Demand for electrical power has become one of the major challenges faced by the developing countries. Considering the relatively low per capita power consumption, there is a constant need for power capacity addition and technological upgradation whereas non-conventional energy systems have proved to be good alternative sources for energy. In developing countries like India most of the additional power has been met by conventional electric sources. Hence, the emphasis has shifted towards improving the reliability of transmission and distribution systems and ensuring that the innovations are not harmful to the environment.

Air insulated power transmission and distribution substations suffer variations in the dielectric capability of air to withstand varying ambient conditions and deterioration of the exposed components due to oxidisation and the corrosive nature of the environment. The size of the sub-station is also substantial due to the poor dielectric strength of air. In order to enhance the life and reliability of a power transmission and distribution sub-station, it is desirable to protect the sub-station components from a corrosive and oxidising environment. Metal encapsulation of the sub-station elements provides a simple and effective solution to the problem of durability of the substations. The use of a bus duct, with pressurised nitrogen gas, is a good example of devices with metal encapsulation used in
power sub-stations. The size of the container is a direct function of the dielectric strength of the insulating medium. The container/enclosure sizes are thus large with a poor insulation like air or nitrogen.

The use of a gaseous medium with higher dielectric strength like sulphur hexafluoride (SF₆) instead of air helps in manifold reduction in the size of the sub-station component. The grounded metal encapsulation, on the other hand, makes the equipment safe, as the live components are no longer within the reach of the operator. The electric field intensity, at the enclosure surface, is reduced to zero as the enclosure is solidly grounded. Using this design philosophy, sub-station/switchyard equipment, like circuit breakers, disconnectors, earth switches, busbars and instrument transformers (both current and voltage), have been metal-encapsulated or metal-enclosed and pressurised with SF₆ since 1968. The assembly of such equipment at a sub-station is defined as Gas Insulated and Metal Enclosed System (GIMES) by the International Electro technical Commission (IEC). The equipment is popularly known as a Gas Insulated Sub-station (GIS) system. The term GIS is also sometimes used to refer to Gas Insulated Switchgear [1].

Rapid urbanization and overgrowing population is making the task of expanding transmission network very difficult due to right of way problem and limited space availability. In addition, conventional air insulated substations have many problems such as pollution by salt or dust, meteorological difficulties, safety etc. Hence, there is a need to replace the
conventional transmission lines and substations with underground cable and Gas Insulated Substation (GIS) to overcome the above problems. Due to its many advantages, most of the utilities and industrial units are opting for Gas Insulated Substations [2].

In this context, Gas Insulated Substation (GIS) have found a broad range of applications in power systems for more than two decades because of their high reliability, easy maintenance and small ground space requirement etc. In our country, a few GIS units have been in operation and a large number of units are under various stages of installation. Although, GIS has been in operation for several years, some of the problems need full attention. These problems include generation of over voltages during switching operations like enclosure faults and particle contamination.

The introduction of SF₆ gas has revolutionized not only the technology of circuit breakers but also the layout of substations. The usefulness of SF₆ gas is mainly due to its High dielectric strength, unique arc quenching ability and Good thermal stability and conductivity. Sulphur hexafluoride (SF₆) is a man-made gas that became commercially available in 1947. Now a days, it is one of the most extensively and comprehensively studied molecular gases largely because of its many commercial and research applications. Besides the use of SF₆ by the electric power industry, other uses include: semiconductor processing, blanket gas for magnesium refining, reactive gas in aluminum recycling to reduce porosity, thermal and sound insulation, aero plane tyres, spare tyres, air-soled shoes, scuba
diving, voice communication, leak checking, atmospheric trace gas studies, ball inflation, torpedo propeller quieting, wind supersonic channels and insulation for AWACS radar domes. Its basic physical and chemical properties, behavior in various types of gas discharges, and uses by the electric power industry have been broadly investigated [3-7]. In its normal state it is chemically inert, non-toxic, nonflammable, non-explosive and thermally stable (it does not decompose in the gas phase at temperatures \( T<500^\circ C \)). Because of its relative inertness and nontoxic characteristics, it is generally assumed to be an environmentally safe and acceptable material in the sense that it does not interact unfavorably with the biomass.

Sulphur hexafluoride exhibits many properties that make it suitable for equipment utilized in the transmission and distribution of electric power. SF\(_6\) is a strong electronegative (electron attaching) gas both at room temperature and at temperatures well above ambient, which principally accounts for its relatively high dielectric strength and good arc-interruption properties. The breakdown voltage of SF\(_6\) is nearly three times higher than that of air at atmospheric pressure [8]. Furthermore, it has good heat transfer properties and it readily reforms itself when dissociated under high gas pressure conditions in an electrical discharge or an arc (that is, it has a fast recovery and is self-healing). Most of its stable decomposition byproducts do not significantly degrade its dielectric strength and are removable by filtering. It produces no polymerization, no carbon, or other conductive deposits during arcing and is chemically compatible with most of
the solid insulating and conducting materials used in electrical equipment at temperatures up to 200°C.

Besides its good insulating and heat transfer properties, SF₆, when contained has a relatively high pressure at room temperature. The pressure required to liquify SF₆ at 21°C is about 2,100 Kpa [6,9,10]; its boiling point is reasonably low - 63.8°C, and allows pressures of 400 KPa to 600 KPa to be employed in SF₆-insulated equipment. It is easily liquified under pressure at room temperature, allowing for compact storage in metal cylinders. It presents no handling problems, is readily available, and is reasonably inexpensive. The current price of SF₆ for quantity purchases is about 1.2 lakh per cylinder of 50kg. The electrical industry has become familiar and experienced in using SF₆ as electrical equipment.

However, SF₆ has some undesirable properties: it forms highly toxic and corrosive compounds when subjected to electrical discharges; nonpolar contaminants, e.g., air, CF₄, are not easily removed from it; its breakdown voltage is sensitive to water vapour, conducting particles, and conductor surface roughness; and it exhibits non-ideal gas behavior at the lowest temperatures that can be encountered in the environment, i.e., in cold climatic conditions (about-50°C), SF₆ becomes partially liquified. Sulphur hexafluoride is also an efficient infrared (IR) absorber, and due to its chemical inertness, it is not rapidly removed from the earth’s atmosphere. Both these latter properties make SF₆ a potent greenhouse gas, although
due to its chemical inertness (and the absence of chlorine atoms in the SF₆ molecule) it is benign with regard to stratospheric zone depletion.

Generally, there are four major types of electrical equipment that use SF₆ for insulation and/or interruption purposes: Gas Insulated Substations, Gas Insulated Circuit Breakers, Gas Insulated Bus duct / Gas Insulated Transmission Lines and Gas Insulated Transformers. It is estimated [11-13] that for these applications the electric power industry uses about 80% of the SF₆ produced worldwide, with circuit breaker applications accounting for major component of power transmission and distribution systems all over the world, and it employs SF₆ almost exclusively. It offers significant savings in land use, is aesthetically acceptable, has relatively low radio and audible noise emissions, and enables substations to be installed in cities very close to the loads.

The increased application of SF₆ in Gas Insulated Switchgears / Substations (GIS), Gas Insulated Cable, electrical accelerators and X-ray equipment etc. have led to growing concern for investigating the mechanism of SF₆ decomposition and the effects of decomposition products. In the presence of corona (PD), spark breakdown and electric power arc, SF₆ decomposes into lower oxy-fluorides of Sulphur. These may react with the electrodes or gas impurities or other solid dielectrics to form a number or chemically active products. Although SF₆ is chemically inert and nontoxic, the decomposition products of SF₆ are known to be toxic and corrosive. The
accumulation of decomposition products in the equipment has caused concern regarding personal safety and material compatibility.

The decomposition of SF₆ is greatly influenced by gaseous impurities. In industrial grade of SF₆ the typical impurities are CF₄, N₂, O₂ (air) and H₂O. The gaseous impurities are generally introduced during filling and partly due to the decomposition of moisture into the dry SF₆ after filling. A survey of major North America utilities revealed that the average air concentration in SF₆ compartments is 500ppmv (parts per million volt) and the average moisture content is about 500ppmv. In practical, GIS environments having the presence of such impurities are unavoidable.

The Various modules of GIS are factory assembled and are filled with SF₆ gas at a pressure of about 0.3 (Mega Pascal’s (MPA)) to 0.6 MPA. They are taken to site for final assembly, such substations are compact and can be installed conveniently on any floor of a multi-stored building or in an underground substation. As the units are factory assembled, the installation time is substantially reduced. Such installations are preferred in cosmopolitan cities, industrial townships, etc., where cost of land is very high and higher cost of SF₆ insulated switchgear is justified by saving due to reduction in floor area requirement. They are also preferred in heavily polluted areas where dust, chemical fumes and salt layers can cause frequent flashovers in conventional outdoor air insulated substations.

A Gas Insulated Switchgear is a compact, multi component assembly enclosed inside a grounded metallic encapsulation, which shields all
energized parts from the environment. GIS are available internationally, covering the complete voltage range from 11 kV to 800 kV. The thermal current-carrying capacities and the fault-withstanding capabilities are tailored to meet all the sub-station requirements. More than 100,000 GIS bays have been in service all over the world since the introduction of such sub-station systems in the transmission and distribution field.

1.1 CLASSIFICATION OF GIS

Gas Insulated Metal-enclosed Substation systems are classified according to the type of modules or the configuration. The following configurations have been evolved over the years and are generally used:

- Isolated-phase (segregated phase) module
- Three-phase common modules
- Hybrid modules
- Compact modules
- Highly integrated systems

The isolated-phase GIS module consists of an assembly of individual circuit elements like a pole of a circuit breaker, a single pole disconnector, one-phase assembly of a current transformer etc. A single-phase circuit is formed by using individual components and pressurising the elements with gas forming a leak-free gas circuit. Three such circuits, arranged side by side, form a complete three-phase GIS bay. The circuits, since assembled
individually, require larger bay width as compared to the other GIS configurations.

In hybrid systems, a suitable combination of isolated-phase and three-phase common elements is used like three-phase busbar and single-phase elements, to achieve an optimal techno-commercial solution. While the three-phase common busbar system simplifies the connections from the busbar, the isolated-phase equipment prevents phase-to-phase faults in active modules like the circuit breaker. Savings in terms of space vary with the design and configuration of the section.

Hybrid GIS technology has gained popularity, specially in the medium and high voltage range, where advancements in technology have helped to reduce the sub-station size. With hybrid design, it is possible to construct techno-economical sub-stations providing additional flexibility for maintaining and expanding sub-stations in future at lower costs. In compact systems, there is flexibility of horizontal expansion (same voltage class), while replacement of the total equipment is necessary for vertical expansion (higher voltage class).

Compact GIS systems are essentially three-phase common systems, with more than one functional element in one enclosure. A single enclosure, housing a three-phase circuit breaker, current transformer, and earth switches, supports the busbar and the other feeder elements. The depth of the section is considerably reduced in this configuration as compared to the three-phase modules. A total reduction of up to 47 per cent in the
equipment area is possible by using this configuration [1]. Highly Integrated Systems (HIS), introduced in the year 2000, are single unit metal encapsulated and gas insulated sub-stations, and are gaining user appreciation as this equipment provides a total sub-station solution for outdoor/yard sub-stations. The foundation work is limited to just one equipment, thus resulting in saving of substantial installation time.

These units are directly connected to the overhead lines. The incomer and feeder side connections (bushings) are directly mounted on the metal enclosure in this system. It is a ready-to-instal sub-station, with pre-defined circuit elements housed, sealed and pressurised in a single enclosure. A different version of one-unit GIS is also available as a Plug and Switch System (PASS). This variant can similarly be installed as a single unit, replacing the existing identical bay of a yard sub-station. A full sub-station can be built by multiplying these units.

1.2 COMPONENTS OF GAS INSULATED SUBSTATION

Various circuit components in main circuit are Circuit Breakers, Bus bars, Isolator earthing switches for conductors, Current Transformers, Disconnecting switches, Voltage Transformers, Cable ends, Gas supplying and gas monitoring equipment, Earth Switch, Densimeters and Local control. The various modules are connected in accordance with the single line diagram shown in Fig. 1.1
1.2.1 Busbar

The busbar is one of the most elementary components of the GIS system. Co-axial busbars are common in isolated-phase GIS as this configuration results in an optimal stress distribution. Busbars of different lengths are used in GIS to cater to the requirement of circuit or the bay formation. The high voltage conductor (copper/aluminum) is centrally placed in a tubular metal enclosure. The conductor is supported, at a uniform distance, by the disc or post insulator to maintain concentricity. Two sections of bus are joined by using plug-in connecting elements. Various sizes of the bus enclosures are shown in Fig 1.2.
1.2.2 Connectors

The high voltage and high current electrical connections from one module to another in a gas insulated sub-station system are carried out with the help of spring loaded fingers or bridge contacts and Multi-lam contacts. These two plug-in contact systems impart the maximum flexibility during assembly and dismantling. Both these contacts offer plug-in features and are suitable for tubular conductors. The connections made are reliable without the need for any additional hardware to secure their location. The spring-loaded connector and Multi-lam contact are shown in Fig 1.3 and 1.4.
A T-joint (metal casting) used for tapping a high voltage connection in GIS is shown in Figure 1.5. The joint houses a pair of multi-lam contacts in the cavity provided for connection to the new element. The size and diameter of the HT conductor in an isolated-phase system are governed by the ratio of the conductor and the enclosure (maintained around $1/2.82$), while the thermal current rating controls the section of this HT conductor. Tubular sections provide a large surface area for heat transfer and improve the heat dissipation rate to the gas.

![Image of T-joint for GIS system](image)

**Fig 1.5 T-joint for a GIS system**

1.2.3 **Insulating Materials and Insulators**

Stable polymers like PTFE (poly tetra fluoroethane) are selectively used in GIS and associated accessories. Ceramic and high-alumina ceramics are also used in GIS as solid insulation materials between the live conductor and the enclosures. However, their poor mechanical and thermal shock withstanding capabilities and difficult processing and manufacturing cycles have limited the use of ceramics in GIS. Alumina-filled epoxy matrix is a common insulating material for GIS-related applications.
Disc and post are the preferred shapes and types of support insulators for GIS. The disc insulators are conical in shape and are also known as funnel insulators. The disc insulators are further sub-divided into communicating and non-communicating insulators. The two types of disc insulators are shown in Fig. 1.6 and Fig. 1.7. The communicating insulators help in establishing gas continuity between the two adjacent enclosures, while in situations where the gas communication between two sections is undesirable, a non-communicating insulator is used. Solid core epoxy insulators are commonly used to support busbars in three-phase common GIS systems.

Fig 1.6 Support insulator for GIS (communicating)  
Fig 1.7 Support insulator for GIS (non-communicating)

The post insulators are cylindrical or oval in shape. The surface of the insulator is smooth for minimizing particle attachment. Rib insulator, a variant of the post insulator, combines two post insulators in one. This insulator supports a tubular bus conductor and provides additional rigidity to the conductor. Since it is anchored at two ends to the enclosure, the
insulator is lightly stressed during faults. Bus systems with such insulators provide better fault withstanding capabilities. Figure 1.8 shows the view of a 145 kV, three-phase bus with rib insulators. The equipment uses two rib insulators per phase for supporting the individual busbars. A three-phase disc insulator, Fig. 1.9, is used to support a three-phase busbar and to limit the pressure-rise to the affected enclosure in the conditions of an arc fault.

1.2.4 Disconnectors (Isolators)

Isolators are placed in series with the circuit breaker to provide additional protection and physical isolation. The isolators can be motorised or driven manually. In GIS systems, motorised isolators are preferred. A pair of fixed contacts and a moving contact forms the active parts of an isolator. The fixed contacts are separated by an isolating gas gap. During the closing
operation, this gap is bridged by the moving contact. The moving contact is attached to a suitable drive, which imparts the desired linear displacement to the moving contact at a pre-determined design speed. A firm contact is established between the two contacts with the help of spring-loaded fingers or the multi-lam contacts. The isolation gap is designed for the voltage class of the isolator and the safe dielectric strength of the gas. Figure 1.10 shows a cross-section of an isolated-phase GIS isolator. Isolators in high voltage GIS operate at SF₆ pressures of 0.38 MPa to 0.45 MPa. The operating speed of the isolator moving contact ranges from 0.1 to 0.3 m/sec.

Fig 1.10 Cross-section of an isolated-phase GIS isolator

1.2.5 Circuit Breaker

The circuit breaker is the most critical part of a gas insulated sub-station system. The circuit breaker in a gas-insulated system is metal-clad and utilizes SF₆ gas, both for insulation and fault interruption. The SF₆ gas
pressure in a circuit breaker is around 0.65 MPa. The circuit breaker is directly connected to either current transformers or the isolators in gas. A barrier is maintained between the circuit breaker and the other connected equipment, operating at lower gas pressure to maintain a pressure difference. The circuit breaker enclosure also serves as the main support element for the individual GIS bay. The GIS circuit breakers are oriented both in horizontal and vertical configurations, depending on the system requirements and ease of installation.

![Cross section of a GIS circuit breaker](image)

**Fig 1.11 Cross section of a GIS circuit breaker**

### 1.2.6 Current Transformer

The conventional sub-stations use either live-tank or dead-tank type current transformers with Oil/SF₆ insulation. A porcelain insulator is used to insulate the low potential section of the current transformer from the high voltage zone. Ribbon or cut silicon steel cores are used for the magnetic circuit of the current transformer for obtaining the desired ratio and accuracy. Hairpin shaped primary conductor is the standard geometry for a dead-tank type current transformer. The current transformers in gas
insulated systems are essentially in-line current transformers. Gas insulated current transformers, with classical coaxial geometry, consist of the following parts: the tubular primary conductor; an electrostatic shield; ribbon-wound toroidal core and the gas-tight enclosure.

The primary of a current transformer is a tubular metal conductor linking two gas-insulated modules, placed on either side of the current transformer. Disc insulators, at either end of the current transformer enclosure, support this high voltage conductor. One end of the conductor end is solidly fastened, while the other end is provided with a sliding joint, which compensates for the thermal expansion of the conductor and simplifies the assembly of the current transformer module. A ribbon-wound silicon steel core (formed in toroidal shape) is used for the magnetic circuit of the current transformer. A coaxial electrostatic shield, at ground potential, is placed between the high voltage primary and the toroidal magnetic core of the current transformer for ensuring zero potential at the secondary of the current transformer.

1.2.7 Earth Switch

Fast earth switch and maintenance earth switch are the two types of earth switches used for gas insulated sub-station systems. The maintenance earth switch is a slow device used to ground the high voltage conductors during maintenance schedules, in order to ensure the safety of the maintenance staff. The fast earth switch, on the other hand, is used to protect the circuit-connected instrument voltage transformer from core
saturation caused by direct current flowing through its primary as a consequence of remnant charge (stored online during isolation/switching off of the line). The earth switch is the smallest module of a gas insulated sub-station system. The module is made up of two parts: a fixed contact, which is located at the live bus conductor and which forms a part of the main gas insulated system; and a moving contact system mounted on the enclosure of the main module and aligned to the fixed contact. The moving contact system is an assembly of the moving contact, current transfer contacts, a mechanical system to convert the linear motion of the moving contact to rotary motion and an enclosure or the housing.

1.2.8 Control Panel

Both local and remote control panels are used in GIS. The local control panel (LCP) provides an access to the various controls and circuit parameters of an individual GIS bay. The local control panel facilitates the monitoring of gas pressures, status of the switchgear element and operating fluid pressures, of oil, SF6 and air. The local control panel essentially features interlocks, operating buttons and a single line diagram. The panel has a swing panel and a clear glass door with padlocks. The operator can verify the status of the circuit through a glass panelled clear door, containing the mimicked single line diagram, indicators and push buttons.

The auxiliary gas insulated module or accessories, excluding control panel, that are required to complete a sub-station are Terminations, Instrument voltage transformer and Surge and lightning arrestor.
An instrument voltage /potential transformer, used for metering and protection, forms a part of the GIS and is gas insulated. This equipment is directly mounted and connected to GIS, at times with an isolator /disconnector in series. Both the single-phase and the three-phase instrument voltage transformers (IVTs) are available for voltages up to 170 kV. Single-phase IVTs are common for system voltages higher than 145 kV. A gas insulated surge arrester is a critical accessory required for a substation. This device protects the system from switching surges. Surge arresters are commonly used for installation above 170 kV class, where appreciable switching surge intensity is recorded.

1.3 CONSTRUCTIONAL ASPECTS OF GIS

1.3.1 Enclosure

The enclosures for gas insulated sub-station equipment are fabricated using carbon steel and alloy steel, or are cast using aluminium. While corrosion-resistant stainless steel (SS-304 and SS-316) is the dominant enclosure material for isolated-phase equipment, cast aluminium enclosures are preferred as they are lightweight and entail low production costs. Sharp protrusions and loosely/weakly held metal inclusions are checked and removed from the inner surfaces of the enclosures. While the inclusions are potential sources of conducting particles detrimental to the life of GIS, sharp protrusions form potential discharge locations. The inner
surfaces of the enclosures are thus carefully examined and verified before the enclosures are permitted for use in GIS. Electro-polishing or anodising process is used to chemically blunt the sharp edges of the protrusions on the inner surface of the enclosure. The enclosures are tested for their reliable design by conducting a proof test, which is recommended at 2.3 times the operating pressure for fabricated enclosures, as per IEC-517. The cast enclosures are tested and certified for withstanding 3.5 times the operating pressure as per this standard.

1.3.2 Seals and Gaskets

Seals and gaskets are important components, which determine the insulation life and top-up frequency of a GIS. These critical components arrest leakage of the gaseous insulation in a pressurised installation, like a gas insulated sub-station system. O-rings with circular cross-sections and rectangular gaskets with rectangular cross-sections are the most common shapes of the pressure seals used in GIS. Single O-ring seals are common for indoor installation. Double O-ring seals or a single O-ring seal backed by a gasket is a common practice for outdoor installations. The following properties are considered before selecting the sealing materials for GIS:

- Resistance to decomposed SF₆;
- Resistance to oil;
- Resistance to tension, compression and elongation;
- SF₆ and moisture permeability;
- Environmental impact/ease of handling; and
Materials like EP rubber, nitrile rubber, silicon rubber and viton are common commercial elastomers. Nitrile and viton rubbers are used in GIS as they have the above properties. The compression distortion and the service temperature directly influence the service life of a sealing system. The compression distortion in the range of 10-12 per cent is considered optimal for a good sealing performance. A service temperature in the range of 20-35°C ensures a life expectancy of more than 100 years for this optimal compression.

1.3.3 Gas Circuit

The GIS enclosures are pressurised with SF₆ gas at design pressures. The operating pressure for GIS varies from 0.1 MPa to 0.8 MPa. 0.1 MPa is a standard working pressure for vacuum interrupter-based medium voltage GIS systems. SF₆ interrupter-based equipment, in medium voltage, uses pressures in the range of 0.25 MPa-0.45 MPa. The high voltage (>72.5 kV) gas insulated substation system modules operate at a gas pressure of 0.4 MPa; in these modules, the gas is principally used as an insulant.

The GIS circuit breaker module is designed to operate at a gas pressure of 0.65 MPa or higher, as the gas is used in the module for both interruption as well as for insulation. The enclosures are required to retain this insulant for the life of the equipment. Leaks, virtual or real, will allow leakage of the gas and reduction in the pressure or the density of the gas. Leak/ loss of insulant directly cause deterioration in the dielectric
performance of the gaseous insulation. In order to ensure leak-tightness, the complete enclosure and seals are checked using the Mass Spectrometric Leak Detection (MSLD) system at manufacturing stage. These leak tests are also performed during the initial stages at the component level.

1.3.4 Expansion Joints

The copper and steel elements used in GIS, if assembled rigidly, are likely to change dimensions with a change in the ambient temperature. For an indoor sub-station, with a limited number of bays /sections, the expansion may not be such a critical issue. However, in major GIS systems, expansion and contraction of the metal-clad equipment with temperature is a critical issue that needs to be addressed seriously. The sub-station life is likely to be reduced due to thermal cycling, fatigue, etc. Expansion joint has been found to be an ideal solution for such duties. The addition of an expansion joint between two adjacent bays limits variation in dimension to the individual circuit, thereby maintaining the mechanical stability of the sub-station.

The expansion joint also helps in the addition and removal of bays, if so required, during the life of a sub-station and makes such installations more flexible to changes in the circuit/configuration. These joints also provide margins for radial and axial non-alignment. Stainless steel flexible joints are the only alternatives for expansion joints in GIS, because of their flexibility, strength and thermal cycling capabilities. In indoor GIS,
maintaining a constant sub-station temperature (minimum variation) controls the expansion and contraction of the metallic equipment.

1.3.5 Current Transfer and Plug-in-Joints

In order to configure different circuit formations, gas insulated functional modules are connected in accordance with the desired circuit requirement or single line diagram. Various modules are connected suitably using bolted or plug-in joints. The use of copper flexible (stranded wire) connections is not permitted in GIS, since the strands are the potential sources of long metallic particles. A combination of solid bolted joints and plug-in joints is thus universal for GIS applications. Silver-plated interfaces are preferred for the bolted joints. The free sliding, plug-in-joints carry the full thermal current reliably and withstand large short time current efficiently. These joints are designed in a manner so as to contain the electrostatic and electrodynamic stresses to safe working limits. The geometry, material and the surface finish of these joints thus play a vital role in ensuring the satisfactory performance of a GIS. The following three types of plug-in-joints are generally used:

- Static
- Quasi-static
- Dynamic

The static joints are mostly plugged in only once at the time of the equipment assembly and are not disengaged throughout the life of the equipment. Quasi-static joints have flexibility for engagement and
disengagement, which may be required as and when the equipment undergoes inspection, addition, etc. The dynamic flexible joints are used with functional elements like circuit breaker, disconnectors, etc., where the application demands dynamic current transfer during the normal operations of such equipments.

1.3.6 Support Structure

Gas insulated sub-station modules, when assembled to form a circuit configuration, assume the shape of a robust pipe structure with exceptionally good mechanical rigidity. In the initial stages of the installation, the main modules may require support for stability. These supports can be withdrawn after the installation is complete. Some permanent supports may also be necessary to support the terminal equipment. In isolated-phase construction, with vertical circuit breaker, the requirement to support the modules connected horizontally is always felt. The necessary support structure is thus designed for this configuration of GIS. Module assemblies mounted horizontally are suitably supported in GIS.

Three-phase compact GIS configurations are self-supporting and the centre of gravity of the structure lies within the circuit breaker module. The circuit breaker module supports the rest of the bay equipment in such a configuration. Structures made of hollow rectangular sections or standard structural sections suffice for the purpose. In outdoor installations,
sufficient care is taken to prevent corrosion of the support structure due to moisture and other pollutants.

Early designs of GIS followed a cautious approach and complete segregation of the three phases i.e., separate chambers were provided for each functional component such as circuit breakers, current transformers etc., of each phase. Each gas compartment, within a phase, is provided with a gas service connection to which a vacuum pump, gas refilling tank or a gas recuperating plant can be connected. To warrant proper functioning of the SF$_6$ gas system, protective items, such as absorbers and bursting discs are provided. In addition densimeters are provided to monitor pressure and temperature of gas in compartments of each phase. The densimeter also gives alarm for gas loss. Leakage rate of SF$_6$ gas in normally guaranteed as $\leq$1 percent per annum. However, after gaining sufficient service experience and ability to maintain dielectric integrity three phases in one or phase integrated modules are now available.

The three-phase construction has the added advantage of having only a reduced number of gas seals and moving parts. The live parts are supported on cast resin insulators. Some of the insulators are designed as barriers between neighboring module such that the gas does not pass through them. The entire installation is subdivided into compartments, which are gas tight with respect to each other; there by the gas monitoring system of each compartment can be independent and simpler. The
enclosures are of non-magnetic material such as aluminum or stainless steel and are earthed. M/s Asea Brown Boveri generally adopts a common enclosure for all the three phases for system highest voltage upto 170 KV; segregated construction for each phase is adopted for higher voltages [14].

Gas insulated substations are subjected to the same magnitude of ground fault current and require the same low impedance grounding as conventional substations. However, because of smaller area available, it may be difficult to obtain adequate grounding solely by conventional methods. Fault conditions, which arise in the GIS, lead to lengthy disconnection periods due to the mechanical complexity of the GIS and there is therefore a requirement to provide diagnostic measurements during in service use of the GIS in order to predict the possibility of a fault condition and to enable corrective action at a planned and convenient time. These potential faults almost always show partial electrical discharge activity before breakdown occurs and this discharge activity can be sensed from the consequential ultra high frequency resonance modes established in the pressure vessels. Accordingly the UHF modes can be sensed by couplers built into the pressure vessels at the inspection ports.

Apart from discharges and breakdowns caused by threshold voltage stressing, particle-initiated discharges are common to GIS. The discharges are initiated by the random movement of particles (both conducting and non-conducting) in high intensity fields. The fields are prevalent in an enclosed high voltage system similar to GIS for lower insulation gap
between the HT and mounded conductors. The particle-initiated discharges are controlled in GIS by effectively trapping the discharge initiating particles in particle traps. The traps are located close to devices prone to the generation of particles. Two types of particle traps, namely 'passive' and 'active', are commonly used in GIS. Passive particle traps use gravity and adhesion to trap the particles, while the active traps use electrical fields to attract and retain the particles.

Conducting contamination (i.e. aluminum and copper particles) could, however, seriously reduce the dielectric strength of a gas-insulated system. Metallic particles in GIS have their origin mainly from the manufacturing process or they may originate from moving parts of the system, such as breakers and disconnectors. They may also originate from mechanical vibrations during shipment and service or thermal contraction / expansion at joints.

Metallic particles can be either free to move in the GIS or they may be stuck either to an energized electrode or to an insulator surface (spacer, bushing etc.). If a metallic particle crosses the gap and comes into contact with the inner electrode or if a metallic particle adheres to the inner conductor, the particle will act as a protrusion on the surface of the electrode, and the voltage required for breakdown of the GIS will also cause a significant reduction of the breakdown voltage.
The understanding of the dynamics of a metallic particle in a coaxial electrode system is of vital importance for improving the voltage withstand capacity of a Gas Insulated Systems. If the motion pattern of a metallic particle is generally known, the probability of a particle crossing a coaxial gap, causing a flashover, can be estimated.

Depending on the shape of the particles, as well as the geometry and voltage levels of the system, the particles get more or less influenced by the electric field, which in turn makes them more or less hazardous to the electrical system.

1.4 CONCLUSION

Gas insulated sub-station systems offer a compact, cost-effective, reliable and maintenance-free alternative to the conventional air insulated sub-station systems. Their compact size offers a practical solution to vertically upgrade the existing sub-station and to meet the ever-increasing power demand in developing countries. The assured long life and freedom from frequent maintenance drills offered by these gas insulated sub-stations will help eradicate the conventional air insulated sub-stations in years to come.