

SUBJECT – SGPD

BRANCH-ELECTRICAL

SEMESTER-6th SEM

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Lect.(Electrical)

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

Essential Features of Switchgear:-

(i) Complete Reliability :- With the continued trend of interconnection and the increasing capacity of generating stations, the need for a reliable switchgear has become of paramount importance. When fault occurs on any part of the power system, the switchgear must operate to isolate the faulty section from the remainder circuit.

(ii) Absolutely certain discrimination :- When fault occurs on any section of the power system, the switchgear must be able to discriminate between the faulty section and the healthy section. It should isolate the faulty section from the system without affecting the healthy section. This will ensure continuity of supply.

(iii) Quick operation :- When fault occurs on any part of the power system, the switchgear must operate quickly so that no damage is done to generators, transformers and other equipment by the short-circuit currents. If fault is not cleared by switchgear quickly, it is likely to spread into healthy parts, thus endangering complete shut down of the system.

(iv) Provision for manual control :- A switchgear must have provision for manual control. In case the electrical (or electronics) control fails, the necessary operation can be carried out through manual control.

(v) Provision for instruments :- There must be provision for instruments which may be required. These may be in the form of ammeter or voltmeter on the unit itself or the necessary current and voltage transformers for connecting to the main switchboard or a separate instrument panel.

Switchgear Equipment :-

⇒ Switchgear covers a wide range of equipment concerned with switching and interrupting currents 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 can not interrupt the fault currents.

⇒ When the contacts of a switch are opened, an arc is produced in the air between the contacts. The switches may be classified into (i) air switches (ii) oil switches.

(i) Air-break switch :-

It is an air switch and is designed to open a circuit under load. In order to quench the arc that occurs on opening such a switch, special arcing horns are provided.

⇒ Arcing horns are pieces of metal between which arc is formed during opening operation. 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 outdoor for circuits of medium capacity such as lines supplying an industrial load from a main transmission line or feeder.

(ii) Isolator or disconnecting switch :- It is essentially 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 circuit breakers in order that repairs and replacement of circuit breakers can be made without any danger.

⇒ They should never be opened until the circuit breaker in the same circuit has been opened and should always be closed before the circuit breaker is closed.

(iii) Oil switches :- The contacts 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 capacity.

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. Therefore, it carries the normal load current without overheating.

⇒ However, 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 damage due to excessive currents.

3. Circuit Breakers :-

⇒ A circuit breaker is an equipment which can open or close a circuit under all conditions i.e. 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.

⇒ For the latter operation, a relay circuit is used with a circuit breaker. Fig 1(a) shows the parts of a typical oil circuit breaker whereas Fig 1(b) shows its control by a relay circuit. The CB essentially consists 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 CB 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 energises the trip coil of the breaker and moving contacts are pulled down, thus opening the contacts and hence the circuit.

⇒ Relay performs the function of detecting a fault whereas the CB 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. Fig 1(b) shows a typical relay circuit. It can be divided into 3 parts i.e.

(i) The primary winding of a current transformer (C.T) which is connected in series with the circuit to be protected. The primary winding often consists of the main conductor itself.

(ii) The second circuit is the secondary winding of C.T. connected to the relay operating coil.

(iii) The third circuit is the tripping circuit which consists of a source of supply, trip coil of CB and the relay stationary contacts.

⇒ Under normal load conditions, the e.m.f. of the 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 CB unenergised.

⇒ Consequently, the contacts of the CB remain closed and it carries the normal load current. When a fault occurs, a large current flows through the primary of C.T.

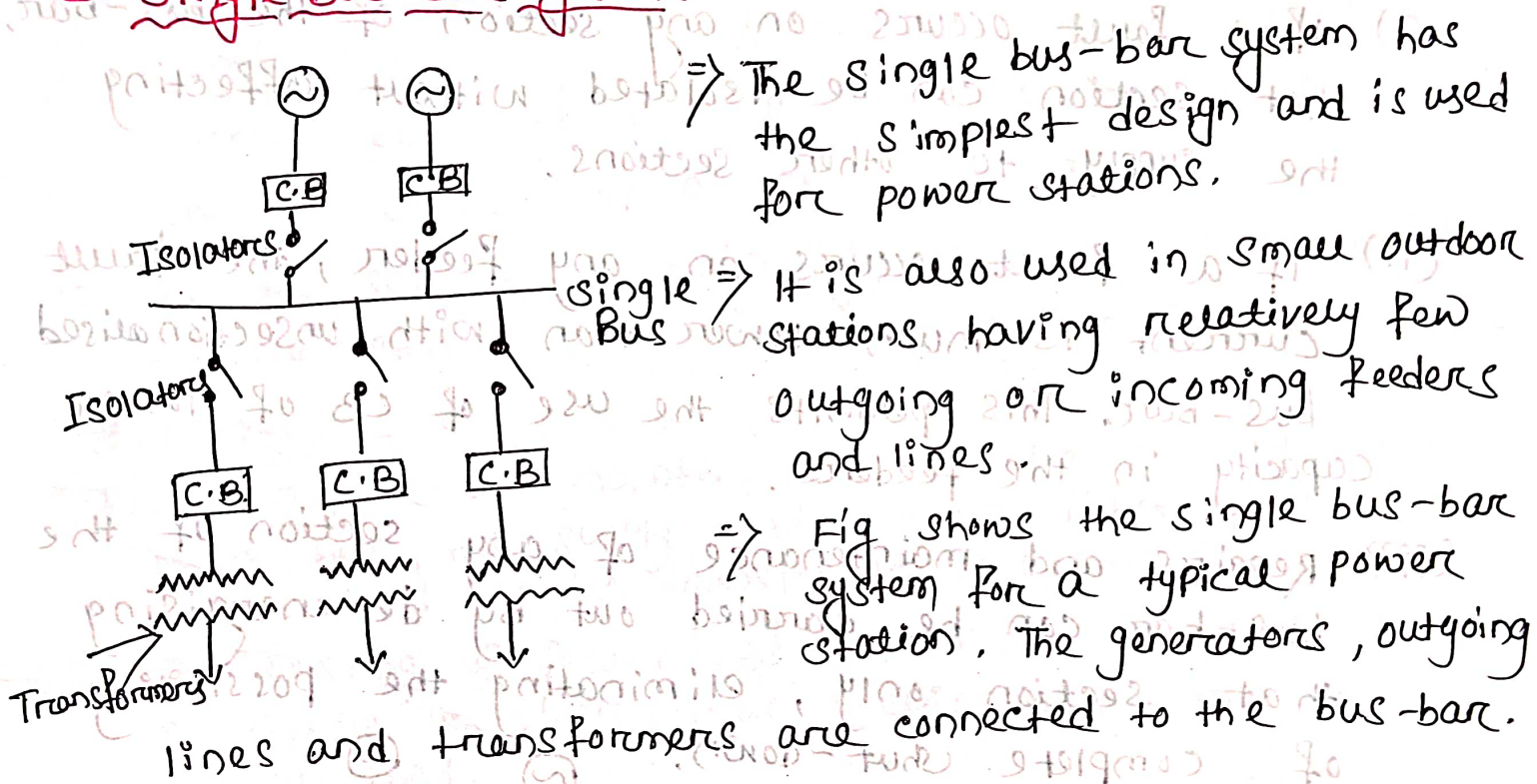
⇒ This increases the secondary e.m.f. and hence the current through the relay operating coil. The relay contacts are closed and the trip coil of the CB is energised to open the contacts of the CB.

Bus-Bar Arrangements :-

⇒ 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 component.

⇒ Bus-bars are copper rods or thin walled tubes and operate at constant voltage. Electrical bus-bar is the collector of electrical energy at one location.

1. Single Bus-bar system :-



⇒ Each generator is controlled by a CB. The isolators permit to isolate generators, feeders and CBs from the bus-bar for maintenance.

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

Disadvantages :-

- (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 currents.

2) Single bus-bar system with sectionalisation :-

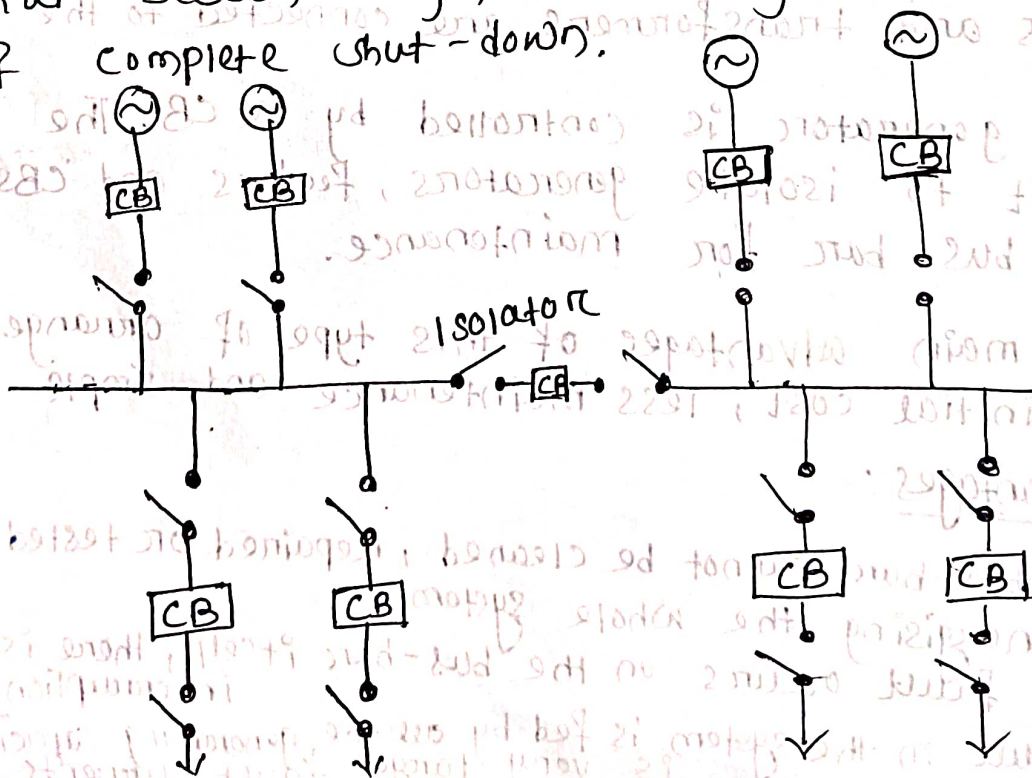
⇒ In large generating stations where several units are installed, it is a common practice to sectionalise the bus so that fault on any section of the bus-bar will not cause complete shut down.

⇒ Fig shows the bus-bar divided into two sections connected by a CB and isolators. 3 main advantages are claimed for this arrangement.

(i) If a fault occurs on any section of the bus-bar, that section can be isolated without affecting the supply to 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 CB 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.



(3) Duplicate bus-bar system :-

⇒ In large stations, it is important that breakdowns and maintenance should interfere with continuity of supply.

⇒ In order to achieve this objective, duplicate bus-bar system is used in important stations. Such a system consists of two bus-bars, a "main bus-bar" and a "spare" bus-bar (as shown in fig).

⇒ Each generator and feeder may be connected to either bus-bar with the help of bus coupler which consists of a CB and isolators.

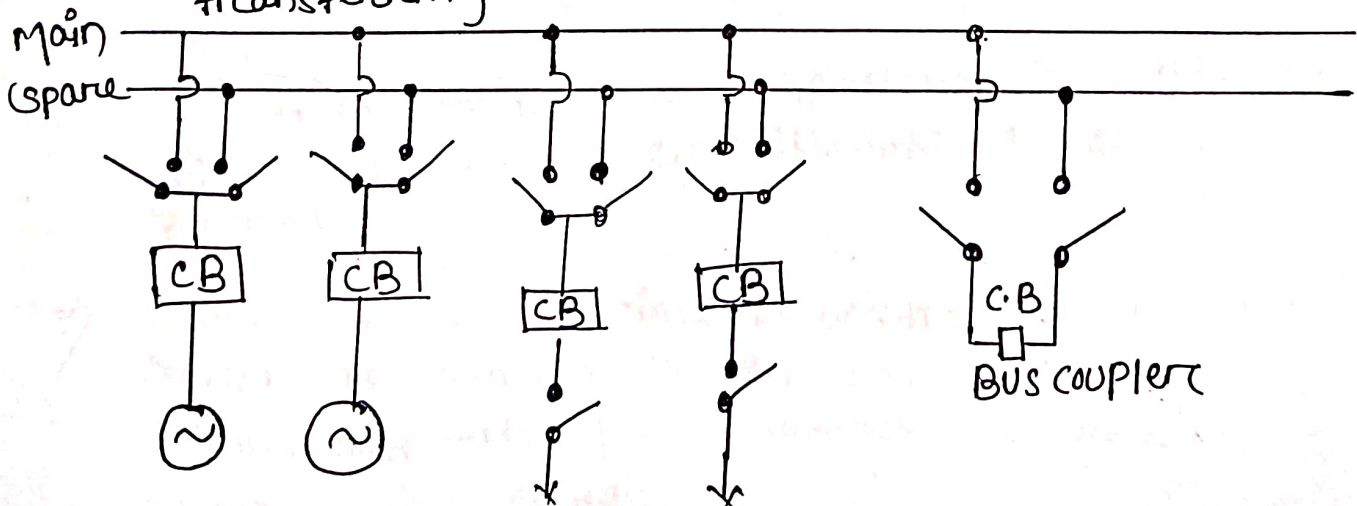
⇒ In the scheme shown in fig, service is interrupted during switch over from one bus to another.

Advantages :-

(i) If repair and maintenance is to be carried on the main bus, the supply need not be interrupted as the entire load can be transferred to the spare bus.

(ii) The testing of feeder CBs can be done by putting them on spare bus-bar, thus keeping the main bus-bar undisturbed.

(iii) If a fault occurs on the bus-bar, the continuity of supply to the circuit can be maintained by transferring it to the other bus-bar.

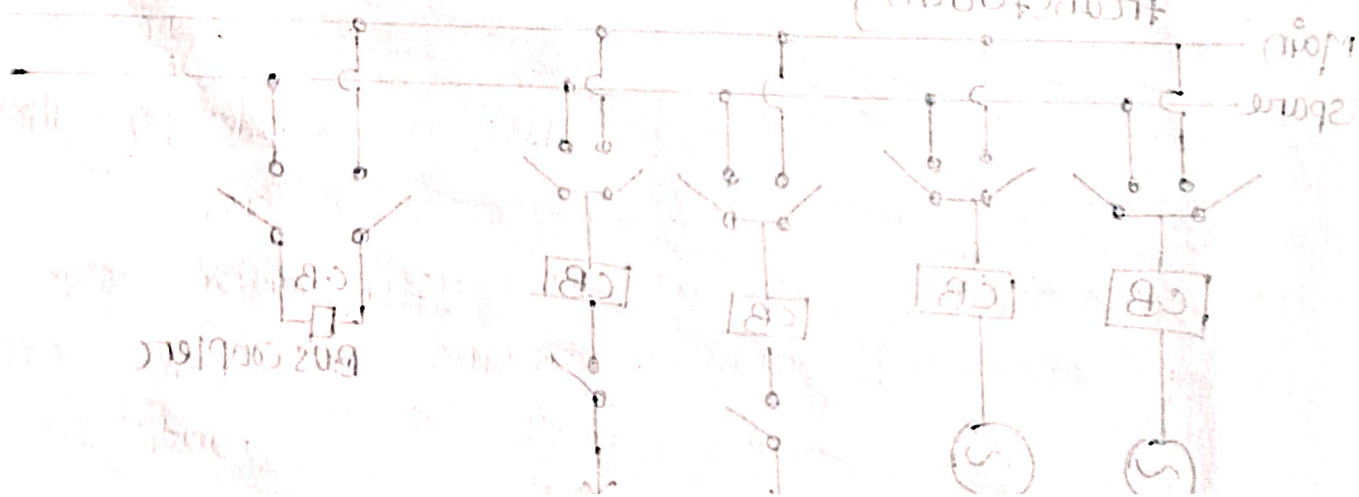


Switchgear Accommodation:-

- ⇒ The main components of a switchgear are circuit breakers, switches, bus-bars, instruments and instrument transformers.
- ⇒ It is necessary to house the 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 of the gear are confined to a limited region.
- ⇒ Depending upon the voltage to be handled, switchgear may be broadly classified into (i) outdoor type (ii) Indoor type.

(i) outdoor type:-

- ⇒ For voltages beyond 66KV, switchgear equipment is installed outdoor. It is because for such voltages, the clearances between conductors and the space required for switches, CBS, transformers and other equipment become so great that it is not economical to install all such equipment indoor.
- ⇒ Fig shows a typical outdoor sub-station with switchgear equipment. The CBS, isolators, transformers and bus-bars occupy considerable space on account of large electrical clearance associated with high voltages.

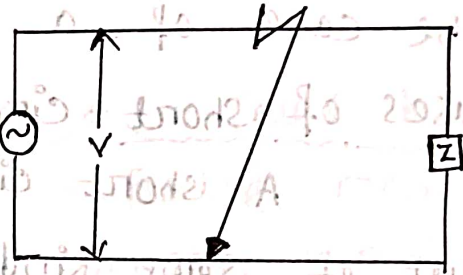


(ii) Indoor type :-

- $\Rightarrow$ For voltages below 66KV, switchgear is generally installed indoor because of economic considerations.
- $\Rightarrow$ The indoor switchgear is generally of metal-criad type. In this type of construction, all live parts are completely enclosed in an earthed metal casing.

Short-circuit :-

- $\Rightarrow$ 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.



- $\Rightarrow$ When a short circuit occurs, a heavy current called short circuit current flows through the circuit. This can be illustrated by referring to Fig where a single phase generator of voltage V and internal impedance Z_i is supplying to a load Z .
- $\Rightarrow$ Under normal conditions, the current in the circuit is limited by load impedance Z (as internal impedance Z_i of the generator is generally small). However, if the load terminals get shorted due to any reason, the circuit impedance is reduced to a very low value, being Z_i in this case.
- $\Rightarrow$ As Z_i is very small, therefore, a large current flows through the circuit. This is called short-circuit current.
- $\Rightarrow$ When a short-circuit occurs, the voltage at fault point is reduced to zero and current of abnormally high magnitude flows through the network to the point of fault.

⇒ on the other hand, an overload means that loads greater than the designed values have been imposed on the system. Under such conditions, the voltage distance beyond the overload point into the remainder of the system.

⇒ The currents in the overloaded equipment are high but are substantially lower than that in the case of a short-circuit.

Causes of short-circuit:-

A short circuit in the power system is the result of some kind of abnormal conditions in the system. It may be caused due to internal and/or external effects.

(i) Internal Effects:- These are caused by breakdown of equipment or transmission lines, from deterioration of insulation in a generator, transformer etc. such troubles may be due to ageing of insulation, inadequate design or improper installation.

(ii) External Effects:- These are causing short circuit include insulation failure due to lightning surges, over loading of equipment causing excessive heating.

Effects of short-circuit:-

When a short-circuit occurs, the current in the system increases to an abnormally high value while the system voltage decreases to a low value.

(i) The heavy current due to short-circuit causes excessive heating which may result in fire or explosion. Sometimes short-circuit takes the form of an arc and causes considerable damage to the system. For ex: - an arc on a transmission line not cleared quickly will burn the conductor severely causing it to break, resulting in a long time interruption of the line.

(ii) The low voltage created by the fault has a very harmful effect on the service rendered by the power system. If the voltage remains low for even a few seconds, the consumers' motors may be shut down and generators on the power system may become unstable.

Due to above effects of short-circuit, it is desirable and necessary to disconnect the faulty section and restore normal voltage and current conditions as quickly as possible.

Short-circuit currents :-

Most of the failures on the power system lead to short-circuit fault and cause heavy current to flow in the system. The calculations of these short-circuit currents are important for the following reasons:-

(i) A short-circuit on the power system is cleared by a CB or a fuse. It is necessary, therefore, to know the max^m possible values of short-circuit current so that switchgear of suitable rating may

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(i) A short-circuit on the power system is cleared by a CB or a fuse. It is necessary, therefore, to know the max^m possible values of short-circuit current so that switchgear of suitable rating may be installed to interrupt them.

(ii) The magnitude of short-circuit current determines the setting and sometimes the types and location of protective system.

(iii) The magnitude of short-circuit current determines the size of the protective reactors which must be inserted in the system so that the CB is able to withstand the fault current.

(iv) The calculation of short-circuit currents enables us to make proper selection of the associated apparatus (e.g. bus-bars, current Transformers etc.) so that they can withstand.

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, accidental damage or short-circuit to overhead lines or by insulation failure resulting from lightning surges.

⇒ Irrespective of the causes, the faults in a 3-Ph. system can be classified into two main categories i.e.

(i) symmetrical faults (ii) unsymmetrical faults.

(i) symmetrical faults:-

That fault which gives rise to symmetrical fault currents (i.e. equal fault currents with 120° displacement) is called a 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.

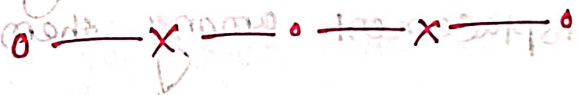
⇒ The unsymmetrical faults may take one of the following forms:-

(a) Single line-to-ground fault;

(b) Line-to-line fault

(c) Double line-to-ground fault.

The great majority of faults on the power system are of unsymmetrical nature, the most common type being a short-circuit from one line to ground.



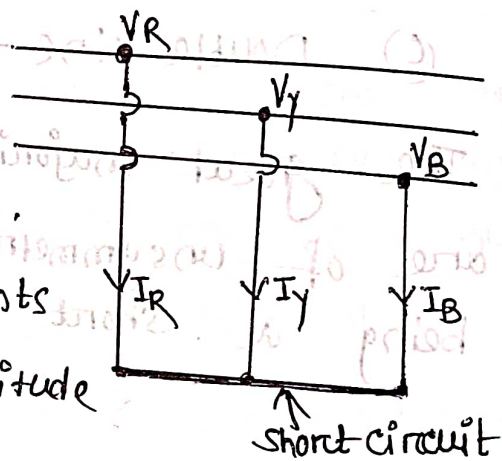
ch-2 Symmetrical Fault Calculation

Symmetrical Faults on 3-phase system:-

That fault on the power system which gives rise to symmetrical fault 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-ph line are brought together simultaneously into a short-circuit condition as shown in fig.

⇒ This type of fault gives rise to symmetrical currents i.e. equal fault currents with 120° displacement. Thus referring to fig, fault currents I_R, I_Y & I_B will be equal in magnitude with 120° displacement among them.



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

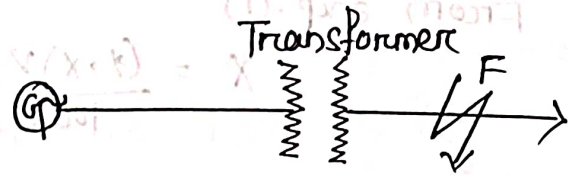
⇒ The following points may be particularly noted :-

- (i) The symmetrical fault rarely occurs in practice as majority of the faults are of unsymmetrical nature.
- (ii) The symmetrical fault is the most severe and imposes more heavy duty on the circuit breaker.

Limitation of fault current :-

⇒ When a short circuit occurs at any point in a system,

the short-circuit current is limited by the impedance of the system upto the point of fault.



⇒ Thus referring to fig above, if a fault occurs on the feeder at point F, then the short circuit current from the generating station will have a value limited by the impedance of generator and transformer and the impedance of the line between the generator and the point of fault.

⇒ This shows that the knowledge of the impedances of various equipment and circuits in the line of the system is very important for the determination of short-circuit currents.

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 i.e.

$$\% X = \frac{IX}{V} \times 100 \quad (1)$$

where I = Full-load current

V = phase voltage

X = Reactance in ohms per phase.

From eq. (1)

$$X = \frac{(\%X)V}{100I} = \frac{(\%X)V \times V}{100 \times VI} = \frac{(\%X) \frac{V}{1000} \cdot \frac{V}{1000} \times 1000}{100 \times \frac{V}{1000} \times I} = \frac{(\%X)(KV)^2 \times 10}{KVA}$$

$$\therefore \%X = \frac{(KVA)X}{10(KV)^2}$$

Alternatively, percentage reactance ($\%X$) can also be expressed in terms of KVA & KV as under:-

$$\%X = \frac{(KVA)X}{10(KV)^2} \quad (2)$$

where X = Reactance in ohms

If X is the only reactance element in the circuit, then short-circuit current is given by:

$$I_{sc} = \frac{V}{X}$$

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

[By putting the value of X from eq. (1)]

i.e. short circuit current is obtained

by multiplying the full-load current by $100/\%X$.

EX:- If the percentage reactance of an element is 20% and the full-load current is 50A, then short circuit current will be $50 \times \frac{100}{20} = 250A$ when only that element is in the circuit.

It is clear from exp. (i) above that the value of an equipment depends upon its KVA rating. Generally, the various equipments used in the power system have different KVA ratings. Therefore, it is necessary to find the percentage of all the elements on a common KVA rating. This common KVA rating is known as base KVA. The value of this base KVA is quite unimportant and may be :-

- (i) equal to that of the largest plant
- (ii) equal to the total plant capacity.
- (iii) any arbitrary value

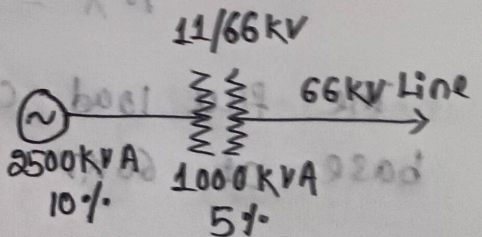
The conversion can be effected by using the following relations :-

$$\frac{\% \text{ age reactance at base KVA}}{1000} = \frac{\text{Base KVA} \times \% \text{ age reactance}}{\text{Rated KVA}}$$

Thus, a 1000KVA transformer with 5% reactance will have a reactance of 10% at 2000KVA base.

Illustration :-

The fact that the value of base KVA does not affect the short circuit current needs illustration.



⇒ consider a 3-ph. transmission line operating at 66KV and connected through a 1000KVA transformer with 5% reactance to a generating station bus-bar.

Percentage Reactance and Base KVA :-

It is clear from exp. (ii) above that percentage reactance of an equipment depends upon its KVA rating.

Generally, the various equipments used in the power system have different KVA ratings. Therefore, it is necessary to find the percentage of all the elements on a common KVA rating. This common KVA rating is known as base KVA. The value of this base KVA is quite unimportant and may be :-

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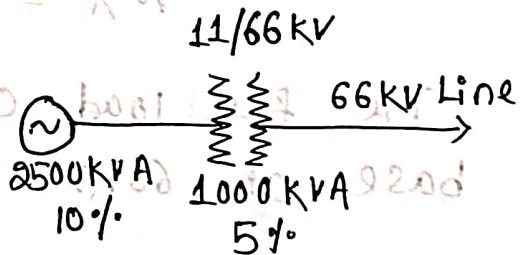
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→ consider a 3-ph. transmission line operating at 66 kV and connected through a 1000 KVA transformer with 5% reactance to a generating station bus-bar.

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⇒ The generator is of 2500KVA with 10% reactance. The single line diagram of the system is shown in fig.

⇒ Suppose a short-circuit fault between 3- ϕ 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.

(i) Suppose we choose 2500KVA as the common base KVA. On this base value, the reactances of the various elements in the system will be :-

Reactance of transformer at 2500KVA base

$$\% \text{ reactance at base KVA} = \frac{\text{base KVA}}{\text{rated KVA}} \times \% \text{ reactance at rated KVA}$$

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

Reactance of generator at 2500KVA base

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

Total percentage reactance on the common base KVA

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

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

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

$$\therefore \text{Short-circuit current, } I_{sc} = \frac{I \times 100}{\% X} = \frac{21.87 \times 100}{22.5} = 97.2 \text{ A}$$

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

Reactance of transformer at 5000 KVA base

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

Reactance of generator at 5000 KVA base

$$= 10 \times \frac{5000}{2500} = 20\%$$

Total percentage reactance on the common base KVA

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

Full-load current corresponding to 5000 KVA at 66 KV is

$$I = \frac{5000 \times 1000}{\sqrt{3} \times 66 \times 100} = 43.74 \text{ A}$$

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

$$= 43.74 \times \frac{100}{45} = 97.2 \text{ A}$$

which is the same as in the previous case.

From the above illustration, it is clear that whatever may be the value of base KVA, short-circuit current is the same.

Short-circuit KVA :-

Although the potential at the point of fault is zero, it is a normal practice to express the short-circuit current in terms of short-circuit KVA based on the normal system voltage at the point of fault.

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 upto the fault point

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

$\therefore$ short-circuit KVA for 3-ph circuit

$$S_{sc} = \frac{3 V I_{sc}}{1000}$$

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

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

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

i.e. short-circuit KVA is obtained by multiplying the base KVA by $100/\%X$.

Reactor control of short-circuit currents :-

With the fast expanding power system, the fault level (i.e. the power available to flow into a fault) is also rising.

$\Rightarrow$ The CBS connected in the power system must be capable of dealing with max^m possible short-circuit currents that can occur at their points of connection.

⇒ Generally, the reactance of the system under fault conditions is low and fault currents may rise to a dangerously high value.

⇒ If no steps are taken to limit the value of these short-circuit currents, not only will the duty required of circuit breakers be excessively heavy, but also damage to lines and other equipment will almost certainly occur.

⇒ In order to limit the short-circuit currents to a value which the CBs can handle, additional reactances 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 over heating as well as from failure due to destructive mechanical forces.

(ii) Increases the chances of continuity of supply.

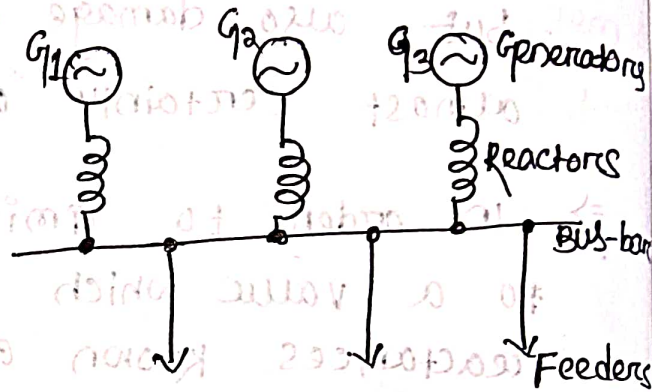
(iii) They permit the installation of CBs of lower rating.

Location of Reactors :-

Short circuit current limiting reactors may be connected (i) in series with each generator
(ii) in series with each feeder
(iii) in bus-bars.

(1) Generator Reactors :-

⇒ When the reactors are connected in series with each generator, they are known as generator reactors (see fig 1).



⇒ 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. Fig(1)

Disadvantages :-

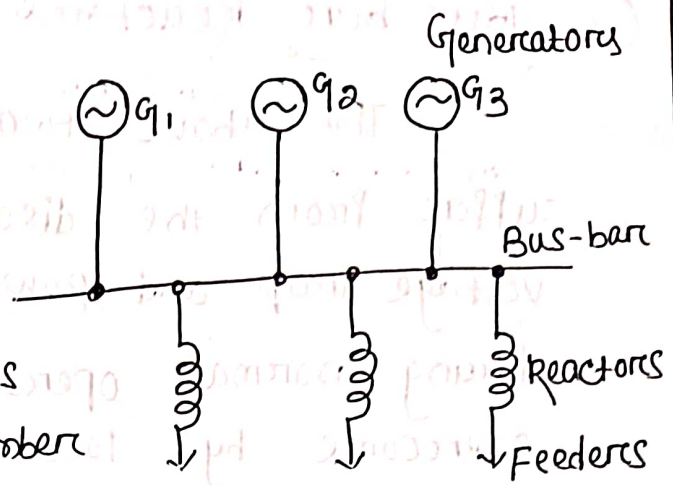
- (i) There is a constant voltage drop and power loss in the reactors even during normal operation.
- (ii) If a bus-bar or feeder fault occurs close to the bus-bar, the voltage at the bus-bar will be reduced to a low value, thereby causing the generators to fall out of step.
- (iii) If a fault occurs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

Due to these disadvantages and also since modern power station generators have sufficiently large leakage reactance to protect them against short-circuit.

(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.



⇒ Two main advantages are claimed for feeder reactors.

- (i) If a fault occurs on any feeder, the voltage drop in its reactor will not affect the bus-bars 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 :-

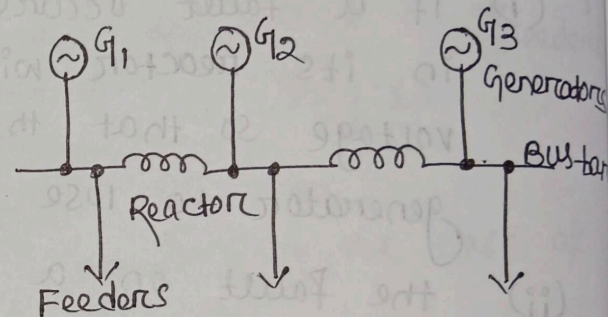
- (i) There is a constant power loss and voltage drop in the reactors even during normal operation.
- (ii) If a short-circuit occurs at the bus-bars, no protection is provided to the generators.
- (iii) If the number of generators is increased, the size of feeder reactors will have to be increased to keep the short-circuit currents within the ratings of the feeder CBS.

(3) Bus-bar Reactors :-

=> The above two methods of locating reactors suffer from the disadvantage that there is considerable voltage drop and power loss in the reactors even during normal operation. This disadvantage can be overcome by locating the reactors in the bus-bars. There are two methods for this purpose, namely:-
Ring system and 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 Fig.



=> 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.

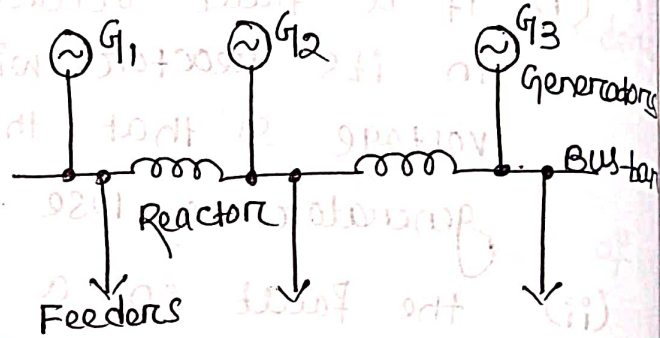
=> This results in low power loss and voltage drop in the reactors. However, the main advantage of the system is that if a fault occurs on any feeder, only one generator mainly feeds the fault current while the current fed from other generators is small due to the presence of reactors. Therefore, only that section of bus-bar is affected to which the feeder is connected, the other sections being able to continue in normal operation.

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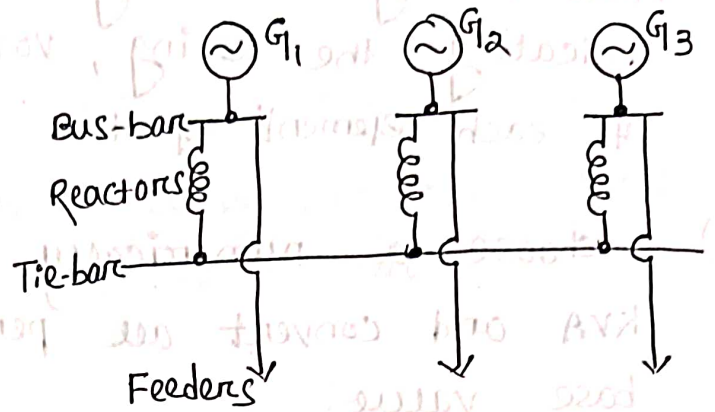


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(ii) Tie-Bar system:-

⇒ Fig shows the tie-bar system. 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 tie-bar system is that additional generators may be connected to the system without requiring changes in the existing reactors. However, this system has the disadvantage that it requires an additional bus-bar i.e. the tie-bar.

Steps for symmetrical Fault calculations:-

⇒ 3-phase short-circuit faults result in symmetrical fault currents i.e. fault currents in the three phases are equal in magnitude but displaced 120° electrical from one another.

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

- (i) Draw a single line diagram of the complete network indicating the rating, voltage and percentage reactance of each element of the network.
- (ii) Choose a numerically convenient value of base KVA and convert all percentage reactances to this base value.
- (iii) Corresponding to the single line diagram of the network, draw the reactance diagram showing one phase of the system and the neutral. Indicate the % reactances on the base KVA in the reactance diagram. The transformer in the system should be represented by a reactance in series.
- (iv) Find the total % reactance of the network upto the point of fault. Let it be $X\%$.
- (v) Find the full-load current corresponding to the selected base KVA and the normal system voltage at the fault point. Let it be I .

(vi) Then various short-circuit calculations are :-

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

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

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.

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.

⇒ In order that it may perform this function satisfactorily, 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.

The above discussion reveals that no material possesses all the characteristics. For instance, lead has low melting point but it has high specific resistance and is liable to oxidation. Similarly, copper has high conductivity and low cost but oxidises rapidly.

Fuse Element Materials :-

- ⇒ The most commonly used materials for fuse element are lead, tin, copper, zinc and silver. For small currents upto 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 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. This minimises the problem of clearing the mass of vapourised material set free on fusion and thus permits fast operating speed.

(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.

Important Terms :-

(i) current rating of fuse element :-

It is the current which the fuse element can normally carry without overheating or melting. It depends upon the temperature rise of the contacts of the fuse holder, fuse material and the surroundings of the fuse.

(ii) Fusing current :-

It is the minimum current at which the fuse element melts and thus disconnects the circuit protected by it. Obviously, its value will be more than the current rating of the fuse element.

For a round wire, the approximate relationship between fusing current I and diameter d of the wire is

$$I = Kd^{3/2}$$

where K is a constant called the fuse constant.

Its value depends upon the metal of which the fuse element is made. Sir W.H. Preece found the value of K for different materials as given in the table below :-

Material	Value of K	
	d in cm	d in mm
Copper	2530	80
Aluminium	1873	59
Tin	405.5	12.8
Lead	340.6	10.8

The fusing current depends upon the various factors such as :-

(a) material of fuse element.

(b) length - the smaller the length, the greater the current because a short fuse can easily conduct away all the heat.

(c) diameter

(d) size and location of terminals.

(e) previous history

(f) type of enclosure used

(iii) Fusing Factor :-

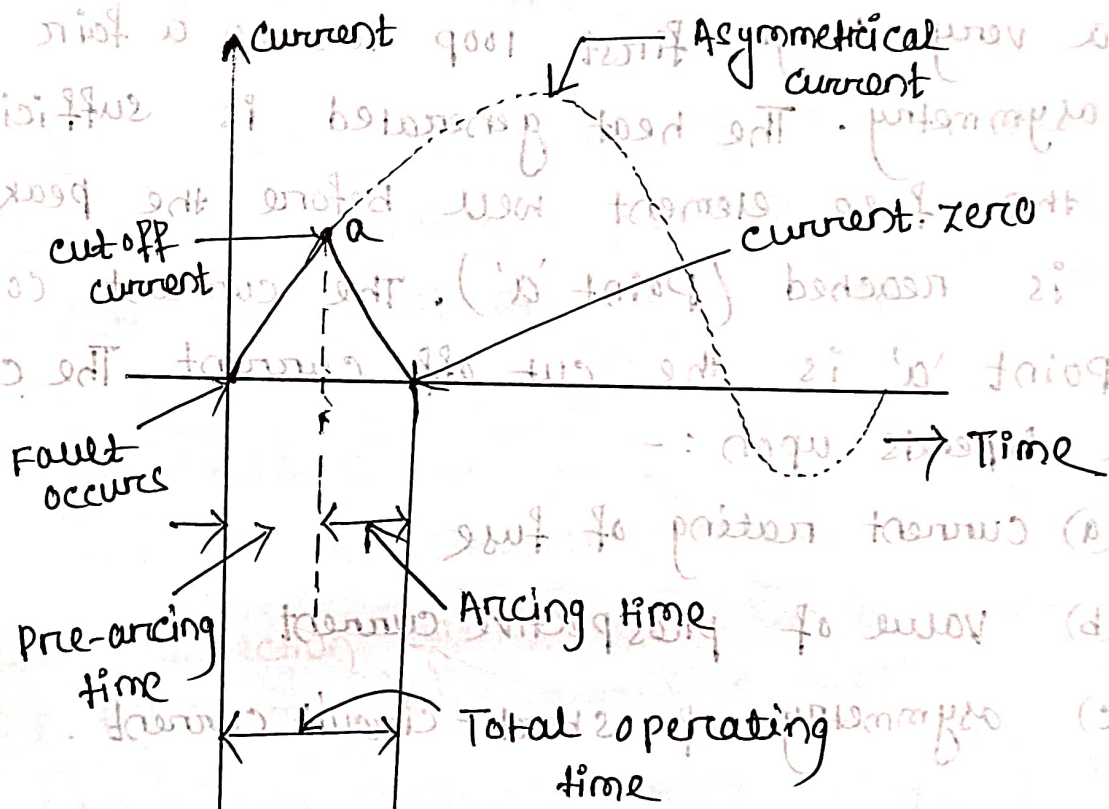
It is the ratio of minimum fusing current to the current rating of the fuse element i.e.

$$\text{Fusing Factor} = \frac{\text{Minimum fusing current}}{\text{current rating of fuse}}$$

Its value is always more than one. The smaller the fusing factor, the greater is the difficulty in avoiding deterioration due to overheating and oxidation at rated carrying current.

⇒ For a semi-enclosed or rewirable fuse which employs copper wire as the fuse element, the fusing factor is usually 2.

⇒ Lower values of fusing factor can be employed for enclosed type cartridge fuses using silver or bimetallic elements.



(iv) Prospective current :-

Fig shows how a.c. current is cut off by a fuse. The fault current would normally have a very large first loop, but it actually generates sufficient energy to melt the fuseable element well before the peak of this first loop is reached.

The r.m.s value of the first loop of fault current is known as prospective current. Therefore, it can be defined as:-

It is the r.m.s value of the first loop of the fault current obtained if the fuse is replaced by an ordinary conductor of negligible resistance.

(v) cut-off current :-

It is the max^m value of fault current actually reached before the fuse melts.

On the occurrence of a fault, the fault current has a very large first loop due to a fair degree of asymmetry. The heat generated is sufficient to melt the fuse element well before the peak of first loop is reached (point 'a'). The current corresponding to point 'a' is the cut off current. The cut off value depends upon :-

- (a) current rating of fuse
- (b) value of prospective current
- (c) asymmetry of short-circuit current.

(vi) pre-arcing time :-

It is the time between the commencement of fault and the instant when cut off occurs.

When a fault occurs, the fault current rises rapidly and generates heat in the fuse element. As the fault current reaches the cut off value,

the fuse element melts and an arc is initiated. The time from the start of the fault to the instant the arc is initiated is known as pre-arcing time. The pre-arcing time is generally small - a typical value being 0.001 second.

(vii) Arising time :- This is the time between the end of pre-arcing time and the instant when the arc is extinguished.

(viii) Total operating time :- It is the sum of pre-arcing and arising times.

(ix) Breaking capacity :- It is the r.m.s value of a.c component of maximum prospective current that a fuse can deal with at rated service voltage.

Types of Fuses :-

Fuse is the simplest current interrupting device for protection against excessive currents. In general, fuses may be classified into :-

(i) Low voltage fuses (ii) High voltage fuses.

Low voltage fuses :-

Low voltage fuses can be subdivided into two classes i.e. (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) is used where low values of fault current are to be interrupted. It consists of (i) a base and (ii) 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 (tinned copper wire) 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 circuit 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. This type of fuse has two advantages.
 - (i) The detachable fuse carrier permits the replacement of fuse element without any danger of coming in contact with live parts.
 - (ii) The cost of replacement is negligible.

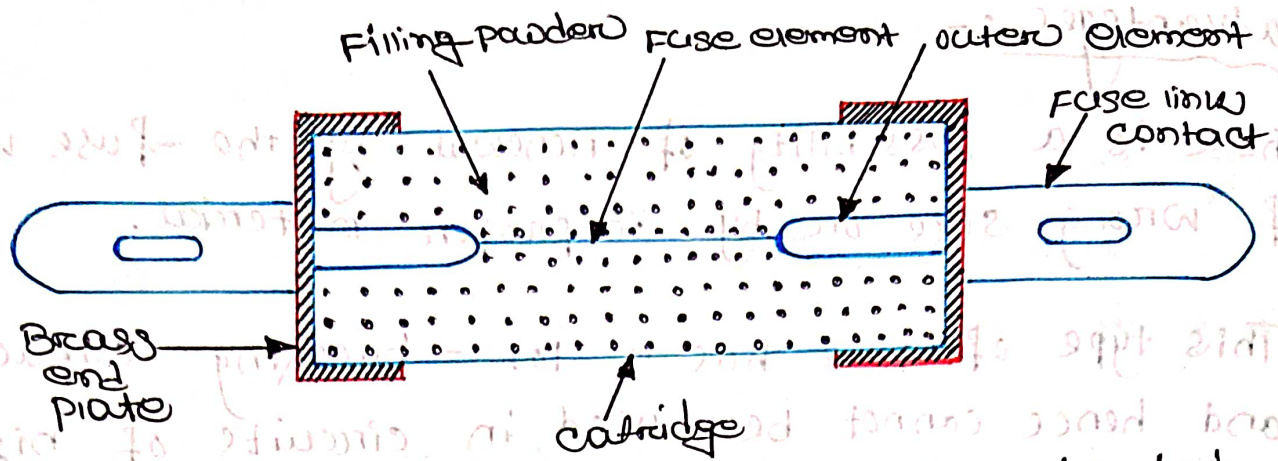
Disadvantages :-

- (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 some time, 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 up to 500 A rated current, but their breaking capacity is low e.g. on 400 V service, the breaking capacity is about 4000 V. Therefore, the use of this type of fuses is limited to domestic and lighting loads.

2. High-Rupturing capacity (H.R.C.) cartridge fuse :-

The primary objection of low and uncertain breaking capacity of semi-enclosed rewirable fuses is overcome in H.R.C. cartridge fuse. Fig shows the essential parts of a typical H.R.C. 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 may be chalk, plaster of paris, quartz or marble dust acts as an arc quenching and cooling medium.
- ⇒ Under normal load conditions, the fuse element is at a temperature 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 do not 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 affect the associated switches.

3. H.R.C. Fuse with tripping device :-

Sometimes, H.R.C. cartridge fuse is provided with a tripping device. When the fuse blows out under fault conditions, the tripping device causes the CB to operate.

⇒ Fig. shows the essential parts of a H.R.C. Fuse with a tripping device. The body of the fuse is of ceramic material with a metallic cap rigidly fixed at each end. These are connected by a no. of silver fuse element.

- ⇒ At one end is a plunger which under fault conditions hits the tripping mechanism of the CB and causes it to operate.
- ⇒ The plunger is electrically connected through a fusible link, chemical charge and a tungsten wire to the other end of the cap as shown.
- ⇒ When a fault occurs, the silver fuse elements are the first to be blown out and then current is transferred to the tungsten wire. The weak link in series with the tungsten wire gets fused and causes the chemical charge to be detonated.
- ⇒ This forces the plunger outward to operate the CB. The travel of the plunger is so set that it is not ejected from the fuse body under fault conditions.

Adv :- H.R.C. Fuse with a tripping device has the following advantages over a H.R.C. fuse without tripping device :-

- (i) In case of a single phase fault on a 3- ϕ system the plunger operates the tripping mechanism of CB to open all the 3 phases and thus prevents 'Single phasing'.

(ii) The Fuse-tripped CB is generally capable of dealing with fairly small fault currents itself. This avoids the necessity for replacing the Fuse except after highest currents for which it is intended.

Low voltage H.R.C. Fuses may be built with a breaking capacity of 16,000A to 30,000A at 440V. They are extensively used on low-voltage distribution system against over-load and short-circuit conditions.

High-voltage Fuses :-

The low-voltage fuses have low normal current rating and breaking capacity. Therefore, they can not be successfully used on modern high voltage circuits. Intensive research by the manufacturers and supply engineers has led to the development of high voltage fuses. Some of the high voltage fuses are :-

(i) cartridge type :-

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 reduces the short-circuit current and finally breaks the circuit.
⇒ High voltage cartridge fuses are used upto 33kV with breaking capacity of about 8700A at that voltage. Rating of the order of 200A at 6.6kV and 11kV and 50A at 33kV are also available.

(ii) Liquid type :-

These fuses are filled with carbon tetrachloride and have the widest range of application to h.v. system. They may be used for circuits upto about 100A rated current on systems upto 132kV and may have breaking capacities of the order of 6100A.

⇒ Fig shows the essential parts of the liquid fuse. It consists of a glass tube filled with carbon tetrachloride solution and sealed at both ends with brass caps. The fuse wire is sealed at one end of the tube and the other end of the wire is held by a strong phosphor bronze spiral spring fixed at the other end of the glass tube.

⇒ When the current exceeds the prescribed limit, the fuse wire is blown out. As the fuse melts,

the spring retracts part of it through a baffle (or liquid director) and draws it well into the liquid. The small quantity of gas generated at the point of fusion forces some part of liquid into the passage through baffle and there it effectively extinguishes the arc.

(iii) Metal clad Fuses :-

Metal clad oil-immersed fuses have been developed with the object of providing a substitute for the oil CB. Such fuses can be used for very high voltage circuits and operate most satisfactorily under short-circuit conditions approaching their rated capacity.

Current Carrying Capacity of Fuse element :-

The current carrying capacity of a fuse element mainly depends on the metal used and the cross-sectional area but is affected also by the length, the state of surface and the surroundings of the fuse. When the fuse element attains steady temperature.

Heat produced per sec = Heat lost per second by convection, radiation and conduction

$$\Rightarrow I^2 R = \text{constant} \times \text{Effective surface area}$$

$$\Rightarrow I^2 \left(\frac{\pi d l}{4} \right) = \text{constant} \times d \times l$$

where d = diameter of fuse element
 l = Length of fuse element

$$\Rightarrow \frac{I^2 \cancel{d} \cancel{L}}{(\pi/4)d^2} = \text{constant} \times d \times L$$

$$\Rightarrow I^2 = \text{constant} \times d^3$$

$$\Rightarrow \boxed{I^2 \propto d^3} \quad \text{--- (i)}$$

Expression (i) is known as ordinary fuse law.

Difference Between a Fuse and Circuit Breaker:

SL NO.	Particular	Fuse	Circuit Breaker
1.	Function	It performs both detection and interruption functions.	It performs interruption function only. The detection of fault is made by relay system.
2.	Operation	Inherently completely automatic.	Requires elaborate equipment (i.e. relays) for automatic action.
3.	Breaking Capacity	Small	very large.
4.	Operating time	very small (0.002 sec or so)	comparatively large (0.1 to 0.2 sec)
5.	Replacement	Requires replacement after every operation.	No replacement after operation.

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