

LECTURE NOTES

ON

Switch gear and Protective Devices (SGPD)

Sixth Semester
Electrical Engineering

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Introduction to SWITCHGEAR.

Switchgear :- The apparatus used for switching, controlling and protecting the electrical circuits and equipment is known as Switchgear.

It is desirable to protect the power system from harm during fault condition and to ensure maximum continuity of supply. For this purpose, it must be provided to switch on or off generators, transmission lines, distribution and other equipment under both normal and abnormal conditions. This is achieved by a switchgear.

Switchgear consist of switching and protective devices such as switches, fuses, circuit breakers, relays etc.

Switchgear equipment

The tumbler switch with ordinary fuse is the simplest form of switchgear.

It is used to control and protect lights and other equipment in homes, offices etc.

For circuits of higher rating, a high-breaking capacity (H.R.C.) fuse with a switch may serve the purpose of controlling and protecting the circuit.

The above circuit breakers cannot be used on high voltage system (3.3 kV) for the following reason.

(i) When a fuse blows, it takes take sometime to replace it and consequently there is interruption of service to the customers.

(ii) The fuse cannot successfully interrupt large fault currents that results from the faults on high voltage system.

* In order to interrupt such heavy fault currents, circuit breakers are used.

Circuit breaker (C.B.) :- A circuit breaker is a switchgear which can open or close an electrical circuit under both normal and abnormal conditions. C.B. can close a circuit as well as break them without replacement and this has wider range of use than a fuse.

Switchgear Equipment : (In detail) (2)

Switchgear covers a wide range of equipment under both normal and abnormal conditions.

It includes switches, fuses, circuit breakers, relays and other equipment.

1. Switches :

A switch is a device which is used to open or close an electrical circuit in a convenient way.

It can be used under full-load or no-load conditions but it cannot interrupt the fault currents.

When the contacts of a switch are opened, an arc is produced in the air between the contacts. This is particularly true for circuits of high voltage and large current capacity.

The switches may be classified into

(i) Air switches and (ii) Oil switches.

(i) Air-break switch :

Open or closed under loading condition.

Air is used as arc-quenching medium.

Voltage withstand and current carrying capacity are less.

It is used in distribution transformer structure.

It is an air switch and is designed to open a circuit underload.

In order to quench the arc that occurs on opening switch such a switch, special arcing horns are provided.

Arcing horns are pieces of metals between which arc is formed during opening condition.

As the switch opens, these horns are spread farther and farther apart. Consequently,

the arc is lengthened, cooled and interrupted.

Air-break switches are generally used outdoors for circuits of medium capacity such as lines.

③ Supplying an industrial load from a main transmission line or feeder.

(ii) Isolator or disconnecting switch:

It is a knife switch and is designed to open a circuit under no load. Its main purpose is to isolate one portion of the circuit from the other and is not intended to be opened while current is flowing in the line.

Such switches are generally used on both sides of the circuit breakers in order that repairs and replacement of breakers can be made without any danger.

(iii) Oil Switches: - The contact of such switches are opened under oil, usually transformer oil.

The effect of oil is to cool and quench the arc that tends to form when the circuit is opened.

These switches are used for circuits of high voltage and large current carrying capacities.

2. FUSES: A fuse is a short piece of wire or thin strip which melts when excessive current flows through it for sufficient time. It is inserted in series with the circuit to be protected.

Under normal operating conditions, the fuse element is at a temperature below its melting point.

When a short circuit or overload occurs, the current through the fuse element increases beyond its rated capacity.

This raises the temperature and the fuse element melts or blows out, disconnecting the circuit protected by it.

In this way, a fuse protects the machines and equipment from machine damage due to excessive currents.

3. CIRCUIT BREAKERS: A circuit breaker is an equipment which can open or close a circuit under all conditions like no load, full load and fault conditions.

It is so designed that it can be operated manually or by remote control under normal conditions and automatically under fault conditions.

Under fault condition, a relay circuit is used with a circuit breaker.

The circuit breaker essentially consist of moving and fixed contacts enclosed in strong metal tank and immersed in oil, known as transformer oil.

Under normal operating conditions, the contacts remain closed and the breaker carries the full-load current continuously.

In this condition, the e.m.f in the secondary winding of current transformer (C.T.) is insufficient to operate the trip coil of the breaker but the contacts can be opened and hence the circuit can be opened by manual or remote control.

When a fault occurs, the resulting overcurrent in the C.T. primary winding increases the secondary e.m.f.

This energizes the trip coil of the breaker and moving contacts are pulled down, thus opening the contacts and hence the circuit.

The arc produced during the opening operation is quenched by the oil.

Relay performs the function of detecting a fault whereas the circuit breaker does the actual circuit interruption.

4. RELAYS: A Relay is a device which detects the fault and supplies information to the breaker for circuit interruption.

The relay circuit can be divided into three parts:

(i) The primary winding of a current Transformer (C.T.) which is connected in series with the circuit to be protected.

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- (ii) The second circuit is the secondary winding of C.T. connected to the relay operating coil.
(iii) The third is the tripping circuit which consists of a source of supply, trip coil of circuit breaker and the relay stationary contacts.

Under normal load conditions, the e.m.f of secondary winding of C.T. is small and the current flowing in the relay operating coil is insufficient to close the relay contacts. This keeps the trip coil of the circuit breaker unenergised. Consequently, the contact of the breaker remain closed and it carries the normal load current.

When a fault occurs, a large current flows through the primary of C.T. This increase the secondary e.m.f and hence the current through the relay operating coil. The relay contacts are closed and the trip coil of the breaker is energised to open the contacts of the breaker.

Bus-Bar Arrangement:

When a number of generators or feeders operating at the same voltage have to be directly connected electrically, bus-bars are used as the common electrical components.

Bus-bars are ~~used as~~ copper rods or thin walled tubes and operate at constant voltage.

Single Bus-bar System:

The single bus-bar system has the simplest design and is used for power stations.

It is also used in small outdoor stations having relatively few outgoing or incoming feeders and lines.

In this system, the generators, outgoing lines and transformers are connected to the bus-bar.

Each generator and feeder is controlled by a circuit breaker.

The isolators permits to isolate generators, feeders and circuit breakers from the bus-bar for maintenance.

The chief advantages of this type of arrangement are low initial cost, less maintenance and simple operation.

Disadvantages: Three ^p principal disadvantages are:-

- (i) The bus-bar cannot be cleaned, repaired, or tested without de-energising the whole system.
- (ii) If a fault occurs on the bus-bar itself, there is complete interruption of supply.
- (iii) Any fault on the system is fed by all the generating capacity, resulting in very large fault current.

Single bus-bar System with Sectionalisation

In large generating stations where several units are installed it is a common practice to sectionalise the bus so that fault on any section of the bus-bar will not cause complete shut-down.

In the figure, the bus-bar divided into two sections connected by a circuit breaker and isolator.

Advantages of Sectionalisation:-

- (i) If a fault occurs on any section of the bus-bar, that section can be isolated without affecting the supply from other sections.
- (ii) If a fault occurs on any feeder, the fault current is much lower than with unsectionalised bus-bar. This permits the use of circuit breakers of lower capacity in the feeders.
- (iii) Repairs and maintenance of any section of the bus-bar can be carried out by de-energising that section only, eliminating the possibility of complete shut-down.

→ A circuit breaker should be used as the sectionalising switch so that uncoupling of the bus-bar may be carried out safely.

The circuit breaker itself should be provided with isolators on both sides so that its maintenance can be done while the bus-bars are alive.

Switchgear Accommodation:

It is necessary to house switchgear in power stations and sub-stations in such a way so as to safeguard personnel during operation and maintenance and to ensure that the effects of fault on any section

E of the switchgear are confined to a limited region. Depending upon the voltage to be handled, switchgear may be classified into (i) Outdoor type (ii) Indoor type

(i) Outdoor type: For voltage beyond 60 KV, switchgear equipment is installed outdoor.

It is because for such voltages, the clearances between conductors and the space required for switchgear, circuit breakers, transformers and other equipment become so great that it is not economical to install all such equipment indoor.

(ii) Indoor type: For voltages below 60 KV, switchgear is generally installed indoor because of economical considerations. The indoor switch-gear is generally of metal-clad type. In this type of construction, all live parts are completely enclosed in an earthed metal casing.

Short-Circuit.

Whenever a fault occurs on a network such that a large current flows in one or more phases, a short circuit is said to have occurred.

When a short circuit occurs, a heavy current called short-circuit current flows through the circuit.

Under normal conditions, the current in the circuit is limited by load impedance.

If the load terminals get shorted due to any reason, the circuit impedance is reduced to a very low value, therefore a large current flows through the circuit. This is called short-circuit current.

Causes of short-circuit: A short circuit in the power system is the result of some kind of abnormal conditions in the system. It is due to the both internal and external effects.

(i) Internal effect: These are caused by breakdown of equipment on transmission lines from deterioration of insulation in a generator, transformer etc. Such troubles may be due to aging of insulation, inadequate design or improper insulation.

(ii) External effects causing short circuit include insulation failure due to lightning surges, overloading of equipment causing excessive heating, mechanical damage by public etc.

Faults in a power system.

A fault occurs when two or more conductors that normally operate with a potential difference come in contact with each other.

These faults may be caused by sudden failure of a piece of equipment, by accidental damage or short-circuit to overhead lines or by insulation failure resulting from lightning surges. Faults in a 3-phase system can be classified into two main categories.

(i) Symmetrical faults: That fault which gives rise to symmetrical fault currents (equal fault currents with 120° displacement) is called symmetrical fault.

The most common example of symmetrical fault is when all the three conductors of a 3-phase line are brought together simultaneously into a short-circuit condition.

(ii) Unsymmetrical faults: Those faults which give rise to unsymmetrical currents (i.e. unequal line currents with unequal displacement) are called unsymmetrical faults.

The great majority of faults on the power system are of unsymmetrical nature.

Symmetrical fault calculations.

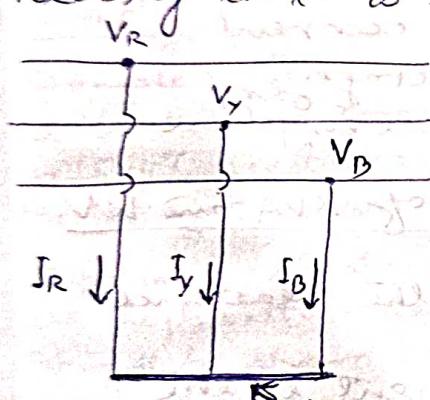
When fault occurs in a power system, a heavy current called short circuit current flows through the equipment, causing considerable damage to the equipment and its interruption of services to the consumers.

The choice of apparatus and the design and arrangement of practically every equipment in the power system depends upon short-circuit current consideration.

Symmetrical faults on 3-phase system:

That fault on the power system which gives rise to symmetrical currents (i.e. equal fault currents in the lines with 120° displacement) is called a symmetrical fault.

The symmetrical fault occurs when all the three conductors of a 3-phase line are brought together simultaneously in to a short circuit condition as shown in figure.



This type of fault gives rise to symmetrical currents. This type of fault gives rise to symmetrical currents i.e. equal fault currents with 120° displacement.

Fault currents I_R , I_Y and I_B will be equal in magnitude.

Because of balance nature of fault only one phase need be considered in calculations since condition in the other two phases will also be similar.

The symmetrical fault rarely occurs in practice as majority of the faults are of unsymmetrical nature.

Limitation of Fault Current.

Percentage Reactance:

The reactance of generators, transformers, reactors etc. is usually expressed in percentage reactance to permit rapid short circuit calculations.

The percentage reactance of a circuit is defined as under.

It is the percentage of the total phase-voltage dropped in the circuit when full-load current is flowing.

$$\% X = \frac{I X}{V} \times 100$$

where I = full-load current

V = Phase voltage ohm

X = reactance in phase

Percentage reactance in terms of KVA and KV

$$\% X = \frac{(KVA) X}{10(KV)^2}$$
 where X is the reactance in ohms.

If X is the only reactance element in the circuit, then

$$\text{Short Circuit Current } (I_{se}) = \frac{V}{X}$$

$$= I \times \left(\frac{100}{\% X} \right)$$

Short Circuit Current is obtained by multiplying the full load current by $\frac{100}{\% X}$

Percentage reactance and Base KVA.

Percentage reactance of an equipment depends upon its KVA rating. Generally the various equipments used in the power system have different KVA rating. Therefore it is necessary to find the percentage reactances of all the elements on a common KVA rating. This common KVA rating is known as base KVA.

The value of this base KVA may be

- Equal to that of the largest plant
- equal to the total capacity
- any arbitrary value.

$$\% \text{ reactance at base KVA} = \frac{\text{Base KVA}}{\text{Rated KVA}} \times \% \text{ age reactance at rated KVA.}$$

- * The value of base KVA does not affect the short circuit current.

Example: Consider a 3-phase transmission line operating at 66 KV and connected through a 1000 KVA transformer with 5% reactance to a generating station bus-bar. The generator is of 2500 KVA with 10% reactance.

Suppose a short circuit fault between three phases occurs at the high voltage terminals of transformer. It will be shown that whatever value of base KVA we may choose the value of short-circuit current will be the same.

- Suppose we choose 2500 KVA as the common base KVA.

Reactance of Transformer at 2500 KVA base

$$= \frac{5 \times 2500}{1000} = 12.5\%$$

Reactance of Generator at 2500 KVA base.

$$= \frac{10 \times 2500}{2500} = 10\%$$

Total percentage reactance on the common base KVA

$$\% X = 12.5 + 10 = 22.5\%$$

The full load current corresponding to 2500 KVA base at 66 KV is given by

$$I = \frac{2500 \times 1000}{\sqrt{3} \times 66 \times 1000} = 21.87 \text{ A.}$$

\therefore Short circuit current $I_{sc} = I \times \frac{100}{\% X}$

$$= 21.87 \times \frac{100}{22.5} = 97.2 \text{ A.}$$

(ii) Now, Suppose we choose 5000 KVA as the common base value.

Reactance of Transformer at 5000 KVA base

$$= \frac{5 \times 5000}{1000} = 25\%$$

$$\text{Reactance of Generator at } 5000 \text{ KVA base} = \frac{10 \times 5000}{2500} = 20\%$$

Total %age reactance on the common base KVA

$$\% X = 25 + 20 = 45\%$$

Full-load Current corresponding to 5000 KVA at 66 KV

$$I = \frac{5000 \times 1000}{\sqrt{3} \times 66 \times 1000} = 43.74 \text{ A.}$$

$$\therefore \text{Short circuit current } I_{sc} = I \times \frac{100}{\% X} = 43.74 \times \frac{100}{45} = 97.2 \text{ A.}$$

From the above example, it is clear that whatever may be the value of base KVA, Short Circuit is the same. However numerically convenient value of the base KVA should be chosen.

Short circuit kVA

The product of normal system voltage and short circuit current at the point of fault expressed in KVA is known as Short-circuit KVA.

Let V = Normal phase voltage in volts

I = Full-load current in Amperes at base KVA

$\% X$ = Percentage reactance of the system on base KVA up to the fault point.

$$\text{Short circuit Current } I_{sc} = I \left(\frac{100}{\% X} \right)$$

Short Circuit KVA for 3-phase circuit

$$= \frac{3V I_{sc}}{1000} = \frac{3V I}{1000} \times \frac{100}{\% X}$$

$$= \text{Base KVA} \times \frac{100}{\% X}$$

Short circuit KVA is obtained by multiplying the base KVA by $100/(\% X)$.

Reactor Control of Short-circuit Currents

In order to limit the short circuit currents to a value which the circuit breakers can handle, additional reactance known as reactors are connected in series with the system at suitable points.

A reactor is a coil of number of turns designed to have a large inductance as compared to its ohmic resistance.

Advantages:

- (i) Reactors limit the flow of short-circuit current and thus protect the equipment from overheating as well as from failure due to destructive mechanical forces.
- (ii) Troubles are localised or isolated at the point where they originate without communicating their disturbing effects to other parts of the power system. This increases the chances of continuity of supply.
- (iii) They permit the installation of circuit breakers of lower rating.

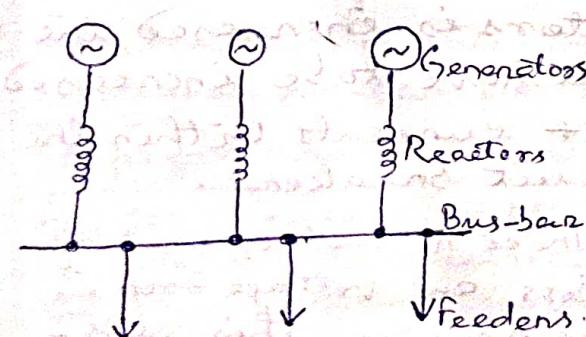
Location of Reactors.

Short circuit current limiting reactors may be connected

- (i) in Series with each generator
- (ii) in Series with each feeder and
- (iii) in bus-bars

Each time of installation of reactor has its own particular demands which must be carefully considered before a choice of reactor location can be made.

(i) Generator reactors.



When the reactors are connected in series with each generator, they are known as generator reactors.

In this case the reactor may be considered as a part of leakage reactance of the generator hence its effect is to protect the generator in the case of any short-circuit beyond the reactors.

Disadvantages:

- (i) There is a constant voltage drop and power loss in the reactors even during normal operation.
- (ii) If a bus-bar or feeder fault occurs close to the bus-bar, the voltage at the bus-bar will be reduced to a low value, thereby causing the generators to fall out of step.
- (iii) If a fault occurs on any feeder, the continuity of supply to others is likely to be affected.

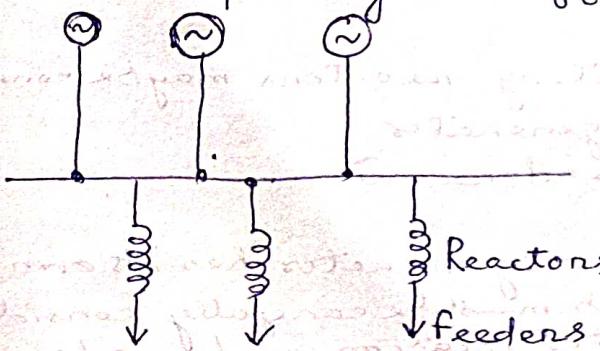
(2) Feeder reactors:

When the reactors are connected in series with each feeder, they are known as feeder reactors.

Since most of the short circuits occur on feeders, a large number of reactors are used for such circuits.

Advantages:- (i) If a fault occurs on any feeder, the voltage drop in its reactor will not affect the bus-bar voltage so that there is a little tendency for the generator to lose synchronism.

(ii) The fault on a feeder will not affect other feeders and consequently the effects of fault are localised.



Disadvantages

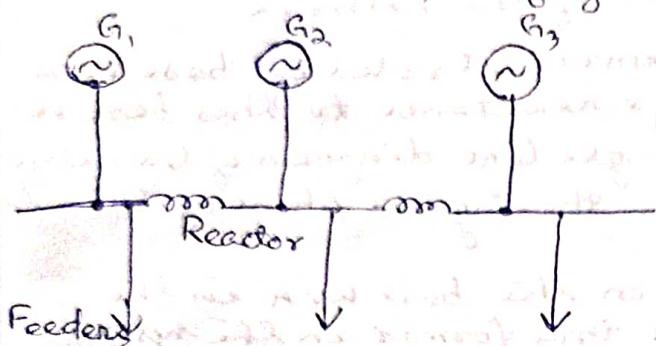
(i) There is a constant power loss and voltage drop in the reactors even during normal operation.

(ii) If a short-circuit occurs at the bus-bars, no protection is provided to the generators.

(iii) If the number of generators is increased, the size of feeder reactors will have to be increased to keep the short-circuit currents within the ratings of the feeder circuit breakers.

(3) Bus-bar reactors: Under nominal operating condition, there is a power loss and voltage drop in feeder reactors and generator reactors. This disadvantages can be overcome by locating the reactors in the bus-bars. There are two methods for this purpose. (i) Ring System (ii) Tie-Bar System.

(i) Ring System: In this system, bus-bar is divided into sections and these sections are connected through reactors as shown in figure.



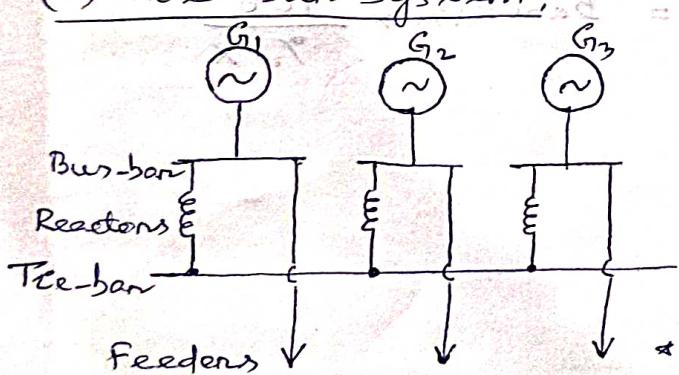
Generally, one feeder is fed from one generator only.

Under normal operating conditions each generator will supply its own section of the load and very little power will be fed by other generators. This results in low power loss and voltage drop in the reactors.

Advantages: If a fault occurs on any feeder, only one generator (to which the particular feeder is connected) mainly feeds the fault while the current fed from other generators is small due to the presence of reactors.

Therefore, only that section of bus bar is affected to which the feeder is connected, the other sections being able to continue in normal operation.

(ii) Tie-Bar System:



Advantages:

Comparing the ring system with tie-bar system, it is clear that in the tie-bar system there are effectively two reactors in series between sections so that reactors must have approximately half the reactance of those used in a comparable ring system.

* Another advantage of this system is that additional generators may be connected to the system without requiring changes in the existing reactors.

* Disadvantages of this system is that it requires an additional bus-bar i.e. the tie-bar.

Steps for Symmetrical Fault Calculations:

Fault currents in the 3- ϕ are equal in magnitude but displaced 120° electrical from one another.

Therefore, problems involving such faults can be solved by considering 1- ϕ only as the same conditions prevail in the other two phases. The procedure for the solution of such faults involves the following steps

(ii) Draw a single line diagram of the complete network indicating the rating, voltage and percentage reactance of each element of the network.

(iii) Choose a numerically convenient value of base KVA and convert all percentage reactance to their base value.

(iv) Corresponding to the single line diagram of the network, draw the reactance diagram, showing one phase of the system and the network.

Indicate the % reactances on the base KVA in the reactance diagram. The transformer in the system should be represented by a reactance in series.

(v) find the total % reactance of the network upto the point of fault. Let it be $X\%$.

(vi) find the full load current corresponding to the selected base KVA and the nominal system voltage at the fault point. Let it be I_{se} .

Then various short-circuit calculations are,

$$\text{Short-circuit Current, } I_{se} = \frac{100}{\% X}$$

Short-circuit KVA

$$= \text{Base KVA} \times \frac{100}{\% X}$$

FUSES

A fuse is a short piece of metal, inserted in the circuit, which melts when excessive current flows through it and thus breaks the circuit. Thus fuse element is generally made of material having low melting point, high conductivity and least deterioration due to oxidation e.g. silver, copper etc. It is inserted in series with the circuit to be protected.

Desirable Characteristics of Fuse Element.

The function of a fuse is to carry the normal current without overheating but when the current exceeds its normal value, it rapidly heats up to melting point and disconnects the circuit protected by it. The fuse element should have the following desirable characteristics;

- (i) low melting point e.g. tin, lead.
- (ii) high conductivity e.g. Silver, copper
- (iii) free from deterioration due to oxidation e.g. Silver.
- (iv) low cost e.g. lead, tin, copper.

Fuse Element Materials.

The most commonly used materials for fuse element are lead, tin, copper, zinc and silver.

For small currents up to 10A, tin or an alloy of lead and tin (lead 37%, tin 63%) is used for making the fuse element.

For larger currents, copper or silver is employed. It is a usual practice to tin the copper to protect it from oxidation.

Zinc (in strip form only) is good if a fuse with considerable time lag is required i.e. one which does not melt very quickly with a small overload.

The present trend is to use silver despite its high cost due to the following reasons.

- (i) It is comparatively free from oxidation.
- (ii) It does not deteriorate when used in dry air.
- (iii) The coefficient of expansion of silver is so small that no critical fatigue occurs. Therefore, the fuse element can carry the rated current continuously for a long time.
- (iv) The conductivity of silver is very high. Therefore for a given rating of fuse element, the mass of silver metal required is smaller than that of other materials.

(v) Due to comparatively low specific heat, silver fusible elements can be raised from normal temperature to vapourisation quicker than other fusible elements.

(vi) Silver vapourises at a temperature much lower than the one at which its vapour will readily ionise.

Therefore, when an arc is formed through the vapourised portion of the element, the arc path has high resistance. As a result, short-circuit current is quickly interrupted.

Types of Fuses:

Fuses may be classified into:-

(i) Low voltage fuses

(ii) High voltage fuses.

(i) Low Voltage Fuses.

Low Voltage fuses can be subdivided into two classes:-

(i) Semi-enclosed rewirable fuse.

(ii) High rupturing capacity (H.R.C.) Cartridge fuse.

1: Semi-enclosed rewirable fuse

Rewirable fuse also known as kit - Kat type fuse is used where low values of fault current are to be interrupted. It consists of a base and a fuse carrier.

The base is of porcelain and carries the fixed contacts to which the incoming and outgoing phase wires are connected.

The fuse carrier is also of porcelain and holds the fuse element between its terminals.

The fuse carrier can be inserted in or taken out of the base when desired.

When a fault occurs, the fuse element is blown out and the current is interrupted. The fuse carrier is taken out and the blown out fuse element is replaced by the new one. The fuse carrier is then re-inserted in the base to restore the supply.

Advantages: (i) The detachable fuse carrier permits the replacement of fuse element without any danger of coming in contact in contact with live parts.

(ii) The cost of replacement is negligible.

Disadvantages.

- (i) There is a possibility of renewal by the fuse wire of wrong size or by improper material.
- (ii) This type of fuse has a low-breaking capacity and hence cannot be used in circuits of high fault level.
- (iii) The fuse element is subjected to deterioration due to oxidation through the continuous heating up of the element. Therefore, after sometime, the current rating of the fuse is decreased.
- (iv) Accurate calibration of the fuse wire is not possible because fusing current very much depends upon the length of the fuse element.

Semi enclosed rewirable fuses are made upto 500A rated current, but their breaking capacity is low e.g. on 400 V service, the breaking capacity is about 4000A.

Therefore the use of this type of fuse is limited to domestic and lighting loads.

High Rupturing Capacity (H.R.C.) Cartridge Fuse

The primary objection of semi enclosed rewirable fuses is overcome in H.R.C. cartridge fuse.

The figure shows the essential parts of a HRC cartridge fuse. It consists of a heat resisting ceramic body having metal end caps to which is welded silver current carrying element.

The space within the body surrounding the element is completely packed with a filling powder. The filling material maybe chalk, plaster of Paris, quartz or marble dust and acts as an arc quenching and cooling medium.

Under normal load conditions, the fuse element is at a temp. below its melting point. Therefore, it carries the normal current without overheating.

When a fault occurs, the current increases and the fuse element melts before the fault current reaches its first peak. The heat produced in the process vapourises the melted silver element. The chemical reaction between the silver vapour and the filling powder results in the formation of a high resistance substance which helps in quenching the arc.

Advantages: (i) They are capable of clearing high as well as low fault currents.
(ii) They don't deteriorate with age.

- (iii) They have high speed of operation.
- (iv) They require no maintenance.
- (v) They are cheaper than other circuit interrupting devices of equal breaking capacity.
- (vi) They permit consistent performance.

Disadvantages

- (i) They have to be replaced after each operation.
- (ii) Heat produced by the arc may effect the associated switches.

High Voltage Fuse

The low voltage fuses discussed so far have low nominal current rating and breaking capacity. Therefore, they cannot be successfully used on modern high voltage circuit.

Then, manufacturers have led to the development of high voltage fuses. Some of the high voltage fuses are:- Cartridge type, liquid type and Metal clad fuses.

Cartridge type fuse:

This is similar in general construction to the low voltage cartridge type except that special design features are incorporated. Some designs employ fuse elements wound in the form of a helix so as to avoid corona effects at higher voltages.

On some designs, there are two fuse elements in parallel: one of low resistance (silver wire) and the other of high resistance (tungsten wire).

Under normal load conditions, the low resistance element carries the normal current.

When a fault occurs, the low resistance element is blown out and the high resistance element is blown out reduces the short-circuit current and finally breaks the circuit.

High ~~resistance~~ cartridge fuses are used up to 33 KV with breaking capacity of about 8700A at that voltage.

Ratings of the order of 200A at 6.6 KV and 11 KV and 50A at 33 KV are also available.

Difference between a Fuse and Circuit Breaker.

<u>Particulars</u>	<u>Fuse</u>	<u>Circuit breaker</u>
1. Function - It performs both detection & interruption and interruption function only. The detection function is made by relay system.		
2. Operation - Inherently completely automatic.		- Requires elaborate equipment (i.e. relays) for automatic action.
3. Breaking capacity - Small voltage level - very large.		
4. Operating time - Very small time (0.002 sec. or so)		- Comparatively large (0.1 to 0.2 sec.)
5. Replacement - Requires replacement after every operation.		No replacement after operation.

CIRCUIT BREAKERS

A Circuit breaker is a piece of equipment which can (i) make or break a circuit either manually or by remote control under normal conditions.

(ii) break a circuit automatically under fault conditions.

(iii) make a circuit either manually or by remote control under fault conditions.

Operating principle: A circuit breaker consists of fixed and moving contacts, called electrodes. Under normal operating conditions, these contacts remain closed and will not open automatically until and unless the system becomes faulty. The contacts ~~can~~ can be opened opened manually or by remote control whenever desired.

When a fault occurs on any part of the system, the trip coils of the breaker get energised and the moving contacts are pulled apart by some mechanism, thus opening the circuit.

The main problem ^{is} of a circuit is to extinguish the arc within the shortest possible time so that heat generated by it may not reach a dangerous value.

Arc Phenomenon.

When a short-circuit occurs, a heavy current flows through the contacts of the circuit breaker.

At the instant when the contacts begin to separate the contact area decreases rapidly and large fault current causes increased current density and hence rise in temperature.

The heat produced in the medium between contacts (usually the medium oil or air) is sufficient to ionise the air or vapourise and ionise the oil.

The ionised air or vapour acts as conductor and arc is struck between the contacts.

The potential difference between the contacts is quite small and ^{just} is sufficient to maintain the arc. The arc provides a low resistance path and

Consequently the current in the circuit remains uninterrupted so long as the arc persists.

During the arcing period, the current flowing between the contacts depends upon the arc resistance.

The greater the arc resistance, the smaller the current that flows between the contacts.

Principles of Arc Extinction.

(i) When the contacts have a small separation, the P.D. between them is sufficient to maintain the arc.

One way to extinguish the arc is to separate the contacts to such a distance that the P.D. between becomes inadequate to maintain the arc.

(ii) The ionised particles between the contacts tend to maintain the arc. If the arc path is deionised, the arc extinction will be facilitated. This may be achieved by cooling the arc or by bodily removing the ionised particles from the space between the contacts.

Methods of Arc Extinction:

There are two methods of extinction of arc in circuit breaker (i) High resistance method.

(ii) Low resistance or Current Zero method.

High Resistance Method.: In this method, arc resistance is made to increase with time so that current is reduced to a value insufficient to maintain the arc.

Consequently, the current is interrupted

on the arc is extinguished.

The principal disadvantage of this method is that enormous energy is dissipated in the arc. Therefore, it is employed only in d.c. circuit breakers and low capacity a.c. circuit breaker.

The resistance of the arc may be increased by

(i) Lengthening the arc: The resistance of the arc is directly proportional to its length. The length of the arc can be increased by increasing the gap between contacts.

(ii) Cooling the arc: Cooling helps in the deionisation of the medium between the contacts. This increases the arc resistance. Efficient cooling may be obtained by a gas blast directed along the arc.

(iii) Reducing X-Section of the arc: If the area of cross-section of the arc is reduced, the voltage necessary to maintain the arc is increased. The cross-section of the arc can be reduced by letting the arc pass through a narrow opening or by having smaller area of contacts.

(iv) Splitting the arc: The resistance of the arc can be increased by splitting the arc into a number of smaller arcs in series. Each one of these arcs experiences the effect of lengthening and cooling. The arc may be split by introducing some conducting plates between the contacts.

Important Terms

Arc Voltage: It is the voltage that appears across the contacts of the circuit breaker during the arcing period. At current zero, the arc voltage rises rapidly to peak value and this peak voltage tends to maintain the current flow in the form of arc.

Restriking Voltage: It is the transient voltage that appears across the contacts at or near current zero during arcing period.

At current zero, a high frequency transient voltage appears across the contacts and is caused by the rapid distribution of energy between the magnetic and electric fields associated with the plant and transmission lines of the system. The current interruption in the circuit depends upon this voltage.

Recovery Voltage: It is the normal frequency (50 Hz) r.m.s. voltage that appears across the contacts of the circuit breaker after final arc extinction. It is approximately equal to the system voltage.

Classification of Circuit Breaker

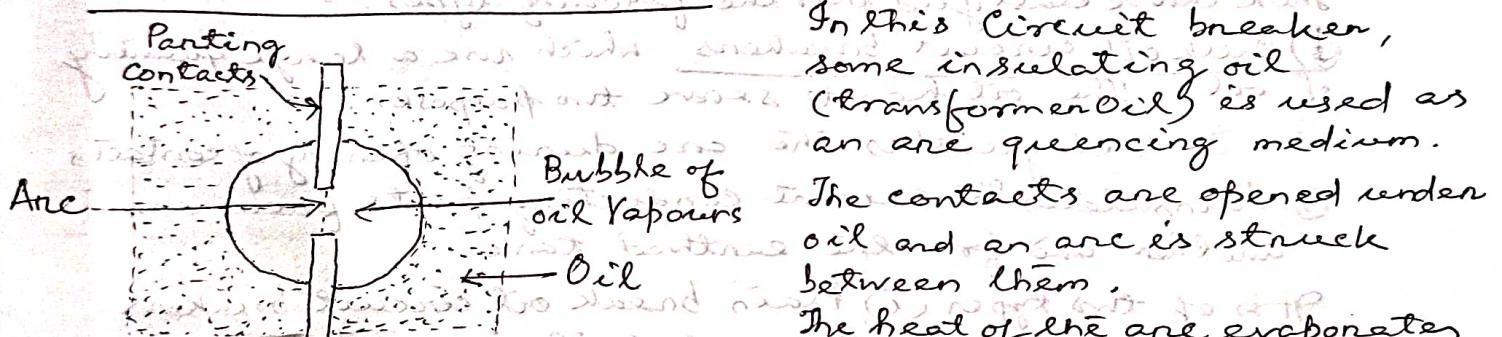
Circuit breaker may be classified into:

- (i) Oil circuit breakers, which employ some insulating oil (e.g. transformer Oil) for arc extinction.
- (ii) Air-blast Circuit breakers in which high pressure air-blast is used for extinguishing the arc.
- (iii) Sulphur Hexa Fluoride Circuit breakers in which Sulphur Hexa Fluoride (SF_6) gas is used for arc extinction.
- (iv) Vacuum Circuit Breakers in which Vacuum is used for arc extinction.

The above classification is done on the basis of medium used for arc extinction.

Each type of circuit breaker has its own advantages and disadvantages.

Oil Circuit Breaker



In this Circuit breaker, some insulating oil (Transformer Oil) is used as an arc quenching medium.

The contacts are opened under oil and an arc is struck between them.

The heat of the arc evaporates the surrounding oil and dissociates it into a

substantial volume of gaseous hydrogen at high pressure. The hydrogen gas occupies a volume about one thousand times that of the oil decomposed.

The oil is, therefore, pushed away from the arc and an expanding hydrogen gas bubble surrounds the arc region and adjacent portions of the contact.

The arc extinction is facilitated mainly by two processes. Firstly, the hydrogen gas has high heat conductivity and cools the arc, thus aiding the de-ionisation of the medium between the contacts.

Secondly, the gas sets up turbulence in the oil and forces it into the space between contacts, thus eliminating the arcing products from the arc path. The result is that arc is extinguished and circuit current interrupted.

Advantages of Circuit Breaker.

- (i) It absorbs the arc energy to decompose the oil into gases which have excellent cooling properties.
- (ii) It acts as an insulator and permits smaller clearance between like conductors and earthed components.
- (iii) The surrounding oil presents cooling surface in close proximity to the arc.

Disadvantages: The disadvantages of oil as an arc quenching medium are:-

- (i) It is inflammable and there is a risk of fire.
- (ii) It may form an explosive mixture with air.
- (iii) The arcing products (carbon) remain in the oil and its quality deteriorates with successive operations. This necessitates periodic checking and replacement of oil.

Types of Oil Circuit Breakers.

Oil circuit breaker find extensive use in the power system;

These can be classified into the following types:-

- (1) Bulk oil circuit breakers, which use a large quantity of oil. The oil has to serve two purposes:
- (a) It extinguishes the arc during opening of contacts.
- (b) It insulates the current conducting parts from one another and from the earthed tank.

It is of two types (i). Plain break oil circuit breakers.

(ii). Arc control oil circuit breakers.

In plain break oil circuit breaker no special means is available for controlling the arc and the contacts are directly exposed to the whole of the oil in the tank.

In Arc control oil circuit breaker, special arc control devices are employed to get the beneficial action of the arc as efficiently as possible.

- (2) Low oil Circuit breaker which use minimum amount of oil. In such breakers, oil is used only for arc extinction. The current conducting parts are insulated by air or porcelain or organic insulating material.