire to earth or a person by mistake touching to the live terminal then the net current through the core will no longer remain as zero but equal to IL -IN or I, which will set up flux and emf in CT. As per the preset value the unbalance in current is detected by C.T. and relay coil is energized which will give tripping signal for the circuit breaker. As C.T. operates with low value of current, the core must be very permeable at low flux densities.

Phase Fault Protection

This protection is also called short circuit protection. At the time of such a fault, the current increases by 8 to 10 times the full load current of the motor. Attracted armature type relay unit is connected in each phase with a current setting of 4-5 times the full load current. This is because starting current can he 4-5 times full load current.



Earth fault protection by ZSCT



Phase and earth fault protection

The phase faults can cause burn out of coils and stampings and hence motor should be disconnected as quickly as possible when fault occurs. Fast over current relays also are used to provide phase fault protection. As mentioned above to avoid relay functioning during starting, the short circuit protection current setting must be just above the maximum starting current of the motor.

Phase Reversal Protection: The direction of induction motor depends on the direction of rotating magnetic field produced by the stator windings. For a particular phase sequence RYB the motor rotates in a particular direction due to corresponding direction of rotating magnetic field. But if any two lines are interchanged after repairs the phase sequence reverses such as YRB. Then the direction of rotating magnetic field also reverses and induction motor starts rotating in opposite direction. Such a change of direction is dangerous if the induction motor is used for cranes, hoists, lifts or in threading mills etc.

Thus to disconnect induction motor from supply if there is phase reversal, phase reversal protection is provided. This protection is provided using motor driven disc working on electromagnetic principle. The secondaries of two current transformers connected in two lines drive the motor to operate the disc. The arrangement is such that for a normal direction of motor, disc rotates in a particular direction which keeps the auxiliary contacts closed. But if there is phase reversal then the torque produced reverses to rotate the disc in opposite direction. Due to this auxiliary contacts get opened. This in turn either operates the circuit breaker or de-energizes starter coil to disconnect the motor from the supply. Thus phase reversal protection for the induction motor is achieved. Now a day's solid state phase reversal relay sensing the phase reversal is used

MODULE - 3

SWITCHES AND FUSES

- **Switches and fuses:** Introduction, energy management of power system
- Definition of switchgear,
- **Switches** - isolating, load breaking and earthing
- Introduction to fuse, fuse law, cut -off characteristics
- Time current characteristics, fuse material, HRC fuse, and liquid fuse
- Application of fuse

Energy demand management, also known as demand side management (DSM), is the modification of consumer demand for energy through various methods such as financial incentives and education. Usually, the goal of demand side management is to encourage the consumer to use less energy during peak hours, or to move the time of energy use to off-peak times such as nighttime and weekends. Peak demand management does not necessarily decrease total energy consumption, but could be expected to reduce the need for investments in networks and/or power plants.

The term DSM was coined during the time of the 1973 energy crisis and 1979 energy crisis.

Electricity use can vary dramatically on short and medium time frames, and the pricing system may not reflect the instantaneous cost as additional higher-cost ("peaking") sources are brought on-line. In addition, the capacity or willingness of electricity consumers to adjust to prices by altering demand (elasticity of demand) may be low, particularly over short time frames. In many markets, consumers (particularly retail customers) do not face real-time pricing at all, but pay rates based on average annual costs or other constructed prices.

Various market failures rule out an ideal result. One is that suppliers' costs do not include all damages and risks of their activities. External costs are incurred by others directly or by damage to the environment, and are known as externalities. Theoretically the best approach would be to add external costs to the direct costs of the supplier as a tax (internalization of external costs). Another possibility (referred to as the second-best approach in the theory of taxation) is to intervene on the demand side by some kind of rebate.

Energy demand management activities should bring the demand and supply closer to a perceived optimum.

Governments of many countries mandated performance of various programs for demand management after the 1973 energy crisis. An early example is the National Energy Conservation Policy Act of 1978 in the U.S., preceded by similar actions in California and Wisconsin in 1975.

Switch gear

In an electric power system, switchgear is the combination of electrical disconnect switches, fuses or circuit breakers used to control, protect and isolate electrical equipment. Switchgear is used both to de-energize equipment to allow work to be done and to clear faults downstream. This type of equipment is important because it is directly linked to the reliability of the electricity supply.

The very earliest central power stations used simple open knife switches, mounted on insulating panels of marble or asbestos. Power levels and voltages rapidly escalated, making opening manually operated switches too dangerous for anything other than isolation of a de-energized circuit. Oil-filled equipment allowed arc energy to be contained and safely controlled. By the early 20th century, a switchgear line-up would be a metal-enclosed structure with electrically operated switching elements, using oil circuit breakers. Today, oil-filled equipment has largely been replaced by air-blast, vacuum, or SF6 equipment, allowing large currents and power levels to be safely controlled by automatic equipment incorporating digital controls, protection, metering and communications.

High voltage switchgear was invented at the end of the 19th century for operating motors and other electric machines. The technology has been improved over time and can be used with voltages up to 1,100 kV.

Typically, the switchgear in substations is located on both the high voltage and the low voltage side of large power transformers. The switchgear on the low voltage side of the transformers may be located in a building, with medium-voltage circuit breakers for distribution circuits, along with metering, control, and protection equipment. For industrial applications, a transformer and switchgear line-up may be combined in one housing, called a unitized substation or USS.

Fuse

In electronics and electrical engineering, a fuse is a type of low resistance resistor that acts as a sacrificial device to provide overcurrent protection, of either the load or source circuit. Its essential component is a metal wire or strip that melts when too much current flows, which interrupts the circuit in which it is connected. Short circuit, overloading, mismatched loads or device failure are the prime reasons for excessive current.

A fuse interrupts excessive current (blows) so that further damage by overheating or fire is prevented. Wiring regulations often define a maximum fuse current rating for particular circuits. Overcurrent protection devices are essential in electrical systems to limit threats to human life and property damage. Fuses are selected to allow passage of normal current plus a marginal percentage and to allow excessive current only for short periods. Slow blow fuses are designed to allow harmless short term higher currents but still clear on a sustained overload. Fuses are manufactured in a wide range of current and voltage ratings and are widely used to protect wiring systems and electrical equipment. Self-resetting fuses automatically restore the circuit after the overload has cleared; these are useful, for example, in aerospace or nuclear applications where fuse replacement is impossible.

1. A safety device that protects an electric circuit from becoming overloaded. Fuses contain a length of thin wire (usually of a metal alloy) that melts and breaks the circuit if too much current flows through it. They were traditionally used to protect electronic equipment and prevent fires, but have largely been replaced by circuit breakers.

2. A cord of readily combustible material that is lighted at one end to carry a flame along its length to detonate an explosive at the other end.

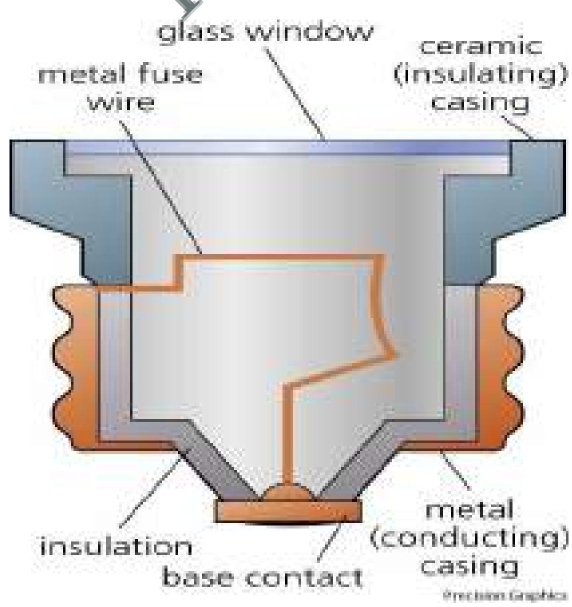
Construction

A fuse consists of a metal strip or wire fuse element, of small cross-section compared to the circuit conductors, mounted between a pair of electrical terminals, and (usually) enclosed by a non-combustible housing. The fuse is arranged in series to carry all the current passing through the protected circuit. The resistance of the element generates heat due to the current flow. The size and construction of the element is (empirically) determined so that the heat produced for a normal current does not cause the element to attain a high temperature. If too high a current flows, the element rises to a higher temperature and either directly melts, or else melts a soldered joint within the fuse, opening the circuit.

The fuse element is made of zinc, copper, silver, aluminum, or alloys to provide stable and predictable characteristics. The fuse ideally would carry its rated current indefinitely, and melt quickly on a small excess. The element must not be damaged by minor harmless surges of current, and must not oxidize or change its behavior after possibly years of service.

The fuse elements may be shaped to increase heating effect. In large fuses, current may be divided between multiple strips of metal. A dual-element fuse may contain a metal strip that melts instantly on a short - circuit, and also contain a low-melting solder joint that responds to long-term overload of low values compared to a short-circuit. Fuse elements may be supported by steel or nichrome wires, so that no strain is placed on the element, but a spring may be included to increase the speed of parting of the element fragments.

The fuse element may be surrounded by air, or by materials intended to speed the quenching of the arc. Silica sand or non-conducting liquids may be used.



Characteristic parameters and Fuse law

A maximum current that the fuse can continuously conduct without interrupting the circuit.

Speed: The speed at which a fuse blows depends on how much current flows through it and the material of which the fuse is made. The operating time is not a fixed interval, but decreases as the current increases. Fuses have different characteristics of operating time compared to current, characterized as fast-blow, slow-blow, or time-delay, according to time required to respond to an overcurrent condition. A standard fuse may require twice its rated current to open in one second, a fast-blow fuse may require twice its rated current to blow in 0.1 seconds, and a slow-blow fuse may require twice its rated current for tens of seconds to blow.

Fuse selection depends on the load's characteristics. Semiconductor devices may use a fast or ultrafast fuse as semiconductor devices heat rapidly when excess current flows. The fastest blowing fuses are designed for the most sensitive electrical equipment, where even a short exposure to an overload current could be very damaging. Normal fast-blow fuses are the most general purpose fuses. The time delay fuse (also known as anti-surge, or slow-blow) are designed to allow a current which is above the rated value of the fuse to flow for a short period of time without the fuse blowing. These types of fuse are used on equipment such as motors, which can draw larger than normal currents for up to several seconds while coming up to speed.

The I2t value: The amount of energy spent by the fuse element to clear the electrical fault. This term is normally used in short circuit conditions and the values are used to perform co-ordination studies in electrical networks. I2t parameters are provided by charts in manufacturer data sheets for each fuse family. For coordination of fuse operation with upstream or downstream devices, both melting I2t and clearing I2t are specified. The melting I2t, is proportional to the amount of energy required to begin melting the fuse element. The clearing I2t is proportional to the total energy let through by the fuse when clearing a fault. The energy is mainly dependent on current and time for fuses as well as the available fault level and system voltage. Since the I2t rating of the fuse is proportional to the energy it lets through, it is a measure of the thermal damage and magnetic forces that will be produced by a fault.

Breaking capacity: The breaking capacity is the maximum current that can safely be interrupted by the fuse. Generally, this should be higher than the prospective short circuit current. Miniature fuses may have an interrupting rating only 10 times their rated current. Some fuses are designated High Rupture Capacity (HRC) and are usually filled with sand or a similar material. Fuses for small, low-voltage, usually residential, wiring systems are commonly rated, in North American practice, to interrupt 10,000 amperes. Fuses for larger power systems must have higher interrupting ratings, with some low-voltage current-limiting high interrupting fuses rated for 300,000 amperes. Fuses for high-voltage equipment, up to 115,000 volts, are rated by the total apparent power (megavolt-amperes, MVA) of the fault level on the circuit.

Rated voltage: Voltage rating of the fuse must be greater than or equal to what would become the open circuit voltage. For example, a glass tube fuse rated at 32 volts would not reliably interrupt current from a voltage source of 120 or 230 V. If a 32 V fuse attempts to interrupt the 120 or 230 V source, an arc may result. Plasma inside that glass tube fuse may continue to conduct current until current eventually so diminishes that plasma reverts to an insulating gas. Rated voltage should be larger than the maximum voltage source it would have to disconnect. Rated voltage remains same for any one fuse, even when similar fuses are connected in series. Connecting fuses in series does not increase the rated voltage of the combination (nor of any one fuse).

Medium-voltage fuses rated for a few thousand volts are never used on low voltage circuits, because of their cost and because they cannot properly clear the circuit when operating at very low voltages.

Voltage drop: A voltage drop across the fuse is usually provided by its manufacturer. Resistance may change when a fuse becomes hot due to energy dissipation while conducting higher currents. This resulting voltage drop should be taken into account, particularly when using a fuse in low-voltage applications. Voltage drop often is not significant in more traditional wire type fuses, but can be significant in other technologies such as resettable fuse (PPTC) type fuses.

Temperature de rating: Ambient temperature will change a fuse's operational parameters. A fuse rated for 1 A at 25 °C may conduct up to 10% or 20% more current at −40 °C and may open at 80% of its rated value at 100 °C. Operating values will vary with each fuse family and are provided in manufacturer data sheets.

Fuse Materials

Fuses come in a vast array of sizes and styles to serve in many applications, manufactured in standardized package layouts to make them easily interchangeable. Fuse bodies may be made of ceramic, glass, plastic; fiberglass, molded mica laminates, or molded compressed fiber depending on application and voltage class.

Multiple fuse holders

Cartridge (ferrule) fuses have a cylindrical body terminated with metal end caps. Some cartridge fuses are manufactured with end caps of different sizes to prevent accidental insertion of the wrong fuse rating in a holder, giving them a bottle shape.

Fuses for low voltage power circuits may have bolted blade or tag terminals which are secured by screws to a fuse holder. Some blade-type terminals are held by spring clips. Blade type fuses often require the use of a special purpose extractor tool to remove them from the fuse holder.

Renewable fuses have replaceable fuse elements, allowing the fuse body and terminals to be reused if not damaged after a fuse operation.

Fuses designed for soldering to a printed circuit board have radial or axial wire leads. Surface mount fuses have solder pads instead of leads.

High-voltage fuses of the expulsion type have fiber or glass-reinforced plastic tubes and an open end, and can have the fuse element replaced.

Semi-enclosed fuses are fuse wire carriers in which the fusible wire itself can be replaced. The exact fusing current is not as well controlled as an enclosed fuse, and it is extremely important to use the correct diameter and material when replacing the fuse wire, and for these reasons these fuses are slowly falling from favor. These are still used in consumer units in some parts of the world, but are becoming less common. While glass fuses have the advantage of a fuse element visible for inspection purposes, they have a low breaking capacity which generally restricts them to applications of 15 A or less at 250 VAC. Ceramic fuses have the advantage of a higher breaking capacity, facilitating their use in circuits with higher current and voltage. Filling a fuse body with sand provides additional cooling of the arc and increases the breaking capacity of the fuse. Medium-voltage fuses may have liquid-filled envelopes to assist in the extinguishing of the arc. Some types of distribution switchgear use fuse links immersed in the oil that fills the equipment.

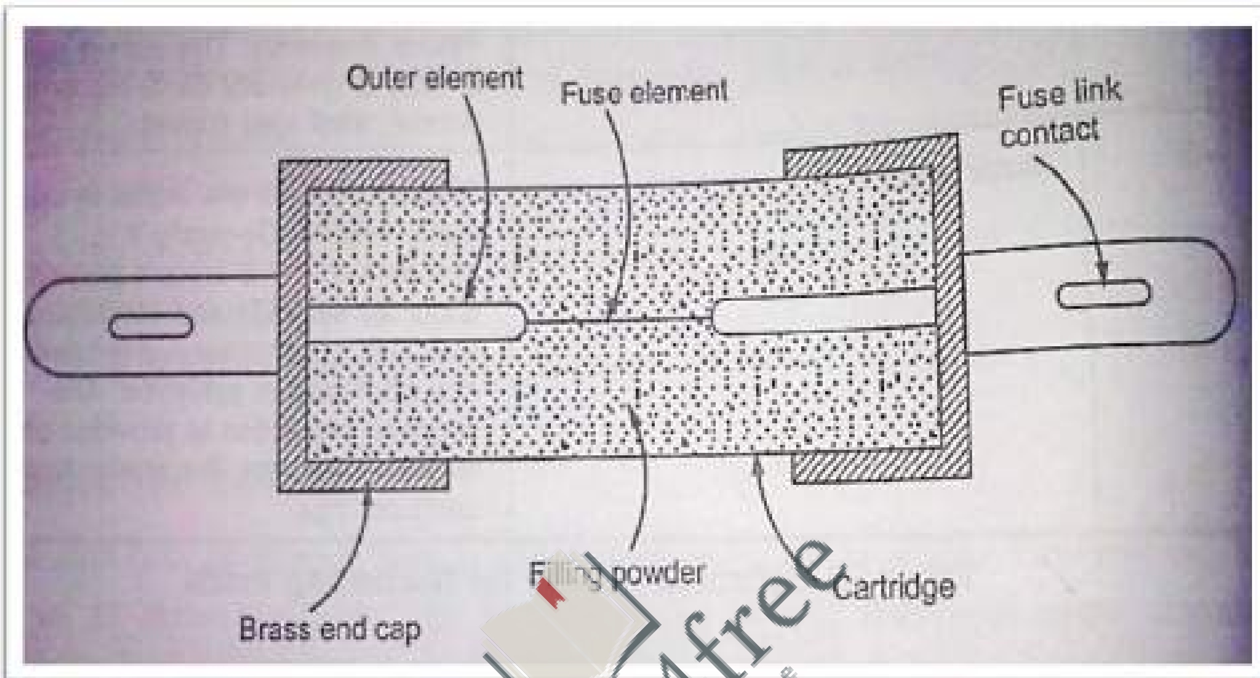
Fuse packages may include a rejection feature such as a pin, slot, or tab, which prevents interchange of otherwise similar appearing fuses. For example, fuse holders for North American class RK fuses have a pin that prevents installation of similar-appearing class H fuses, which have a much lower breaking capacity and a solid blade terminal that lacks the slot of the RK type.

Fuse wire rating (A)	Cu Wire diameter (mm)
3	0.15
5	0.20
10	0.35
15	0.50
20	0.60
25	0.75
30	0.85
45	1.25
60	1.53
80	1.8
100	2.0

HRC Fuse

It is a high rupturing capacity cartridge type of fuse. It is one of the simplest form of fuse which is used for distribution purposes. The low and uncertain breaking capacity of semi closed fuses is overcome in HRC Fuses.

Construction: The body of this fuse is of heat resisting ceramic with metal end caps and is of cylindrical shape. Between end caps, the fixed elements are mounted, which are welded to the end caps. The fuse element is generally silver, attached between the fixed elements. The body space surrounding the fuse is completely filled with quartz sand, plaster of paris or marble dust. The filling powder material is selected such that its chemical reaction with silver vapour forms very high resistance substance.



Operation

The various steps in the operation of the HRC Fuse are

1. Occurrence of fault or short circuit

2. Increase in current through fuse element to high value

3. Melting of silver element

4. Vaporization of the silver element

5. Fusion of the silver vapour and formation of high resistance substance

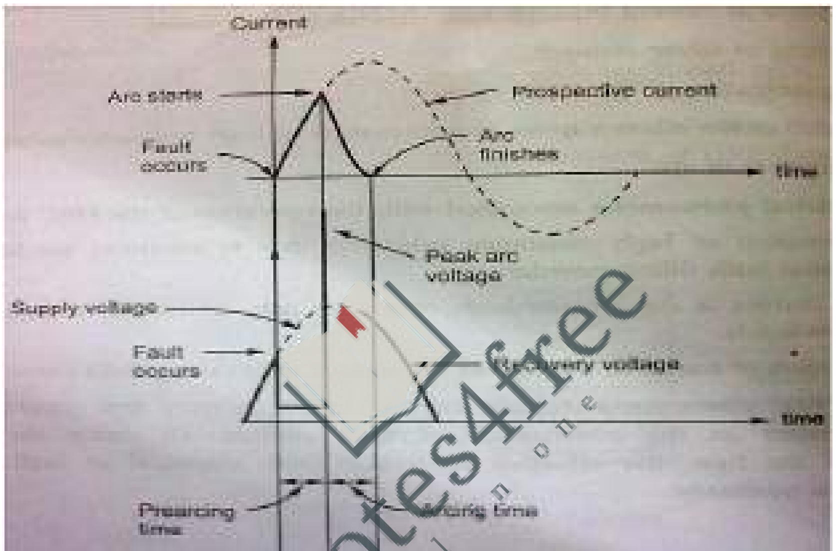
6. Extinction of arc

The electrical phenomena associated with the operation of the HRC Fuse are

1. Formation of high resistance substance due to chemical reaction of silver vapour with filling powder

2. As current is cut off, the high resistance gets converted to an insulator like glass beads 3. Creation of transient voltage at the instant of breaking fault current The physical phenomena include the rise in temperature and generation of high internal pressure on the interruption of fault current.

Cut off characteristics



Applications of HRC fuse

The main applications of HRC Fuse are to protect the low voltage distribution system against the overload and short circuit conditions. For the back up protection to circuit breakers. Protection of meshed feeders with the steady load.

MODULE 4

PRINCIPLES OF CIRCUIT BREAKERS

- Principles of circuit breakers**:** Introduction, requirement of a circuit breakers
- Difference between an isolator and circuit breaker
- basic principle of operation of a circuit breaker, phenomena of arc, properties of arc, initiation and maintenance of arc,
- arc interruption theories - slepian's theory and energy balance theory,
- Re striking voltage, recovery voltage, Rate of rise of Re striking voltage,
- DC circuit breaking, AC circuit breaking, current chopping, capacitance switching, resistance switching
- Rating of Circuit breakers.

Introduction

Where fuses are unsuitable or inadequate, protective relays and circuit breakers are used in combination to detect and isolate faults. Circuit breakers are the main making and breaking devices in an electrical circuit to allow or disallow flow of power from source to the load. These carry the load currents continuously and are expected to be switched ON with loads (making capacity). These should also be capable of breaking a live circuit under normal switching OFF conditions as well as under fault conditions carrying the expected fault current until completely isolating the fault side (rupturing/breaking capacity). Under fault conditions, the breakers should be able to open by instructions from monitoring devices like relays. The relay contacts are used in the making and breaking control circuits of a circuit breaker, to prevent breakers getting closed or to trip breaker under fault conditions as well as for some other interlocks.

Purpose of circuit breakers (switchgear)

The main purpose of a circuit breaker is to:

• Switch load currents

• Make onto a fault

• Break normal and fault currents

• Carry fault current without blowing itself open (or up!) i.e. no distortion due to magnetic forces under fault conditions.

The important characteristics from a protection point of view are:

• The speed with which the main current is opened after a tripping impulse is received

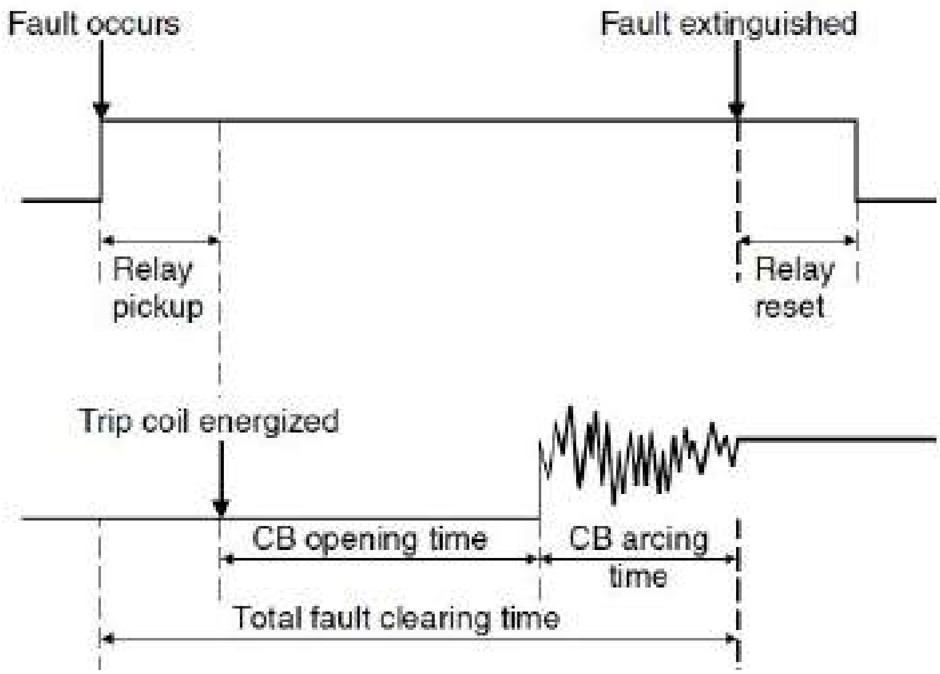
• The capacity of the circuit that the main contacts are capable of interrupting.

The first characteristic is referred to as the 'tripping time' and is expressed in cycles. Modern high-speed circuit breakers have tripping times between three and eight cycles. The tripping or total clearing or break time is made up as follows:

• Opening time: The time between instant of application of tripping power to the instant of separation of the main contacts.

• Arcing time: The time between the instant of separation of the main circuit breaker contacts to the instant of arc extinction of short-circuit current.

•Total break or clearing time



The second characteristic is referred to as 'rupturing capacity' and is expressed in MVA. The selection of the breaking capacity depends on the actual fault conditions expected in the system and the possible future increase in the fault level of the main source of supply. In the earlier chapters we have studied simple examples of calculating the fault currents expected in a system. These simple calculations are applied with standard ratings of transformers, etc., to select the approximate rupturing capacity duty for the circuit breakers.

Requirement of circuit breakers

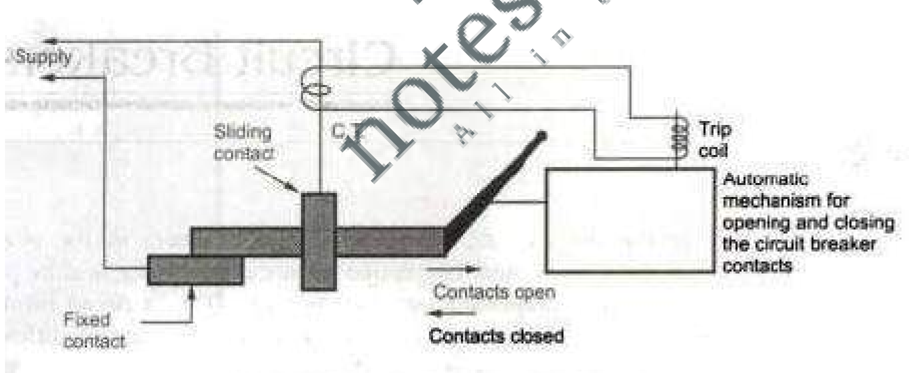
Introduction

As already seen in the last chapter, whenever any fault occurs in the power system then that part of the system must be isolated from the remaining healthy part of the system. This function is accomplished by circuit breakers. Thus a circuit breaker will make or break a circuit either manually or automatically under different conditions such as no load, full load or short circuit. Thus it proves to be an effective device for switching and protection of different parts of a power system. In earlier days fuse was included in. the protective system. But due to some limitations they are not used in practice now a day. The main difference between a fuse and circuit breaker is that under fault condition the fuse melts and it is to be replaced whereas the circuit breaker :an close or break the circuit without replacement.

Requirements of Circuit Breaker: The power associated with the circuit breakers is large and it forms the link between the consumers and suppliers. The necessary requirements of circuit breakers are as follows, 1. The normal working current and the short circuit current must be safely interrupted by the circuit breaker. 2. The faulty section of the system must be isolated by circuit breaker as quickly as possible keeping minimum delay. 3 It should not operate with flow of overcurrent during healthy conditions. 4. The faulty circuit only must be isolated without affecting the healthy one.

Basic principle of operation of a circuit breaker

The Fig. Shows the elementary diagram of a circuit breaker. It consists of two contacts a fixed contact and a moving contact. A handle is attached at the end of the moving contact. It can be operated manually or automatically. The automatic operation needs a separate mechanism which consists of a trip coil. The trip coil is energized by secondary of current transformer. The terminals of the circuit breaker are bought to the supply.



Basic action of circuit breaker

Under normal working conditions the e.m.f produced in the secondary winding of the transformer is insufficient to energize the trip coil completely for its operation. Thus the contacts remain in closed position carrying the normal working current. The contacts can be opened manually also by the handle. Under abnormal or faulty conditions high current in the primary winding of the current transformer induces sufficiently high e.m.f in the secondary winding so that the trip coil is energized. This will start opening motion of the contacts. This action will not be instantaneous as there is always a time lag between the energization of the trip circuit and the actual opening of the contacts. The contacts are moved towards right away from fixed contact. As we have seen already the separation of contacts will not lead to breaking or interruption of circuit as an arc is struck between the contacts. The production of arc delays the current interruption and in addition to this it produces large amount of heat which may damage the system or the breaker. Thus it becomes necessary to extinguish the arc as early as possible in minimum time, so that heat produced will lie within the allowable limit. This will also ensure that the mechanical stresses produced on the parts of circuit breaker are less the time interval which is passed in between the enervation of the trip coil to the instant of contact separation is called the opening time. It is dependent on fault current level. The time interval from the contact separation to the extinction of arc is called arcing time It depends not only on fault current but also on availability of voltage for maintenance of arc and mechanism used for extinction of arc.

Phenomena of arc, properties of arc, initiation and maintenance of arc

Formation of an Arc: Under faulty conditions heavy current flows through the contacts of the circuit breaker before they are opened. As soon as the contacts start separating, the area of contact decreases which will increase the current density and consequently rise in the temperature. The medium between the contacts of circuit breaker may be air or oil. The heat which is produced in the medium is sufficient enough to ionize air or oil which will act as conductor. Thus an arc is struck between the contacts. The p.d. between the contacts is sufficient to maintain the arc. So long as the arc is remaining between the contacts the circuit is said to be uninterrupted. The current flowing between the contacts depends on the arc resistance. With increase in arc resistance the current flowing will be smaller. The arc resistance depends on following factors,

a) Degree of ionization: If there is less number of ionized particles between the contacts then the arc resistance increases.

b) Length of arc: The arc resistance is a function of length of arc which is nothing but separation between the contacts. More the length more is the arc resistance.

c) Cross-section of arc: If the area of cross-section of the arc is less then arc resistance is large.

Initiation of Arc There must be some electrons for initiation of an arc when fault occurs circuit breaker contacts start separating from each other and the electrons are emitted which are produced by following methods. By high voltage gradient at the cathode, resulting in field emission by increase of temperature resulting in thermionic emission. By High Voltage Gradient As the moving contacts start separating from each other, the area of contact and pressure between the separating contacts decreases. A high fault current causes potential drop (of the order)between the contacts which will remove the electrons from cathode surface. This process is called field emission.

By Increase of Temperature With the separation of contacts there is decrease in contact area which will increase the current density and consequently the temperature of the surface as seen before which will cause emission of electrons which is called thermal electron emission. In most of the circuit breakers the contacts are made up of copper which is having less thermionic emission.

Maintenance of an Arc In the previous section we have seen the initiation of the arc by field emission emission. The electrons while travelling towards anode collide with another electron to dislodge them and thus the arc is maintained. The ionizing is lactated by,

i) High temperature of the medium around the contacts due to high current densities. Thus the kinetic energy gained by moving electrons is increased.

ii) ii) The increase in kinetic energy of moving electrons due to the voltage gradient which dislodge more electrons from neutral molecules. iii) The separation of contacts of circuit breaker increases the length of path which will increase number of neutral molecules. This will decrease the density of gas which will increase free path movement of the electrons.

Arc Extinction It is essential that arc should be extinguished as early as possible. There are two methods of extinguishing the arc in circuit breakers which are namely,

a) High resistance method b) Low resistance or current zero method

High Resistance Method In high resistance method the arc resistance is increased with time. This will reduce the current to such a value which will be insufficient to maintain the arc thus the current is interrupted and the arc is extinguished. This method is employed in only d.c circuit.

The resistance of the arc may he increased by lengthening the arc, cooling the arc, reducing the cross-section of the arc and splitting the arc. These methods will be discussed in detail later in this chapter.

Low Resistance Method The low resistance or current zero method is employed for arc extinction in ac. circuits. In this method arc resistance is kept low until current zero where extinction of arc takes place naturally and is prevented from restriking. This method is employed in many of the modern a.c. circuit breakers.

Low Resistance or Zero Point Extinction

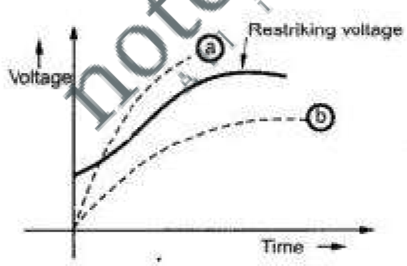
This method is used in ac. arc interruption. -I he current becomes zero two tires in a cycle. So at each current zero point the arc vanishes for small instant and again it appears. But in auxillary circuit breakers the arc is interrupted at a current zero point. The space between the contacts is ionized quickly if there is fresh unionized medium such as oil or fresh air or SF, gas between the contacts at current zero point. This will make dielectric strength of the contact space to increase such that arc will be interrupted and discontinued after current zero. This action produces high voltage across the contacts which are sufficient to reestablish the arc. Thus the dielectric strength must be building more than the restricting voltage for faithful interruption of arc. Then the arc is extinguished at next current zero. While designing the circuit breakers the care is taken so as to remove the hot gases from the contact space immediately after the arc. So that it can be filled by fresh dielectric medium having high dielectric strength. In summary we can say that the arc extinction process is divided in thee parts, a) Arcing phase b) Current zero phase c) Post arc phase In arcing phase, the temperature of the contact space is increased due to the arc. The heat produced must be removed quickly by providing radial and axial flow to gases. The arc can not be broken abruptly but its diameter can be reduced by the passage of gas over the arc. When ax. Current wave is near its zero, the diameter of the arc is very less and consequently arc is extinguished. This is nothing but current 7ero phase. Now in order to avoid the reestablishment of arc, the contact space must be filled with dielectric medium having high dielectric strength. This is post arc phase in which hot gases are removed and fresh dielectric medium is introduced.

Arc Interruption Theories There are two main theories explaining current zero interruption of arc

I) Recovery Rate Theory or Slepian's Theory

2) Energy balance theory or Cassie's Theory

Slepian's Theory Slepian described the process as a race between the dielectric strength and restriking voltage. After every current zero, there is a column of residual ionized gas. This may cause arc to strike again by developing necessary restriking voltage and this voltage stress is sufficient to detach electrons out of their atomic orbits which releases great heat. Si in this theory rate at which positive ions and electrons recombine to form neutral molecules is compared with rate of rise of restriking voltage. Due to recombination dielectric strength of gap gets recovered. So rate of recovery of dielectric strength is compared with rate of rise of restriking voltage. If the restriking voltage rises more rapidly than the dielectric strength, gap space breaks down and arc strikes again and persists. In the Fig. a) Rate of dielectric strength is more than restriking voltage. b) Rate of dielectric strength is less ------ -0 than rate of rise of restriking voltage. The assumption made while developing this theory is that the restriking voltage and rise of dielectric strength are comparable quantities which is not quite correct the second drawback is that the theory does not consider the energy relations in the arc extinction. The arcing phase is not covered by this theory so it is incomplete.



Cassie's Theory Alternative explanation of above process s afforded by Cassie's theory or also called Energy balance theory. Cassie suggested that the reestablishment of arc or interruptions of an arc both are energy balance process. If the energy input to an arc continues to increase, the arc restrikes and if not, arc gets interrupted. Theory makes the following assumptions

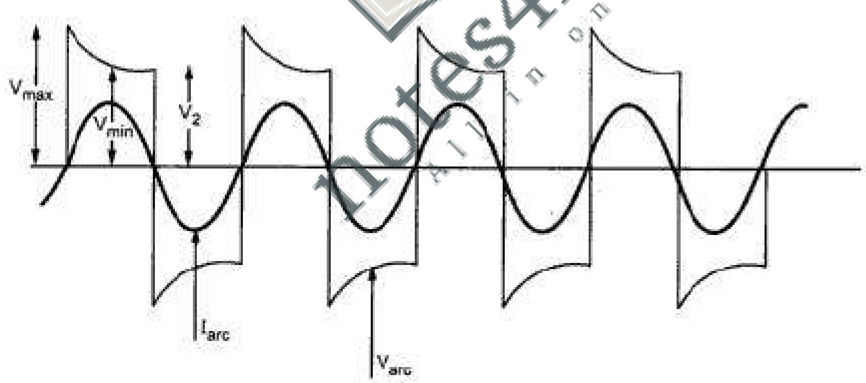
a) Arc consists of a cylindrical column having uniform temperature at its cross section. The energy distributed in the column is uniform

b) The temperature remains constant.

c) The cross section of the arc adjusts itself to accommodate the arc current.

d) Power dissipation is proportional to cross sectional area of arc column interruption theories - slepian's theory and energy balance theory.

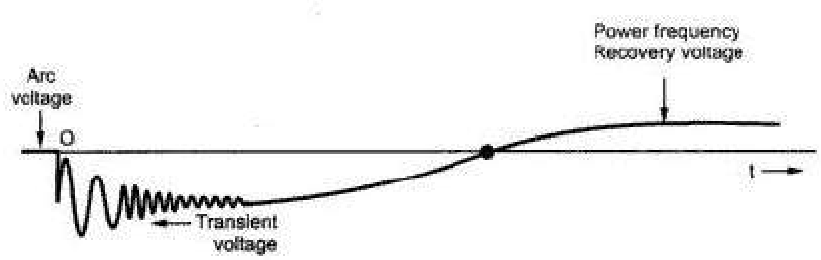
Breakdown occurs if power fed to the arc s more than power loss. The theory is true for high currents. Immediately after current zero, contact space contains ionized gas and therefore has a finite post zero resistance. Now there is rising restriking voltage. This rising res. triking voltage causes a current to flow between the contacts. Due to this current flow, power gets dissipated as heat in the contact space of circuit breaker. Initially when restriking voltage is zero, automatically current and hence power is zero. It is again zero when the space has become fully deionize and resistance between the contacts is infinitely high. In between these two extreme limits, power dissipated rises to a maximum. If the heat so generated exceeds the rate at which heat can be removed from contact space, ionization will persist and breakdown will occur, giving an arc for another half cycle.



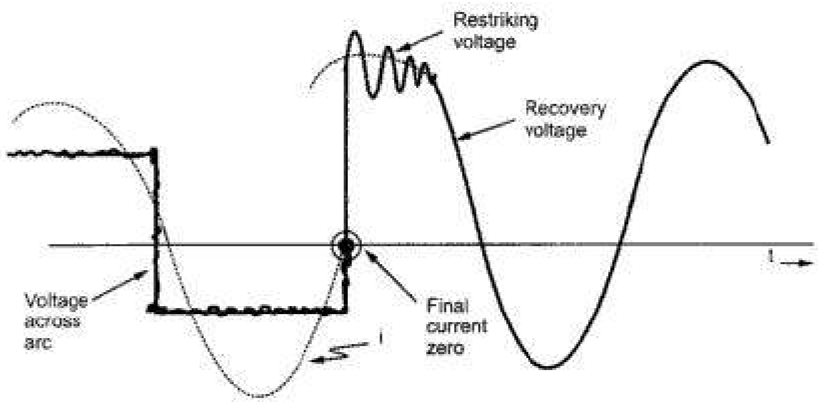
Re -striking voltage, recovery voltage, Rate of rise of Re striking voltage

Transient Recovery Voltage The transient recovery while has effect on the behavior of circuit breaker. This voltage appears between the contacts immediately after final arc interruption. This causes high dielectric stress between the contacts. If this dielectric strength of the medium between the contacts does not build up faster than the rate of rise of the transient recovery voltage then the breakdown takes place which will cause restriking of arc Thus it is very important that the dielectric strength of the contact space must build very rapidly that rate of rise of transient recovery voltage so that the Interruption of current by the circuit breaker takes place successfully. The rate of rise of this transient voltage depends on the circuit parameters and the type of the switching duty invoked. The rate of building up of the dielectric strength depends on the effective design of the interrupter and the circuit breaker. If it is desired to break the capacitive currents while opening the capacitor banks, there may appear a high voltage across the contacts which can cause re ignition of the arc after initial arc extinction. Thus if contact space breaks down within a period of one fourth of a cycle from initial arc extinction the phenomenon is called Reigniting. Moving contacts of circuit breakers move a very small distance from the fixed contacts then reigniting may occur without overvoltage. But the arc gets extinguished in the next current zero by which time moving contacts should be moved by sufficient distance from fixed contacts. Thus the re ignition is in a way not harmful as it will not lead to any overvoltage beyond permissible limits. If the breakdown occurs after one fourth of a cycle, the phenomenon is called Restrike. In restriking, high voltage appear across the circuit breaker contacts during capacitive current breaking. In restrikes, voltage will go on increasing which may lead to damage of circuit breaker. Thus the circuit breakers used for capacitors should be free from Restrike I.e. they' should have adequate rating.

Effect of Different Parameters on Transient Recovery Voltage (TRV) As seen from the previous section, after the final current, zero high frequency transient voltage appears across the circuit breaker poles which is superimposed on power frequency system voltage and tries to restrike the arc. This voltage may last for a few tens or hundreds of microseconds. If the shape of this TRV is seen on the oscilloscope then it can be seen that it may be oscillatory, non-oscillatory or a combination of two depending upon the characteristics of the circuit and the circuit breaker. The waveform is as shown in the Fig.



Transient voltage Shape of transient recovery voltage This voltage has a power frequency component and an oscillatory transient component. The oscillatory component is due to inductance and capacitance in the circuit. The power frequency component is due to the system voltage. This is shown in the Fig.



Zero power factor If we consider zero power factor currents, the peak voltage E is impressed on the circuit breaker contacts at the current zero instant This instantaneous voltage gives more transient and provides high rate of rise of TRV. Hence if the p.f. is low then interrupting of such current is difficult.

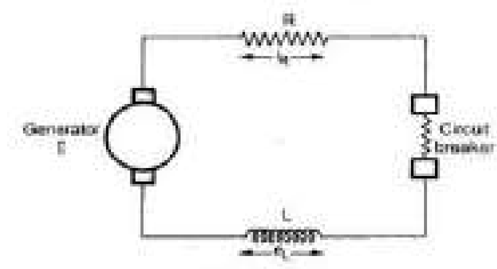
Recovery Voltage As seen previously it is the voltage having normal power frequency which appears after the transient voltage.

Effect of Reactance Drop on Recovery Voltage Home fault is taking place let us consider that the voltage appearing across circuit breaker is V. As the fault current increases, the voltage drop in reactance also increases. After fault clearing the voltage appearing say V2 is slightly less than V,. The system takes some time to regain the original value.

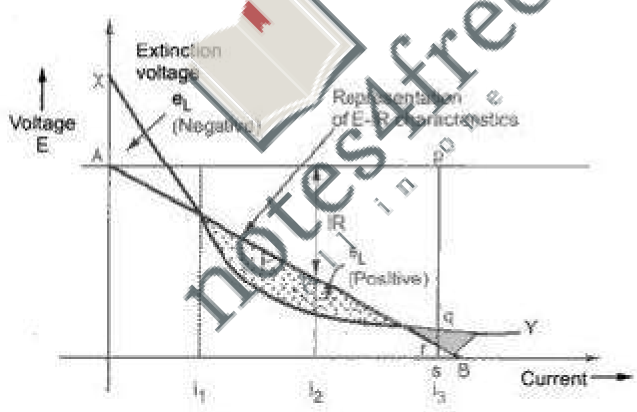
Affect of Armature Reaction on Recovery Voltage Me short circuit currents are at lagging power factor. These lagging p.f. currents have a demagnetizing armature reaction in alternators.Thus the induced end of alternators decreases To regain the original value this emf takes some time. Thus the frequency component of recovery voltage is less than the normal value of system voltage.

DC circuit breaking, AC circuit breaking

D.C. Circuit Breaking The breaking in case of d.c. can be explained as follows. For this, we will consider a circuit which will consist of generator with voltage E, resistance R. inductor L and the circuit breaker as shown in the Fig.



The voltage-current relationship can be represented as shown in the graph it could be seen that curve AB represents the voltage E - iR, i is nothing but current at any instant. The curve XY represents the voltage-current characteristics of the arc for decreasing currents.



Voltage-current relationship

When the circuit breaker starts opening it carries the load current I. In the graph shown the current is shown to be reduced respectively. Section represents voltage drop i3R whereas qs represent arc voltage which is greater than available voltage. The arc becomes unstable and the difference in voltage is supplied by inductance L across which the voltage is L. For decreasing values of t currents this voltage is negative and according to Lenz's law it tries to maintain the arc.

The voltage across inductance L is seen to be positive in the region of currents i, mid i2 since the arc characteristics lies below the curve AB. The arc current in this region tries to increase so interruption of current is not possible in this region. Afterwards the arc is lengthened with Increase in contact separation which will raise the arc voltage above the curve AB. The operation in case of d.c. circuit breakers is said to be ideal if the characteristics of the arc voltage are above the curve AB even in the region of currents i1 and i2. This is shown in the fig..

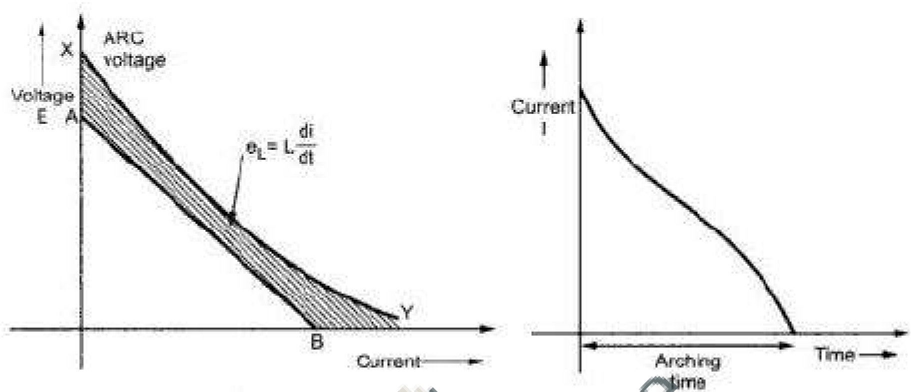


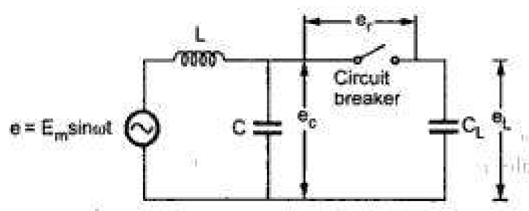
Fig. Arc voltage characteristics

It can be seen that arc voltage is greater than E - Iit and the balance between the voltages is supplied by the voltage across the inductance el, which is proportional to d i rate of change of current dI.

Thus the function of the circuit breaker is to raise the arc characteristics without affecting its stability. This is done by reducing the arcing time which is the time from contact separation to final extinction of arc. But it will increase extinction voltage. Hence compromise between arcing time and arc extinction voltage is made.

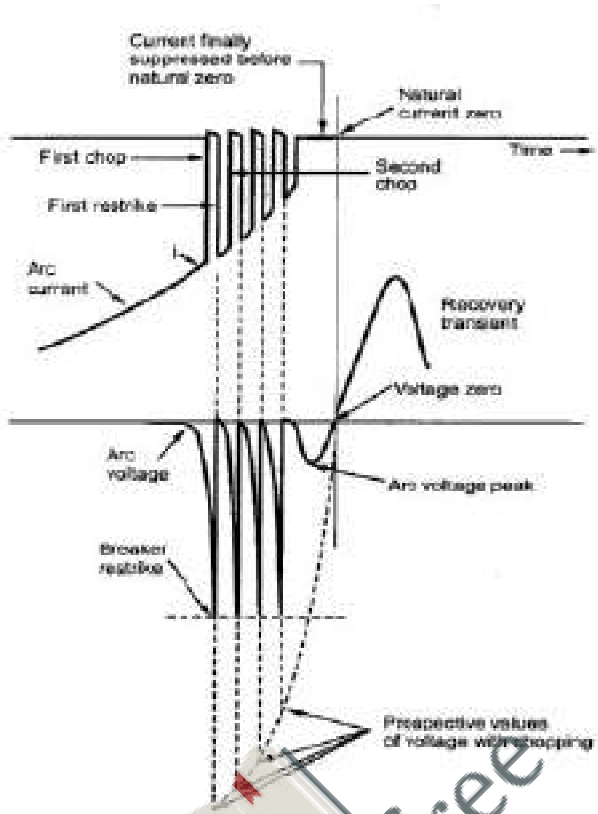
A.C. Circuit Breaking There is a difference between breaking in case of d c. and ac. circuits. In ac. circuits the current passes through zero twice in one complete cycle. When the currents are reduced to zero the beakers are operated to cut-off the current. This will avoid the striking of the arc. But this conditions is difficult to achieve and very much expensive. The restriking of arc when current is interrupted is dependent on the voltage between the contact gap at that instant which will in turn depend on power factor. Higher the power factor, lesser is the voltage appearing across the gap than its peak value.

Current chopping, capacitance switching, resistance switching



In power systems capacitor banks are used in the network which supplies reactive power at leading power factors there are various aspects like long transmission where it is required interrupt the capacitive current which is difficult. To understand this difficulty let us consider a simple circuit shown in the Fig

The value of load capacitance CL is greater than C. The voltage across a capacitor cannot change instantaneously. The currents supplied to the capacitor are generally small and interruption of such currents take place at first current zero. Also at the beginning, the rate of rise of recovery voltage is low and increases slowly. Whenever such circuit is opened a charge is trapped in the capacitance Ct The voltage across the load capacitance will hold the same value when circuit was opened. This voltage is making but peak of supply voltage as power factor angle is nearly 90° leading. After opening the circuit the voltage Vc across the capacitance C oscillates and approaches a new steady value. But due to small value of capacitance C. the value attained is close to the supply voltage. The recovery voltage Cr is nothing but difference between and CL. Its initial value is zero as the circuit breaker will be closed and increases slowly in the beginning. When Vc reverses after half cycle, the recovery voltage is about twice the normal peak value. Therefore it is possible that at this instant arc may restrike as the electrical strength between the circuit breaker contacts is not sufficient. The circuit will be reclosed and et oscillates at a high frequency. The supply voltage at this instant will be at its negative peak; therefore a high frequency oscillation takes place. At the instant of rest rucking the arc, the recovery voltage V, is zero. The voltage across the load capacitance reaches - times the peak value of normal supply voltage. The recovery voltage then starts increasing. If again restriking of arc takes place, a high frequency of oscillation of CL takes place. Such several repetitions of the restriking cycle will increase the voltage across load capacitance to a dangerously high value. In practice this voltage is limited to 4 times the normal peak of the voltage.



Resistance switching

Resistance Switching It can be seen from previous sections that the interruption of low inductivecurrents, interruption of capacitive currents gWe rise to severe voltage oscillations. These excessive voltage surges during circuit interruption can be prevented by the use of shunt resistance R across the circuit breaker contacts. This process is known as Resistance Switching. When the rtsistance is connected across the arc, a part of the arc current flows through the resistance. This will lead to decrease in arc current and increase in rate of deionization of the are path and resistance of arc. This will increase current through shunt resistance . This process continues until the current through the arc is diverted through the resistance either External 4.---

resistance completely or in major part. If C irt the small value of the current remains in the arc then the path . A becomes so unstable that it is Fxed Moved switch easily extinguished. contact contact . The resistance may be automatically switched in and arc current can be transferred. The time required for this action is very small As shown in.. Fig the arc first appears across points A and B which is then transferred across A and C. The shunt resistance also ensures the effective damping of the high frequency re-striking Fig. voltage transients. This is shown in the Fig.

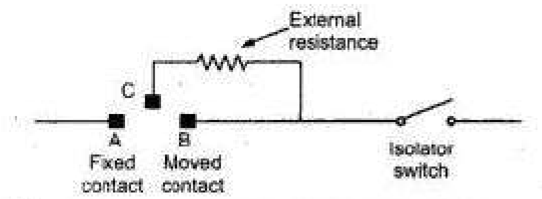
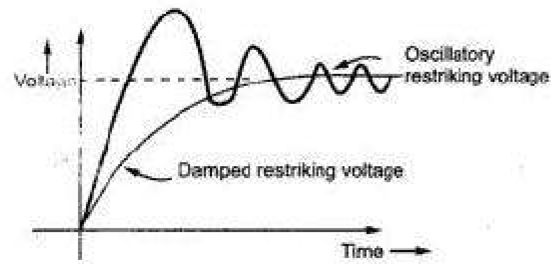
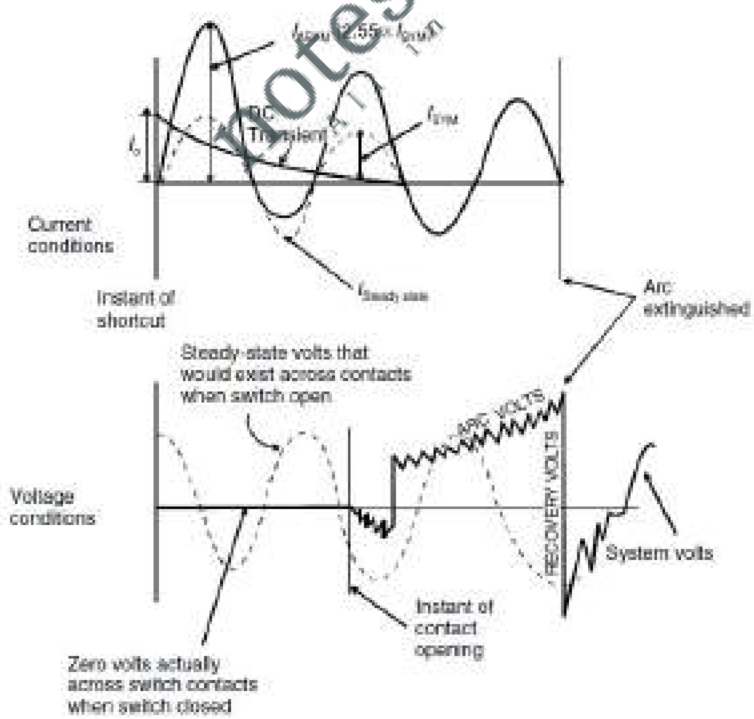


Fig. 9.23 Typical resistor connection



Behavior under fault conditions

Before the instant of short-circuit, load current will be flowing through the switch and this can be regarded as zero when compared to the level of fault current that would flow



1.Arc

The arc has three parts: 1. **Cathode end (–ve):** There is approximately 30–50 V drop due to emission of electrons.

2. Arc column: Ionized gas, which has a diameter proportional to current. Temperature can be in the range of 6000–25 000 °C.

3. Anode end (+ve): Volt drops 10–20 V.

When short-circuit occurs, fault current flows, corresponding to the network parameters. The breaker trips and the current are interrupted at the next natural current zero. The network reacts by transient oscillations, which gives rise to the transient recovery voltage (TRV) across the circuit breaker main contacts.

All breaking principles involve the separation of contacts, which initially are bridged by a hot, highly conductive arcing column. After interruption at current zero, the arcing zone has to be cooled to such an extent that the TRV is overcome and it cannot cause a voltage breakdown across the open gap. Three critical phases are distinguished during arc interruption, each characterized by its own physical processes and interaction between system and breaker.

High current phase

This consists of highly conductive plasma at a very high temperature corresponding to a low mass density and an extremely high flow velocity. Proper contact design prevents the existence of metal vapor in the critical arc region.

Thermal phase

Before current zero, the diameter of the plasma column decreases very rapidly with the decaying current but remains existent as an extremely thin filament during the passage through current zero. This thermal phase is characterized by a race between the cooling of the rest of the plasma and the reheating caused by the rapidly rising voltage. Due to the temperature and velocity difference between the cool, relatively slow axial flow of the surrounding gas and the rapid flow in the hot plasma core, vigorous turbulence occurs downstream of the throat, resulting in effective cooling of the arc. This turbulence is the dominant mechanism, which determines thermal re-ignition or interruption.

Dielectric phase

After successful thermal interruption, the hot plasma is replaced by a residual column of hot, but no longer electrically conducting medium. However, due to marginal ion-conductivity, local distortion of the electrical field distribution is caused by the TRV appearing across the open break. This effect strongly influences the dielectric strength of the break and has to be taken into account when designing the geometry of the contact arrangement.

Introduction, requirement of a circuit breakers, difference between an isolator and circuit breaker, basic principle of operation of a circuit breaker, phenomena of arc, properties of arc, initiation and maintenance of arc, arc interruption theories - slepian's theory and energy balance theory, Re striking voltage, recovery voltage, Rate of rise of Re striking voltage, DC circuit breaking, AC circuit breaking, current chopping, capacitance switching, resistance switching, Rating of Circuit breakers.

MODULE - 5

CIRCUITS BREAKERS

- **Air Circuit breakers** – Air break and Air blast Circuit breakers
- oil Circuit breakers – Single break, double break, minimum OCB
- SF6 breaker - Preparation of SF6 gas
- Puffer and non Puffer type of SF6 breakers
- Vacuum circuit breakers - principle of operation and constructional details
- Advantages and disadvantages of different types of Circuit breakers
- Testing of Circuit breakers, Unit testing
- Synthetic testing, substitution test
- Compensation test and capacitance test
- **Lightning arresters:** Causes of over voltages – internal and external lightning
- Working Principle of different types of lightning arresters. Shield wires

Types of circuit breakers

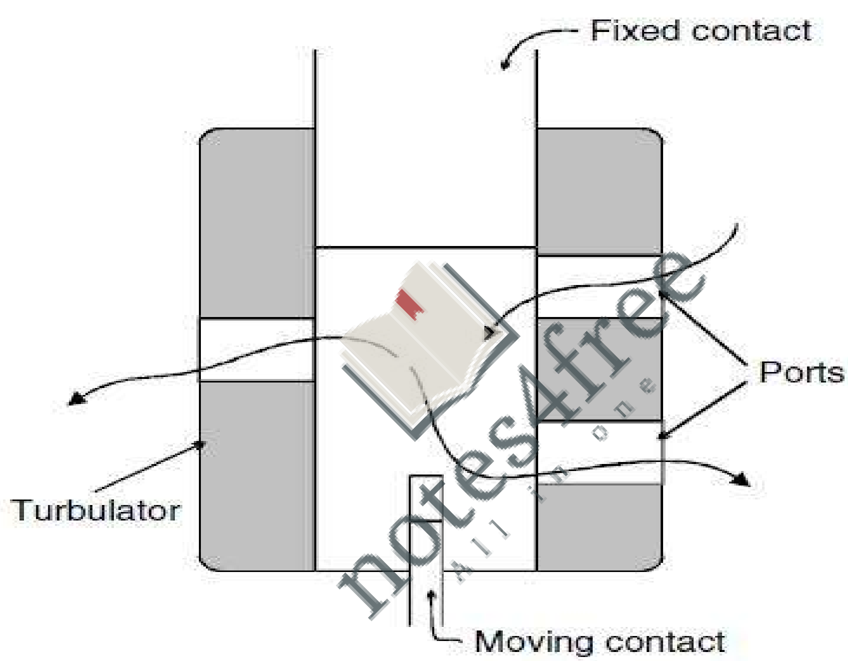
The types of breakers basically refer to the medium in which the breaker opens and closes. The medium could be oil, air, vacuum or SF6. The further classification is single break and double break. In a single break type only the busbar end is isolated but in a double break type, both busbar (source) and cable (load) ends are broken. However, the double break is the most common and accepted type in modern installations.

Arc control device: A breaker consists of moving and fixed contact, and during the breaker operation, the contacts are broken and the arc created during such separation needs to be controlled. The arc control devices, otherwise known as tabulator or explosion pot achieves this:

1. Turbulence caused by arc bubble.

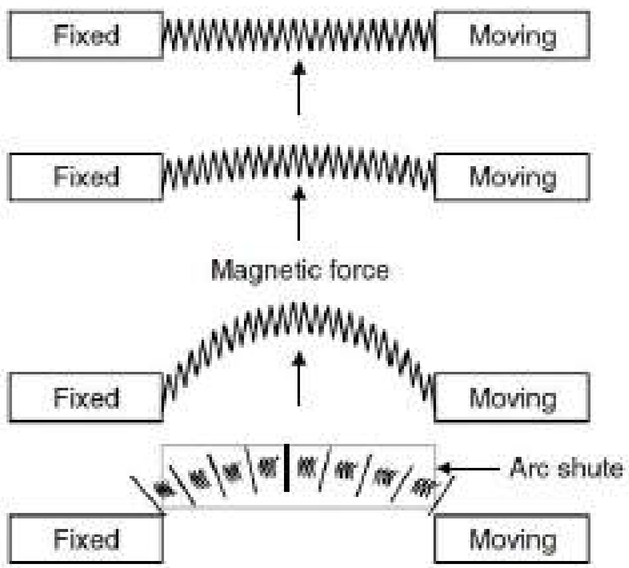
2. Magnetic forces tend to force main contacts apart and movement causes oil to be sucked in through ports and squirted past gap.

3. When arc extinguished (at current zero), ionized gases get swept away and prevents prestriking of the arc



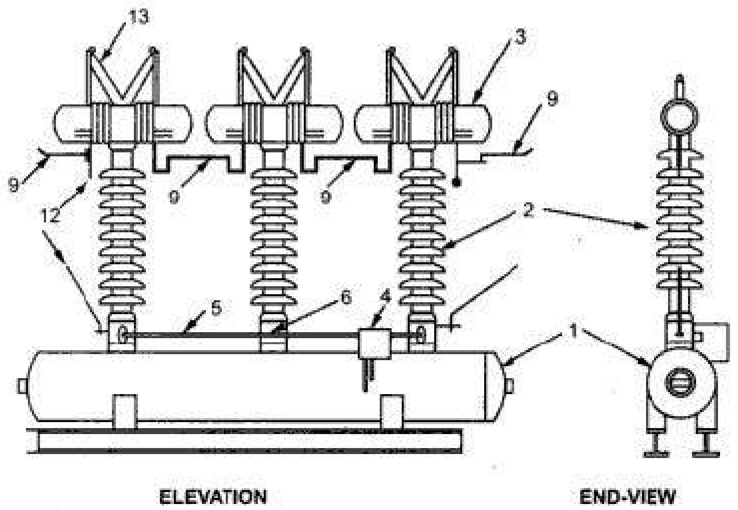
Air break switchgear

Interrupting contacts situated in air instead of any other artificial medium Arc is chopped into a number of small arcs by the Arc-Shute as it rises due to heat and magnetic forces. The air circuit breakers are normally employed for 380~480 V distribution.

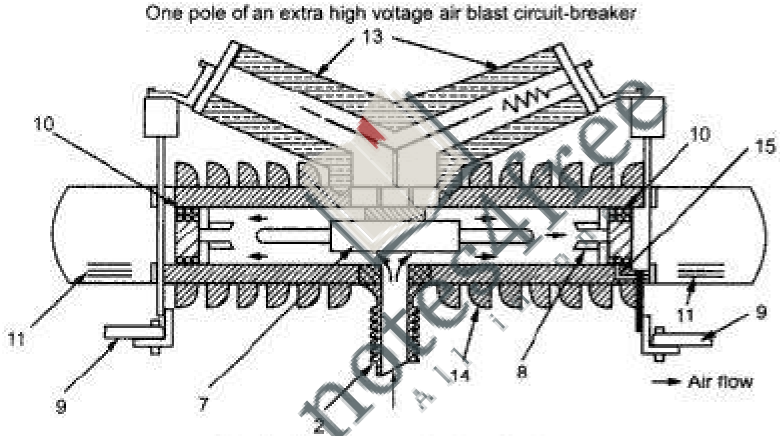


Air break switchgear

These types of circuit breakers are used in earlier days for the voltage ranges of 11kv to 1100kV. At the bottom there is a tank which is called air reservoir with the valves. On this reservoir there are three hollow insulator columns. On the top of each insulator column there is double arc extinguishing chamber. The current carrying parts are connected to the arc extinction chambers in series. The assembly of entire arc extinction chamber is mounted on insulators as there exists large voltage between the conductors and air reservoir. The double arc extinction chamber is shown separately in the Fig below. It can be seen that for each circuit breaker pole there are six break as there are three double arc extinction poles in series. Each arc extinction chamber consists of two fixed and two moving contacts. These contacts can move axially so as to open or close. The position depends on air pressure and spring pressure. The opening rod is operated by when it gets control signal (may be electrical or prtearnatic). This will lead to flow of high pressure air by opening the valve. The high pressure air enters the double arc extinction chamber rapidly. Due to the flow of air the pressure on moving contacts increases than spring pressure and contacts open The contacts travel through a small distance against the spring pressure. Due to the motion of moving contacts the port for outgoing air is closed and the whole arc extinction chamber is filled with high pressure air. But during the arcing period the air passes through the openings shown and takes away ionized air of arc. In case of making operation the valve is turned which connects hdlow column of insulator and the reservoir. The air is passed to the atmosphere due to which pressure of air in the chamber is dropped to atmospheric pressure and closing of moving contacts is achieved against spring pressure.



One pole of an extra high voltage air blast circuit-breaker



Details of double arc extinction chamber

1. Tank air reservior (receiver)
2. Hollow insulator assembly
3. Double arc extinction chamber
4. Pneumatic operating mechanism
5. Operating rod
6. Pneumatic value
7. Fixed contact (in 3)
8. Moving contact (in 3)
9. Connection for current
10. Compression springs
11. Openings for air outlet
12. Arcing horns Optional
13. Resistance switching unit
14. Enclosure
15. Port

Working: An auxiliary compressed air system is required by this type of circuit breaker. This will supply air to the air reservior of the breaker. During the opening operation, the air is allowed to enter in the extinction chamber which push., away moving contacts. The contacts are separated and the blast of air will take ionized gases with it and helps in extinguishing the arc.

Advantages: The vanous advantages of air blast circuit breakers are, i) No fire hazards are possible with this type of circuit breaker. ii) The nigh speed operation is achieved. iii) The time for which arc persists is short. Thus the arc gets extinguished early. iv) As arc duration is short and consistent, the amount of heat released is less and the contdct points are burnt to a less extent. So life of circuit breaker is increased. v) The extinguishing medium in this type of circuit breaker is compressed air which is supplied fresh at each operation. The arc energy at each operation is less than that compared with oil circuit breaker. So air blast circuit breaker is most suitable where frequent operation is required. vi) This type of circuit breaker is almost maintenance free. vii) It provides facility of high speed reclosure. viii) The stability of the system can be well maintained.

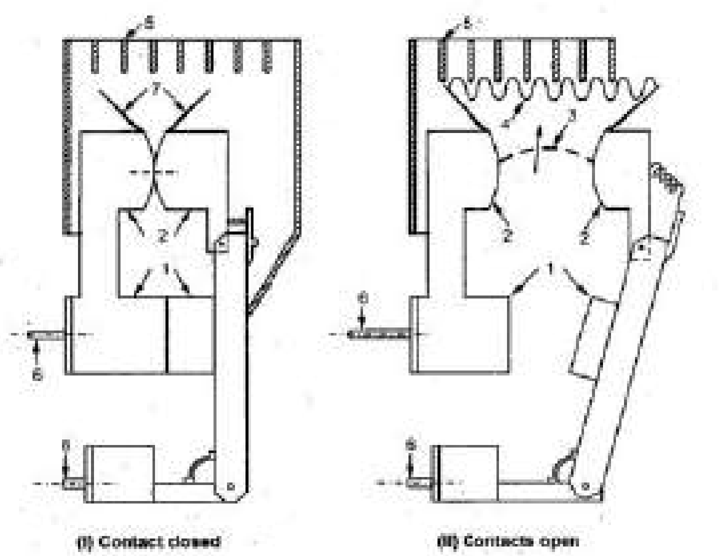
Disadvantages: The various disadvantages of air blast circuit breakers are, i) If air blast circuit breaker is to be used for frequent operation it is necessary to have a compressor with sufficient capacity of high prewure air. ii) The maintenance of compressor and other re!ated equipments is required. iii) There is possibility of air leakages at the pipe fittings. iv) It is very sensitive to restriking voltage. Thus current chopping may occur which may be avoided by employing resistance switching.

Applications :The air blast circuit breakers are preferred for arc furnace duty and traction system because they are suitable for repeated duty. These type of circuit breakers are finding their best application in systems operating in range of 132 kV to 400 kV with breaking capacities upto 700 MVA. This will require only one or two cycles. There are two major types - cross blast and aVial blast.

Air Break(circuit breaker)

In air circuit breakers the atmospheric pressure air s used as an arc extinguishing medium. the principle of high resistance interruption is employed for such type of breakers. The length of the arc is increased using arc runners which will increase its resistance in such a way that the voltage drop across the arc becomes mom than the supply voltage and the arc will he extinguished This type of circuit breaker is employed in both ac and d.c. type of circuits upto 12 kV. These are normally indoor type and installed on vertical panels. The lengthening of arc is done with the help of mangetic fields. Some typical ratings of this type of circuit breaker are 460V - 3.3 kV with current range 400 - 3503 A or 6.6 kV with current range 403-2400 A etc.

Construction The Fig. shows the constructional details of air break circuit breaker.



Principle of air-break circuit-breaker

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

It consists of two sets of contacts I) Main contacts 2) Arcing contacts

During the normal operation the main contacts are closed. They are having low resistance with silver plating. The arcing contact: are very hard, heat resistant. They are made up of copper alloy. Arc runners are provided at the one end of arcing contact. On the upper side arc splitter plates are provided.

Working As seen from the Fig the contacts remain in closed position during normal condition. Whenever fault occurs, the tripping signal makes the circuit Current breaker contacts to open. The arc is drawn in between the contacts When ever the arc is struck between the contacts, the surrounding air gets ionized. The arc i5 then cooled to reduce the diameter of arc core. While separating the main contacts are separated first. The current is then shifted to arcing contains. Later on the arcing contacts also start separating and arc between them is forced upwards by the electromagnetic forces and thermal action. The arc travels through the arc runners. Further it moves upwards and split by arc splitter plates. Due to all this finally the arc gets extinguished as the resistance of the arc is increased. Due to lengthening and cooling, arc resistance increases which will reduce the fault current and will not allow reaching at high value. The current zero points in the ac. wave will help the arc extinction with increase in arc resistance the drop across it will go on increasing. Whenever arc leaves the contacts it is passed through arc runners with the help of blow out coils which provide a magnetic field due to which it will experience a force as given by electromagnetic theory (F = 131/). This force wilts assist in moving the arc upwards. The magnetic field produced is insufficient to extinguish the arc. For systems having low inductances arc gets extinguished before reaching extremity of runners because lengthening of arc will increase the voltage drop which is insufficient to maintain the arc.

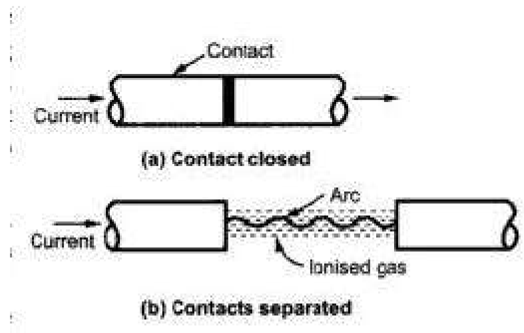


Fig working of air breaks circuit breaker

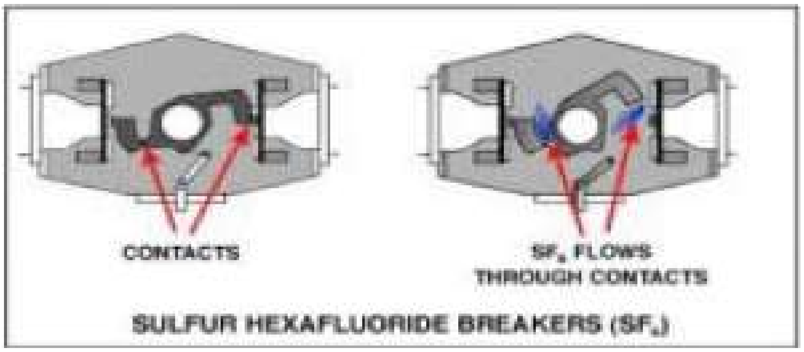
For high inductance circuits if it is not extinguished while travelling through arc runners then it is passed through arc splitters where it is cooled. This will make the effective deionized by removing the heat from arc.

Applications: this type of circuit breakers are commonly employed for industrial switchgear, auxiliary switch gear in generating stations.

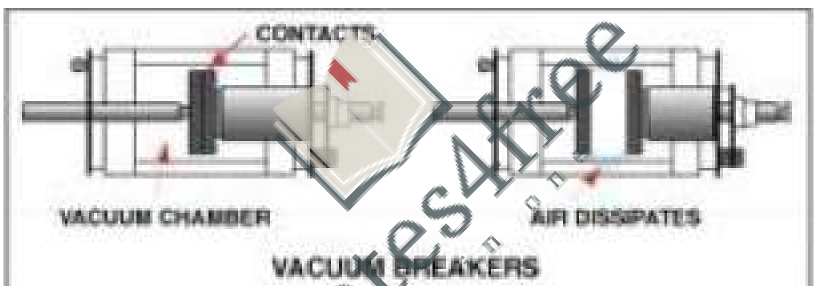
Sulphur Hexafluoride (SF6) Circuit Breaker Pure sulphur hexafluride gas is inert and thermally stable. It is having good dielectric and arc extinguishing properties. It is also an electronegative gas and has strong tendency to absorb free electrons. SF, gas remains in gaseous state up to a temperature of r C. Its density is about five times that of air and the free heat convection is 1.6 times as much as that of air. Also being inert it is non-in flammable, non-poisonous and odour less. The contacts of the breaker arc opened in a high pressure flow of SF6, gas and an arc is struck between them The conducting electrons front the arc are captured by the gas to form relatively immobile negative ions. The loss of this conducting electrons developes enough strength of insulation which will extinguish the arc. Thus SF, circuit breakers are found to be very effective for high power and high voltage service and widely used in electrical equipment. Only the care to be taken is that some by-products are produced due to breakdown of gas which are hazard to the health of the personnel it should be properly disposed. Several types of SF, circuit breakers are designed by various manufacturers in the world during the recent years which are rated for voltages from 3.6 to 760 kV. The property of this gas is that the gas liquifies at certain low temperatures. The liquification temperature can be increased with pressure this gas is commercially manufactured in many countries and now used extensively, in electrical industry. The gas is prepared by burning coarsely crushed roll sulphur in fluorine gas in a steel box. The box must be provided with staggered horizontal shelves each containing about 4 kg of sulphur. The steel box is gas tight. After the chemical reaction taking place in the box, the SF6 gas obtained contains impurities in the form of fluorides such as S21410, SF4 etc. Thus it must be purified before it is supplied. The manufacturing of this gas at large scale reduces its cost. The dielectric strength of SF6 gas at any pressure is more than that of air. When the gas comes in contact with the electric arc for long period, the decomposition effects are small and dielectric strength is not considerably reduced and the metallic fluorides that are formed are good insulators and are not harmful to the breaker.

Sulphur-hexa flouride (SF6) is an inert insulating gas, which is becoming increasingly popular in modern switchgear designs both as an insulating as well as an arc-quenching medium. Gas insulated switchgear (GIS) is a combination of breaker, isolator, CT, PT, etc., and are used to replace outdoor substations operating at the higher voltage levels, namely 66 kV and above. For medium- and low-voltage installations, the SF6 circuit breaker remains constructionally the same as that for oil and air circuit breakers mentioned above, except for the arc interrupting chamber which is of a special design, filled with SF6. To interrupt an arc drawn when contacts of the circuit breaker separate, a gas flow is required to cool the arcing zone at current interruption (i.e. current zero). This can be achieved by a gas flow generated with a piston (known as the ‘puffer’ principle), or by heating the gas of constant volume with the arc’s energy. The resulting gas expansion is directed through nozzles to provide the required gas flow. The pressure of the SF6 gas is generally maintained above atmospheric; so good sealing of the gas chambers is vitally important. Leaks will cause loss of insulating medium and clearances are not designed for use in air. **Sulfur hexafluoride (SF6)**

Sulfur hexafluoride (SF6) is an insulating gas used in circuit breakers in two ways. In "puffer" designs, it's blown across contacts as they open to displace the arcing gas. In "blast" designs, it's used at high pressures to open contacts as it simultaneously extinguishes the arc.SF6 breakers are rated for the highest voltage of all breaker designs



Vacuum breakers enclose the contacts within a vacuum chamber, so when the arc of metallic vapor forms it is magnetically controlled and thereby extinguished at current zero. Vacuum breakers are rated up to 34.5 kV.



Salient features:

- Simple and compact design.
- Line to ground clearances as per customer specification.
- Self aligning contacts for easy re-assembly.
- Inspection / maintenance of pole unit possible without dismantling the breaker.
- Separate main and arcing contacts thus eliminating the possibility of erosion of the main contacts.
- Single break up to 245 kV level.
- Consistent operating characteristics as the closing spring is in relaxed condition.

- Stainless steel latches /catches for high reliability.
- Corrosion resistant materials for construction.
- Maintenance free operation of the pole unit for 15-20 years under normal conditions.
- Easy erection.
- No site adjustments.
- Easy access to all parts of operating mechanism through front/back opening panels.
- Low operating noise levels.
- Auto drain valve for unmanned substation operations.
- Pressure relief device.
- High seismic withstand capability - earthquake safety.

Construction & operation:

All our SF6 Circuit breakers have a similar interrupter design. The range of breakers from 72.5 kV to 245 kV is manufactured with single break interrupter design while 420 kV breakers are manufactured with double break interrupters. These breakers are of live tank design and employ puffer action for interruption ensuring higher operational reliability and safety of power transmission and distribution systems. The interrupting unit filled with SF6 gas is placed at the top of the pole and contains Stationary

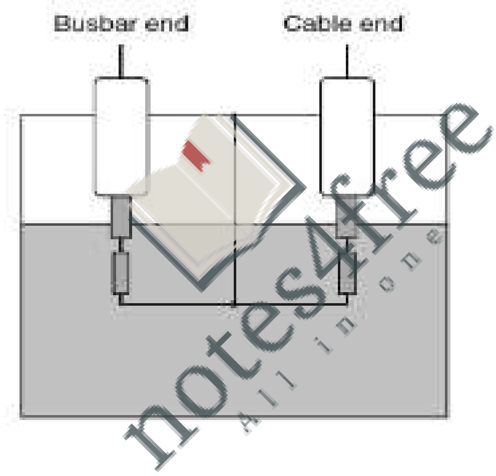
Contact, Nozzle, Moving Contact, Puffer Cylinder and Fixed Piston. During opening operation the Moving Contact along with the Puffer Cylinder is pulled down. The Puffer Cylinder, which moves along with the Moving Contact, compresses the SF6 gas against the Fixed Piston thus generating a powerful SF6 gas blast through the nozzle and over the arc. After travelling through some distance, the dielectric strength of the gap is sufficient to withstand the voltage and thus the arc extinguishes. The reliability of the system is further increased by the single pressure dual flow SF6 gas puffer interrupter which reduces the number of moving parts and auxiliary systems in the circuit breaker.

Oil circuit breakers

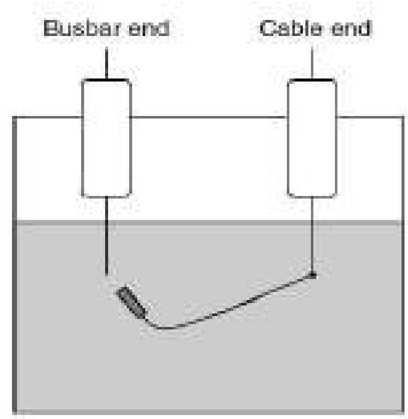
In modern installations, oil circuit breakers, which are becoming obsolete, are being replaced by vacuum and SF6 breakers. However there are many installations, which still employ these breakers where replacements are found to be a costly proposition. In this design, the main contacts are immersed in oil and the oil acts as the ionizing medium between the contacts. The oil is mineral type, with high dielectric strength to withstand the voltage across the contacts under normal conditions.

(a) Double break (used since 1890),.

(b) Single break (more popular in earlier days as more economical to produce –less copper, arc control devices, etc., Arc energy decomposes oil into 70% hydrogen, 22% acetylene, 5% methane and 3% ethylene. Arc is in a bubble of gas surrounded by oil.



Double break oil circuit breaker



Single break oil circuit breaker

Oil has the following advantages:

• Ability of cool oil to flow into the space after current zero and arc goes out

• Cooling surface presented by oil

• Absorption of energy by decomposition of oil

• Action of oil as an insulator lending to more compact design of switchgear.

Disadvantages:

• Inflammability (especially if there is any air near hydrogen)

• Maintenance (changing and purifying).

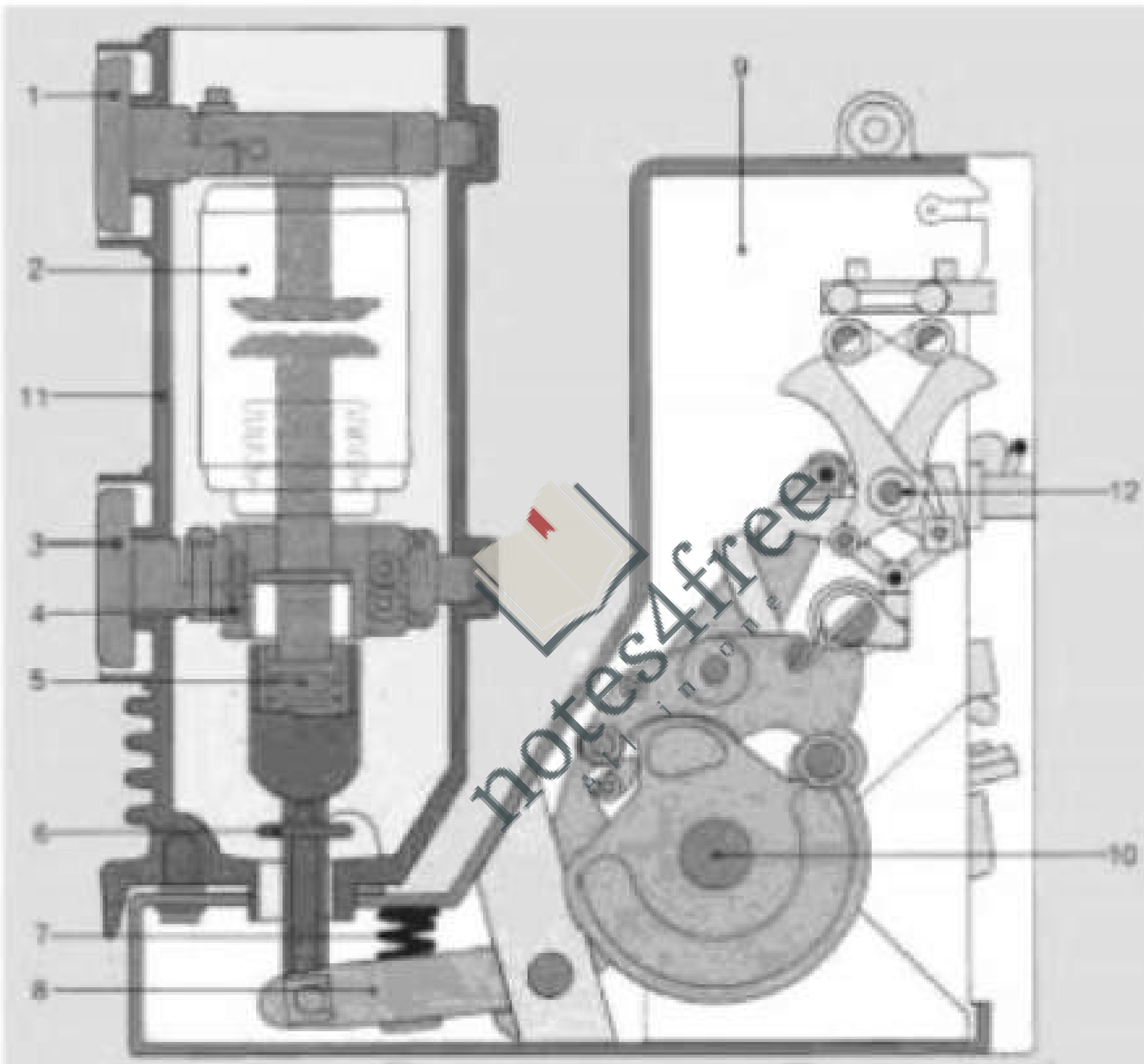
In the initial stages, the use of high-volume (bulk) oil circuit breakers was more common. In this type, the whole breaker unit is immersed in the oil. This type had the disadvantage of production of higher hydrogen quantities during arcing and higher maintenance requirements. Subsequently these were replaced with low oil (minimum oil) types, where the arc and the bubble are confined into a smaller chamber, minimizing the size of the unit.

Vacuum circuit breakers and contactors: Vacuum circuit breakers and contactors were introduced in the late 1960s. A circuit breaker is designed for high through-fault and interrupting capacity and as a result has a low mechanical life. On the other hand, a contactor is designed to provide large number of operations at typical rated loads of 200/400/600 A at voltages of 1500/3300/6600/11 000 V.

The following table illustrates the main differences between a contactor and a circuit breaker

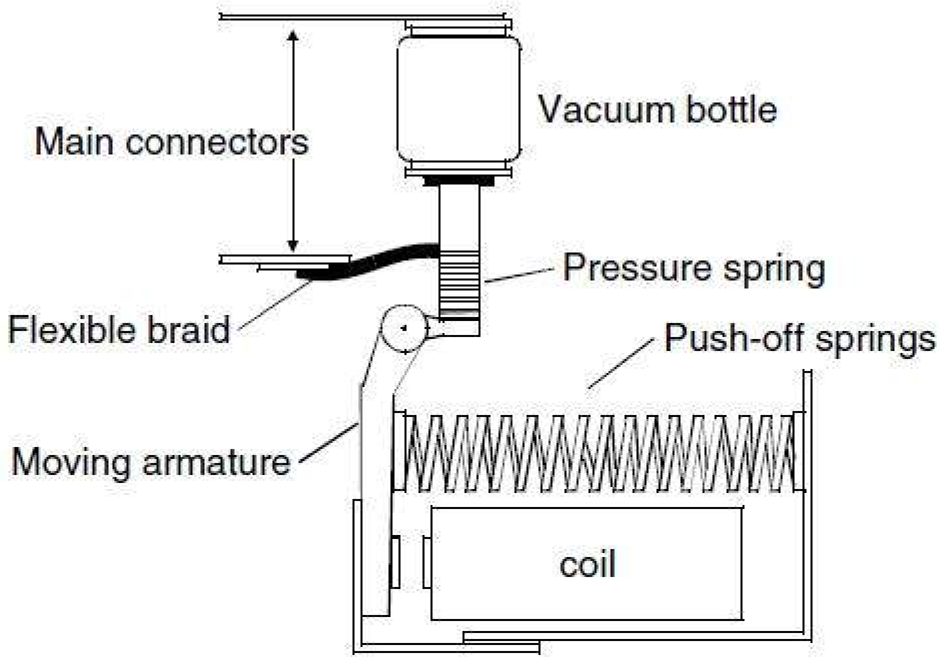
	Contactor	Circuit Breaker
Interrupting capacity	4.0 kA	40 kA
Current rating	400/630 A	630/3000 A
Contact gap at 11 kV	6.0 mm	16.0 mm
Contact force	10 kg	80 kg
Mechanical life	1–2.5 million	10 000

Hence, it is necessary to use back-up fuses when contactors are employed to take care of the high fault conditions. Vacuum breakers are also similar in construction like the other types of breakers, except that the breaking medium is vacuum and the medium sealed to ensure vacuum. Figures below give the components of a vacuum circuit breaker.



1 Upper connection	7 Opening spring
2 Vacuum interrupter	8 Shift lever
3 Lower connection	9 Mechanism housing with spring operating mechanism
4 Roller contact (swivel contact for 630 A)	10 Drive shaft
5 Contact pressure spring	11 Pole tube
6 Insulated coupling rod	12 Release mechanism

General construction of a vacuum circuit breaker



The modern vacuum bottle, which is used in both breakers and contactors, is normally made from ceramic material. It has pure oxygen-free copper main connections; stainless steel bellows and has composite weld-resistant main contact materials. A typical contact material comprises a tungsten matrix impregnated with a copper and antimony alloy to provide a low melting point material to ensure continuation of the arc until nearly current zero.

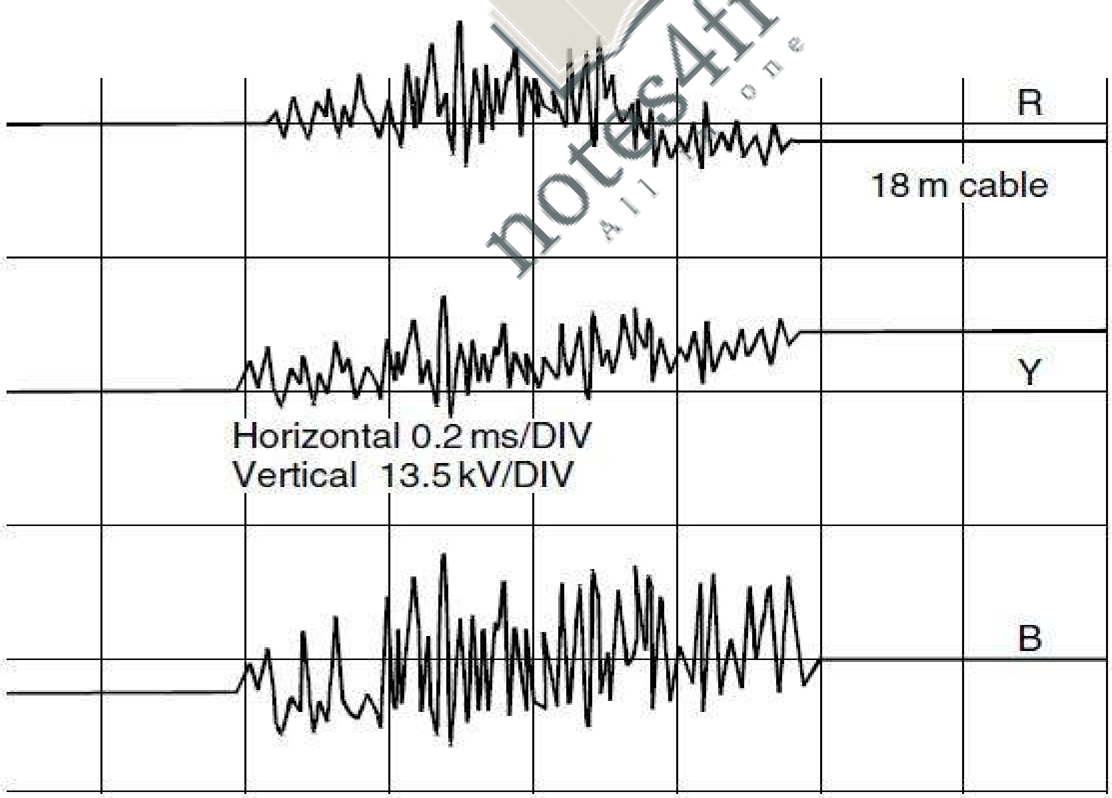
Because it is virtually impossible for electricity to flow in a vacuum, the early designs displayed the ability of current chopping i.e. switching off the current at a point on the cycle other than current zero. This sudden instantaneous collapse of the current generated extremely high-voltage spikes and surges into the system, causing failure of equipment.

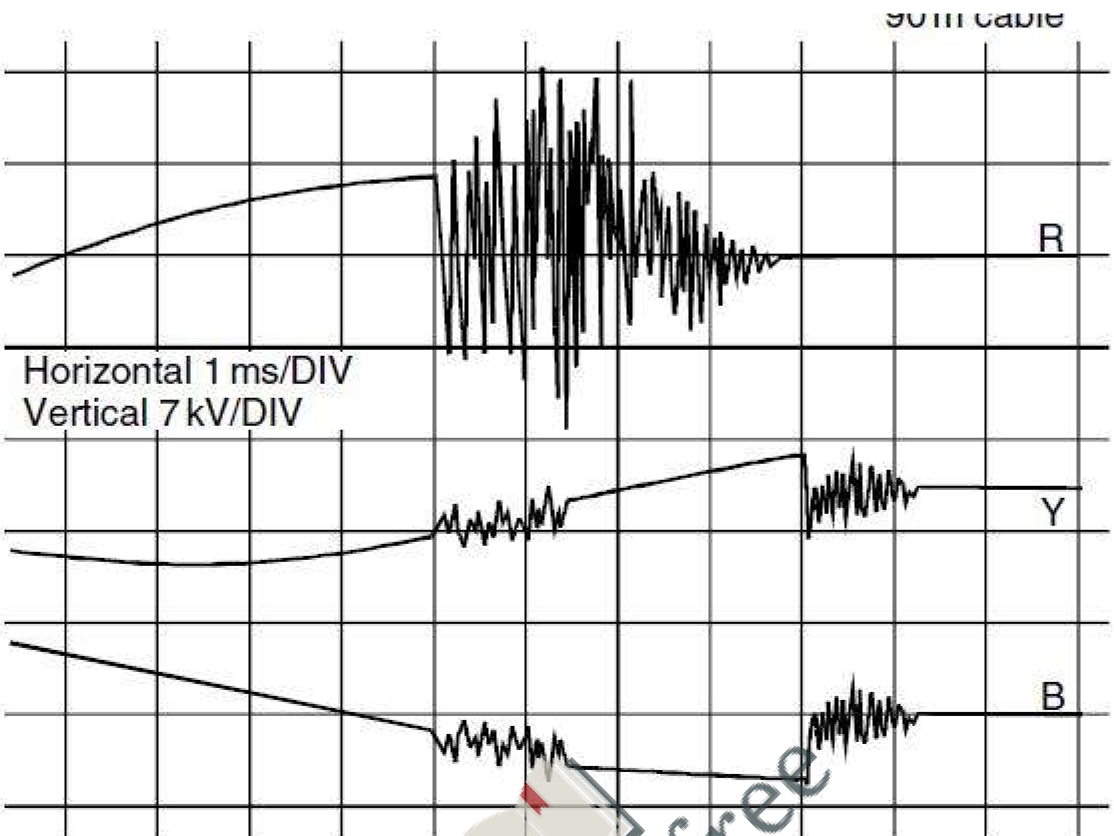
Another phenomenon was pre-strike at switch on. Due to their superior rate of dielectric recovery, a characteristic of all vacuum switches was the production of a train of pulses during the closing operation. Although of modest magnitude, the high rate of rise of voltage in pre-strike transients can, under certain conditions produce high-insulation stresses in motor line end coils. Subsequent developments attempted to alleviate these shortcomings by the use of ‘softer’ contact materials, in order to maintain metal vapor in the arc plasma so that it did not go out during switching. Unfortunately, this led to many instances of contacts welding on closing.

Restrike transients produced under conditions of stalled motor switch off was also a problem. When switching off a stalled induction motor, or one rotating at only a fraction of synchronous speed, there is little or no machine back emf, and a high voltage appears across the gap of the contactor immediately after extinction. If at this point of time the gap is very small, there is the change that the gap will break down and initiate a restrike transient, puncturing the motor's insulation.

Modern designs have all but overcome these problems. In vacuum contactors, higher operating speeds coupled with switch contact material are chosen to ensure high gap breakdown strength, produce significantly shorter trains of pulses. In vacuum circuit breakers, operating speeds are also much higher which, together with contact materials that ensure high dielectric strength at a small gap, have ensured that prestrike transients have ceased to become a significant phenomenon. These have led to the use of vacuum breakers more common in modern installations.

Practical Power Systems Protection





Switch off of stalled 6.6 kV 200 kW motor-escalating restrike on R phase

Dashpots

In oil circuit breakers, when the breaker is closed, if the operation is not damped then contact bounce may occur and the breaker may kick open. Dashpots prevent this. They may also prevent unnecessary physical damage to the contacts on impact. Their use of course depends on the design.

Contacts

Fixed contacts normally have an extended finger for arc control purposes. Moving contacts normally have a special tip (Elkonite) to prevent burning from arcing.

Comparison of insulating methods for CBs

Property	Air	Oil	SF6	Vacuum
Number of operations	Medium	Low	Medium	High
'Soft' break ability	Good	Good	Good	Fair
Monitoring of medium	N/A	Manual test	Automatic	Not possible
Fire hazard risk	None	High	None	None
Health hazard risk	None	Low	Low	None
Economical voltage range	Up to 1 kV	3.3–22 kV	3.3–800 kV	3.3–36 kV

Comparison of breaker types

Following curve gives the requirement of electrode gaps for circuit breakers with different insulating mediums

Practical Power Systems Protection

The following table highlights the features for different types of circuit breakers.

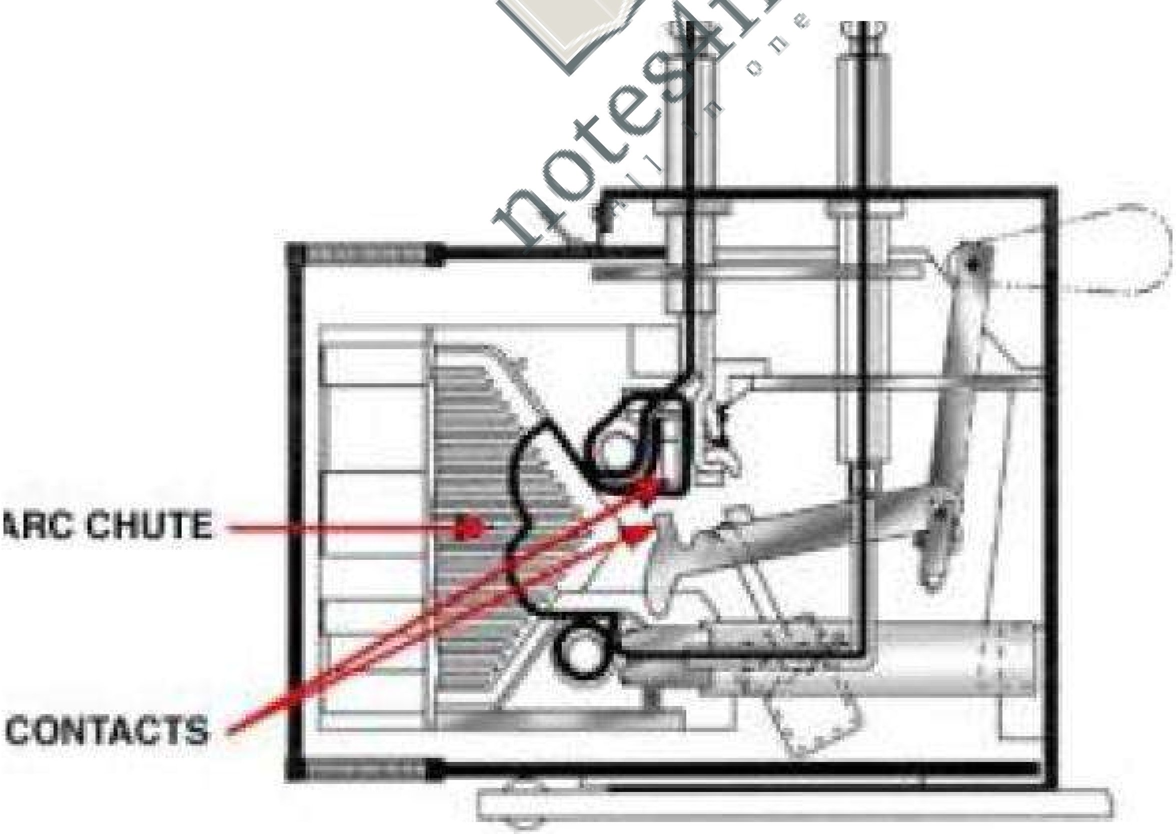
Factor	Oil Breakers	Air Breakers	Vacuum/SF6
Safety	Risk of explosion and fire due to increase in pressure during multiple operations	Emission of hot air and ionized gas to the surroundings	No risk of explosion
Size	Quite large	Medium	Smaller
Maintenance	Regular oil replacement	Replacement of arcing contacts	Minimum lubrication for control devices
Environmental factors	Humidity and dust in the atmosphere can change the internal properties and affect the dielectric		Since sealed, no effect due to environment
Endurance	Below average	Average	Excellent

Circuit Breaker Operation

In addition to the events that cause a trip, a circuit breaker for switchgear applications must also be selected for the method by which it opens when tripped. This is important, because when contacts are opened quickly at high voltage levels, a conductive metallic vapor can form that allows current to continue to travel between the open contacts. This phenomenon, known as arcing, creates the greatest obstacle to circuit interruption.

As a result, medium- and high-voltage circuit breakers employ one of four different arc interrupting technologies. All take advantage of the fact that even the most powerful AC overcurrent cycles pass the zero current level twice in one cycle. By reducing the amount of conductive gas between the contacts, the arc cannot be sustained when it passes through a current zero. Since the current in DC circuits does not follow a sine-wave pattern, circuit interruption is very difficult. This makes the DC interrupting rating for most breakers much lower than the interrupting rating for AC circuits.

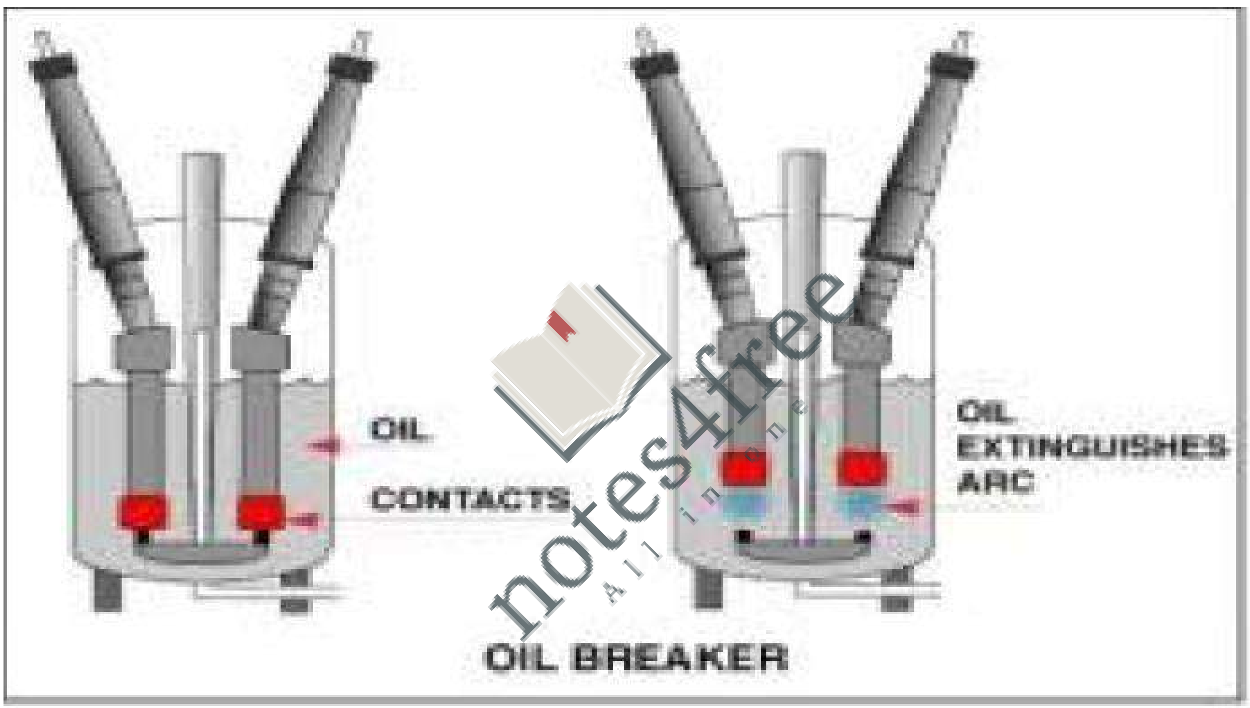
Air magnetic breakers



Air magnetic breakers use the arc to generate a magnetic field that forces the arc into arc chutes, which lengthen and cool the arc, allowing it to be extinguished at a current zero.

Oil breakers

Oil breakers are of several types, including bulk oil, but they all work in a relatively similar way. Here, the contacts are immersed in a container of non-conductive oil. When an overcurrent occurs, the arc heats the surrounding oil forcing it to flow violently. The rapidly flowing oil displaces the arcing gases and breaks the arc path.



Oil breakers always carry the hazards of handling and disposing of spent oil, and the potential for oil fire. Different oil breakers are designed for different power levels, with the highest rated for 345 kV to 500 kV.

Testing of Circuit breakers

Type Tests As mentioned earlier these tests are carried out on first few circuit breakers to prove the rated characteristics of the breakers. The necessary information which includes assigned ratings, drawings, reference standards, rated operating pressure and voltage, support structure etc must he supplied to the testing authorities More conducting these test.. These details are included in the type tests report. After certifying the breaker by carrying out these tests, there should not be any change in design. Type tests are classified as follows,

a) Mechanical tests

b) Tests of temperature rise, milli volt drop test

c) High voltage test

d) Basic short circuit test i) Making test ii) Breaking test iii) Operating sequence tests at 10%, 30%, 60%, 100% of rated breaking current with specified TRV conditions.

e) Critical current tests

f) Single phase short circuit test

g) Short time current test In addition to above tests some more tests are recommended breakers to be used in specific applications, which are, a) Short line fault tests b) Out of phase switching tests c) Cable charging current switching test d) Capacitive current switching tests e) Small inductive current breaking tests of Reactor current switching tests

Routine Tests

Before dispatch of circuit breakers, these tests are performed. Routine test is defined as a test of every circuit breaker made to the same specifications. They include the following tests. a) Mechanical operation tests b) Millivolt drop test, Measurement of resistance c) Power frequency voltage tests d) Voltage tests on auxiliary circuits, control circuits the quality of the circuit breaker can be very well checked by these tests. Also any defect in the materials and construction is detected.

Development Tests These tests, are very much essential to observe the effect of different parameters on the circuit breakers performance. Variety of tests is performed on individual items as well as on complete assemblies. If a circuit breaker is tested frequently with change in its contact speed, then we can see the effect of contact speed on breaking capacity the different parameters and their effects are theoretically predicted. Full scale prototypes are manufactured after testing and measurement. The data available in the company is used by the designers for name for the design of contacts; the configuration can be derived from available designs of contact assemblies. Each subassembly has certain functional requirement e.g. the contacts should give low resistance in closed position. Therefore to verify the capability of contact configurations, development tests are conducted, depending on functional requirements. The modifications are done on the basis of these test results.

Reliability Tests The newly manufactured circuit breakers are tested by type tests and routine tests. But the conditions during these tests are not the conditions that exist at the field. At site the circuit breaker is subjected to various stresses due to,

a) Variation in ambient temperatures

b) Extremely low and high temperatures

c) Rain moisture

d) Vibrations on account of earthquakes

e) Dust and chemical fumes, Overloads and over voltages

Unit Testing The modern FEW circuit breakers contains two or more similar interrupters per pole. These interrupters operate simultaneously and share the voltage across the pole equally. The breaking capacity is also equally shared. The results obtained on one unit can be extended further for total capacity of breaker. This is known as unit testing or element testing. It is internationally accepted method. During the application of unit test, the voltage must be reduced by a factor b so the corresponding impedances are also reduced by b to get test voltage across the unit following expression. a = where m = number of units per pole and one unit is tested

are in opposition. The stress ei produced in the synthetic test and those in actual network must be same but it is not the actual case because of several factors like high current, high voltage, instant of applying voltage etc.

Brown Boveri's Synthetic Testing Circuit This circuit is shown in the Fig. 10.35. The short circuit current is supplied from low voltage circuit. The restriking and recovery voltage is supplied by different high voltage circuit.

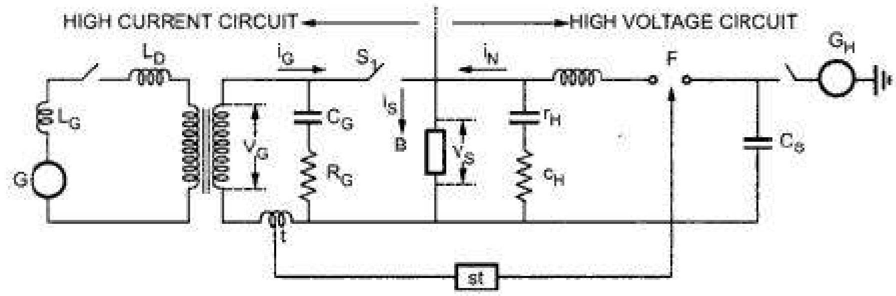


Fig. shows Brown-Boveri's synthetic testing circuit The high current circuit on left side consists of short circuit generator G, short circuit transformer with resistor Rc and capacitor Cc which controls natural frequency of current. The short circuit power is supplied at voltages Vs which corresponds to about 30 kV which is smaller than recovery voltage required for testing. The recovery voltage is supplied by high voltage circuit on right side. The test breaker and auxiliary breaker S, are opened together. Before the current interruption takes place in breaker B, the spark gap is triggered by control St and voltage V is applied to breaker B. During final current zero only current if, Lows through breaker B. which is interrupted by S, and breaker B. But now breaker B has to interrupt only. Hence restriking voltage across breaker B is given by NV circuit.

Lightning arresters

Introduction: The voltage wave having magnitude more than its normal value and which remains for a very short duration are called overvoltage surges or transmit over voltages. For any electrical equipment, its insulation requirements are decided by these transient over voltages. The over voltages in the system occur due to various reasons such as lightning surges, switching surges, faults and travelling waves. There is high rate of rise and high peak value in transient over voltages which are dangerous for the Insulation and hence protection is rewired against these over voltages.

Lightning Phenomenon: A lightning stroke on any overhead line or on outdoor equipment causes lightning surges. Before studying the protection against these lightning surges, let us study the mechanism of lightning. An electrical discharge in the air between clouds, between the separate charge centers in the same cloud or between cloud and the earth is nothing but lightning. It produces the large spark accompanied by the light. This discharge of electricity through the air from the clouds under turbulent conditions is always abrupt and discontinuous. The serious hazards may take place sometimes if this discharge terminates on the earth. There are various theories which explain the potentials required for lightning strokes, are built up. However we will assume that because of some process taking place. In the atmosphere under the turbulent conditions there is accumulation of charges in the clouds. With the dielectric medium as the air the cloud and the ground form plates of a capacitor. If the lower part of the cloud la negatively charged, the earth is positively charged by induction. For lightning discharge to take place, it requires breakdown of air between the cloud and the earth. With increase in the charge, the potential between the cloud and the earth increases. As a result of this the potential in the air increases. The potential gradient required for the breakdown of air is 30 kV/cm peaks. But there is large moisture content in the air and because of lower pressure at high altitude; the breakdown of air takes place at 10 kV/ar. The process of lightning discharge is shown in the Fig.

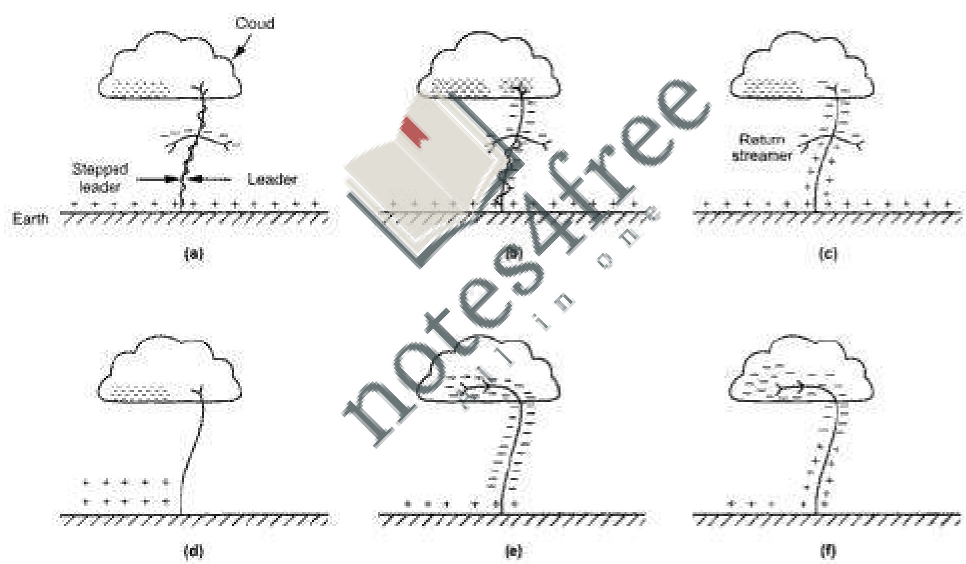


Fig. When charge increases there is difference in potential between cloud and earth which also increases resulting in increase of potential gradient of air which is non uniformly distributed. The potential gradient is more at the center of charge in the cloud. This gradient appears across some part of the air and when it is more than breakdown strength of air, this air breaks down A streamer called pilot streamer or leader streamer starts from cloud towards the earth and carries the charge with it as shown in the Fig. (Till the time the cloud through which this stream is initiated supplies enough charge to maintain the potential gradient at the tip of the leader streamer above the breakdown strength of air, the leader streamer continues to travel towards the earth. With the loss of this gradient, the streamer stops without reaching to the earth. The charge dissipated without forming the complete stroke. The lightning stroke may start with the potentials of the order of 5* 106 Vie 20x 106 V between cloud and earth while the current of the leader streamer is low, typically less than 100 A and its propagation velocity is 0.03 % of that of velocity of light.

Many times the streamer travels towards the earth until it is reached to the earth or some abject on earth. As the initial moves towards earth, it is accompanied by points of luminescence which travel in jumps giving rise to stepped leaders In step the distance travelled is about 50 in while the velocity of stepped leader exceeds one sixth of that of light. The stepped leaders results in first visual phenomenon of discharge. The electrostatic field and potential gradient at earth's surface is high as this streamer reaches to the earth. When sufficiently large then a short upward streamer called return streamer rises form the earth as shown in the Fig. When the contact of leader b made with the earth then a sudden spark may be appeared. This contact is similar to closing of a switch between two opposite charges, the downward leader with negative change and upward streamer with positive charge. Due to this sudden sparks appearing which causes the most neutralization of negative charges on the cloud? This is called lightning. Any further discharge from the cloud must be originated form other portion of it. When lightning occurs then it is associated with high current followed by lower current for significant duration as the charge in the cloud is neutralized. The upward streamer carries high current with a speed of propagation of about 30 m/ iL sec which is faster than the speed of the leader streamer. The current rises sharply within microseconds and then decays slowly compared to its rise. this is similar to discharge of a capacitor through a circuit but it is not periodic. The experiments conducted in the laboratories show that when the charge in the channel is near exhaustion, there is smooth transition in current into its low value which is associated with the remaining charge in the cloud. When the streamer reaches the earth and much of charge in the cloud from which it was originated, is neutralized then potential pertaining to point of charge center reduces. But there may exist high potential between this original charge center and other charge centers. Due to this, there may be discharge from other charge centers into the region where the leader streamer was originated. Thus a subsequent discharge takes place along with the original stroke to the earth. Many strokes can be observed which contains more than one current peak which are called multiple or repetitive. Separate peaks are termed as components. In summary we can say that lightning is a phenomenon of breakdown of air and discharge which can he seen by eve as a sing 'e flash but contains number of separate strokes that travels with same path practically. The variation of time interval between them is from 0.5 m sec< to 300 msec. 87 % of the lightning strokes originate from negatively charged clouds while remaining 13 % originate from positively charged clouds. Lightning discharge current magnitude lies in the range of 10 kA to 90 kA.

MODULE 4

PRINCIPLES OF CIRCUIT BREAKERS

- Principles of circuit breakers**:** Introduction, requirement of a circuit breakers
- Difference between an isolator and circuit breaker
- basic principle of operation of a circuit breaker, phenomena of arc, properties of arc, initiation and maintenance of arc,
- arc interruption theories - slepian's theory and energy balance theory,
- Re striking voltage, recovery voltage, Rate of rise of Re striking voltage,
- DC circuit breaking, AC circuit breaking, current chopping, capacitance switching, resistance switching
- Rating of Circuit breakers.

Introduction

Where fuses are unsuitable or inadequate, protective relays and circuit breakers are used in combination to detect and isolate faults. Circuit breakers are the main making and breaking devices in an electrical circuit to allow or disallow flow of power from source to the load. These carry the load currents continuously and are expected to be switched ON with loads (making capacity). These should also be capable of breaking a live circuit under normal switching OFF conditions as well as under fault conditions carrying the expected fault current until completely isolating the fault side (rupturing/breaking capacity). Under fault conditions, the breakers should be able to open by instructions from monitoring devices like relays. The relay contacts are used in the making and breaking control circuits of a circuit breaker, to prevent breakers getting closed or to trip breaker under fault conditions as well as for some other interlocks.

Purpose of circuit breakers (switchgear)

The main purpose of a circuit breaker is to:

• Switch load currents

• Make onto a fault

• Break normal and fault currents

• Carry fault current without blowing itself open (or up!) i.e. no distortion due to magnetic forces under fault conditions.

The important characteristics from a protection point of view are:

• The speed with which the main current is opened after a tripping impulse is received

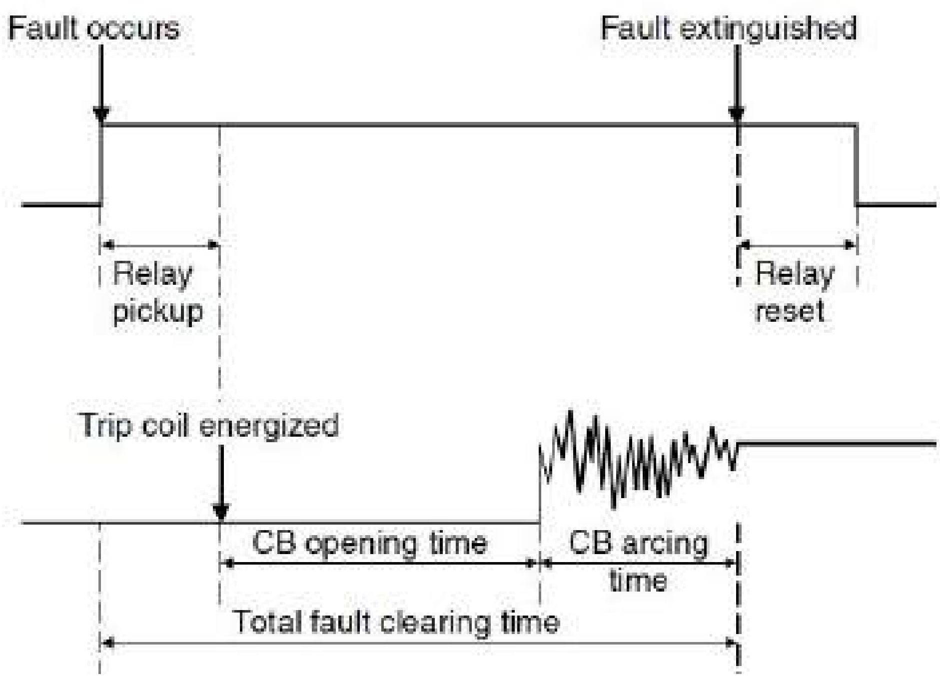
• The capacity of the circuit that the main contacts are capable of interrupting.

The first characteristic is referred to as the 'tripping time' and is expressed in cycles. Modern high-speed circuit breakers have tripping times between three and eight cycles. The tripping or total clearing or break time is made up as follows:

• Opening time: The time between instant of application of tripping power to the instant of separation of the main contacts.

• Arcing time: The time between the instant of separation of the main circuit breaker contacts to the instant of arc extinction of short-circuit current.

•Total break or clearing time



The second characteristic is referred to as 'rupturing capacity' and is expressed in MVA. The selection of the breaking capacity depends on the actual fault conditions expected in the system and the possible future increase in the fault level of the main source of supply. In the earlier chapters we have studied simple examples of calculating the fault currents expected in a system. These simple calculations are applied with standard ratings of transformers, etc., to select the approximate rupturing capacity duty for the circuit breakers.

Requirement of circuit breakers

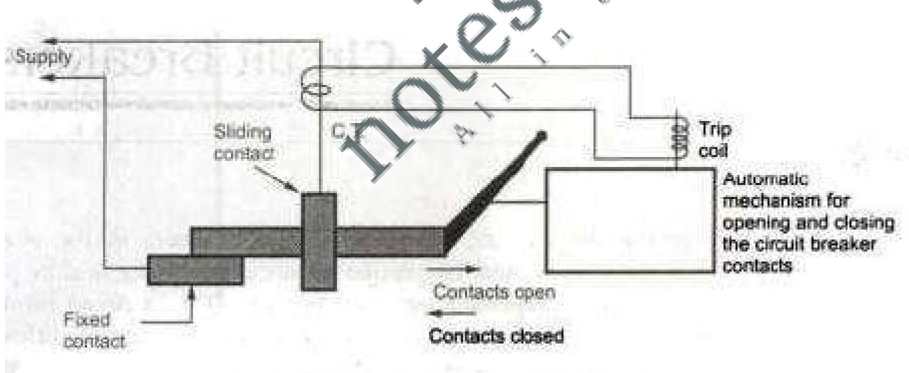
Introduction

As already seen in the last chapter, whenever any fault occurs in the power system then that part of the system must be isolated from the remaining healthy part of the system. This function is accomplished by circuit breakers. Thus a circuit breaker will make or break a circuit either manually or automatically under different conditions such as no load, full load or short circuit. Thus it proves to be an effective device for switching and protection of different parts of a power system. In earlier days fuse was included in. the protective system. But due to some limitations they are not used in practice now a day. The main difference between a fuse and circuit breaker is that under fault condition the fuse melts and it is to be replaced whereas the circuit breaker :an close or break the circuit without replacement.

Requirements of Circuit Breaker: The power associated with the circuit breakers is large and it forms the link between the consumers and suppliers. The necessary requirements of circuit breakers are as follows, 1. The normal working current and the short circuit current must be safely interrupted by the circuit breaker. 2. The faulty section of the system must be isolated by circuit breaker as quickly as possible keeping minimum delay. 3 It should not operate with flow of overcurrent during healthy conditions. 4. The faulty circuit only must be isolated without affecting the healthy one.

Basic principle of operation of a circuit breaker

The Fig. Shows the elementary diagram of a circuit breaker. It consists of two contacts a fixed contact and a moving contact. A handle is attached at the end of the moving contact. It can be operated manually or automatically. The automatic operation needs a separate mechanism which consists of a trip coil. The trip coil is energized by secondary of current transformer. The terminals of the circuit breaker are bought to the supply.



Basic action of circuit breaker

Under normal working conditions the e.m.f produced in the secondary winding of the transformer is insufficient to energize the trip coil completely for its operation. Thus the contacts remain in closed position carrying the normal working current. The contacts can be opened manually also by the handle. Under abnormal or faulty conditions high current in the primary winding of the current transformer induces sufficiently high e.m.f in the secondary winding so that the trip coil is energized. This will start opening motion of the contacts. This action will not be instantaneous as there is always a time lag between the energization of the trip circuit and the actual opening of the contacts. The contacts are moved towards right away from fixed contact. As we have seen already the separation of contacts will not lead to breaking or interruption of circuit as an arc is struck between the contacts. The production of arc delays the current interruption and in addition to this it produces large amount of heat which may damage the system or the breaker. Thus it becomes necessary to extinguish the arc as early as possible in minimum time, so that heat produced will lie within the allowable limit. This will also ensure that the mechanical stresses produced on the parts of circuit breaker are less the time interval which is passed in between the enervation of the trip coil to the instant of contact separation is called the opening time. It is dependent on fault current level. The time interval from the contact separation to the extinction of arc is called arcing time It depends not only on fault current but also on availability of voltage for maintenance of arc and mechanism used for extinction of arc.

Phenomena of arc, properties of arc, initiation and maintenance of arc

Formation of an Arc: Under faulty conditions heavy current flows through the contacts of the circuit breaker before they are opened. As soon as the contacts start separating, the area of contact decreases which will increase the current density and consequently rise in the temperature. The medium between the contacts of circuit breaker may be air or oil. The heat which is produced in the medium is sufficient enough to ionize air or oil which will act as conductor. Thus an arc is struck between the contacts. The p.d. between the contacts is sufficient to maintain the arc. So long as the arc is remaining between the contacts the circuit is said to be uninterrupted. The current flowing between the contacts depends on the arc resistance. With increase in arc resistance the current flowing will be smaller. The arc resistance depends on following factors,

a) Degree of ionization: If there is less number of ionized particles between the contacts then the arc resistance increases.

b) Length of arc: The arc resistance is a function of length of arc which is nothing but separation between the contacts. More the length more is the arc resistance.

c) Cross-section of arc: If the area of cross-section of the arc is less then arc resistance is large.

Initiation of Arc There must be some electrons for initiation of an arc when fault occurs circuit breaker contacts start separating from each other and the electrons are emitted which are produced by following methods. By high voltage gradient at the cathode, resulting in field emission by increase of temperature resulting in thermionic emission. By High Voltage Gradient As the moving contacts start separating from each other, the area of contact and pressure between the separating contacts decreases. A high fault current causes potential drop (of the order)between the contacts which will remove the electrons from cathode surface. This process is called field emission.

By Increase of Temperature With the separation of contacts there is decrease in contact area which will increase the current density and consequently the temperature of the surface as seen before which will cause emission of electrons which is called thermal electron emission. In most of the circuit breakers the contacts are made up of copper which is having less thermionic emission.

Maintenance of an Arc In the previous section we have seen the initiation of the arc by field emission emission. The electrons while travelling towards anode collide with another electron to dislodge them and thus the arc is maintained. The ionizing is lactated by,

i) High temperature of the medium around the contacts due to high current densities. Thus the kinetic energy gained by moving electrons is increased.

ii) ii) The increase in kinetic energy of moving electrons due to the voltage gradient which dislodge more electrons from neutral molecules. iii) The separation of contacts of circuit breaker increases the length of path which will increase number of neutral molecules. This will decrease the density of gas which will increase free path movement of the electrons.

Arc Extinction It is essential that arc should be extinguished as early as possible. There are two methods of extinguishing the arc in circuit breakers which are namely,

a) High resistance method b) Low resistance or current zero method

High Resistance Method In high resistance method the arc resistance is increased with time. This will reduce the current to such a value which will be insufficient to maintain the arc thus the current is interrupted and the arc is extinguished. This method is employed in only d.c circuit.

The resistance of the arc may he increased by lengthening the arc, cooling the arc, reducing the cross-section of the arc and splitting the arc. These methods will be discussed in detail later in this chapter.

Low Resistance Method The low resistance or current zero method is employed for arc extinction in ac. circuits. In this method arc resistance is kept low until current zero where extinction of arc takes place naturally and is prevented from restriking. This method is employed in many of the modern a.c. circuit breakers.

Low Resistance or Zero Point Extinction

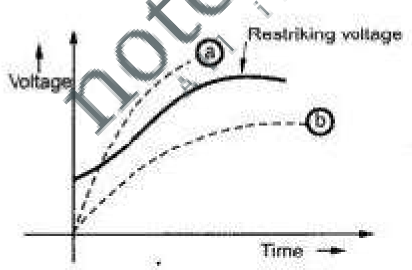
This method is used in ac. arc interruption. -I he current becomes zero two tires in a cycle. So at each current zero point the arc vanishes for small instant and again it appears. But in auxillary circuit breakers the arc is interrupted at a current zero point. The space between the contacts is ionized quickly if there is fresh unionized medium such as oil or fresh air or SF, gas between the contacts at current zero point. This will make dielectric strength of the contact space to increase such that arc will be interrupted and discontinued after current zero. This action produces high voltage across the contacts which are sufficient to reestablish the arc. Thus the dielectric strength must be building more than the restricting voltage for faithful interruption of arc. Then the arc is extinguished at next current zero. While designing the circuit breakers the care is taken so as to remove the hot gases from the contact space immediately after the arc. So that it can be filled by fresh dielectric medium having high dielectric strength. In summary we can say that the arc extinction process is divided in thee parts, a) Arcing phase b) Current zero phase c) Post arc phase In arcing phase, the temperature of the contact space is increased due to the arc. The heat produced must be removed quickly by providing radial and axial flow to gases. The arc can not be broken abruptly but its diameter can be reduced by the passage of gas over the arc. When ax. Current wave is near its zero, the diameter of the arc is very less and consequently arc is extinguished. This is nothing but current 7ero phase. Now in order to avoid the reestablishment of arc, the contact space must be filled with dielectric medium having high dielectric strength. This is post arc phase in which hot gases are removed and fresh dielectric medium is introduced.

Arc Interruption Theories There are two main theories explaining current zero interruption of arc

I) Recovery Rate Theory or Slepian's Theory

2) Energy balance theory or Cassie's Theory

Slepian's Theory Slepian described the process as a race between the dielectric strength and restriking voltage. After every current zero, there is a column of residual ionized gas. This may cause arc to strike again by developing necessary restriking voltage and this voltage stress is sufficient to detach electrons out of their atomic orbits which releases great heat. Si in this theory rate at which positive ions and electrons recombine to form neutral molecules is compared with rate of rise of restriking voltage. Due to recombination dielectric strength of gap gets recovered. So rate of recovery of dielectric strength is compared with rate of rise of restriking voltage. If the restriking voltage rises more rapidly than the dielectric strength, gap space breaks down and arc strikes again and persists. In the Fig. a) Rate of dielectric strength is more than restriking voltage. b) Rate of dielectric strength is less ------ -0 than rate of rise of restriking voltage. The assumption made while developing this theory is that the restriking voltage and rise of dielectric strength are comparable quantities which is not quite correct the second drawback is that the theory does not consider the energy relations in the arc extinction. The arcing phase is not covered by this theory so it is incomplete.



Cassie's Theory Alternative explanation of above process s afforded by Cassie's theory or also called Energy balance theory. Cassie suggested that the reestablishment of arc or interruptions of an arc both are energy balance process. If the energy input to an arc continues to increase, the arc restrikes and if not, arc gets interrupted. Theory makes the following assumptions

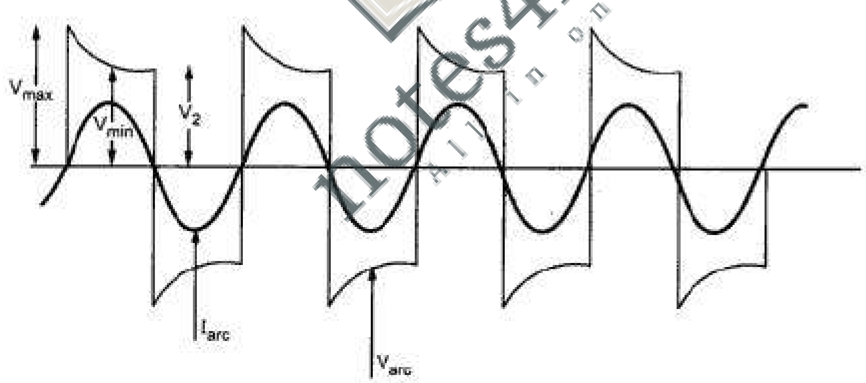
a) Arc consists of a cylindrical column having uniform temperature at its cross section. The energy distributed in the column is uniform

b) The temperature remains constant.

c) The cross section of the arc adjusts itself to accommodate the arc current.

d) Power dissipation is proportional to cross sectional area of arc column interruption theories - slepian's theory and energy balance theory.

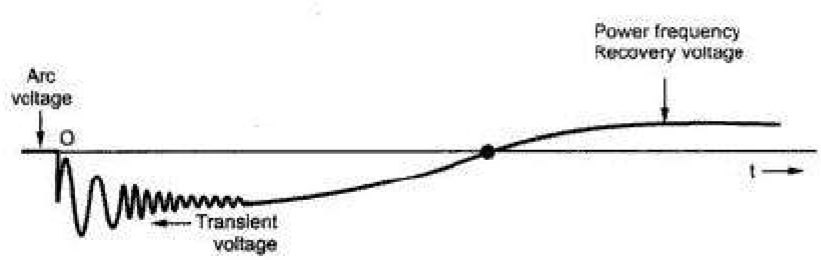
Breakdown occurs if power fed to the arc s more than power loss. The theory is true for high currents. Immediately after current zero, contact space contains ionized gas and therefore has a finite post zero resistance. Now there is rising restriking voltage. This rising res. triking voltage causes a current to flow between the contacts. Due to this current flow, power gets dissipated as heat in the contact space of circuit breaker. Initially when restriking voltage is zero, automatically current and hence power is zero. It is again zero when the space has become fully deionize and resistance between the contacts is infinitely high. In between these two extreme limits, power dissipated rises to a maximum. If the heat so generated exceeds the rate at which heat can be removed from contact space, ionization will persist and breakdown will occur, giving an arc for another half cycle.



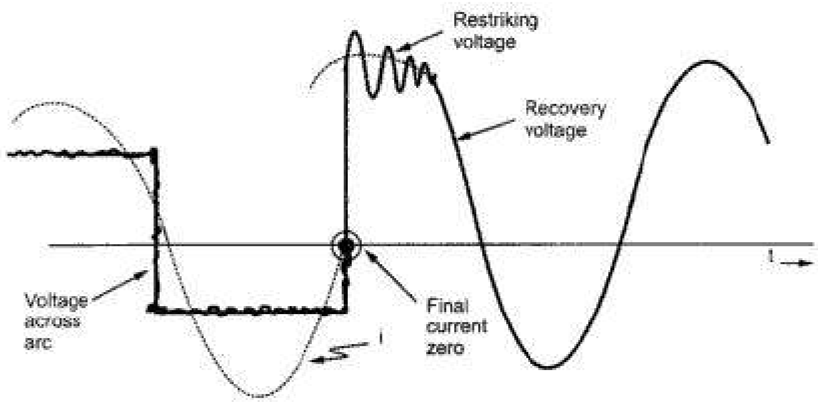
Re -striking voltage, recovery voltage, Rate of rise of Re striking voltage

Transient Recovery Voltage The transient recovery while has effect on the behavior of circuit breaker. This voltage appears between the contacts immediately after final arc interruption. This causes high dielectric stress between the contacts. If this dielectric strength of the medium between the contacts does not build up faster than the rate of rise of the transient recovery voltage then the breakdown takes place which will cause restriking of arc Thus it is very important that the dielectric strength of the contact space must build very rapidly that rate of rise of transient recovery voltage so that the Interruption of current by the circuit breaker takes place successfully. The rate of rise of this transient voltage depends on the circuit parameters and the type of the switching duty invoked. The rate of building up of the dielectric strength depends on the effective design of the interrupter and the circuit breaker. If it is desired to break the capacitive currents while opening the capacitor banks, there may appear a high voltage across the contacts which can cause re ignition of the arc after initial arc extinction. Thus if contact space breaks down within a period of one fourth of a cycle from initial arc extinction the phenomenon is called Reigniting. Moving contacts of circuit breakers move a very small distance from the fixed contacts then reigniting may occur without overvoltage. But the arc gets extinguished in the next current zero by which time moving contacts should be moved by sufficient distance from fixed contacts. Thus the re ignition is in a way not harmful as it will not lead to any overvoltage beyond permissible limits. If the breakdown occurs after one fourth of a cycle, the phenomenon is called Restrike. In restriking, high voltage appear across the circuit breaker contacts during capacitive current breaking. In restrikes, voltage will go on increasing which may lead to damage of circuit breaker. Thus the circuit breakers used for capacitors should be free from Restrike I.e. they' should have adequate rating.

Effect of Different Parameters on Transient Recovery Voltage (TRV) As seen from the previous section, after the final current, zero high frequency transient voltage appears across the circuit breaker poles which is superimposed on power frequency system voltage and tries to restrike the arc. This voltage may last for a few tens or hundreds of microseconds. If the shape of this TRV is seen on the oscilloscope then it can be seen that it may be oscillatory, non-oscillatory or a combination of two depending upon the characteristics of the circuit and the circuit breaker. The waveform is as shown in the Fig.



Transient voltage Shape of transient recovery voltage This voltage has a power frequency component and an oscillatory transient component. The oscillatory component is due to inductance and capacitance in the circuit. The power frequency component is due to the system voltage. This is shown in the Fig.



Zero power factor If we consider zero power factor currents, the peak voltage E is impressed on the circuit breaker contacts at the current zero instant This instantaneous voltage gives more transient and provides high rate of rise of TRV. Hence if the p.f. is low then interrupting of such current is difficult.

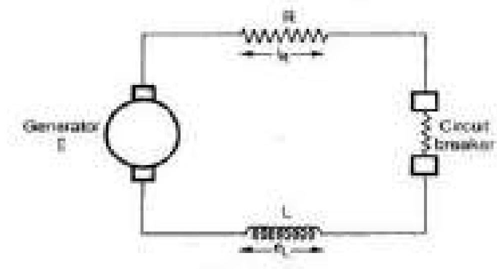
Recovery Voltage As seen previously it is the voltage having normal power frequency which appears after the transient voltage.

Effect of Reactance Drop on Recovery Voltage Home fault is taking place let us consider that the voltage appearing across circuit breaker is V. As the fault current increases, the voltage drop in reactance also increases. After fault clearing the voltage appearing say V2 is slightly less than V,. The system takes some time to regain the original value.

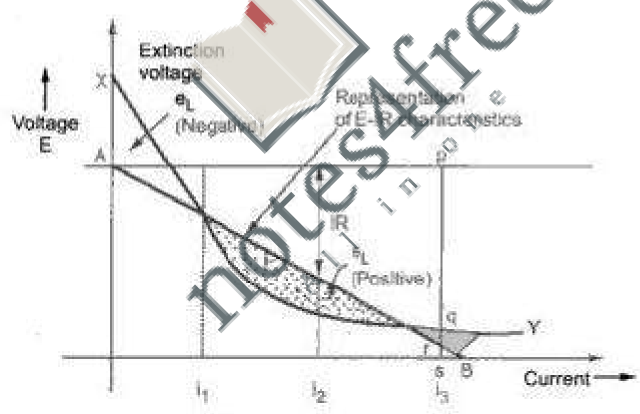
Affect of Armature Reaction on Recovery Voltage Me short circuit currents are at lagging power factor. These lagging p.f. currents have a demagnetizing armature reaction in alternators.Thus the induced end of alternators decreases To regain the original value this emf takes some time. Thus the frequency component of recovery voltage is less than the normal value of system voltage.

DC circuit breaking, AC circuit breaking

D.C. Circuit Breaking The breaking in case of d.c. can be explained as follows. For this, we will consider a circuit which will consist of generator with voltage E, resistance R. inductor L and the circuit breaker as shown in the Fig.



The voltage-current relationship can be represented as shown in the graph it could be seen that curve AB represents the voltage E - iR, i is nothing but current at any instant. The curve XY represents the voltage-current characteristics of the arc for decreasing currents.



Voltage-current relationship

When the circuit breaker starts opening it carries the load current I. In the graph shown the current is shown to be reduced respectively. Section represents voltage drop i3R whereas qs represent arc voltage which is greater than available voltage. The arc becomes unstable and the difference in voltage is supplied by inductance L across which the voltage is L. For decreasing values of t currents this voltage is negative and according to Lenz's law it tries to maintain the arc.

The voltage across inductance L is seen to be positive in the region of currents i, mid i2 since the arc characteristics lies below the curve AB. The arc current in this region tries to increase so interruption of current is not possible in this region. Afterwards the arc is lengthened with Increase in contact separation which will raise the arc voltage above the curve AB. The operation in case of d.c. circuit breakers is said to be ideal if the characteristics of the arc voltage are above the curve AB even in the region of currents i1 and i2. This is shown in the fig..

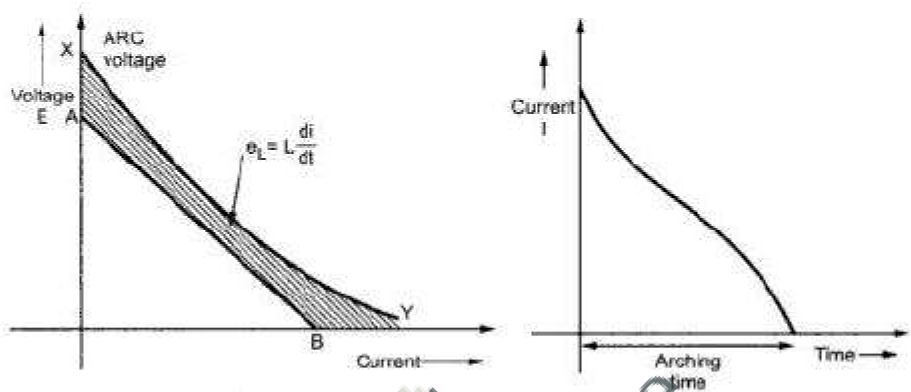


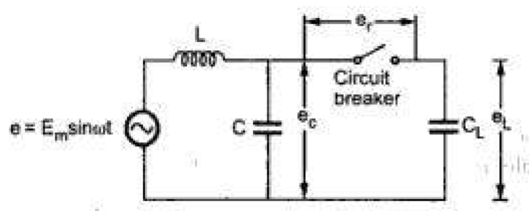
Fig. Arc voltage characteristics

It can be seen that arc voltage is greater than E - lit and the balance between the voltages is supplied by the voltage across the inductance el, which is proportional to d i rate of change of current dI.

Thus the function of the circuit breaker is to raise the arc characteristics without affecting its stability. This is done by reducing the arcing time which is the time from contact separation to final extinction of arc. But it will increase extinction voltage. Hence compromise between arcing time and arc extinction voltage is made.

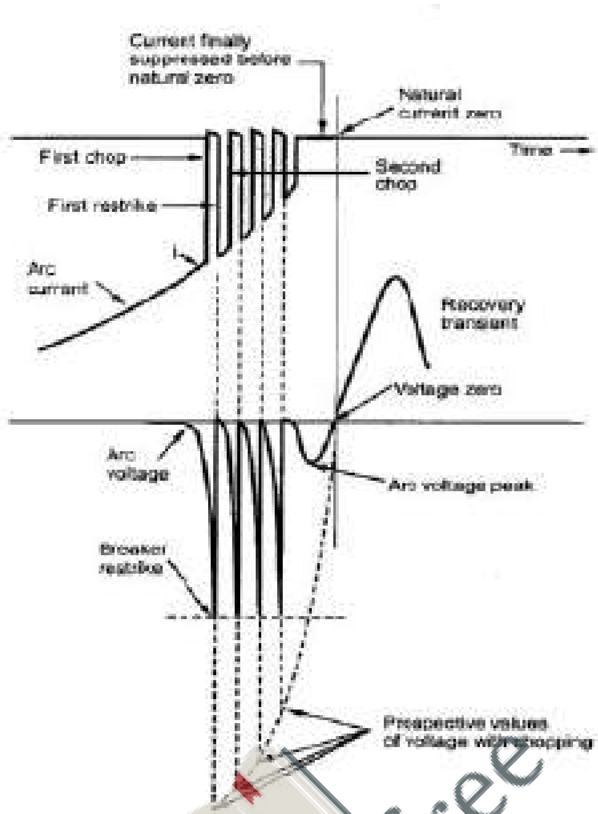
A.C. Circuit Breaking There is a difference between breaking in case of d c. and ac. circuits. In ac. circuits the current passes through zero twice in one complete cycle. When the currents are reduced to zero the beakers are operated to cut-off the current. This will avoid the striking of the arc. But this conditions is difficult to achieve and very much expensive. The restriking of arc when current is interrupted is dependent on the voltage between the contact gap at that instant which will in turn depend on power factor. Higher the power factor, lesser is the voltage appearing across the gap than its peak value.

Current chopping, capacitance switching, resistance switching



In power systems capacitor banks are used in the network which supplies reactive power at leading power factors there are various aspects like long transmission where it is required interrupt the capacitive current which is difficult. To understand this difficulty let us consider a simple circuit shown in the Fig

The value of load capacitance CL is greater than C. The voltage across a capacitor cannot change instantaneously. The currents supplied to the capacitor are generally small and interruption of such currents take place at first current zero. Also at the beginning, the rate of rise of recovery voltage is low and increases slowly. Whenever such circuit is opened a charge is trapped in the capacitance Ct The voltage across the load capacitance will hold the same value when circuit was opened. This voltage is making but peak of supply voltage as power factor angle is nearly 90° leading. After opening the circuit the voltage Vc across the capacitance C oscillates and approaches a new steady value. But due to small value of capacitance C. the value attained is close to the supply voltage. The recovery voltage Cr is nothing but difference between and CL. Its initial value is zero as the circuit breaker will be closed and increases slowly in the beginning. When Vc reverses after half cycle, the recovery voltage is about twice the normal peak value. Therefore it is possible that at this instant arc may restrike as the electrical strength between the circuit breaker contacts is not sufficient. The circuit will be reclosed and et oscillates at a high frequency. The supply voltage at this instant will be at its negative peak; therefore a high frequency oscillation takes place. At the instant of rest rucking the arc, the recovery voltage V, is zero. The voltage across the load capacitance reaches - times the peak value of normal supply voltage. The recovery voltage then starts increasing. If again restriking of arc takes place, a high frequency of oscillation of CL takes place. Such several repetitions of the restriking cycle will increase the voltage across load capacitance to a dangerously high value. In practice this voltage is limited to 4 times the normal peak of the voltage.



Resistance switching

Resistance Switching It can be seen from previous sections that the interruption of low inductivecurrents, interruption of capacitive currents gWe rise to severe voltage oscillations. These excessive voltage surges during circuit interruption can be prevented by the use of shunt resistance R across the circuit breaker contacts. This process is known as Resistance Switching. When the rtsistance is connected across the arc, a part of the arc current flows through the resistance. This will lead to decrease in arc current and increase in rate of deionization of the are path and resistance of arc. This will increase current through shunt resistance . This process continues until the current through the arc is diverted through the resistance either External 4.---

resistance completely or in major part. If C irt the small value of the current remains in the arc then the path . A becomes so unstable that it is Fxed Moved switch easily extinguished. contact contact . The resistance may be automatically switched in and arc current can be transferred. The time required for this action is very small As shown in.. Fig the arc first appears across points A and B which is then transferred across A and C. The shunt resistance also ensures the effective damping of the high frequency re-striking Fig. voltage transients. This is shown in the Fig.

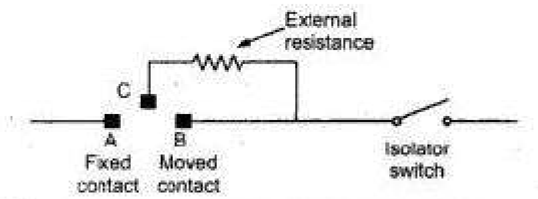
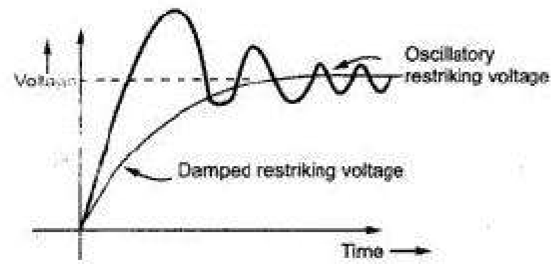
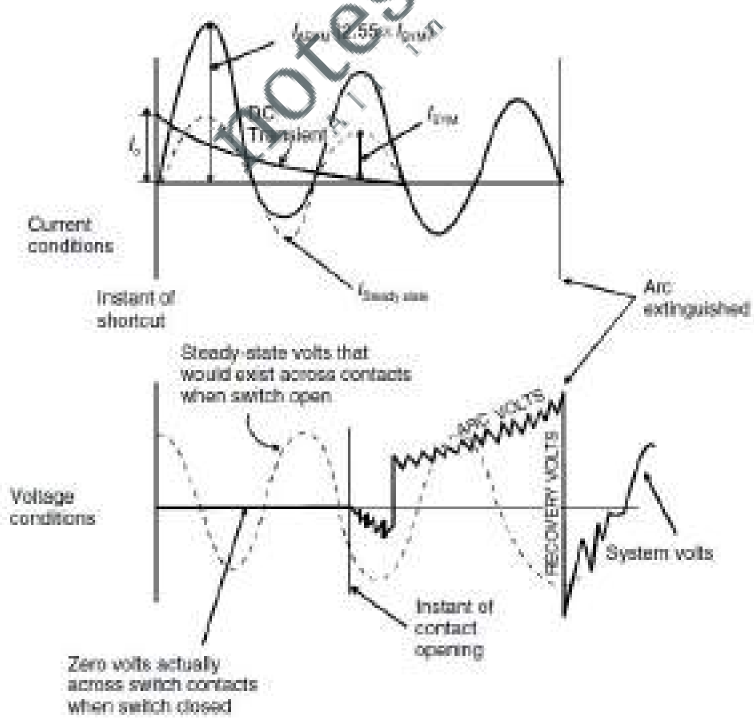


Fig. 9.23 Typical resistor connection



Behavior under fault conditions

Before the instant of short-circuit, load current will be flowing through the switch and this can be regarded as zero when compared to the level of fault current that would flow



1.Arc

The arc has three parts: 1. **Cathode end (–ve):** There is approximately 30–50 V drop due to emission of electrons.

2. Arc column: Ionized gas, which has a diameter proportional to current. Temperature can be in the range of 6000–25 000 °C.

3. Anode end (+ve): Volt drops 10–20 V.

When short-circuit occurs, fault current flows, corresponding to the network parameters. The breaker trips and the current are interrupted at the next natural current zero. The network reacts by transient oscillations, which gives rise to the transient recovery voltage (TRV) across the circuit breaker main contacts.

All breaking principles involve the separation of contacts, which initially are bridged by a hot, highly conductive arcing column. After interruption at current zero, the arcing zone has to be cooled to such an extent that the TRV is overcome and it cannot cause a voltage breakdown across the open gap. Three critical phases are distinguished during arc interruption, each characterized by its own physical processes and interaction between system and breaker.

High current phase

This consists of highly conductive plasma at a very high temperature corresponding to a low mass density and an extremely high flow velocity. Proper contact design prevents the existence of metal vapor in the critical arc region.

Thermal phase

Before current zero, the diameter of the plasma column decreases very rapidly with the decaying current but remains existent as an extremely thin filament during the passage through current zero. This thermal phase is characterized by a race between the cooling of the rest of the plasma and the reheating caused by the rapidly rising voltage. Due to the temperature and velocity difference between the cool, relatively slow axial flow of the surrounding gas and the rapid flow in the hot plasma core, vigorous turbulence occurs downstream of the throat, resulting in effective cooling of the arc. This turbulence is the dominant mechanism, which determines thermal re-ignition or interruption.

Dielectric phase

After successful thermal interruption, the hot plasma is replaced by a residual column of hot, but no longer electrically conducting medium. However, due to marginal ion-conductivity, local distortion of the electrical field distribution is caused by the TRV appearing across the open break. This effect strongly influences the dielectric strength of the break and has to be taken into account when designing the geometry of the contact arrangement.

Introduction, requirement of a circuit breakers, difference between an isolator and circuit breaker, basic principle of operation of a circuit breaker, phenomena of arc, properties of arc, initiation and maintenance of arc, arc interruption theories - slepian's theory and energy balance theory, Re striking voltage, recovery voltage, Rate of rise of Re striking voltage, DC circuit breaking, AC circuit breaking, current chopping, capacitance switching, resistance switching, Rating of Circuit breakers.

MODULE - 5

CIRCUITS BREAKERS

- **Air Circuit breakers** – Air break and Air blast Circuit breakers
- oil Circuit breakers – Single break, double break, minimum OCB
- SF6 breaker - Preparation of SF6 gas
- Puffer and non Puffer type of SF6 breakers
- Vacuum circuit breakers - principle of operation and constructional details
- Advantages and disadvantages of different types of Circuit breakers
- Testing of Circuit breakers, Unit testing
- Synthetic testing, substitution test
- Compensation test and capacitance test
- **Lightning arresters:** Causes of over voltages – internal and external lightning
- Working Principle of different types of lightning arresters. Shield wires

Types of circuit breakers

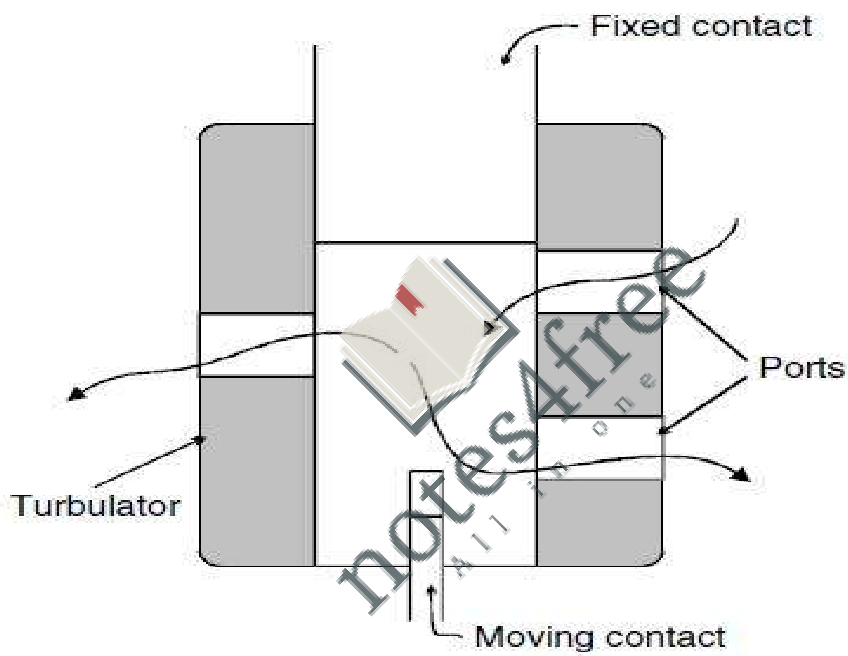
The types of breakers basically refer to the medium in which the breaker opens and closes. The medium could be oil, air, vacuum or SF6. The further classification is single break and double break. In a single break type only the busbar end is isolated but in a double break type, both busbar (source) and cable (load) ends are broken. However, the double break is the most common and accepted type in modern installations.

Arc control device: A breaker consists of moving and fixed contact, and during the breaker operation, the contacts are broken and the arc created during such separation needs to be controlled. The arc control devices, otherwise known as tabulator or explosion pot achieves this:

1. Turbulence caused by arc bubble.

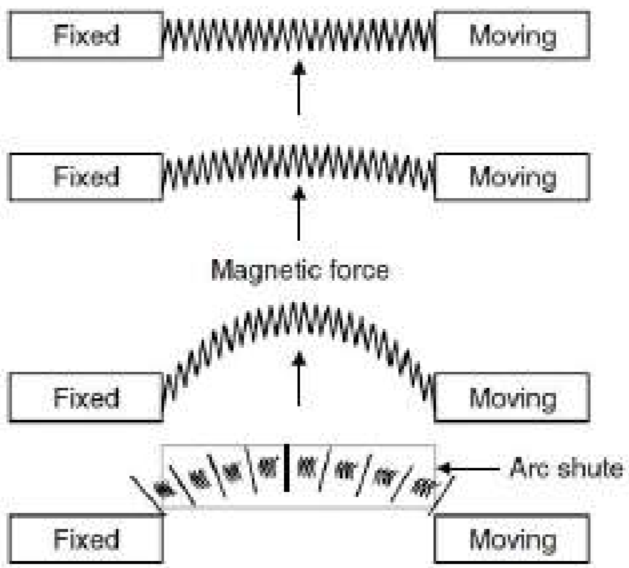
2. Magnetic forces tend to force main contacts apart and movement causes oil to be sucked in through ports and squirted past gap.

3. When arc extinguished (at current zero), ionized gases get swept away and prevents prestriking of the arc



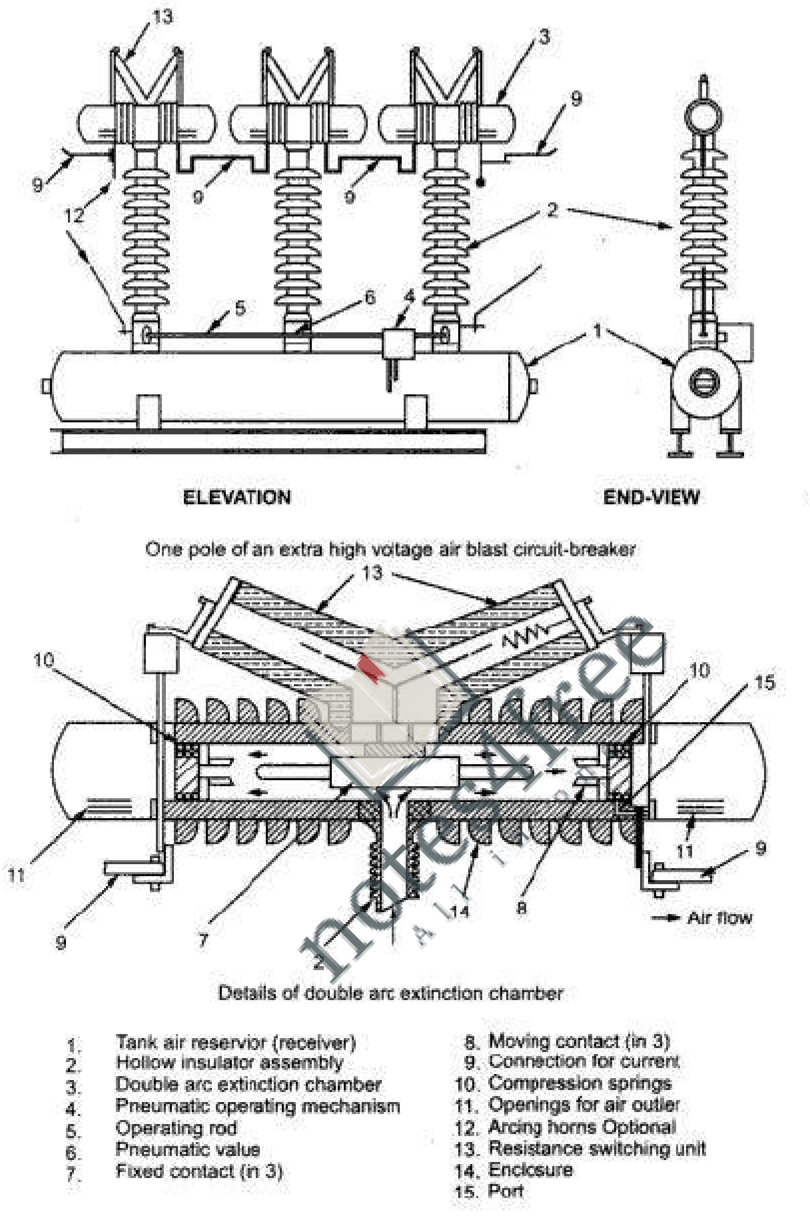
Air break switchgear

Interrupting contacts situated in air instead of any other artificial medium Arc is chopped into a number of small arcs by the Arc-Shute as it rises due to heat and magnetic forces. The air circuit breakers are normally employed for 380~480 V distribution.



Air break switchgear

These types of circuit breakers are used in earlier days for the voltage ranges of 11kv to 1100kV. At the bottom there is a tank which is called air reservoir with the valves. On this reservoir there are three hollow insulator columns. On the top of each insulator column there is double arc extinguishing chamber. The current carrying parts are connected to the arc extinction chambers in series. The assembly of entire arc extinction chamber is mounted on insulators as there exists large voltage between the conductors and air reservoir. The double arc extinction chamber is shown separately in the Fig below. It can be seen that for each circuit breaker pole there are six break as there are three double arc extinction poles in series. Each arc extinction chamber consists of two fixed and two moving contacts. These contacts can move axially so as to open or close. The position depends on air pressure and spring pressure. The opening rod is operated by when it gets control signal (may be electrical or prtearnatic). This will lead to flow of high pressure air by opening the valve. The high pressure air enters the double arc extinction chamber rapidly. Due to the flow of air the pressure on moving contacts increases than spring pressure and contacts open The contacts travel through a small distance against the spring pressure. Due to the motion of moving contacts the port for outgoing air is closed and the whole arc extinction chamber is filled with high pressure air. But during the arcing period the air passes through the openings shown and takes away ionized air of arc. In case of making operation the valve is turned which connects hdlow column of insulator and the reservoir. The air is passed to the atmosphere due to which pressure of air in the chamber is dropped to atmospheric pressure and closing of moving contacts is achieved against spring pressure.



Working: An auxiliary compressed air system is required by this type of circuit breaker. This will supply air to the air reservior of the breaker. During the opening operation, the air is allowed to enter in the extinction chamber which push., away moving contacts. The contacts are separated and the blast of air will take ionized gases with it and helps in extinguishing the arc.

Advantages: The vanous advantages of air blast circuit breakers are, i) No fire hazards are possible with this type of circuit breaker. ii) The nigh speed operation is achieved. iii) The time for which arc persists is short. Thus the arc gets extinguished early. iv) As arc duration is short and consistent, the amount of heat released is less and the contdct points are burnt to a less extent. So life of circuit breaker is increased. v) The extinguishing medium in this type of circuit breaker is compressed air which is supplied fresh at each operation. The arc energy at each operation is less than that compared with oil circuit breaker. So air blast circuit breaker is most suitable where frequent operation is required. vi) This type of circuit breaker is almost maintenance free. vii) It provides facility of high speed reclosure. viii) The stability of the system can be well maintained.

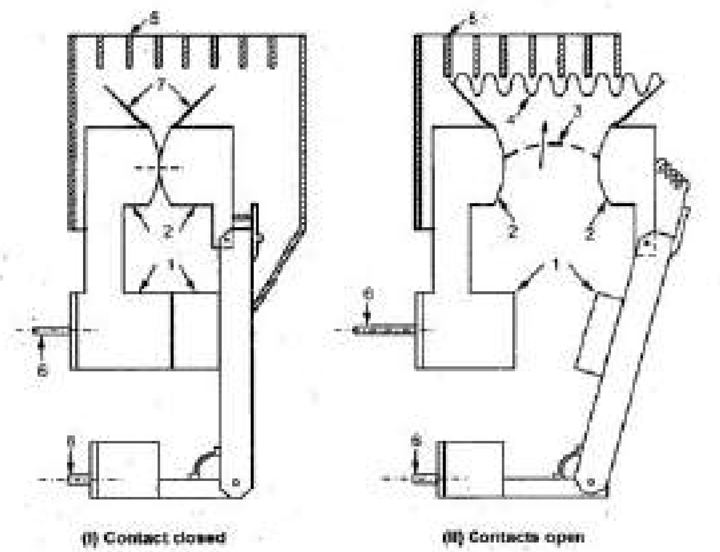
Disadvantages: The various disadvantages of air blast circuit breakers are, i) If air blast circuit breaker is to be used for frequent operation it is necessary to have a compressor with sufficient capacity of high prewure air. ii) The maintenance of compressor and other re!ated equipments is required. iii) There is possibility of air leakages at the pipe fittings. iv) It is very sensitive to restriking voltage. Thus current chopping may occur which may be avoided by employing resistance switching.

Applications :The air blast circuit breakers are preferred for arc furnace duty and traction system because they are suitable for repeated duty. These type of circuit breakers are finding their best application in systems operating in range of 132 kV to 400 kV with breaking capacities upto 700 MVA. This will require only one or two cycles. There are two major types - cross blast and aVial blast.

Air Break(circuit breaker)

In air circuit breakers the atmospheric pressure air s used as an arc extinguishing medium. the principle of high resistance interruption is employed for such type of breakers. The length of the arc is increased using arc runners which will increase its resistance in such a way that the voltage drop across the arc becomes mom than the supply voltage and the arc will he extinguished This type of circuit breaker is employed in both ac and d.c. type of circuits upto 12 kV. These are normally indoor type and installed on vertical panels. The lengthening of arc is done with the help of mangetic fields. Some typical ratings of this type of circuit breaker are 460V - 3.3 kV with current range 400 - 3503 A or 6.6 kV with current range 403-2400 A etc.

Construction The Fig. shows the constructional details of air break circuit breaker.



Principle of air-break circuit-breaker

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

It consists of two sets of contacts I) Main contacts 2) Arcing contacts

During the normal operation the main contacts are closed. They are having low resistance with silver plating. The arcing contact: are very hard, heat resistant. They are made up of copper alloy. Arc runners are provided at the one end of arcing contact. On the upper side arc splitter plates are provided.

Working As seen from the Fig the contacts remain in closed position during normal condition. Whenever fault occurs, the tripping signal makes the circuit Current breaker contacts to open. The arc is drawn in between the contacts When ever the arc is struck between the contacts, the surrounding air gets ionized. The arc i5 then cooled to reduce the diameter of arc core. While separating the main contacts are separated first. The current is then shifted to arcing contains. Later on the arcing contacts also start separating and arc between them is forced upwards by the electromagnetic forces and thermal action. The arc travels through the arc runners. Further it moves upwards and split by arc splitter plates. Due to all this finally the arc gets extinguished as the resistance of the arc is increased. Due to lengthening and cooling, arc resistance increases which will reduce the fault current and will not allow reaching at high value. The current zero points in the ac. wave will help the arc extinction with increase in arc resistance the drop across it will go on increasing. Whenever arc leaves the contacts it is passed through arc runners with the help of blow out coils which provide a magnetic field due to which it will experience a force as given by electromagnetic theory (F = 131/). This force wilts assist in moving the arc upwards. The magnetic field produced is insufficient to extinguish the arc. For systems having low inductances arc gets extinguished before reaching extremity of runners because lengthening of arc will increase the voltage drop which is insufficient to maintain the arc.

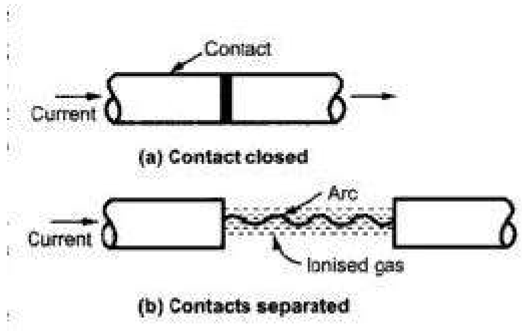


Fig working of air breaks circuit breaker

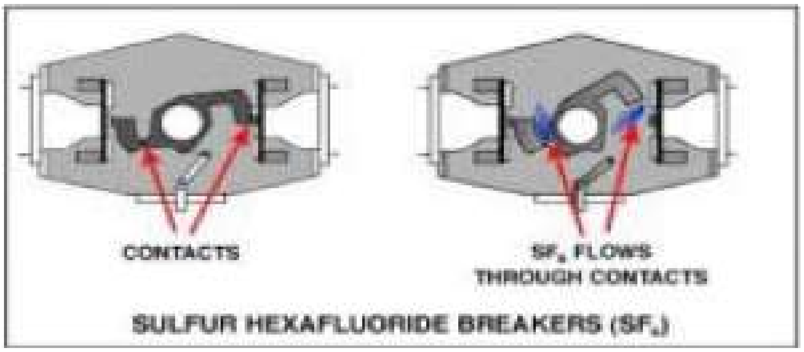
For high inductance circuits if it is not extinguished while travelling through arc runners then it is passed through arc splitters where it is cooled. This will make the effective deionized by removing the heat from arc.

Applications: this type of circuit breakers are commonly employed for industrial switchgear, auxiliary switch gear in generating stations.

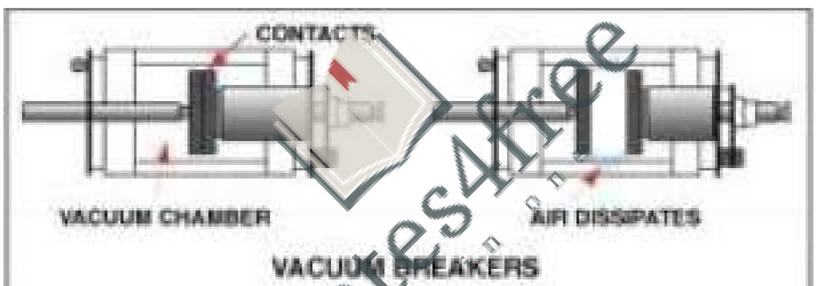
Sulphur Hexafluoride (SF6) Circuit Breaker Pure sulphur hexafluride gas is inert and thermally stable. It is having good dielectric and arc extinguishing properties. It is also an electronegative gas and has strong tendency to absorb free electrons. SF, gas remains in gaseous state up to a temperature of r C. Its density is about five times that of air and the free heat convection is 1.6 times as much as that of air. Also being inert it is non-in flammable, non-poisonous and odour less. The contacts of the breaker arc opened in a high pressure flow of SF6, gas and an arc is struck between them The conducting electrons front the arc are captured by the gas to form relatively immobile negative ions. The loss of this conducting electrons developes enough strength of insulation which will extinguish the arc. Thus SF, circuit breakers are found to be very effective for high power and high voltage service and widely used in electrical equipment. Only the care to be taken is that some by-products are produced due to breakdown of gas which are hazard to the health of the personnel it should be properly disposed. Several types of SF, circuit breakers are designed by various manufacturers in the world during the recent years which are rated for voltages from 3.6 to 760 kV. The property of this gas is that the gas liquifies at certain low temperatures. The liquification temperature can be increased with pressure this gas is commercially manufactured in many countries and now used extensively, in electrical industry. The gas is prepared by burning coarsely crushed roll sulphur in fluorine gas in a steel box. The box must be provided with staggered horizontal shelves each containing about 4 kg of sulphur. The steel box is gas tight. After the chemical reaction taking place in the box, the SF6 gas obtained contains impurities in the form of fluorides such as S21410, SF4 etc. Thus it must be purified before it is supplied. The manufacturing of this gas at large scale reduces its cost. The dielectric strength of SF6 gas at any pressure is more than that of air. When the gas comes in contact with the electric arc for long period, the decomposition effects are small and dielectric strength is not considerably reduced and the metallic fluorides that are formed are good insulators and are not harmful to the breaker.

Sulphur-hexa flouride (SF6) is an inert insulating gas, which is becoming increasingly popular in modern switchgear designs both as an insulating as well as an arc-quenching medium. Gas insulated switchgear (GIS) is a combination of breaker, isolator, CT, PT, etc., and are used to replace outdoor substations operating at the higher voltage levels, namely 66 kV and above. For medium- and low-voltage installations, the SF6 circuit breaker remains constructionally the same as that for oil and air circuit breakers mentioned above, except for the arc interrupting chamber which is of a special design, filled with SF6. To interrupt an arc drawn when contacts of the circuit breaker separate, a gas flow is required to cool the arcing zone at current interruption (i.e. current zero). This can be achieved by a gas flow generated with a piston (known as the ‘puffer’ principle), or by heating the gas of constant volume with the arc’s energy. The resulting gas expansion is directed through nozzles to provide the required gas flow. The pressure of the SF6 gas is generally maintained above atmospheric; so good sealing of the gas chambers is vitally important. Leaks will cause loss of insulating medium and clearances are not designed for use in air. **Sulfur hexafluoride (SF6)**

Sulfur hexafluoride (SF6) is an insulating gas used in circuit breakers in two ways. In "puffer" designs, it's blown across contacts as they open to displace the arcing gas. In "blast" designs, it's used at high pressures to open contacts as it simultaneously extinguishes the arc.SF6 breakers are rated for the highest voltage of all breaker designs



Vacuum breakers enclose the contacts within a vacuum chamber, so when the arc of metallic vapor forms it is magnetically controlled and thereby extinguished at current zero. Vacuum breakers are rated up to 34.5 kV.



Salient features:

- Simple and compact design.
- Line to ground clearances as per customer specification.
- Self aligning contacts for easy re-assembly.
- Inspection / maintenance of pole unit possible without dismantling the breaker.
- Separate main and arcing contacts thus eliminating the possibility of erosion of the main contacts.
- Single break up to 245 kV level.
- Consistent operating characteristics as the closing spring is in relaxed condition.

- Stainless steel latches /catches for high reliability.
- Corrosion resistant materials for construction.
- Maintenance free operation of the pole unit for 15-20 years under normal conditions.
- Easy erection.
- No site adjustments.
- Easy access to all parts of operating mechanism through front/back opening panels.
- Low operating noise levels.
- Auto drain valve for unmanned substation operations.
- Pressure relief device.
- High seismic withstand capability - earthquake safety.

Construction & operation:

All our SF6 Circuit breakers have a similar interrupter design. The range of breakers from 72.5 kV to 245 kV is manufactured with single break interrupter design while 420 kV breakers are manufactured with double break interrupters. These breakers are of live tank design and employ puffer action for interruption ensuring higher operational reliability and safety of power transmission and distribution systems. The interrupting unit filled with SF6 gas is placed at the top of the pole and contains Stationary

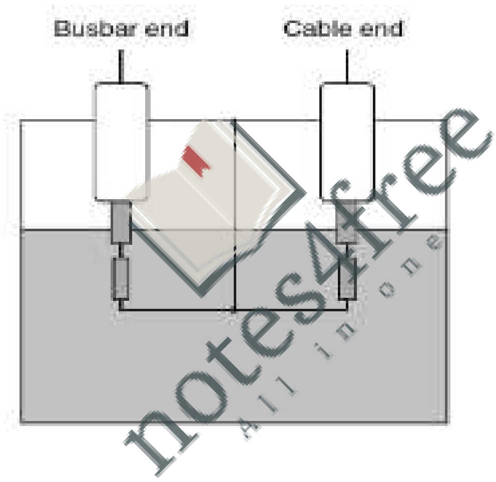
Contact, Nozzle, Moving Contact, Puffer Cylinder and Fixed Piston. During opening operation the Moving Contact along with the Puffer Cylinder is pulled down. The Puffer Cylinder, which moves along with the Moving Contact, compresses the SF6 gas against the Fixed Piston thus generating a powerful SF6 gas blast through the nozzle and over the arc. After travelling through some distance, the dielectric strength of the gap is sufficient to withstand the voltage and thus the arc extinguishes. The reliability of the system is further increased by the single pressure dual flow SF6 gas puffer interrupter which reduces the number of moving parts and auxiliary systems in the circuit breaker.

Oil circuit breakers

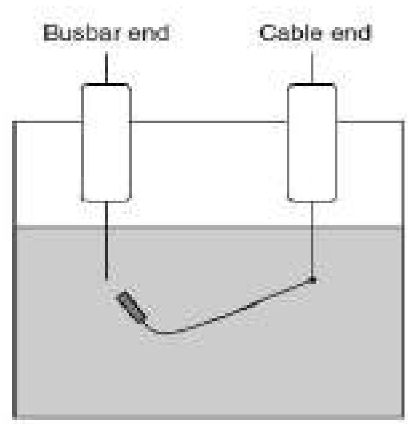
In modern installations, oil circuit breakers, which are becoming obsolete, are being replaced by vacuum and SF6 breakers. However there are many installations, which still employ these breakers where replacements are found to be a costly proposition. In this design, the main contacts are immersed in oil and the oil acts as the ionizing medium between the contacts. The oil is mineral type, with high dielectric strength to withstand the voltage across the contacts under normal conditions.

(a) Double break (used since 1890),.

(b) Single break (more popular in earlier days as more economical to produce –less copper, arc control devices, etc., Arc energy decomposes oil into 70% hydrogen, 22% acetylene, 5% methane and 3% ethylene. Arc is in a bubble of gas surrounded by oil.



Double break oil circuit breaker



Single break oil circuit breaker

Oil has the following advantages:

• Ability of cool oil to flow into the space after current zero and arc goes out

• Cooling surface presented by oil

• Absorption of energy by decomposition of oil

• Action of oil as an insulator lending to more compact design of switchgear.

Disadvantages:

• Inflammability (especially if there is any air near hydrogen)

• Maintenance (changing and purifying).

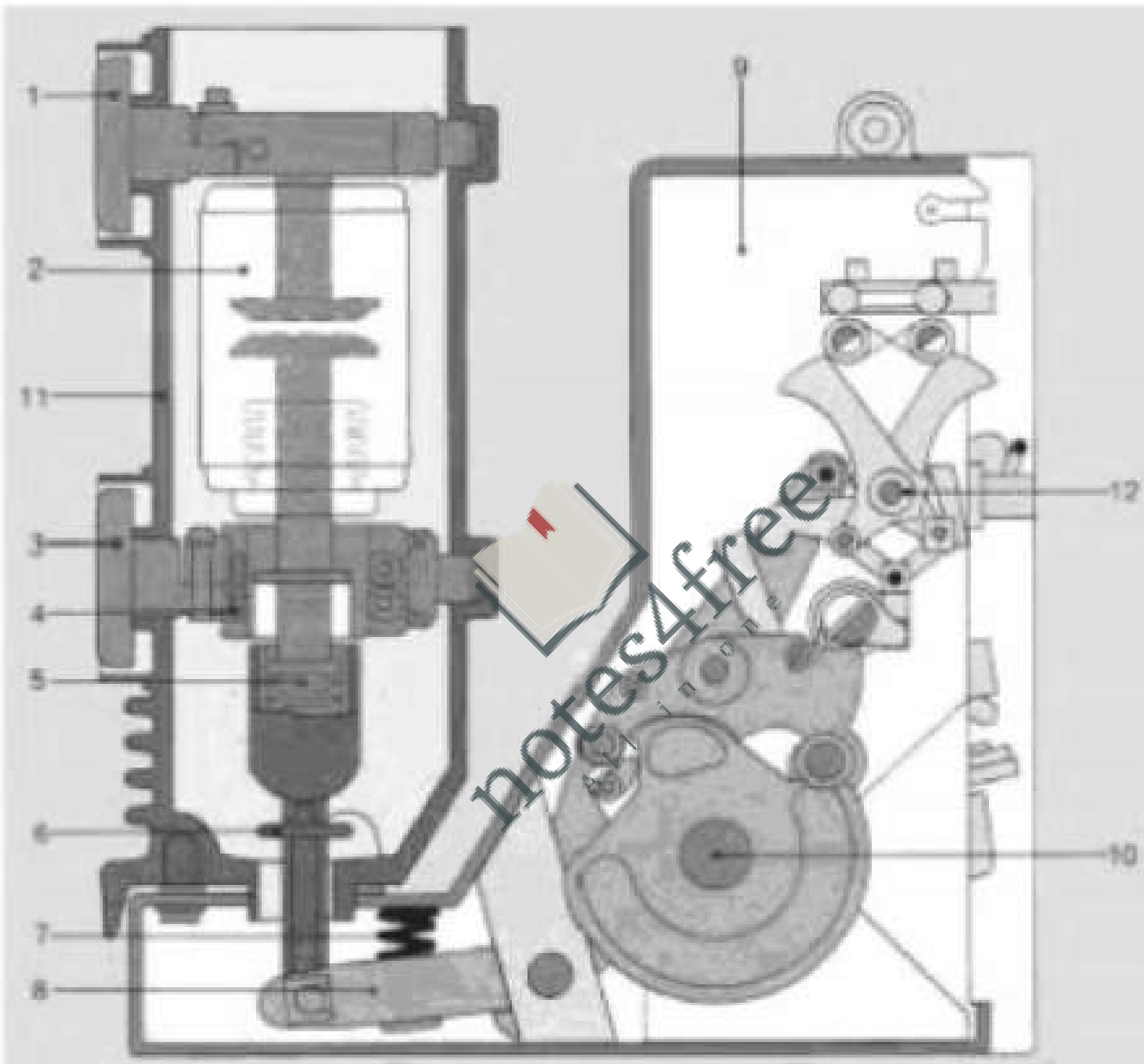
In the initial stages, the use of high-volume (bulk) oil circuit breakers was more common. In this type, the whole breaker unit is immersed in the oil. This type had the disadvantage of production of higher hydrogen quantities during arcing and higher maintenance requirements. Subsequently these were replaced with low oil (minimum oil) types, where the arc and the bubble are confined into a smaller chamber, minimizing the size of the unit.

Vacuum circuit breakers and contactors: Vacuum circuit breakers and contactors were introduced in the late 1960s. A circuit breaker is designed for high through-fault and interrupting capacity and as a result has a low mechanical life. On the other hand, a contactor is designed to provide large number of operations at typical rated loads of 200/400/600 A at voltages of 1500/3300/6600/11 000 V.

The following table illustrates the main differences between a contactor and a circuit breaker

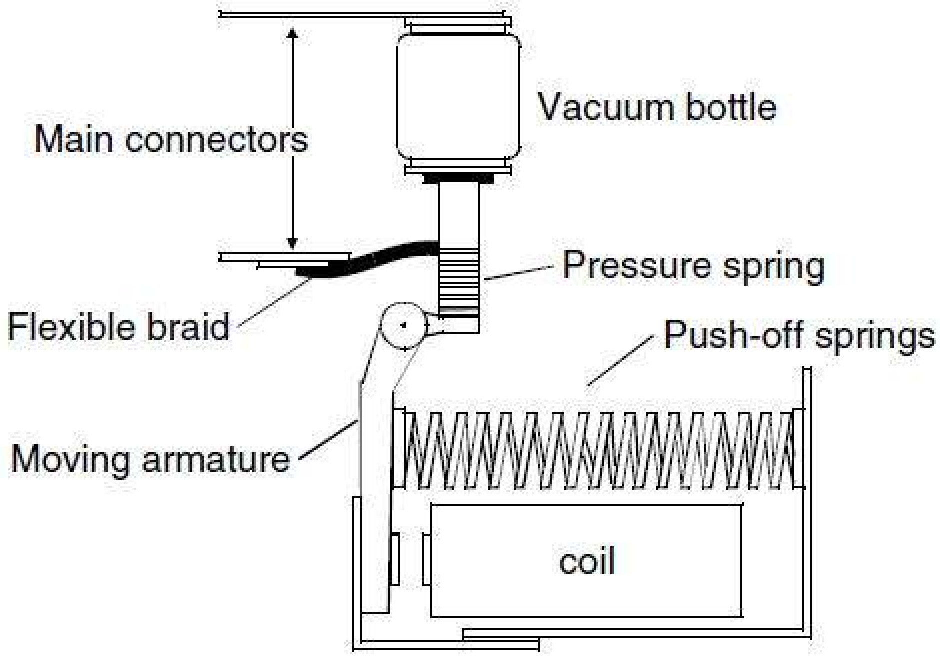
	Contactor	Circuit Breaker
Interrupting capacity	4.0 kA	40 kA
Current rating	400/630 A	630/3000 A
Contact gap at 11 kV	6.0 mm	16.0 mm
Contact force	10 kg	80 kg
Mechanical life	1–2.5 million	10 000

Hence, it is necessary to use back-up fuses when contactors are employed to take care of the high fault conditions. Vacuum breakers are also similar in construction like the other types of breakers, except that the breaking medium is vacuum and the medium sealed to ensure vacuum. Figures below give the components of a vacuum circuit breaker.



1 Upper connection	7 Opening spring
2 Vacuum interrupter	8 Shift lever
3 Lower connection	9 Mechanism housing with spring operating mechanism
4 Roller contact (swivel contact for 630 A)	10 Drive shaft
5 Contact pressure spring	11 Pole tube
6 Insulated coupling rod	12 Release mechanism

General construction of a vacuum circuit breaker



The modern vacuum bottle, which is used in both breakers and contactors, is normally made from ceramic material. It has pure oxygen-free copper main connections; stainless steel bellows and has composite weld-resistant main contact materials. A typical contact material comprises a tungsten matrix impregnated with a copper and antimony alloy to provide a low melting point material to ensure continuation of the arc until nearly current zero.

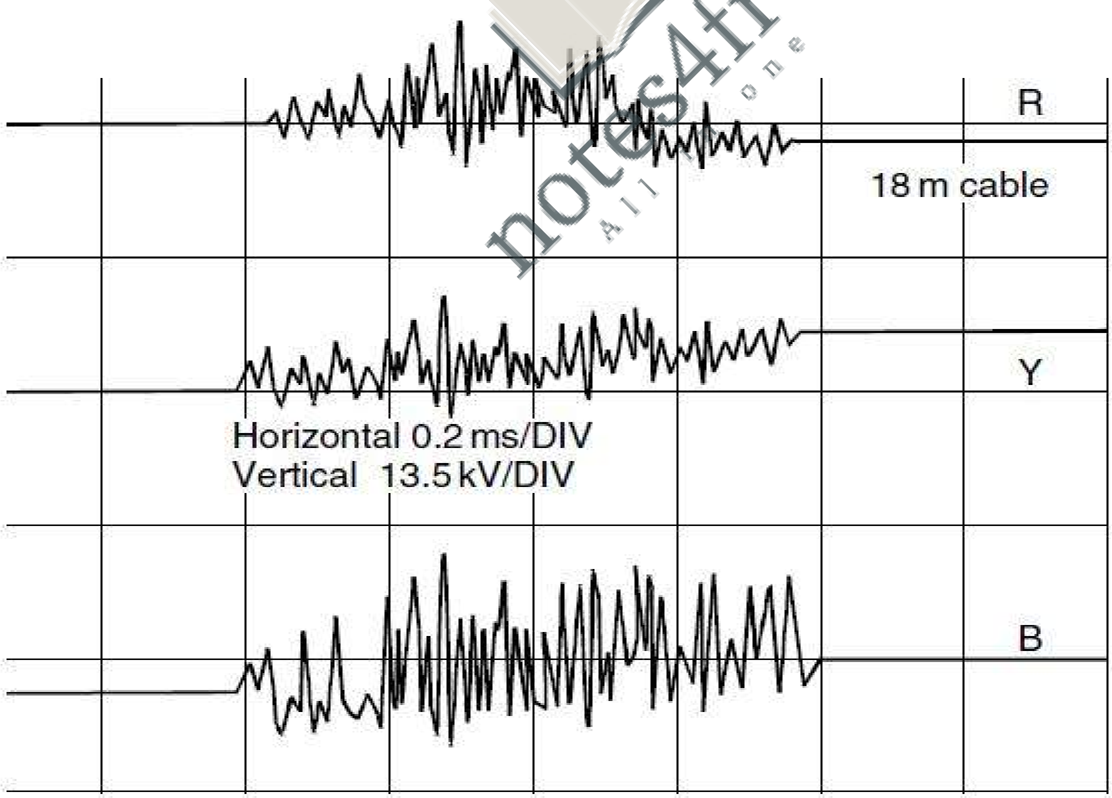
Because it is virtually impossible for electricity to flow in a vacuum, the early designs displayed the ability of current chopping i.e. switching off the current at a point on the cycle other than current zero. This sudden instantaneous collapse of the current generated extremely high-voltage spikes and surges into the system, causing failure of equipment.

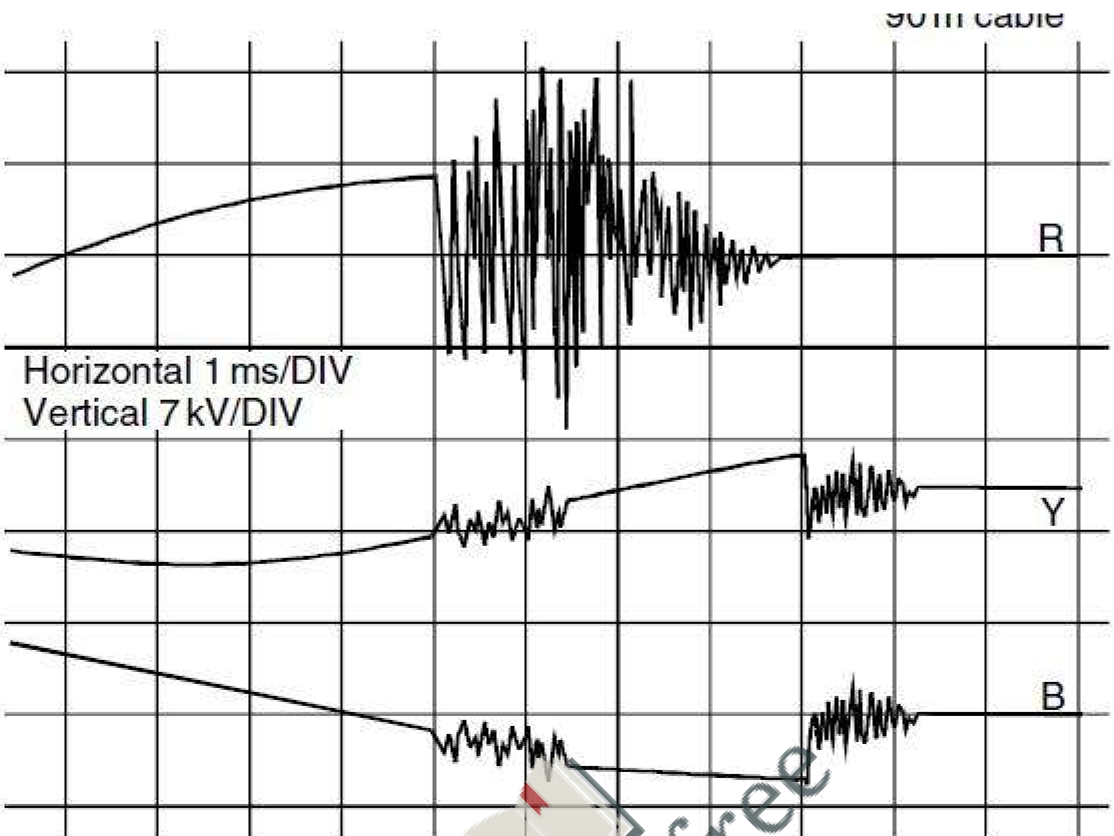
Another phenomenon was pre-strike at switch on. Due to their superior rate of dielectric recovery, a characteristic of all vacuum switches was the production of a train of pulses during the closing operation. Although of modest magnitude, the high rate of rise of voltage in pre-strike transients can, under certain conditions produce high-insulation stresses in motor line end coils. Subsequent developments attempted to alleviate these shortcomings by the use of 'softer' contact materials, in order to maintain metal vapor in the arc plasma so that it did not go out during switching. Unfortunately, this led to many instances of contacts welding on closing.

Restrike transients produced under conditions of stalled motor switch off was also a problem. When switching off a stalled induction motor, or one rotating at only a fraction of synchronous speed, there is little or no machine back emf, and a high voltage appears across the gap of the contactor immediately after extinction. If at this point of time the gap is very small, there is the change that the gap will break down and initiate a restrike transient, puncturing the motor's insulation.

Modern designs have all but overcome these problems. In vacuum contactors, higher operating speeds coupled with switch contact material are chosen to ensure high gap breakdown strength, produce significantly shorter trains of pulses. In vacuum circuit breakers, operating speeds are also much higher which, together with contact materials that ensure high dielectric strength at a small gap, have ensured that prestrike transients have ceased to become a significant phenomenon. These have led to the use of vacuum breakers more common in modern installations.

Practical Power Systems Protection





Switch off of stalled 6.6 kV 200 kW motor-escalating restrike on R phase

Dashpots

In oil circuit breakers, when the breaker is closed, if the operation is not damped then contact bounce may occur and the breaker may kick open. Dashpots prevent this. They may also prevent unnecessary physical damage to the contacts on impact. Their use of course depends on the design.

Contacts

Fixed contacts normally have an extended finger for arc control purposes. Moving contacts normally have a special tip (Elkonite) to prevent burning from arcing.

Comparison of insulating methods for CBs

Property	Air	Oil	SF6	Vacuum
Number of operations	Medium	Low	Medium	High
'Soft' break ability	Good	Good	Good	Fair
Monitoring of medium	N/A	Manual test	Automatic	Not possible
Fire hazard risk	None	High	None	None
Health hazard risk	None	Low	Low	None
Economical voltage range	Up to 1 kV	3.3–22 kV	3.3–800 kV	3.3–36 kV

Comparison of breaker types

Following curve gives the requirement of electrode gaps for circuit breakers with different insulating mediums

Practical Power Systems Protection

The following table highlights the features for different types of circuit breakers.

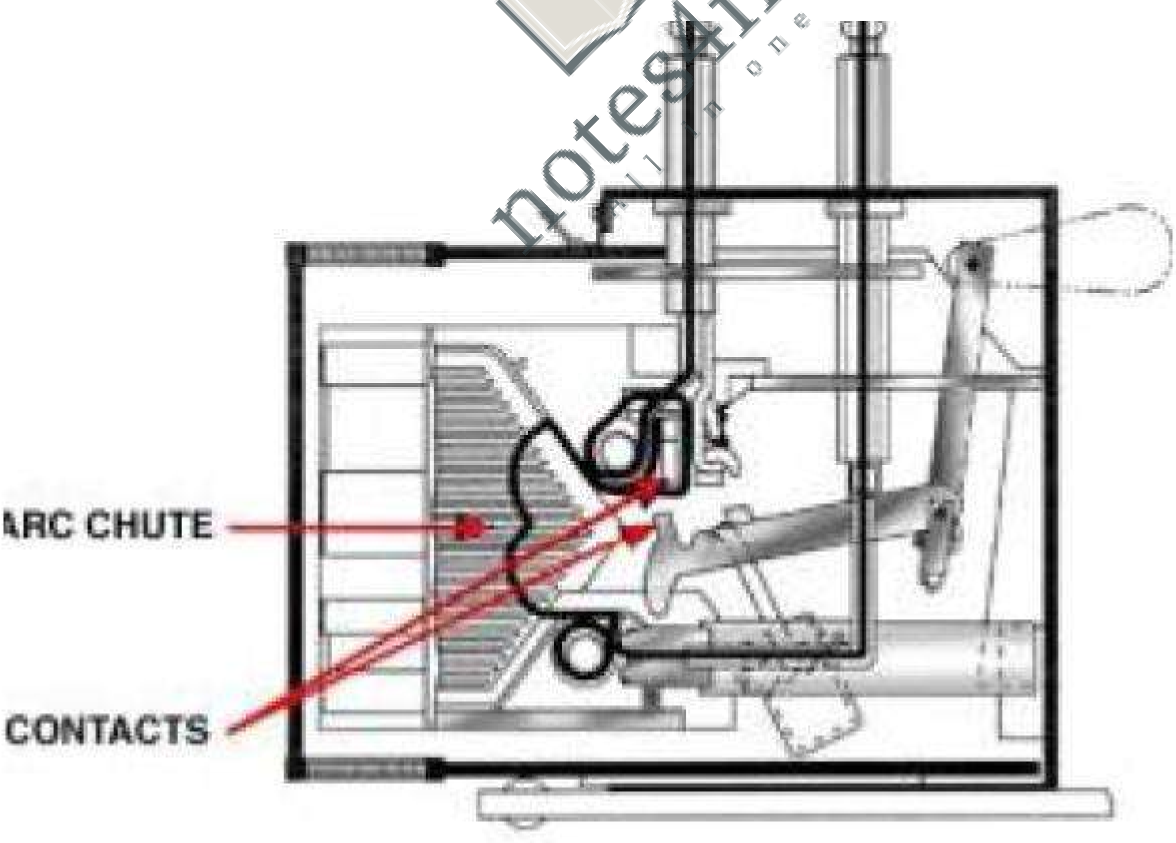
Factor	Oil Breakers	Air Breakers	Vacuum/SF6
Safety	Risk of explosion and fire due to increase in pressure during multiple operations	Emission of hot air and ionized gas to the surroundings	No risk of explosion
Size	Quite large	Medium	Smaller
Maintenance	Regular oil replacement	Replacement of arcing contacts	Minimum lubrication for control devices
Environmental factors	Humidity and dust in the atmosphere can change the internal properties and affect the dielectric		Since sealed, no effect due to environment
Endurance	Below average	Average	Excellent

Circuit Breaker Operation

In addition to the events that cause a trip, a circuit breaker for switchgear applications must also be selected for the method by which it opens when tripped. This is important, because when contacts are opened quickly at high voltage levels, a conductive metallic vapor can form that allows current to continue to travel between the open contacts. This phenomenon, known as arcing, creates the greatest obstacle to circuit interruption.

As a result, medium- and high-voltage circuit breakers employ one of four different arc interrupting technologies. All take advantage of the fact that even the most powerful AC overcurrent cycles pass the zero current level twice in one cycle. By reducing the amount of conductive gas between the contacts, the arc cannot be sustained when it passes through a current zero. Since the current in DC circuits does not follow a sine-wave pattern, circuit interruption is very difficult. This makes the DC interrupting rating for most breakers much lower than the interrupting rating for AC circuits.

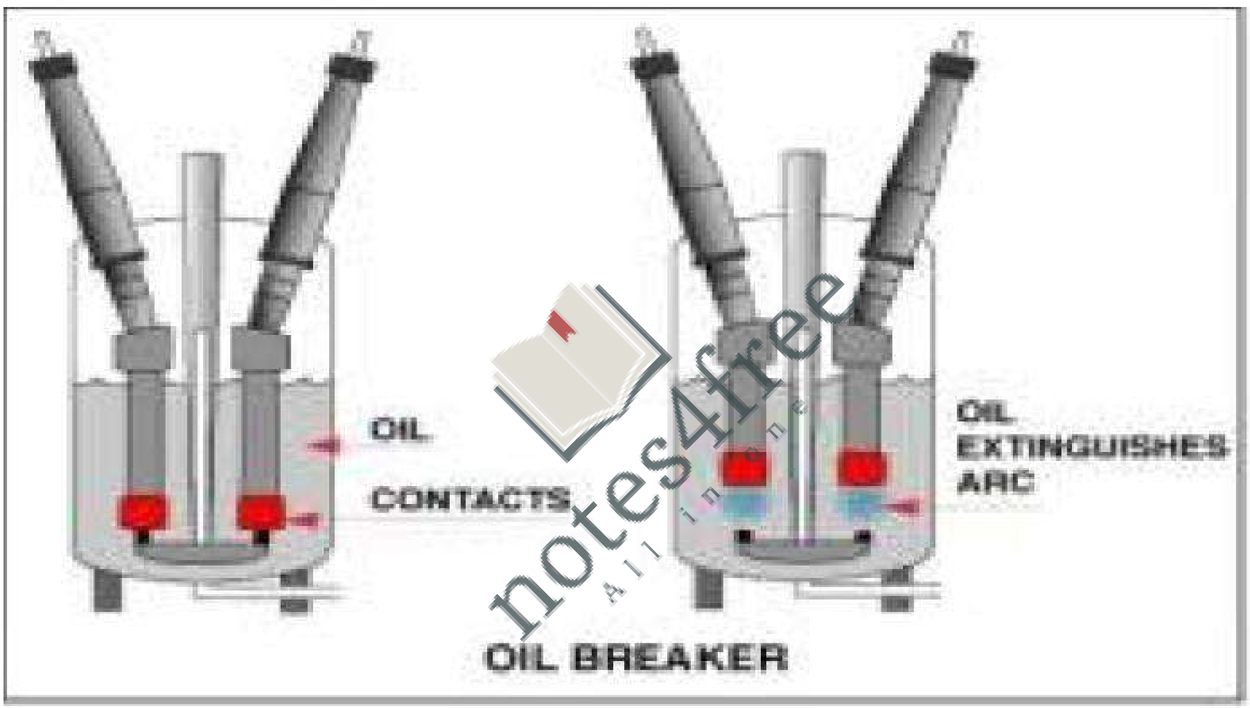
Air magnetic breakers



Air magnetic breakers use the arc to generate a magnetic field that forces the arc into arc chutes, which lengthen and cool the arc, allowing it to be extinguished at a current zero.

Oil breakers

Oil breakers are of several types, including bulk oil, but they all work in a relatively similar way. Here, the contacts are immersed in a container of non-conductive oil. When an overcurrent occurs, the arc heats the surrounding oil forcing it to flow violently. The rapidly flowing oil displaces the arcing gases and breaks the arc path.



Oil breakers always carry the hazards of handling and disposing of spent oil, and the potential for oil fire. Different oil breakers are designed for different power levels, with the highest rated for 345 kV to 500 kV.

Testing of Circuit breakers

Type Tests As mentioned earlier these tests are carried out on first few circuit breakers to prove the rated characteristics of the breakers. The necessary information which includes assigned ratings, drawings, reference standards, rated operating pressure and voltage, support structure etc must he supplied to the testing authorities More conducting these test.. These details are included in the type tests report. After certifying the breaker by carrying out these tests, there should not be any change in design. Type tests are classified as follows,

a) Mechanical tests

b) Tests of temperature rise, milli volt drop test

c) High voltage test

d) Basic short circuit test i) Making test ii) Breaking test iii) Operating sequence tests at 10%, 30%, 60%, 100% of rated breaking current with specified TRV conditions.

e) Critical current tests

f) Single phase short circuit test

g) Short time current test In addition to above tests some more tests are recommended breakers to be used in specific applications, which are, a) Short line fault tests b) Out of phase switching tests c) Cable charging current switching test d) Capacitive current switching tests e) Small inductive current breaking tests of Reactor current switching tests

Routine Tests

Before dispatch of circuit breakers, these tests are performed. Routine test is defined as a test of every circuit breaker made to the same specifications. They include the following tests. a) Mechanical operation tests b) Millivolt drop test, Measurement of resistance c) Power frequency voltage tests d) Voltage tests on auxiliary circuits, control circuits the quality of the circuit breaker can be very well checked by these tests. Also any defect in the materials and construction is detected.

Development Tests These tests, are very much essential to observe the effect of different parameters on the circuit breakers performance. Variety of tests is performed on individual items as well as on complete assemblies. If a circuit breaker is tested frequently with change in its contact speed, then we can see the effect of contact speed on breaking capacity the different parameters and their effects are theoretically predicted. Full scale prototypes are manufactured after testing and measurement. The data available in the company is used by the designers for name for the design of contacts; the configuration can be derived from available designs of contact assemblies. Each subassembly has certain functional requirement e.g. the contacts should give low resistance in closed position. Therefore to verify the capability of contact configurations, development tests are conducted, depending on functional requirements. The modifications are done on the basis of these test results.

Reliability Tests The newly manufactured circuit breakers are tested by type tests and routine tests. But the conditions during these tests are not the conditions that exist at the field. At site the circuit breaker is subjected to various stresses due to,

a) Variation in ambient temperatures

b) Extremely low and high temperatures

c) Rain moisture

d) Vibrations on account of earthquakes

e) Dust and chemical fumes, Overloads and over voltages

Unit Testing The modern FEW circuit breakers contains two or more similar interrupters per pole. These interrupters operate simultaneously and share the voltage across the pole equally. The breaking capacity is also equally shared. The results obtained on one unit can be extended further for total capacity of breaker. This is known as unit testing or element testing. It is internationally accepted method. During the application of unit test, the voltage must be reduced by a factor b so the corresponding impedances are also reduced by b to get test voltage across the unit following expression. a = where m = number of units per pole and one unit is tested

are in opposition. The stress ei produced in the synthetic test and those in actual network must be same but it is not the actual case because of several factors like high current, high voltage, instant of applying voltage etc.

Brown Boveri's Synthetic Testing Circuit This circuit is shown in the Fig. 10.35. The short circuit current is supplied from low voltage circuit. The restriking and recovery voltage is supplied by different high voltage circuit.

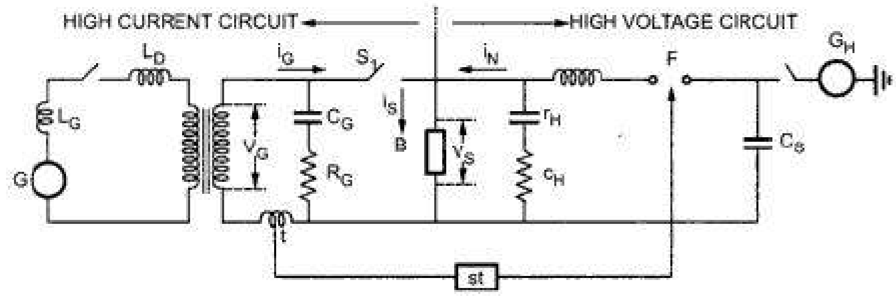


Fig. shows Brown-Boveri's synthetic testing circuit The high current circuit on left side consists of short circuit generator G, short circuit transformer with resistor Rc and capacitor Cc which controls natural frequency of current. The short circuit power is supplied at voltages Vs which corresponds to about 30 kV which is smaller than recovery voltage required for testing. The recovery voltage is supplied by high voltage circuit on right side. The test breaker and auxiliary breaker S, are opened together. Before the current interruption takes place in breaker B, the spark gap is triggered by control St and voltage V is applied to breaker B. During final current zero only current if, Lows through breaker B. which is interrupted by S, and breaker B. But now breaker B has to interrupt only. Hence restriking voltage across breaker B is given by NV circuit.

Lightning arresters

Introduction: The voltage wave having magnitude more than its normal value and which remains for a very short duration are called overvoltage surges or transmit over voltages. For any electrical equipment, its insulation requirements are decided by these transient over voltages. The over voltages in the system occur due to various reasons such as lightning surges, switching surges, faults and travelling waves. There is high rate of rise and high peak value in transient over voltages which are dangerous for the Insulation and hence protection is rewired against these over voltages.

Lightning Phenomenon: A lightning stroke on any overhead line or on outdoor equipment causes lightning surges. Before studying the protection against these lightning surges, let us study the mechanism of lightning. An electrical discharge in the air between clouds, between the separate charge centers in the same cloud or between cloud and the earth is nothing but lightning. It produces the large spark accompanied by the light. This discharge of electricity through the air from the clouds under turbulent conditions is always abrupt and discontinuous. The serious hazards may take place sometimes if this discharge terminates on the earth. There are various theories which explain the potentials required for lightning strokes, are built up. However we will assume that because of some process taking place. In the atmosphere under the turbulent conditions there is accumulation of charges in the clouds. With the dielectric medium as the air the cloud and the ground form plates of a capacitor. If the lower part of the cloud la negatively charged, the earth is positively charged by induction. For lightning discharge to take place, it requires breakdown of air between the cloud and the earth. With increase in the charge, the potential between the cloud and the earth increases. As a result of this the potential in the air increases. The potential gradient required for the breakdown of air is 30 kV/cm peaks. But there is large moisture content in the air and because of lower pressure at high altitude; the breakdown of air takes place at 10 kV/ar. The process of lightning discharge is shown in the Fig.

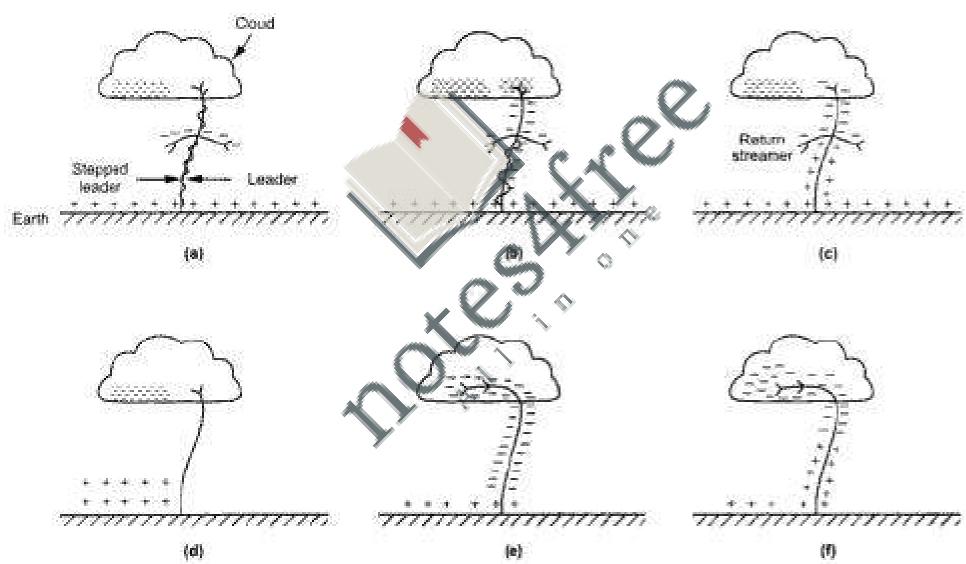


Fig. When charge increases there is difference in potential between cloud and earth which also increases resulting in increase of potential gradient of air which is non uniformly distributed. The potential gradient is more at the center of charge in the cloud. This gradient appears across some part of the air and when it is more than breakdown strength of air, this air breaks down A streamer called pilot streamer or leader streamer starts from cloud towards the earth and carries the charge with it as shown in the Fig. (Till the time the cloud through which this stream is initiated supplies enough charge to maintain the potential gradient at the tip of the leader streamer above the breakdown strength of air, the leader streamer continues to travel towards the earth. With the loss of this gradient, the streamer stops without reaching to the earth. The charge dissipated without forming the complete stroke. The lightning stroke may start with the potentials of the order of 5* 106 Vie 20x 106 V between cloud and earth while the current of the leader streamer is low, typically less than 100 A and its propagation velocity is 0.03 % of that of velocity of light.

Many times the streamer travels towards the earth until it is reached to the earth or some abject on earth. As the initial moves towards earth, it is accompanied by points of luminescence which travel in jumps giving rise to stepped leaders In step the distance travelled is about 50 in while the velocity of stepped leader exceeds one sixth of that of light. The stepped leaders results in first visual phenomenon of discharge. The electrostatic field and potential gradient at earth's surface is high as this streamer reaches to the earth. When sufficiently large then a short upward streamer called return streamer rises form the earth as shown in the Fig. When the contact of leader b made with the earth then a sudden spark may be appeared. This contact is similar to closing of a switch between two opposite charges, the downward leader with negative change and upward streamer with positive charge. Due to this sudden sparks appearing which causes the most neutralization of negative charges on the cloud? This is called lightning. Any further discharge from the cloud must be originated form other portion of it. When lightning occurs then it is associated with high current followed by lower current for significant duration as the charge in the cloud is neutralized. The upward streamer carries high current with a speed of propagation of about 30 m/ iL sec which is faster than the speed of the leader streamer. The current rises sharply within microseconds and then decays slowly compared to its rise. this is similar to discharge of a capacitor through a circuit but it is not periodic. The experiments conducted in the laboratories show that when the charge in the channel is near exhaustion, there is smooth transition in current into its low value which is associated with the remaining charge in the cloud. When the streamer reaches the earth and much of charge in the cloud from which it was originated, is neutralized then potential pertaining to point of charge center reduces. But there may exist high potential between this original charge center and other charge centers. Due to this, there may be discharge from other charge centers into the region where the leader streamer was originated. Thus a subsequent discharge takes place along with the original stroke to the earth. Many strokes can be observed which contains more than one current peak which are called multiple or repetitive. Separate peaks are termed as components. In summary we can say that lightning is a phenomenon of breakdown of air and discharge which can he seen by eve as a sing 'e flash but contains number of separate strokes that travels with same path practically. The variation of time interval between them is from 0.5 m sec< to 300 msec. 87 % of the lightning strokes originate from negatively charged clouds while remaining 13 % originate from positively charged clouds. Lightning discharge current magnitude lies in the range of 10 kA to 90 kA.