Chapter (3)

Medium Voltage Switchgear

Medium Voltage Switchgear: Historical Background

With the advent of electricity and its commercial production, the need to control it also became evident. Historically, the initial form of a circuit breaker used by scientists was mercury switch in which two rods of electrodes were dipped in mercury and moved in and out to make or break the circuit current. Interestingly, however, this apparatus was not named as a 'circuit breaker' at the time of usage. A quick-break knife switch was perhaps the earliest recognized form of circuit breaker. Such switches, however, had no formal arc control other than that provided by the switch operator who used an insulated hatchet to chop the arc. Later during the early twentieth century, more effective switches where developed by dipping the quick-break knife switches into a tank containing insulating transformer oil. Thus was born the plain break oil circuit breaker. During the early stage, as the power increased, it was recognized that a paramount requirement for circuit breakers was the ability to interrupt not only load currents but also the current which occurred during a short-circuit when the currents could reach a magnitude which was many times that of the full load. Initial developments carried out in the arc interruption capability of switchgears were based on in-house experiments using production facilities of industries or actual field testing. Standard test houses for verifying the claims made by manufacturers were not available. This gave rise to many difficulties and uncertainties about the performance of switchgears being bought by the utilities. More scientific developments in circuit breaking started in the year 1925 when special short-circuit test plants came into existence followed by the development of cathode ray oscillographs for the proper recording and measurement of test quantities. Bulk oil circuit breakers (Fig. 3.1) were developed with many improved features such as multi-break interrupter and axial flow blast interrupter to enhance the interrupting capacity. Bulk oil circuit breakers were widely used by industry in the medium voltage range from 1920 to 1970 until the advent of other improved technologies.

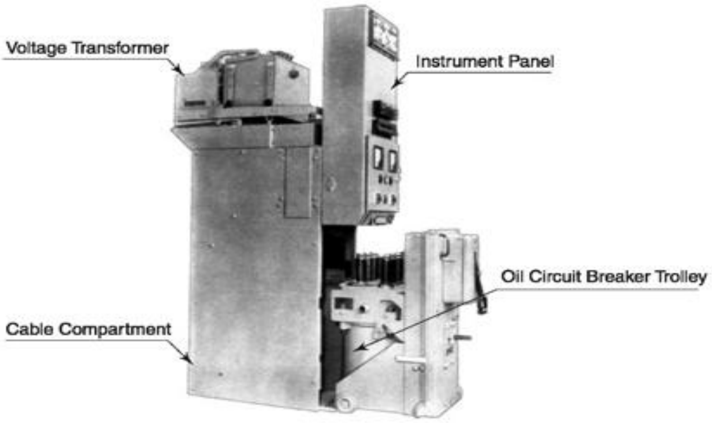


Fig. 3.1: Medium voltage bulk oil switchgear

The development of both minimum oil circuit breakers (Fig. 3.2) and air circuit breakers started almost simultaneously around the period 1930-35. New circuit breakers using very small volumes of oil were developed primarily in Europe, in order to tackle the problems of scarcity of space and high cost of oil. These breakers used alternative insulating material to achieve insulation between live and earth parts, and a small volume of oil for arc interruption, which is why the name minimum oil circuit breaker was used for these breakers.

One of the earliest successful approaches to high power air break circuit breakers was that developed by Slepian at Westinghouse in 1929. Contact separation and arc extinction in these breakers took place in air at atmospheric pressure. As the two current-carrying contacts are separated, an arc is drawn between them. The extinguishing force is generated in these breakers by elongating, cooling, splitting and/or constraining the arc (Fig. 3.3). Accordingly, they are called plain break, de-ion or air magnetic circuit breakers.

While the plain type circuit breaker is used in low voltage applications only, the other two types are used in medium voltage applications. However, the advent of compact and external arc free designs of modern switchgears has virtually abolished the use of these air break switchgears

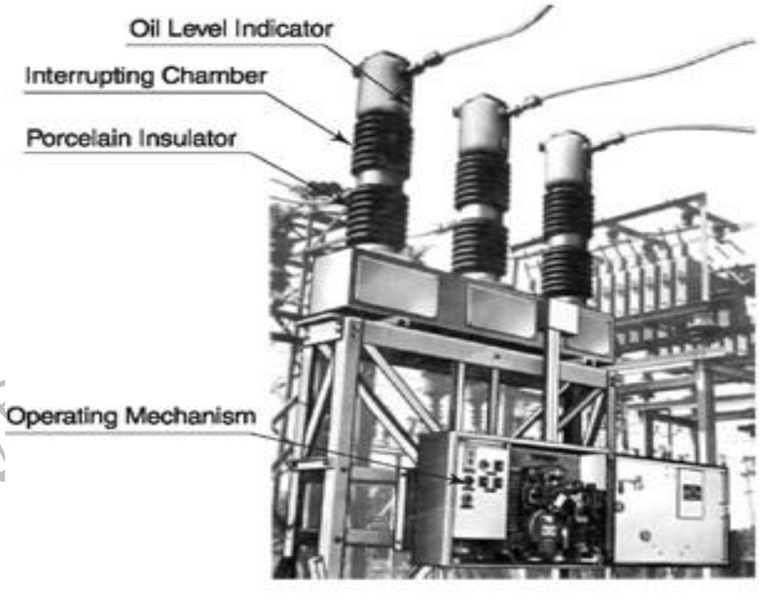


Fig. 3.2: Medium voltage minimum oil switchgear

In medium voltage application in the industry. Air blast circuit breaker designs, developed during the period 1935-45, were more popular in the EHV range and did not find a place in medium voltage application due to the complexity of their design, high cost and problems of maintenance in compressed air systems.

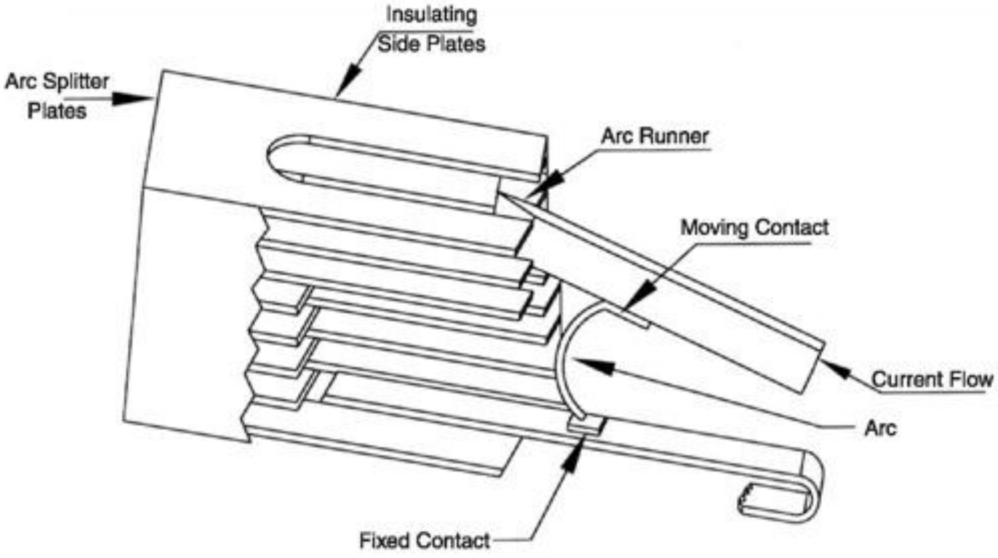


Fig. 3.3: Air break circuit breakers

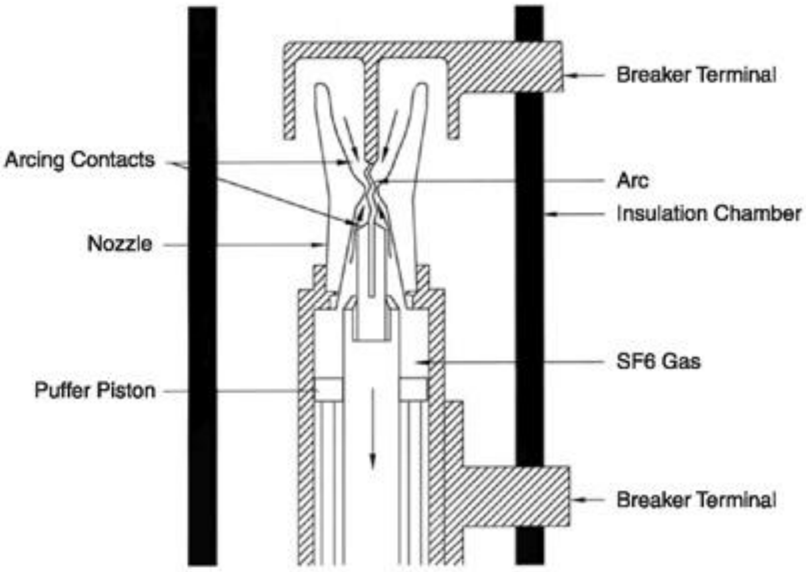


Fig. 3.4: SF6 puffer type circuit breaker

Development work on circuit breakers using sulphur hexafluoride (SF6) gas started in the 1950s and a few initial designs were made in early 1960s. The excellent dielectric properties of SF6 gas helped in the rapid development of circuit breaker designs for medium voltage and extra high voltage (Fig. 3.4). This technology assumed significance immediately after its introduction in the high voltage range of switchgear beyond 72.5 kV and above.

However, in medium voltage application, vacuum switchgear and other contemporary technologies continued to be used along with SF6 technology for quite some time. Finally vacuum switchgear, because of its simple and rugged design, low energy mechanism requirement, large number of switching operations and environment-friendly arc interruption feature, gained importance over the others. Vacuum switchgears (Fig. 3.5) virtually eliminated all other technologies in medium voltage application except SF6 switchgears, which also found only limited usage.

Although development work on the use of vacuum as a switching medium started in the 1920s, the commercial vacuum interrupter for medium voltage application entered the market only in the 1960s. The major areas of work were related to research on contact materials and their geometry, and problems of maintaining vacuum levels over the life span of the interrupter. Gradually as the manufacturing techniques of vacuum interrupter improved and the volume of production increased, the prices of vacuum interrupter started coming down. Its affordable price coupled with ease of handling and improved arc interruption behaviour made it the leading technology in medium voltage switchgear, and the usage of oil and air circuit breakers was virtually eliminated. The two superior technologies, i.e. switching in vacuum and SF6, continued to be used simultaneously in medium voltage application in the 1970s. However, the excellent switching property of vacuum and its limitation in the design of high voltage interrupters restricted its use to medium voltage range. The SF6 gas-based circuit breakers due to its excellent switching properties at high voltage levels, SF6 gas-based technology became the best choice for the voltage class of 72.5 kV and above, but difficulties in handling the gas and its harmful arc products made SF6 unpopular for use in the medium voltage range

Fig. 3.5: Medium voltage vacuum switchgear

Medium Voltage Switchgear: Present Status

Developments in the field of vacuum and SF6 circuit breakers have facilitated reduction in the mass of material used, thereby optimising the size of the switchgear. At the same time, the interrupter capacity has also been enhanced so as to handle larger fault levels, which occur due to the connectivity of parallel networks. Reductions in the moving masses of interrupters have led to the use of simpler, low energy mechanisms, thereby increasing the life span of the mechanism. Today, however, the main emphasis is on reliability and maintenance-free designs. These requirements have been made specific in the recently issued circuit breaker standard IEC 62271-100. Circuit breakers of class Ml must qualify for 2,000 mechanical operations, while circuit breakers for class M2 must meet the mechanical operation requirement of 10,000 numbers. Similar criteria have also been upgraded in the standards for medium voltage range upto 52 kV for short-circuit current make break duties, thus defining class E1 and class E2 circuit breakers.

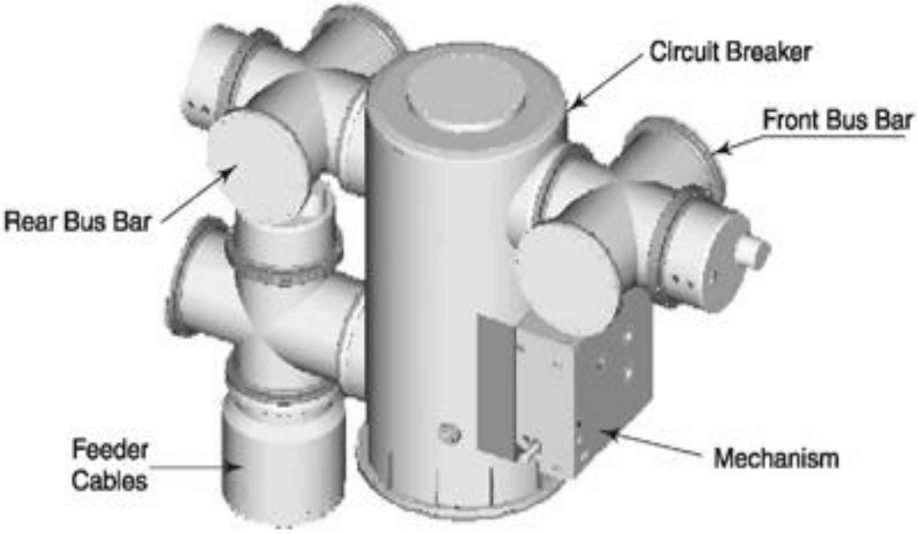


Fig. 3.6: Medium voltage gas insulated switchgear

Gas insulated switchgear constructions (Fig. 3.6) are increasingly being adopted by utilities wherein reliability is important. This concept is initially finding popularity mostly in metropolitan cities where space is a constraint. But it is very likely that most future installations would have this configuration.

Medium Voltage Switchgear: Future Trends

Work on solid state switching devices is in experimental stage for medium voltage application and is yet to find usage in commercial application. Sealed for life breakers are becoming a reality today. Synchronous switching and condition monitoring are two aspects being explored to improve switching performance and facilitate preventive maintenance. Synchronous switching and condition monitoring have acquired a great deal of relevance not only because of their potential for enhancing reliability and for helping to improve the overall power quality of the electric systems, but also for economic reasons. These concepts can be instrumental in minimising the use of auxiliary components such as pre-insertion resistors, in reducing equipment wear and unnecessary maintenance, and thus in reducing the total cost of ownership throughout the life span of the equipment.

Synchronous switching is not a new idea as the feasibility of synchronised switching is being studied for the last 30 years. Condition monitoring is another concept resulting from recent developments of electronic sensors and data acquisition equipment, which have made this idea not only technically feasible but also economically attractive. Condition monitoring is an essential component for synchronous switching because a lot depends on how accurately the operating characteristics of the circuit breaker can be controlled. It is well known that the operating characteristic can be affected by extreme ambient temperatures, and by other prevailing conditions such as the mechanism operating energy levels, control voltages, operating frequency of the equipment, its chronological age, and its maintenance history among others. Collection of information about these variations would help to build a data source from which suitable correction factors may be selected to compensate for those operating deviations, which are critical for an accurate synchronous operation.

Due to usage the development of information technology, coupled with the use of current and voltage sensors, dedicated numerical relays and condition monitoring devices, has led to the evolution of intelligent switchgears. Future switchgears are likely to be sealed for life, as plug-in type of devices need no maintenance. The advent of solid state switchgears can also not be ruled out. Such developments would completely redefine the subject and present international switchgear standards would have to undergo a major change to cover them.

Medium Voltage Switchgear: Constructional Forms

Medium voltage switchgears are available in a variety of constructional forms in consonance with the application requirements. These switchgears are installed in indoor as well as outdoor substations. Live tank design and dead tank design also affect the constructional aspects. All the constructional forms can be covered under the category of metal enclosed design, live tank design and dead tank design. These are explained below.

Metal-enclosed Switchgears

Metal-enclosed switchgear assemblies have earthed metallic enclosures. These are complete, ready-to-install assemblies requiring high voltage and low voltage cable connections. These switchgears generally have three high voltage compartments, namely circuit breaker compartment, bus bar compartment, and current transformer and cable compartment, which are separated by partitions.

Switchgears which have compartments with metal partitions that are intended to be earthed are called metal-clad switchgears. Switchgears with one or more non-metallic partitions are known as compartmented switchgears. Metal-enclosed switchgear, other than metal-clad and compartmented switchgear, is termed as cubicle switchgear.

Design and Construction

Metal-enclosed switchgears are designed such that normal service, inspection and maintenance operations, including the usual checking of the phase sequence, earthing of connected cables, and voltage tests on connected cables or other apparatus can be carried out safely. All components of the same rating and construction that may need to be replaced are designed to be interchangeable.

If there are removable parts with different ratings and if parts are interchangeable within the assembly of metal-enclosed switchgear, any possible combination of removable and fixed parts is designed to withstand the rated insulation level of the switchgear. The various components contained within the switchgear are subject to the individual specifications applying to them.

Interlocks between different components of the equipment are provided to ensure safety and the desired sequence of the operation. The following provisions are mandatory for the main circuits.

(a) Metal-enclosed switchgear with removable parts:

The withdrawal or engagement of a circuit breaker should be impossible unless it is in the open position.

The operation of a circuit breaker should be impossible unless it is in the service, disconnected, removed, test or earthing position.

It should be impossible to close the circuit breaker in the service position unless it is connected to the auxiliary circuit.

(b) Metal-enclosed switchgear without removable parts and provided with a disconnector:

Interlocks should be provided to prevent the operation of disconnector under conditions other than those they are intended for.

The operation of a disconnector should be impossible unless the associated circuit breaker is in the open position.
The operation of the circuit breaker should be impossible unless the associated disconnector is in the closed, open or earthing position.
The provision of additional or alternative interlocks is subject to an agreement between the manufacturer and the user. Wherever practical, preference is given to mechanical interlocks.

Enclosure Enclosures are earthed sheet metal constructions housing the switchgear components. When the metal-enclosed switchgear is installed, the enclosure is provided with at least the degree of protection specified in Table 3.1 (see section 3.4.1.1.8). The floor surface, even if it is not metallic, may be considered as part of the enclosure. Enclosures of a gas insulated switchgear (gas-filled compartments) are designed to withstanding the normal and transient pressures to which they are subjected in service. While these compartments are permanently pressurized in service, they are subjected to particular conditions of service, which distinguish them from compressed air receivers and similar storage vessels. These conditions are:

Gas-filled compartments enclose the main circuit to prevent a hazardous approach to live or moving parts. In addition, they are shaped in such a way as to ensure that the rated insulation level for the equipment is achieved at or above the minimum functional pressure.

Gas-filled compartments are normally filled with a non-corrosive inert gas (such as SF6 or nitrogen), in a thoroughly dried state. Since this condition is fundamental to the operation of the switchgear and since the compartments will not be subjected to internal corrosion, there is no need to make allowances for these factors in determining the design of the compartments.

The service pressure is relatively low (less than 2.5 bar as per IEC 298).

For outdoor installation, the influence of climatic conditions is taken into account.

The design of a gas-filled compartment is based on the design temperature and on the design pressure as defined in this standard.

The design temperature of the gas-filled compartment is generally the upper limit of the ambient air temperature. The design pressure of the enclosure is at least the upper limit of the pressure reached within the enclosure at the design temperature.

The permissible gas leakage rate for the gas-filled compartments is ensured as per the standards.

Covers and Doors Covers and doors, which are parts of the enclosure, are required to facilitate operation and maintenance as and when needed. These are made of sheet metal construction. When they are closed, they provide the degree of protection specified for the enclosure.

The following two categories of covers or doors are recognised with regard to access to high-voltage compartments:

(a) Those, which need not be opened for the normal purposes of operation or maintenance (fixed covers). It should not be possible for them to be opened, dismantled or removed without the use of tools; and

(b) Those, which need to be opened for the normal purposes of operation (removable covers, doors). These should not require tools for their opening or removal. They should be provided with locking facilities (for example, provision for padlocks), unless the safety of persons is assured by a suitable interlocking device.

In the case of metal-clad or compartmented switchgear, covers or doors should be opened only when the part of the main circuit contained in the compartment being made accessible is dead.

Inspection Windows Inspection windows are provided to view the position of withdrawable parts and disconnector, etc. during routine inspection and operation. Inspection windows are designed to provide at least the degree of protection specified for the enclosure.

They should be covered by a transparent sheet of mechanical strength comparable to that of the enclosure. Precautions should be taken to prevent the formation of dangerous electrostatic charges, either by clearance or by electrostatic shielding.

Ventilating Openings Ventilating openings are provided in the switchgear to allow venting of gas or vapour that is escaping under pressure, without harming the operator. Sometimes these openings are also provided for thermal management. Ventilating openings and vent outlets are arranged or shielded in such a way that the same degree of protection as that specified for the enclosure is obtained. Such openings may make use of wire mesh provided it is of suitable mechanical strength.

Wherever pressure relief devices are provided, they are arranged so as to minimise the danger to an operator during the time that he is performing his normal operating duties, if gases or vapour are escaping under pressure.

In certain designs, pressure relief may be achieved by allowing the arc to burn through the enclosure at designated points. Where such means are employed, the resultant hole is deemed to be a pressure relief device.

Partitions and Shutters Partitions are provided in switchgear assemblies to segregate them into three compartments to help carry out the desired functions of operation and maintenance safely and smoothly. They also prevent the fault from spreading to another compartment.
Partitions and shutters should provide at least the degree of protection specified in Table 3.1 (see Section 3.4.1.1.8).

Openings in the enclosure of switchgear and in the partitions of metal-clad or compartmented switchgear through which contacts or removable parts engage fixed contacts are provided with automatic shutters that are properly operated in normal service operations in order to ensure the protection of persons in any of the positions of the withdrawable part.

Partitions of metal-clad switchgear should be metallic and earthed. Partitions of compartmented and cubicle switchgear may be non-metallic. Partitions between two gas-filled compartments or between a gas-filled compartment and another compartment may be of insulating material. The shutters of the three types of metal-enclosed switchgear may be either metallic or non-metallic, and are designed to meet the conditions of switchgear standards.

Disconnectors and Earthing Switches Disconnectors and earthing switches are provided to meet the isolation and earthing requirements of the circuit configuration. The device for ensuring the isolating distance between the high-voltage conductors is called a disconnector. The device for ensuring the earthing of circuit is called the earthing switch. The requirement that it should be possible to know the operating position of the disconnector or earthing switch, is met if one of the following conditions is fulfilled:

The isolating distance is visible;

The position of the withdrawable part, in relation to the fixed part, is clearly visible and the positions corresponding to full connection and full isolation are clearly identified; and

A reliable indicating device indicates the position of the disconnector or earthing switch.

Earthing In order to ensure safety while maintenance is being carried out, all parts of the main circuit to which access is required or provided should be capable of being earthed prior to becoming accessible. This does not apply to withdrawable and removable parts, which become accessible after being separated from the switchgear.

This requirement is met by providing an earthing conductor extending across the entire length of the metal-enclosed switchgear. The current density in the earthing conductor, if it is made of copper, is kept within 200 A/mm2 under the specified earth fault conditions; however, its cross-section area is always kept more than 30 mm2. It is terminated by an adequate terminal intended for connection to the earth system of the installation.

In general, the continuity of the earth system is ensured by taking into account the thermal and mechanical stresses, which may be caused by the current that it may have to carry. The maximum value of earth fault currents depends upon the type of system neutral earthing employed and is indicated by the user.

The enclosure of each functional unit is connected to this earthing conductor. All the metallic parts intended to be earthed and not belonging to the main or auxiliary circuit, should also be connected to the earthing conductor directly or through metallic structural parts.

For inter-connection within the functional unit, fastening by bolting or welding is acceptable for providing electrical continuity between the frames, covers, doors, partitions or other structural parts. Doors of the high-voltage compartments are connected to the frame by adequate means. The metallic parts of a withdrawable part, which are normally earthed, should also remain earth-connected in the test and disconnected positions under the prescribed conditions for the isolating distance, and also in any intermediate position whilst the auxiliary circuits are not totally disconnected.

Degree of Protection The degree of protection needed to prevent persons from coming into contact with live parts of main circuits and with any moving parts (other than smooth rotating shafts and moving linkages) should be indicated by means of the designation specified in Table 3.1.

Degree of protection	Protection against approach to live parts and contact with moving parts to be verified with the following test object
1P2X	By fingers or similar objects of diameter greater than 12 mm
IP3X	By tools, wires, etc., of diameter or thickness greater than 2.5 mm
IP4X	By wires of diameter or strips of thickness greater than 1.0 mm

Table 3.1 Specifications for Degree of Protection

For metal-clad and for compartmented switchgear, the degree of protection should be specified separately for the enclosure and for partitions.

For cubicle switchgear, it is necessary to specify only the degree of protection for the enclosure. For main circuits of gas-filled compartments, no degree of protection needs to be specified.

Metal-enclosed Switchgears (Constructional Forms)

The commonly used constructional forms for indoor and outdoor applications are explained below.

Metal-enclosed Switchgears (Indoor) Metal-enclosed switchgears are generally designed in a horizontal draw-out pattern though some manufacturers also follow a vertical isolation pattern. These designs are made suitable for extension of switchboard on both sides. The design incorporates the single/double bus bar system as per the requirement.

A typical switchgear panel consists of a fixed portion (and a withdrawable portion) having three high voltage chambers, namely a breaker chamber, a bus bar chamber, and a current transformer (CT) and cable chamber (Fig. 3.8). The instrument panel is a separate low voltage chamber. The withdrawable portion comprises a wheel-mounted truck fitted with an operating mechanism, interrupters and isolating contacts. Generally there is a manual charging provision for springs to tackle the possibility of failure of auxiliary power to the spring charging motor.

The main breaker chamber of earthed sheet steel construction is designed so as to accept the withdrawable portion at the floor level. However, some designs have the withdrawable portion at a height. These designs have a trolley for placing the withdrawable portion in the breaker chamber. The primary isolating contact system comprises a self-aligning type female contact on the moving portion and male contact on the fixed portion of the switchgear panel. This chamber also includes features like a secondary isolating contacts socket, guides for the withdrawable portion, an earthing contact which mates with an earthing strip on the moving portion, and safety shutters.

The withdrawable portion with circuit breaker (CB) generally has three positions, i.e. the 'service', 'test' and 'isolated' positions. The position of the withdrawable portion can be seen through the glass window on the door.

The bus bar chamber of earthed metal construction houses the bus bars, which consist of multiple parallel bars of aluminium or copper as per the requirement of current. Bus bars are generally supported on epoxy support insulators of adequate strength and voltage class. The bus bars are either bare or of the insulated type. The bus bar chamber is generally provided with a partition between two adjacent bus bar chambers. The current transformer (CT) and cable Termination chamber of earthed metal construction are designed to be able to mount the CT and have a provision for cable termination.

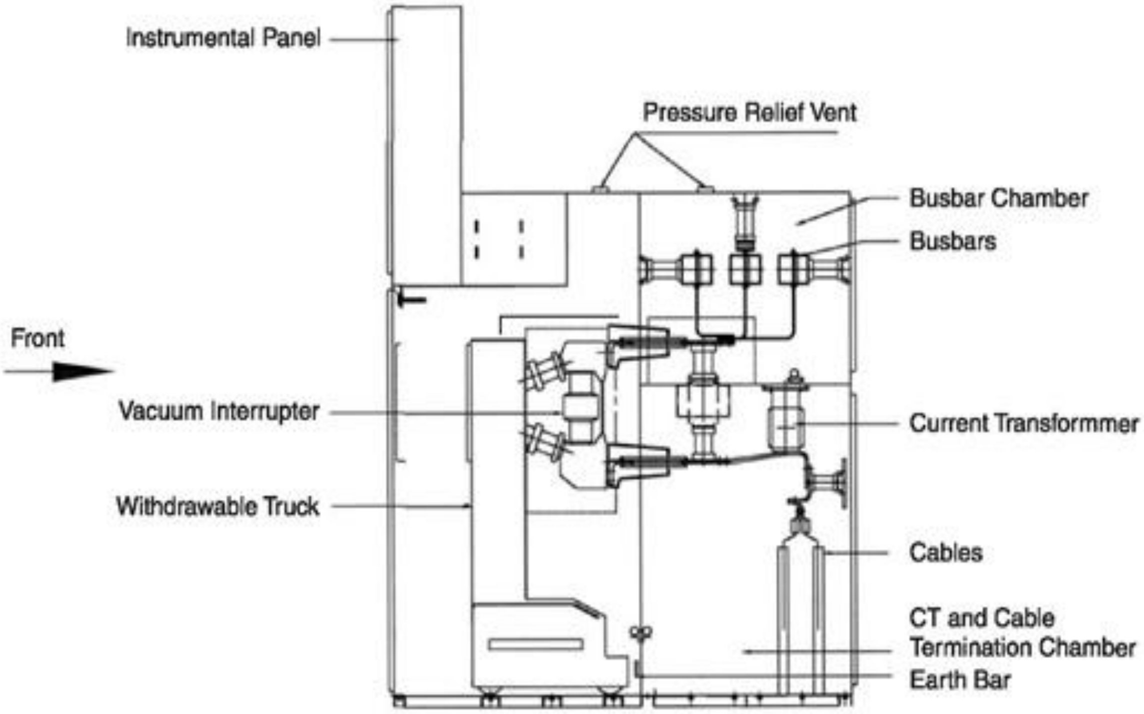


Fig. 3.7: Typical switchgear panel

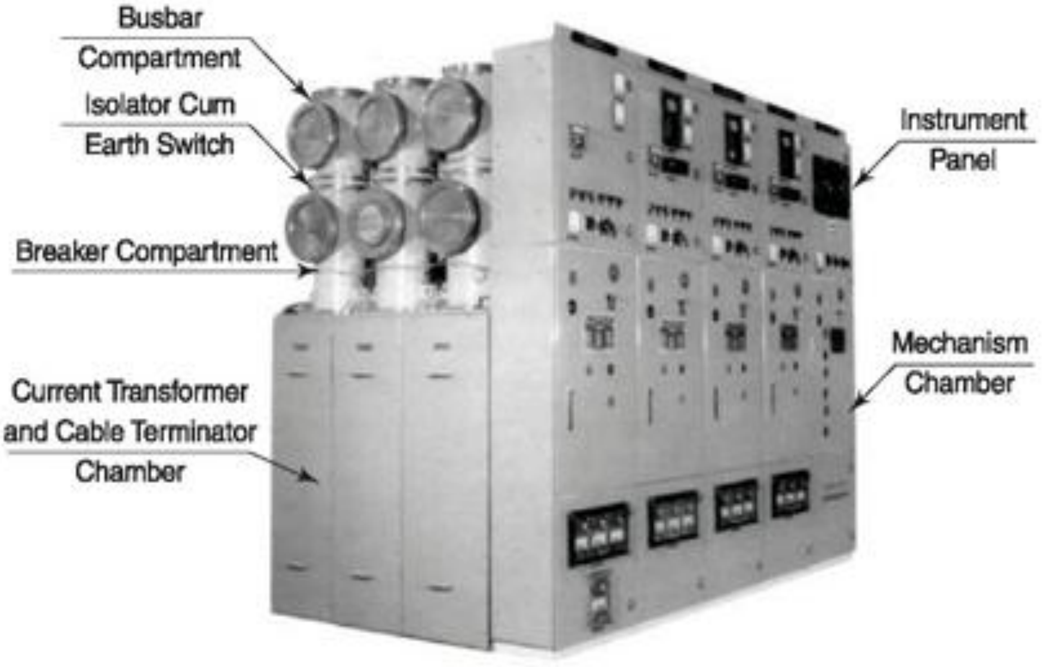


Fig. 3.8: Medium voltage gas insulated switchgear

The withdrawable part consists of a truck frame with four wheels on which three interrupters and the operating mechanism are mounted.

The interlocks are designed to meet the requirements mentioned in Section 3.4.1.1.1 above.

The instrument and relay chambers are earthed metal constructions with a hinged instrument panel door suitable for flush mounting of instruments in the front in order to provide better access for operation and maintenance.

MV GIS Construction These are fixed type metal enclosed designs and do not have withdrawable parts. Generally these designs have two major compartments, namely the busbar and breaker compartments. The busbar compartment generally has a three-position switch, marked with the 'service' 'isolated' and 'earth' positions. The operation of the switch is interlocked with the circuit breaker. The breaker compartment houses three interrupters. It has a provision for mounting ring type CT and terminating cables. The common practice is to provide the plug-in type of cable termination in GIS. Two types of constructions are followed by designers, namely 'isolated phase construction' and 'three-phase construction'. The interrupter used is mostly of the vacuum type with very few designs offering SF6 interrupters. Figure 3.8 shows the typical GIS bay. Details of this product are covered in Chapter 5.

Metal-enclosed Switchgears (Outdoor) The design of these switchgears is similar to that of indoor metal-enclosed switchgears in all internal features except the external housing. The enclosure is normally a welded sheet steel fabrication suitable for outdoor application having slanting roof and rain shields, etc. (See Fig. 3.9). Although this type of design is not commonly used, some utilities find it convenient to use it for city distribution networks with underground cable systems. Such installations are set up at easily accessible locations in the city.

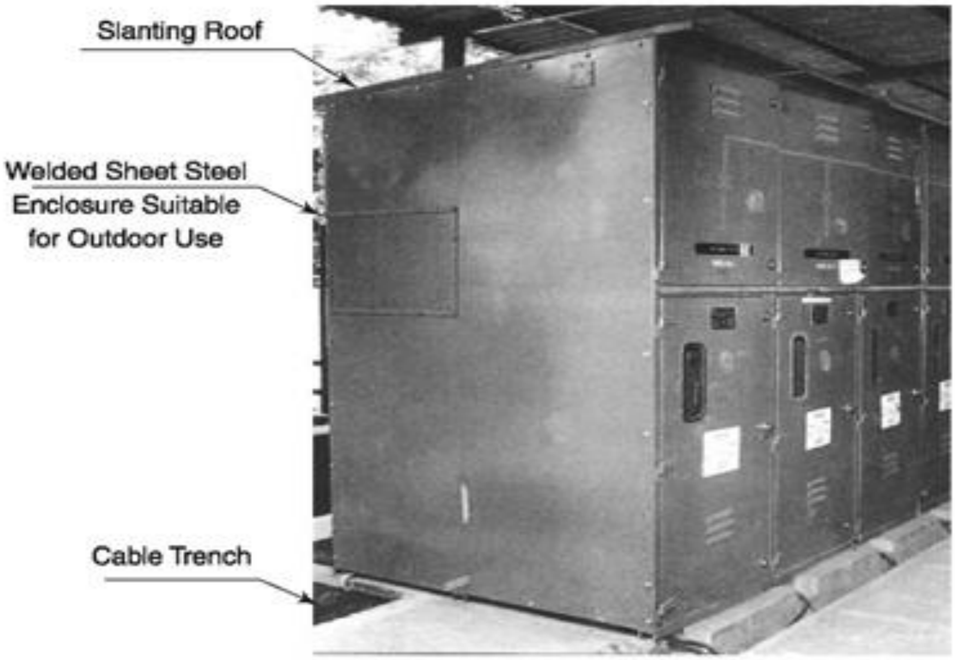


Fig. 3.9: Outdoor metal-enclosed switchgear

Live Tank Switchgears (Outdoor Porcelain-clad Construction)

Porcelain-clad construction is a live tank design for power distribution applications suitable for outdoor sub-stations. This design has interrupters in porcelain housing having current collection flanges at both the ends. The fixed contact of the interrupter is directly secured to the top flange and the moving contact has a current transfer arrangement so as to allow movement of the contact and also to transfer current to the other flange. This porcelain chamber is mounted on the hollow insulator to withstand system voltage requirements. The hollow insulator carries an insulating operating link to facilitate opening and closing of the interrupter through an operating mechanism. The complete three-pole assembly is mounted on a structure, which also provides support to the mechanism (see Fig. 3.10). Add-on structures are suitably designed to support the current transformer, voltage transformer, and the control and relay cabinet as per the sub-station requirement.

A similar live tank design for single-phase application is also used for railway trackside power supply systems at 25 kV.

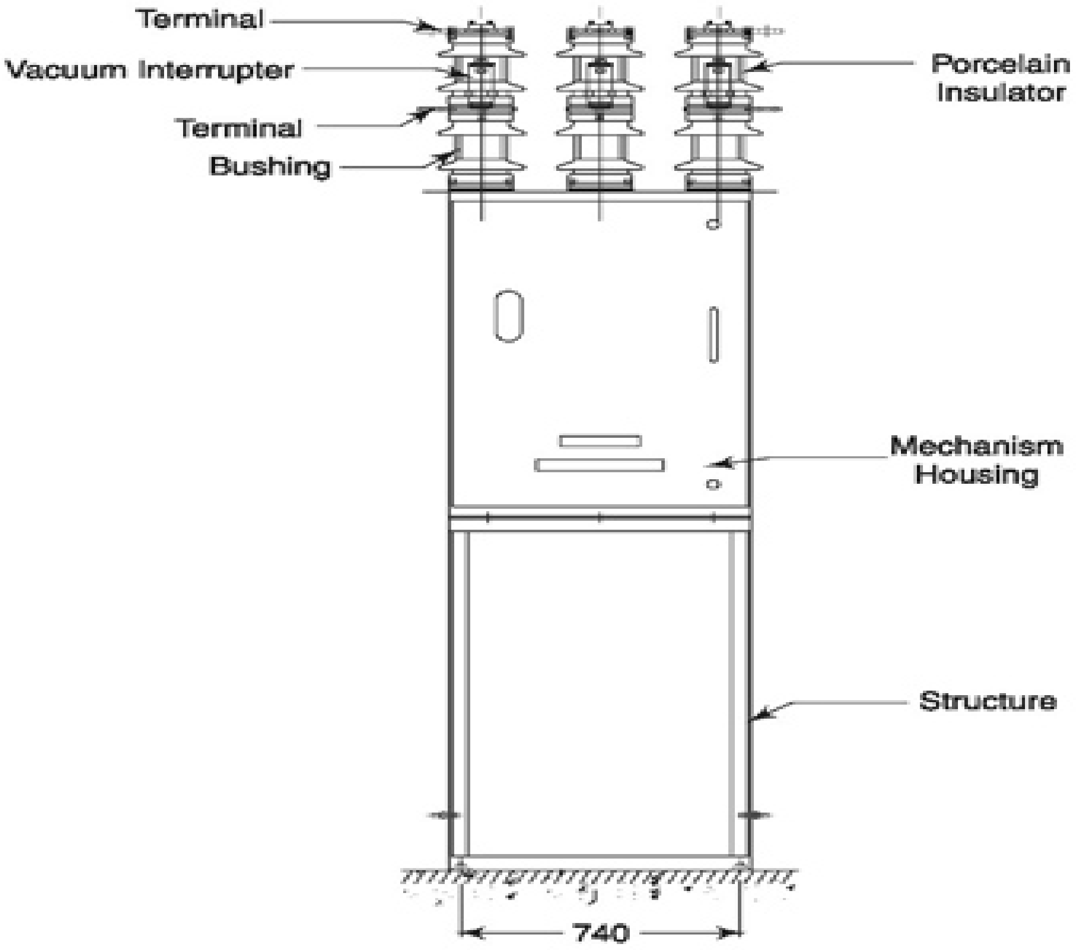


Fig. 3.10: Live tank switchgears (outdoor porcelain clad-contruction)

Dead Tank Switchgears

The two commonly used types of dead tank designs are the kiosk type and the pole-mounted auto-reclosure. These are briefly explained below.

The outdoor kiosk type of design (see Fig. 3.11) is a very simple configuration. It has a welded sheet steel-earthed enclosure suitable for outdoor application. Six roof bushings are provided for connecting to the incoming and outgoing power circuits. The kiosk houses the circuit breaker, current transformer, potential transformer and sometimes even the isolators. This becomes a complete unit ready for commissioning. At times, the control and relay cabinets are also housed in this outdoor design. These designs mostly have a fixed type of construction but designs with withdrawable circuit breakers are also available.

Auto-reclosure circuit breakers (see Fig. 3.12) are mostly used in rural applications where transient faults occur more frequently. These configurations are suitable for mounting on single-pole, two-pole and independent support structures. They have earthed metal enclosures housing the circuit breaker and current transformer. The control supply is mostly drawn from the high voltage line by deploying a control transformer, which can be housed inside the auto-reclosure, the enclosure or sometimes mounted outside on the extended structure. Details of this product are covered in Chapter 6.

Medium Voltage Switchgear: Design Parameters

Normal Current Rating (Thermal Aspects of Design)

The normal current rating of the switchgear is decided on the basis of the value of current it can carry without exceeding the temperature rise limits specified in the switchgear standards (see Table 3.2). The thermal losses (I^2Rt) in the switchgear should be kept to a minimum value so as to maintain the temperature rise within limits. The temperature rise depends on the rate of heat generation and its dissipation. The most important characteristic of the material used as a conductor in switchgear is to have a low resistance. Excessive temperature rise due to high resistance conductors in small enclosures will reduce the life of associated insulation materials. The next important characteristic is that the material must resist corrosion. Any corrosion in the joint area increases the resistance and higher resistance leads to higher temperature, which, in turn, leads to more corrosion.

Care should also be taken while choosing the material for the conducting path. Two materials, namely copper and aluminium, are the most suitable materials for making current-carrying conductors. Copper has lower resistivity and also resists oxidation better than aluminium, particularly at temperatures below about 80°C. Aluminium has a much smaller specific gravity and though larger cross-sections of conductors are needed to give the same resistance as the equivalent of that obtained by using copper, the weight and, therefore, the cost of material often prove to be an advantage over copper. Table 3.3 shows the differences between the relative properties of copper and aluminium.

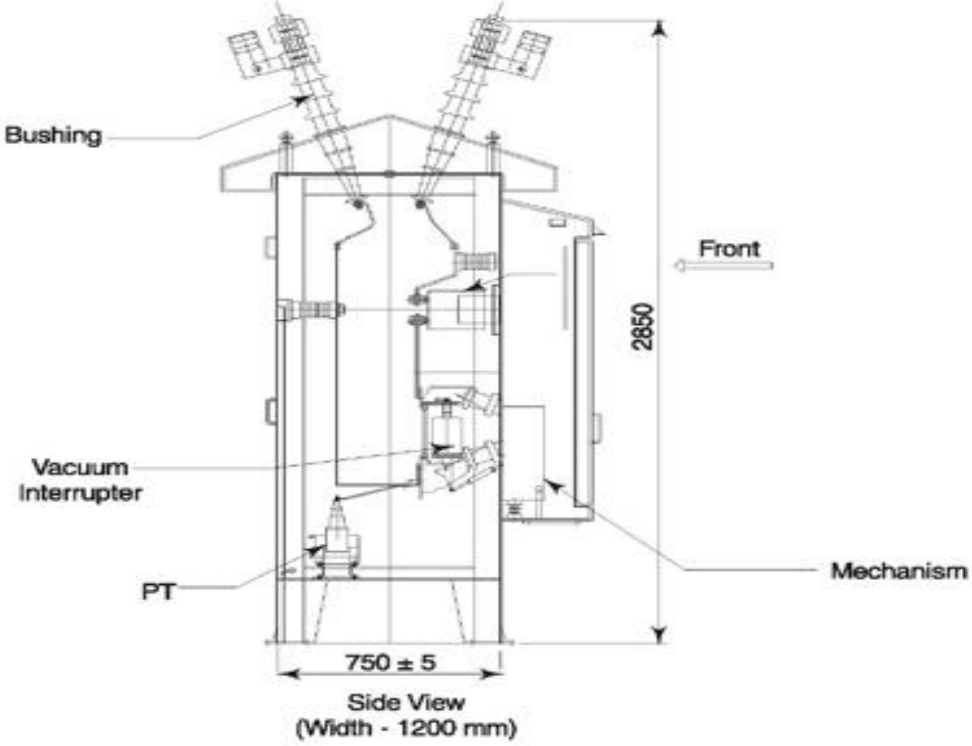


Fig. 3.11: Dead tank switchgear (Outdoor kiosk type)

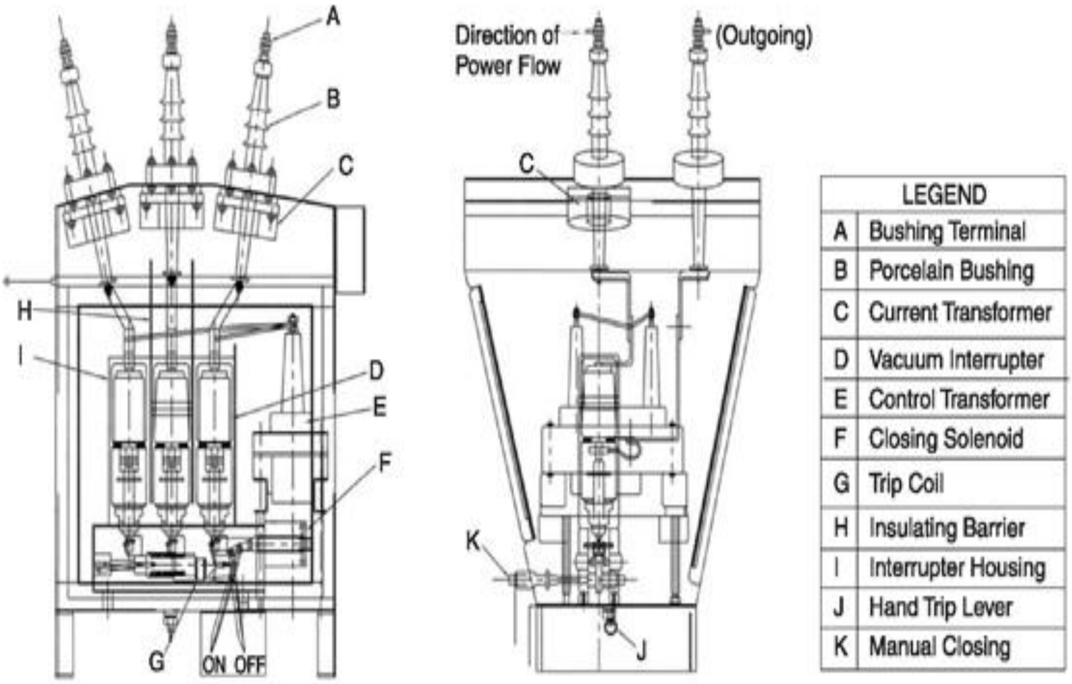
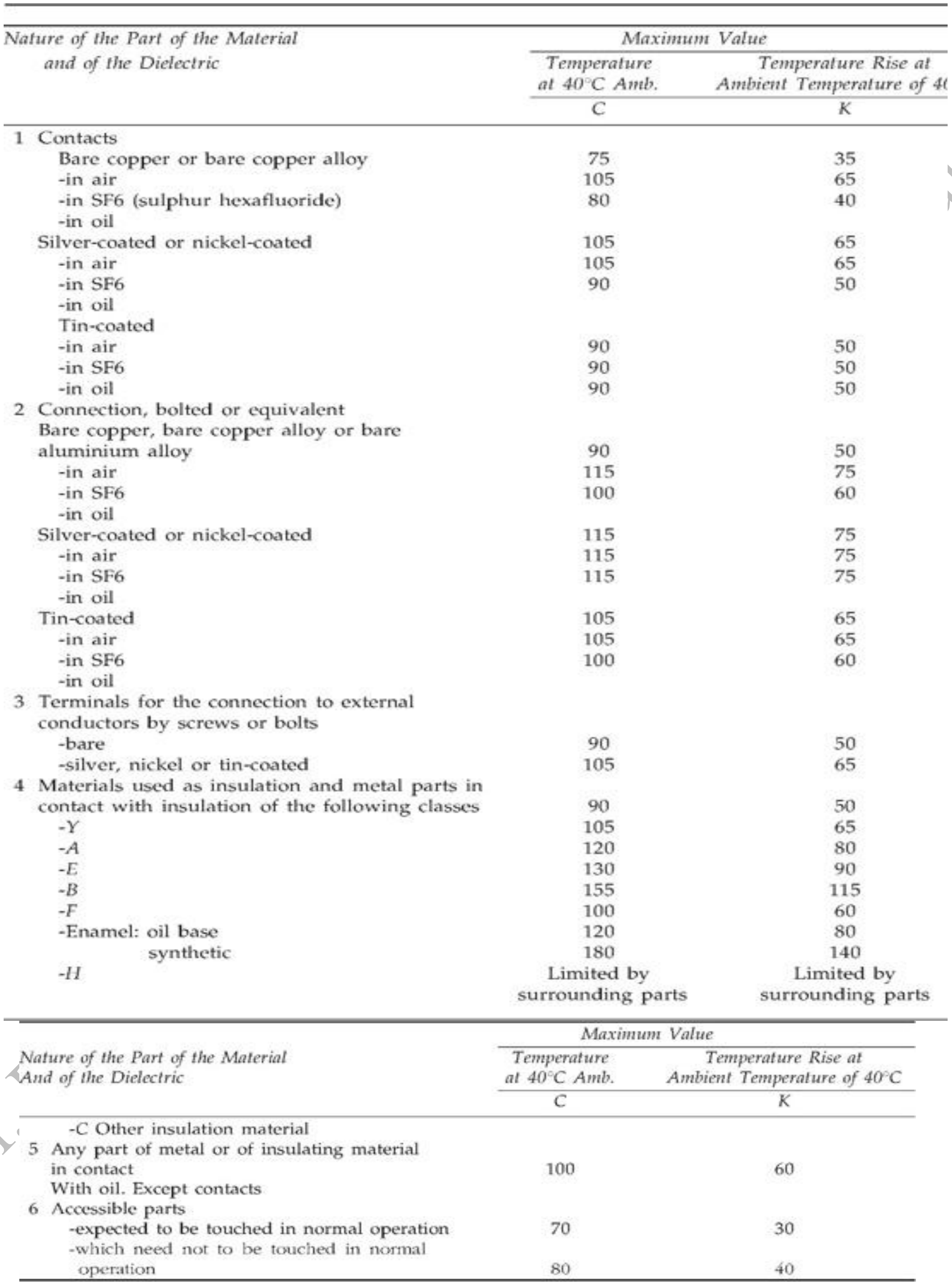
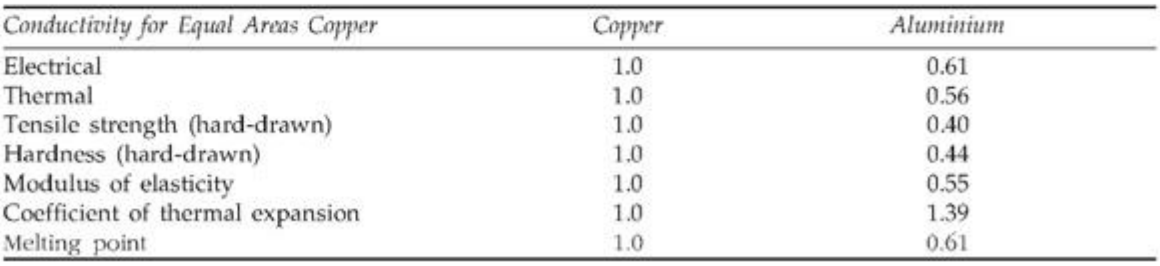


Fig. 3.12: Deed tank switchgears (Pole mounted auto reclosed)



Nature of the Part of the Material and of the Dielectric	*Maximum Value*	
	Temperature at 40°C Amb.	*Temperature Rise at Ambient Temperature of 40°C*
	C	K
1 Contacts		
Bare copper or bare copper alloy	75	35
-in air	105	65
-in SF6 (sulphur hexafluoride)	80	40
-in oil		
Silver-coated or nickel-coated	105	65
-in air	105	65
-in SF6	90	50
-in oil		
Tin-coated		
-in air	90	50
-in SF6	90	50
-in oil	90	50
2 Connection, bolted or equivalent		
Bare copper, bare copper alloy or bare aluminium alloy	90	50
-in air	115	75
-in SF6	100	60
-in oil		
Silver-coated or nickel-coated	115	75
-in air	115	75
-in SF6	115	75
-in oil		
Tin-coated	105	65
-in air	105	65
-in SF6	100	60
-in oil		
3 Terminals for the connection to external conductors by screws or bolts		
-bare	90	50
-silver, nickel or tin-coated	105	65
4 Materials used as insulation and metal parts in contact with insulation of the following classes	90	50
-*Y*	105	65
-*A*	120	80
-*E*	130	90
-*B*	155	115
-*F*	100	60
-Enamel: oil base	120	80
synthetic	180	140
-*H*	Limited by surrounding parts	Limited by surrounding parts
-*C* Other insulation material		
5 Any part of metal or of insulating material in contact With oil. Except contacts	100	60
6 Accessible parts		
-expected to be touched in normal operation	70	30
-which need not to be touched in normal operation	80	40

Table 3.2 Temperature Rise Limits



Conductivity for Equal Areas Copper	*Copper*	*Aluminium*
Electrical	1.0	0.61
Thermal	1.0	0.56
Tensile strength (hard-drawn)	1.0	0.40
Hardness (hard-drawn)	1.0	0.44
Modulus of elasticity	1.0	0.55
Coefficient of thermal expansion	1.0	1.39
Melting point	1.0	0.61

Table 3.3 Differences in Relative Properties of Copper and Aluminium

For achieving equal conductivity, aluminium is lighter in weight than copper. In many switchboard applications, where space considerations are more important than weight, copper is preferred over aluminium.

Silver plating finds extensive use in switchgear equipment as a thin coating in the range of 0.02-0.05 mm. Coating of greater thickness is used when a sliding motion takes place between the plated surfaces. The use of silver coating permits the conductor to be used for higher currents with the same temperature rise as the base material. It also prevents oxide formation, which ensures longer life of the conductor. It is possible to electroplate aluminium with either copper or silver by using a special process. This is required to prevent electrochemical corrosion if aluminium conductors are used in association with copper.

Resistance of the Main Circuit

The current-carrying paths of the switchgear have many joints to meet the design parameter. Each joint will have joining resistance. Care should be taken to minimise the total resistance of the circuit, i.e. the total watt loss should be kept minimum to ensure low temperature rise. The measured value will set the limiting parameter during a routine test.

The resistance of the main circuit depends on factors such as the material of the current-carrying conductor, its cross-section, type, quality and number of joints in the main circuit. The values of conductivity and cross-section of the material chosen for the current-carrying conductor should be such that while the normal current is being required, the temperature rise is maintained within limits. The higher the cross-section of the material, the smaller will be the value of the resistance. While selecting the material for current path in the switchgear, care should be taken to ensure that the conductivity and cross-section of the material is sufficient to carry the rated normal current without over-heating. The higher the number of joints, the higher will be the resistance. Also while making the bolted joints of conductors, sufficient contact pressures should be maintained to ensure the minimum possible resistance.

Joints

There are mainly three types of joints between two contacts, viz. permanent, semi-permanent and temporary joints, depending upon the possible need to break a joint between two conductors. The joint can be bolted or brazed depending upon the material. The most common method of making joints is by bolting or clamping the conductor. Clamping requires more space and is used for outdoor applications, it precludes the need for making holes in the conductor. The surfaces of the conductors must be cleaned before making the joints. In the case of flat conductors, the overlap should be equal or greater than the width of the bars or ten times the bar thickness, whichever is greater. In a joint of any design, the current is transferred through a number of point contacts formed by irregularities of the surface. The effectiveness of the joint depends upon the pressure applied and its distribution. Before the joints are made, it must be ensured that the surface is clean and oxide-free as far as possible. The bolt diameter needs to be such that the necessary pressure to crush the oxide layer does not lead to over-stressing of the bolt itself.

Since aluminium oxide is a good insulator, it is important to follow good jointing practices when aluminium conductors are being bolted together. When bolt pressure is applied, the resistance is initially reduced as the oxide filler is crushed and the area of contact around each bolt increases. Then a limit is reached beyond which further tightening causes very little reduction in resistance, so a properly designed joint does not need excessive tightening.

Contact Design

The 'temporary' joints used in switchgear for the contacts of switching devices, and for withdrawable circuit breakers in metal-enclosed units fall into two groups: butt contacts and sliding or wiping contacts. Each group has many variations and the different characteristics of these types have a bearing on the design of the mechanical lives of the joints. Oil circuit breakers, SF6 circuit breakers and air blast circuit breakers need wiping contacts but vacuum circuit breakers must have butt contacts.

Transfer Contacts

Another area of contact design which is worth mentioning is that of providing for current transfer to a moving contact. This is an essential requirement in any circuit breaker and many varieties have been developed. The simplest form is a bolted connection through a flexible conductor, usually laminated from a sufficient number of thin strips for the current rating, in order to ensure adequate flexibility. If these are arranged so that the movement is controlled and does not impose any frictional forces, then a contact system with low mechanical and low electrical resistance can be devised.

One of the recent additions to the methods used for performing this function is the Multilam type of sliding transfer contact. It is made of a silver-plated copper alloy, and is punched out and shaped in such a way that there exist a large number of parallel, individual contact bridges between the two surfaces. Because of the large number of transfer points, this contact does not require much contact pressure on each point, so it provides a very compact contact system with a high current rating and low friction.

Short-circuit Current

Thermal Aspects

When short-circuit current flows through the circuit breaker, different current-carrying parts are subjected to mechanical and thermal stresses. If the conductor area is insufficient to carry the fault current, the temperature of the circuit may increase to a dangerously high level as a result of which insulators in the vicinity of the conductor are severely thermally stressed. The contacts experience temperature stresses proportional to I2RT. The resistance, R depends on the contact pressure and surface condition.

The thermal stresses depend on the r.m.s. value of the fault current and the time period for which this current is carried by the switchgear, which, in turn, depends on the total breaking time of the interrupting device, which operates to isolate the fault. During short-circuit, it is assumed that all the heat is absorbed by the conductor, there is no sufficient time for convection and radiation. The temperature rise is calculated bv usine the formula:

$$T = m\,(I/A)^2\,(1 + \varepsilon)$$

where T = temperature rise/second in degree C
I = current, r.m.s. symmetrical (ampere)
A = area of cross-section of the conductor (mm^2)
ε = temperature coefficient of conductor resistivity at 20°C

During short-circuit, at a temperature of about 160°C aluminium becomes soft and loses its mechanical strength. This sets a limit on the permissible temperature rise during a short-circuit.

Short-circuit Forces

Single-phase Short-circuit Stresses The electromagnetic force developed between two straight parallel conductors of a circular cross-section and length of 1, each carrying a current of 1 ampere, may be calculated by using the following formulae:

$$F_{\max} = 4.5 \times I^2 \times L/S \times 10^{-8} \qquad (1)$$

where $F_{\max}$ = The force of attraction or repulsion in lb

L = length of conductors in inches

S = distance between conductors in inches

I = short-circuit current in amperes

In the case of conductors carrying direct current, I should be the maximum value of the short-circuit current. In the case of alternating currents, special consideration has to be given to the choice of a suitable value for I. In most cases, it is probably sufficient to assume that the maximum forces which a busbar structure is likely to be subjected to would be those calculated by taking a value of I equal to about 1.75 times the initial r.m.s. value of the symmetrical short-circuit current wave.

However, in certain circumstances it is possible that forces greater than these may develop, such as, for instance, in the case of very rigid bars or due to resonance in the case of bars liable to mechanical vibration. Experiments have also shown that the reactions produced in a non-resonating structure by an alternating current at the instant of application or removal of the forces may exceed the reactions experienced while the current is flowing. Thus it is advisable to err on the side of safety and to allow for all contingencies, for which one should take into account the maximum force which could be developed by the initial peak value of the asymmetrical short-circuit current. This force may be taken as having a value which is twice of that calculated from formula (1).

Formula (1) is usually found to be adequate for all practical purposes. However, one must take into account two slight modifications in certain cases, since formula (1) strictly applies only to conductors of circular cross-section and of infinite length.

Correction for End-effect For the purpose of bus bar design, the assumption that the conductors are of an infinite length does not, in general, lead to any great error. However it must be borne in mind that there is a great difference between the flux density near the ends and that near the middle of a long straight conductor carrying a current. With relatively short conductors, its effect may be considerable. Thus if the above formula is used when dealing with comparatively short bars, the forces calculated may be too high.

It has been seen that correct results are given in all cases by a formula in which

$\sqrt{\{(L/S)^2 + 1\}} - 1$ is substituted for L/S.

The formula then becomes

$$F_{\max} = 4.5 \times I^2 \times \left[\sqrt{\{(L/S)^2 + 1\}} - 1\right] \times 10^{-8} \qquad (2)$$

In most other cases, sufficiently accurate results can be obtained by employing the following formula:

$$F_{\max} = 4.5 \times I^2 \times (L/S - 1) \times 10^{-8} \qquad (3)$$

In general, for all practical purposes, formula (1) may be used without serious error as long as the ratio of L/S is greater than, say, 20. When the ratio lies between, say, 20 and 4, formula (3) should be used, and when the ratio is less than 4, formula (2) should be employed in all cases.

Shape Factor of Bars As already mentioned, the previous formulae apply strictly only to conductors of circular cross-section and it is thus necessary to apply a correction when conductors of rectangular cross-section are used.

Except in cases when conductors are very small, or are spaced a considerable distance apart, a correction factor, K has to be introduced into the formula, which then becomes

$$F_{\max} = 4.5 \times I^2 \times L/S \times K \times 10^{-8}$$

The effect of the conductor shape decreases rapidly with increased spacing; while it is maximum for strip conductors of small thickness, it is practically negligible for bars of square cross-section. For a circular conductor, K symbolises unity.

Balanced Three-phase Short-circuits In the case of a balanced three-phase short-circuit, the currents in the conductor retain their normal 120D phase displacement, and as the relative direction of current flow in any two conductors with respect to that in the third conductor is constantly changing, so the magnitude and direction of the short-circuit forces also changes.

The maximum force of attraction between any two bars of a short-circuited three-phase bus bar system (centre line of three bus bars in one plane) when the effect of the third is neglected, is

$$F_A = 1/8\,(4.5 \times I^2 \times L/S)\,K \times 10^{-8} \qquad (4)$$

Similarly the simultaneous maximum force of repulsion between two bars when the effect of the third is neglected, would be

$$F_R = 3/4\ (4.5 \times I^2 \times l/S)\ K \times 10^{-8} \qquad (5)$$

In the above equations, S is the distances between the bars under consideration.

When the component forces due to the currents in all the three bars are taken into consideration, it can be shown that the maximum resultant force on any bar is

$$F_{\max} = 3.375 \times I^2 \times L/S \times K \times 10^{-8} \qquad (6)$$

where S is the distance between adjacent bars.

It will be seen that the above force is less than that produced by a single-phase short-circuit, and since single-phase short-circuits are usually both more numerous and severe than those involving all three phases, the design of the bus bar structure should be based upon the stresses set up by them.

Vibrational Stresses The mechanical stresses to which bus bars are subjected under short-circuit conditions may, in certain circumstances, be materially increased by vibration, particularly under conditions of resonance. Although such stresses may not seriously affect the conductors themselves, they are very important from the point of view of the strength of the supporting structures and insulators. The load on insulators may be increased to as much as five or even more times its normal short-circuit value, if favourable conditions for resonance prevail.

In the case of enclosed compound insulated busbars, the damping effect of the compound is usually sufficient to prevent the establishment of serious vibrations, but in the case of air-insulated bars, the damping is generally not sufficient to prevent the building up of vibrations, should favourable conditions exist.

No supporting insulator is absolutely rigid and since all types of insulators deflect in some degree when a transverse load is applied to them, they have a natural period of vibration, which varies with their size and design. In general, the strength of an insulator does not increase as rapidly as its stiffness, and the ideal insulator support for busbar purposes is one, which has a maximum strength and a low natural period of vibration. Just as the conductor supports alone have a natural period of vibration, so do the conductors. Thus the busbar structure as a whole will have natural frequencies of vibration, which are a combination of the natural frequencies of the bars and their supports. There are usually two dominant frequencies of importance, the fundamental and the first harmonic, and these may differ considerably from either of the original component frequencies.

The natural frequency of busbar structures may vary considerably according to the design over a wide range of anything from, say, 3 to 300 vibrations per second, and there is always a danger of partial resonance if the frequency of the applied electromagnetic forces is within about 30 per cent of the natural frequencies of the structure. Owing to the great variation in the detail design of busbars, it is not possible to give any universally applicable data to help readily ascertain the possible increase in stresses due to vibration. Every case has to be considered separately.

In practically all cases, it will be found that bars and supporting structures are strong enough to withstand increased stresses due to possible vibrations, if they are designed on the assumption that the greatest force to which they may be subjected is that produced by the maximum value of the asymmetrical short-circuit current. In this connection, it should be pointed out that the dc component of the asymmetrical short-circuit current disappears rapidly, usually within five or six cycles, with the duration of the high initial asymmetrical short-circuit current being very brief. There is, therefore, no time for the vibration of the conductors to be built up before the current has declined to a lower and more steady value. If the current wave is initially asymmetrical, the electromagnetic forces set up by it also change rapidly in frequency as well as in magnitude, and it is unlikely that serious vibrational stresses will occur coincident with the high initial value of the short-circuit current.

When short-circuit current flows through the circuit breaker, different current-carrying parts are subjected to mechanical and thermal stresses. The dynamic force occurs at the peak of the first major loop on the short-circuit. Perpendicular conductors tend to straighten out due to electromagnetic forces. The insulators are selected by considering mechanical bending load occurring at that instant of peak short-circuit current. During a short-circuit in the system, short-circuit current flows through the bus bars. The insulator supporting the bus bars experiences the bending force. The insulator should have enough cantilever strength to withstand load dynamic force occurring during a short-circuit.

When current flows in two parallel conductors, there is mechanical force between the conductors of attraction, when currents are in the same direction, and of repulsion, when currents are in opposite directions. While carrying normal current, these forces are negligible but under short-circuit conditions, they may be appreciable and it is necessary to ensure that the bus bar supports can withstand these forces even though they may be of momentary duration. It is important for the support insulator to be arranged so that insulators are not subjected to lateral forces. The busbar configuration should be designed in such a fashion that minimum forces are generated during a short-circuit.

The electrodynamic forces of attraction and repulsion between adjacent phase conductors are proportional to phase spacing. During short time current, the insulator support experiences an impact cantilever force due to electrodynamic forces.

The busbars are generally selected on the basis of considerations of mechanical strength of supporting arrangement. When spacing in busbars is small, mechanical forces become significant.

When circuit breakers are subjected to a short time current test, the contacts may have a tendency to open at the peak current. The adequate contact pressure should avoid an undesirable opening during the test.

Insulation Aspects of Design

An electrical insulation system is the heart of any electrical equipment. The life of the equipment can be increased if the life of the insulation system is increased.

Switchgear parts of different electric potentials are separated by various insulations to prevent flashovers and to ensure the safety of the personnel working on the switchgear, and reliability of its operations. The insulation serves three main purposes. It provides insulation:

Between the current-carrying live parts and earth;

In the contact gap during the 'breaker open' condition; and

Between the current-carrying live parts of different phases.

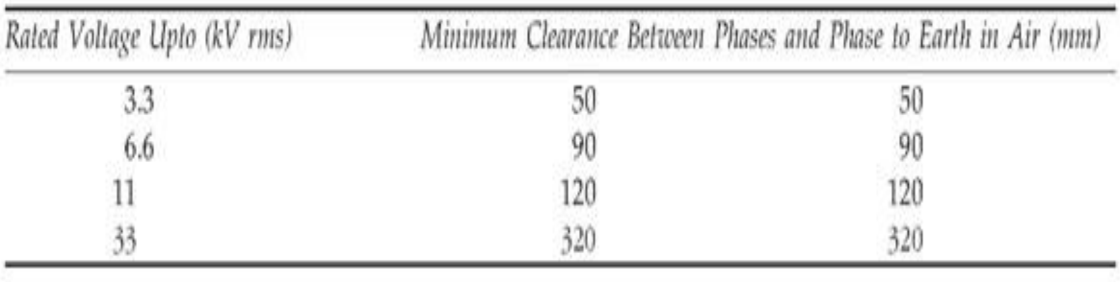
While selecting any insulating material for switchgear, the user should have a wide knowledge of the properties and behaviour of the materials in different environmental situations for their appropriate use. Large varieties of composite insulating materials are used in the seven classes of insulation systems including Y, A, E, B, F, H and C.

During their manufacture and service life, the insulating materials are subjected to several types of stresses as such as electrical, thermal, and mechanical stresses. Although the primary role of the insulation is to withstand electrical stresses, the capability of the materials to fulfil this requirement depends upon their ability to withstand other stresses as well.

A wide range of materials is used for insulation. These materials can be solid, liquid or gas. They are used to fill spaces, support live parts and to extinguish the arc, depending on their physical properties and form. The insulations widely used in switchgear design are detailed below.

Gaseous Materials

Air is the most commonly used gaseous material, which is composed of 80 per cent nitrogen and 20 per cent oxygen. Its properties are therefore close to nitrogen. Air clearances between various phases and between various phases to earth as mentioned in standards, are listed in Table 3.4. Switchgear enclosures are filled with SF6 in GIS, the dielectric strength which is approximately three times that of air. It functions both as an insulation medium as well as an arc-quenching medium in SF6 breakers. Of all the gases, air is the only insulating material which can be used effectively at atmospheric pressure.



Rated Voltage Upto (kV rms)	Minimum Clearance Between Phases and Phase to Earth in Air (mm)	
3.3	50	50
6.6	90	90
11	120	120
33	320	320

Table 3.4 Air Clearances

Fluids

A range of fluids has also been used for insulation in switchgear. Hydrogen carbon oil, often referred to as 'transformer oil', has been used in bulk oil CB. It serves the dual purpose of acting both as an insulator as well as an arc-extinguishing medium. Its dielectric strength is three times that of SF6 at atmospheric pressure. However, it is coming under increasing scrutiny from the safety point of view because of its flammability.

Vacuum

Another medium used for insulation in switchgear is vacuum. But since it is very expensive, its use in distribution switchgear is restricted to the circuit interruption devices only.

Solid Materials

Solid insulating material include those of natural origin such as mica, asbestos, and slate or those derived from natural material such as porcelain and shellac varnish. Solids are mainly used in switchgear to insulate conductors where they pass through the walls of metal enclosures apart from supporting the conductors. The resin is usually epoxy. One major advantage of the resin casting technique is the virtually limitless range of its shapes.

Medium Voltage Switchgear: Vacuum Switchgear

In medium voltage (3-36 kV) power system applications, recent trends in both international and Indian markets show that conventional types like oil, air and SF6 circuit breakers are being mostly replaced by vacuum technologies. This technology will completely dominate the industry in coming years due to the fact that a vacuum circuit breaker represents an ideal solution to the widely varying demands of switching functions in medium voltage applications.

The following section discusses in depth the usage of vacuum technology to meet the switching requirements of MV applications, in distribution, in the industrial and power segments of the market.

Vacuum as an Interrupting Medium

The performance of a circuit breaker depends upon the properties of the dielectric medium and the design of the arc-quenching system. The superior performance of the vacuum circuit breaker is purely due to the inherent characteristics of vacuum as an interrupting medium. This is due to certain important features, which are detailed below.

For a given contact gap, the dielectric strength of high vacuum is approximately eight times that of air or four times that of SF6 (one bar). This higher dielectric strength makes it possible to quench an arc with a very small contact gap. Vacuum has the fastest recovery strength after full arc interruption to its full dielectric value at current zero. This makes it ideally suitable for capacitor switching.

The arc energy dissipated in vacuum for a given interrupting current is approximately one-tenth of that in oil or one-fourth of that in SF6. This is due to the short clearance times and low arc length in vacuum. The low arc energy keeps the contact erosion to a minimum, thereby giving a maintenance-free interruption system. For a given breaking current, the drive energy required in vacuum switchgear is the least as compared to that for other types of breakers (Fig. 3.13).

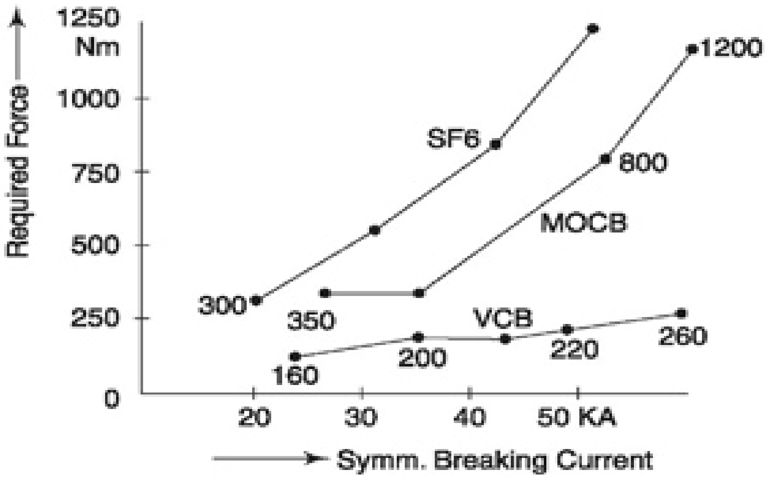


Fig. 3.13: Comparison of energy requirement

This low drive energy is due to the low contact mass, short contact travel and the fact that no compression of medium is required in vacuum switchgear. This low drive energy facilitates a simple mechanism with minimum linkages requiring little maintenance, and gives a high mechanical life of upto 60,000 operations in properly designed mechanisms.

When the contacts open in vacuum, the current to be interrupted initiates a metal vapour arc discharge and continuous flowing through this plasma until the next zero. The arc is extinguished near the current zero and the conductive metal vapour re-condenses on the contact surfaces in a matter of micro-seconds. Only one-hundredth condenses in the arc chamber wall provided for this purpose. As a result, the dielectric strength of the breaker recovers very rapidly and contact erosion is almost negligible.

There are two types of arc shapes. Up to about 10 kA, the arc remains diffused. It takes the form of vapour discharge and covers the entire contact surface. Above 10 kA, the diffused arc is constricted considerably by its own magnetic field and it contracts. The phenomenon gives rise to over-heating of contacts at its centre. In order to prevent this, the design of the contacts should be such that the arc does not remain stationary but keeps travelling by its own magnetic field. Various manufacturers have used different designs to achieve this. Specially designed contact configurations make the constricted stationary arc travel along the surface of the contacts, thereby causing minimum and uniform contact erosion.

3.6.2 Demands Made on Circuit Breakers

The demands made on MV power systems, irrespective of the place of use of the circuit breakers, vary widely in nature. All these functions cannot obviously be performed with the same efficiency. Thus, finally any circuit breaker design can only be a compromise. The main function of circuit breakers is to interrupt short-circuit currents and protect their loads against the effect of such faults. This function must be carried out with a high degree of safety and reliability.

Switching Functions

In an MV power system, apart from the normal ON/OFF operations, the switching operations can be divided into the following:

Short-circuit Interruptions;
Switching of Capacitive Currents;
Switching of Inductive Currents; and
Special Applications.

Short-circuit Interruptions All circuit breakers are designed to interrupt rated short-circuit currents. The number of short-circuit interruptions seen in the life of a circuit breaker depends on its location in the system, quality of the system design, environmental conditions, etc. In countries like India, where most of the distribution is by means of overhead lines (except in the case of large urban cities where underground cable networks are used), the distribution switchgear is subjected to a large number of short-circuit interruptions. This is due to bird hits, snapping of lines, thunderstorms, etc. Vacuum switchgear, which can interrupt rated short-circuit current up to 25 kA 100 times without requiring maintenance, is the obvious choice for this application as compared to other circuit breakers which can do so for only 15-20 operations.

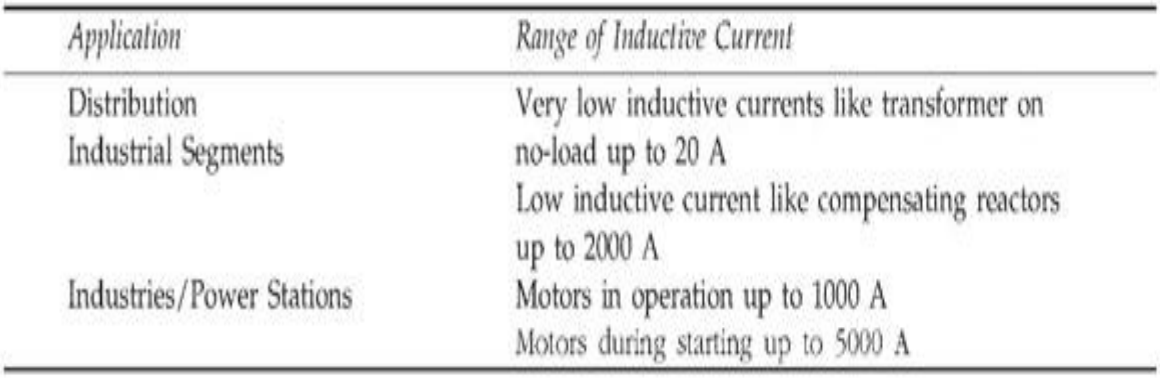
The other important criterion to be considered in distribution through overhead lines is the auto-reclosing feature required due to the transient nature of the faults. The VCBs are ideally suited for auto-reclosing duties because they act fast and can be reclosed with a minimum time interval between two closings as cooling of the dielectric is not involved.

Most of the sub-stations in rural areas are outdoor and situated in far-off places. This necessitates the setting up of outdoor maintenance-free circuit breakers. Porcelain-clad vacuum circuit breakers meet this demand reliably as against the conventional indoor BOCBs used in outdoor kiosks. Moreover, the availability of vacuum technology for auto-reclosers and sectionalisers has given birth to highly economical/unattended sub-stations for rural application.

Switching of Capacitive Currents This includes switching of capacitors, unloaded cables and overhead lines as well as single and parallel capacitor banks. Most of the electricity utilities use capacitors in their systems to improve the power factor and to tackle voltage drops. Vacuum circuit breakers disconnect these loads safely without re-ignition and thus without the associated over-voltages.

When switching in capacitor bank, and especially when paralleling them, very high making currents and high rates of rise of current occur. Conventional circuit breakers with liquid-quenching medium and tulip contacts may suffer from contact pin retardation. Thus additional measures are usually needed for these breakers to reduce such effects. Very low energy loss in the contact gap owing to low arcing during the short pre-arcing time, and flat contact surfaces of vacuum breakers obviate the necessity for additional measures. VCB's are suitable for switching in single capacitor bank as well as paralleling of Multi-Capacitor banks at much higher currents and rates of rise than MOCBs and SF6 circuit breakers, without the need for damping reactors.

Switching of Inductive Currents The following values are likely to be encountered in various cases of switching inductive currents.



Application	Range of Inductive Current
Distribution	Very low inductive currents like transformer on no-load up to 20 A
Industrial Segments	Low inductive current like compensating reactors up to 2000 A
Industries/Power Stations	Motors in operation up to 1000 A Motors during starting up to 5000 A

Table 3.5 Typical Values of Inductive Current Switched by Medium Voltage Switchgear

Vacuum circuit breakers have proved to be adequately suitable for these applications.

Switching of Very Low Inductive Currents Older vacuum circuit breaker designs had current chopping levels that were as high as 20 A. When these breakers were used to switch transformers, special surge protection devices were required. Other types of circuit breakers also have high chopping currents of, say, 20 A. Modern Vacuum Circuit breakers with very low chopping currents of 2 to 4 A are capable of switching unloaded transformers (most difficult inductive loads) with very low over-voltage, thereby requiring no surge limiters.

Switching of Low Inductive Currents Two main applications fall in this category. These are switching of compensating reactors and switching of motors under stalled rotor starting conditions. In these special cases, high over-voltages may occur due to multiple re-ignitions. Vacuum interrupter manufacturers have systematically investigated the switching of motors during starting and made the following observations:

High voltage motors may be safely operated under start-stop conditions by vacuum circuit breakers where surge suppressors are provided to limit associated switching over-voltages.

The front time of the switching impulses is determined by the system configurations mainly by the surge impedance of busbars and cables, and current transformer inductances. These tests were conducted to meet the most severe conditions and it was observed that the occurrence of a front time of less than one micro-second is most unlikely in service. This ensures the safe operation of high voltage motors which are tested with a standard lightning surge wave of 1.2/50 micro-seconds.

Switching off of motors having starting currents of more than 600 A during starting generates low switching over-voltages and the motors do not require protection by surge suppressors even in 11 kV cable systems.

It has also been observed that when other types of breakers are used to handle such switching operations, high over-voltages may occur due to multiple re-ignition. Moreover, it has now been found that when motors are switched 'ON', high over-voltage surges can occur which are independent of the arc-quenching medium including in SF6 circuit breakers. Thus, vacuum circuit breakers, which are provided with surge limiters, offer protection to the motor even when it is switched 'ON.'

Special Applications Special applications like arc furnaces involve a large number of operations per day. Track-side sub-stations require the switchgear to operate in varying set of conditions from switching the charging current of catenary systems to transformer magnetising currents to a whole range of load currents and fault currents varying from 2 kA to 12 kA. These applications also require the switchgear to have the capability to withstand a range of voltages of various waveforms from sinusoidal to steep fronted surges throughout its useful life. Vacuum circuit breakers have been found to be superior to all conventional and SF6 circuit breakers for such applications.

(a) Arc Furnace Applications Electric arc furnaces with ratings up to 100 MVA generally employ special circuit breakers, for which purpose air blast circuit breakers have been used till now. In this application, the falling scrap in the furnace causes short-circuits between the electrodes during the melting process, and the currents to be switched lie between zero and 1-8 times the rated current of the furnace transformer. The frequency of switching can be as high as 100 operations per day with rated currents up to 2000 A. Normal oil, air and SF6 circuit breakers are found to be unsuitable for this application. Special air circuit breakers are very expensive due to stringent requirements for relatively small quantities. The standard vacuum circuit breaker offers an economical and reliable solution for this application.

(b) Use in Traction System The system used for electric traction generally has voltages between 15 and 25 kV and frequency of 16-2/3, 50 and 60 Hz. The main function of the single-phase traction circuit breakers is quick interruption of short-circuits on the overhead catenary system, which occur frequently and are usually transient in nature. Since VCBs have short contact travel and shorter arcing times, the total break time is quite less and thus meets the special requirements of short breaking times easily.

In case of 16-2/3 Hz traction systems, the current zero occurs in every 30 milli-seconds resulting in an arcing time of around 33 milli-seconds. Although the arc energy in the contact gap for a single-phase breaker is much greater than that for three-phase circuit breakers, it is still much lower in a vacuum circuit breaker than in conventional circuit breakers owing to the low arc voltage. Figure 3.14 shows vacuum circuit breakers for use in traction systems.

Fig. 3.14: 25 kV outdoor track-side vacuum switchgear

The number of short-circuits occurring on an overhead catenary system is much higher than those occurring on transmission lines. Thus the higher permissible cumulative current of vacuum circuit breakers, i.e. up to 100 operations at rated short-circuit current or 30,000 operations at rated normal current, makes them especially suitable for this application.

(c) Use on Ships Circuit breakers meant for use on ships have to fulfil the following special requirements:

They must remain operational even in an inclined position; and

Circuit breakers used on ships are subjected to vibrations in actual use.

Circuit breaker manufacturers are able to comply with these requirements more easily in the case of vacuum circuit breakers