1. INTRODUCTION

Metropolitan areas in rapidly developing regions are faced with special problems in augmentation of their power supply system due to uncontrolled growth, uncertainty of development plans, extreme congestion and very high load densities.

The continuous growth of large metropolitan cities and industries, which results in concentration of the demand for electricity, necessitates installation of distribution equipment upto highest voltage. Use of large size transformers to achieve economy of scale and space results in high fault levels within these areas.

The population in Mumbai has been growing at a very rapid rate and today, it is around 15 to 16 million resulting in total congestion of the existing land and leaving no Right Of Way for any additional HV overhead line input into the city. In fact, finding a suitable route for underground cables is also becoming almost impossible due to narrow carriageways, large number of underground utilities and non co-ordinated development of underground services.

In addition, land in South Mumbai is at very high premium, which makes it practically impossible to plan conventional indoor or outdoor EHV Receiving Stations economically with high reliability.

To meet the above constraints, installation of Gas Insulated Switchgear (GIS) was the only alternative to conventional outdoor/ indoor switchgear to ensure economical supply of power with a high degree of reliability.

GIS has excellent adaptability in meeting most difficult terrain or space constraints. Low space requirements on account of high dielectric strength of gas leads to flexibility of application. Entire switchgear being in a sealed environment does not get impacted by polluting conditions like dust, impurities and deteriorating lubricants used in disconnectors. There has been besides above, other factors such as safety, longevity and adaptability which make GIS an attractive proposition as compared to Air Insulated Substation (AIS). It is upto 220 kV level, transportation conditions permit factory assembled bay which is most attractive and favourable feature for indoor & outdoor application alike due to very short erection and commissioning time. Reduced requirement of maintenance make them suitable option for most reliable operation. In fact, quality consciousness of equipment alone make GIS as favoured equipment choice for remote operation. All these factors in totality make GIS most attractive equipment options to adopt. Though initial cost of equipment is higher than that of AIS, the choice of GIS with respect to AIS is a techno economic decision to be made taking into account technical economical & environmental factors.

Considering all the above factors Tata Power had therefore decided to adapt GIS at 245 kV and 145 kV and commissioned in 1988 India’s first such substation at Carnac Receiving Station (R/s) situated in the heart of Mumbai city. Since then Tata Power has experience of operating more than 600 bay years of 245 kV GIS and 284 bay years of 145 kV GIS respectively.

2. EXPERIENCE OF TATA POWER

The performance of GIS in Tata Power has been quite good as compared to conventional AIS. However, some problems faced with GIS are briefly described below:

- 245 kV SF6 gas to oil transformer bushings at one of Tata Power’s substation failed which resulted in a flashover in the power transformer exit bus duct compartment. Impending failure of a similar bushing was detected in incipient stage by monitoring of dissolved gases in bushing oil. This bushing was dismantled and stripped which indicated Very Fast Transient Over Voltage (VFTO) as a possible cause of failure of the bushing. The computer simulation of GIS model was carried out by using the Electro Magnetic Transient Programme (EMTP) for analysis of transients generated by closing and opening of 245 kV breaker of 315 MVA auto transformers. EMTP studies indicated that the maximum rise in voltage during switching operation of breaker was 2 pu in 530 nano secs. The computer model of 245 kV GIS and corresponding theoretical voltage wave form obtained using EMTP simulation is indicated in Figure 1 and 2 respectively. Tests were conducted at site to correlate and validate the
theoretical test results. During actual tests at site, the peak value of the VFTO was of the order of 1.4 pu in 364 nano secs., when the breaker was closed. VFTO waveform record from oscillogram is indicated in Figure 3. The variation in theoretical and actual measurements could have been due to the following:

a) Non inclusion of arc impedance in the computer model since no reliable means are available to assume value of the arc impedance.

b) In the computer model all the three poles of the circuit breaker are assumed to close simultaneously whereas in practice due to mechanical linkages the poles may not close simultaneously.

c) Effect of resistive and inductive values of earth and earthing connections.

After detailed analysis and investigations on careful dismantling of bushing, it was observed that edges of inner 12 layers of aluminium foil towards the oil end had marks of combustion and puncture of the paper. The size of combustion marks increased towards the main copper conductor. Based on these observations, the following corrective measures were taken:

i) Existing OIP bushings were replaced by new bushings in which the zero foil connection to main conductor was shifted from oil end to SF6 gas end to clamp VFTOs as the gas end itself.

ii) The insulation strength of the first layer of insulating papers was improved alongwith its thickness.

iii) The number of connections to connect zero foil with the main conductor was increased from one...
to two and thickness of connecting wire was also increased.

iv) The new bushing was satisfactorily tested at bushing manufacturer’s works to simulate VFTO. The torque withstand capability of the bushing cap was improved from 120 Nm to 190 Nm, as required by GIS manufacturer, to prevent rotation of bushing top cap which was the interface point with the GIS. Earlier lesser top cap torque capability had led to snapping grading lead connections.

v) Thus the results of these studies helped the manufacturer to modify the design & adopt correct interface between GIS, bushing & transformer.

- The earthing system of the GIS requires greater care as compared to that for a conventional outdoor substation. During initial charging of 145 kV GIS when 110 kV XLPE cable was earthed through high speed earth switch, a flash over was observed from 145 kV GIS cable compartment to the metallic gland on which the copper screen of XLPE cable was terminated. The flash over was caused due to non provision of shorting strips which were meant to directly connect GIS enclosure to copper screen of XLPE cables. This had resulted in discontinuity in the GIS earthing system. The case of the flash over was attributed Transient Ground Potential Rise (TGPR). When the cable was switched off, it retained a trapped DC charge between the conductor and the screen of the cable. When the earth switch was closed, this caused a discharge at the shortest path across the sealing end enclosure to the cable screen, due to high inductance of the GIS earthing system in the absence of the shorting strips. After provision of shorting strips, there was no incidence of flash over during abovementioned operation. Figure 4 indicates connection for GIS enclosure to copper screen of XLPE cable.

- 245 kV GIS high speed earth switch bushings used to crack during the operation of high speed earth switch. It was observed that due to solid connection and inadequate dampner, the shock was getting transferred to the porcelain bushing of the high speed earth switch. Subsequently the solid connection was replaced by the manufacturer and there were no subsequent failures of the high speed earth switch bushings.

- In 145 kV GIS circuit breaker compartment one safety disc ruptured. The sequence of events logged by SCADA indicated initially Low pressure alarm and LOLO pressure trip within 715 mseconds. The bay was carrying current of 270 amps prior to tripping. No other relay operated and the breaker tripped on LO-LO SF6 pressure. The internal inspection of the breaker compartment did not reveal flash over marks or any other abnormality. The ruptured disc was replaced by a new safety disc. After reinstalling the top cover of the circuit breaker and evacuation, SF6 gas was filled and breaker taken into load service after carrying out timing, contact resistance and insulation resistance checks. Broken pieces of the safety disc were sent to the manufacturer. After studying the pieces of the faulty disc no defect was found. Carbon matter also did not show any micro cracks. The manufacturer opined that the defective disc was probably knocked during the transport or handling of the circuit breaker, which induced stressed inside the carbon matter until the disc burst suddenly. After the replacement of the safety disc the GIS has been operating satisfactorily.

- Gas leak from gaskets particularly from the outdoor flanges of GIS is frequently experienced. The ultra violet radiations causes faster deterioration of gaskets. The gradual corrosion of the aluminium metal enclosure was also observed due to moisture ingress in outdoor GIS gaskets.

Tata Power replaced leaking gasket alongwith the associated gaskets. The hydraulic mechanism oil leakage was also attended.

- The enclosures of SF6 gas density monitors, especially those which are mounted outside GIS building, were getting corroded and subsequently resulted in mal operation of the same. During investigation, it was observed that environmental condition of Mumbai i.e. extremely humid climate and heavy rains during monsoon season, enclosures of outdoor SF6 monitors are getting corroded. Suitable protective measures have been adopted to address this problem.
3. **MONITORING AND MAINTENANCE PHILOSOPHY**

Achieving and maintaining high level of availability of equipment requires an integrated approach to quality control by both users and manufacturers. Tata Power has standardized quality assurance programmes to be carried out at the time of purchase of GIS, as well as it follows standardized (internally) operation and maintenance philosophy for GIS.

As a part of quality assurance program during initial purchase stage and commissioning stage of GIS, cleanliness during assembly and erection is very vital since any contamination causes deterioration in the properties of SF6 gas. Access to current carrying parts during services is not possible as all the live parts of GIS are enclosed in metal enclosure. Opening of the enclosure for inspection at site can lead to introduction of impurities which can deteriorate dielectric properties. This necessitates stress on diagnostic measurement in case of GIS instead of usual maintenance practices for outdoor switchyard equipment. The values measured during initial commissioning are very useful as a reference in future. Following tests are performed after completion of erection of GIS at site:

1. Checking the moisture content of SF6 gas of various gas compartments.

2. Measurement of contact resistance, operating time of circuit breakers, isolators etc. by using insulated bushings of the earthing switches.


4. Partial discharge test.

5. Power frequency test / Oscillating switching impulse test.

Dielectric tests are carried out on complete installation (except surge arrestors, Cables, Voltage Transformers and Power Transformers) to confirm dielectric integrity of GIS and detect presence of foreign particles and verify correctness of connections. The dielectric tests are carried out through special test set with bushings or backcharged VTs which are specially strengthened. Once GIS is commissioned it requires no or very little maintenance. The maintenance and inspection philosophy for GIS followed by Tata Power consists of following.

1. **Visual Inspection** – To be carried out on periodic internals i.e. every month.

2. **Detailed Inspection** – To be carried out every 6 years or 1000 times of no-load switching operation.

3. **Disassembling Inspection** – Every 18 years or the initial stage and afterward carrying out referring to the initial stage inspection results as per manufacturer’s standards and as per Tata Power, follow trends of various inspection & testing results.

4. **Special Inspection** – (i) In case of any abnormality. (ii) For GCBs : After 10 times of breaking at rated breaking current. (iii) After 1000 times of breaking at rated normal current. (iv) After 2000 times of no-load or small current switching.

The brief procedures for visual, detailed and disassembling inspection (special inspection) are indicated below:

<table>
<thead>
<tr>
<th>Inspection</th>
<th>Description</th>
<th>Brief Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Inspection</td>
<td>Exterior in general</td>
<td>Abnormal noise or odour, Rust damage of any part, tightness of bolts/nuts.</td>
</tr>
<tr>
<td>Operating Mechanism Box</td>
<td>Checking of position indicator, operation counter, oil pressure gauge.</td>
<td></td>
</tr>
<tr>
<td>Leakage</td>
<td>Oil &amp; Gas leakage from operating mechanism system and gas respectively.</td>
<td></td>
</tr>
<tr>
<td>Detailed Inspection</td>
<td>Switching Operation</td>
<td>Checking of position indicator, operation counter, auxiliary switches, low pressure operation and breaker operation.</td>
</tr>
<tr>
<td>Exterior In General</td>
<td>Check the tightening of bolts and nuts, Rusting or peeling of pains,</td>
<td></td>
</tr>
<tr>
<td>Operating Mechanism</td>
<td>Checking operation of the oil pressure switch and density switch, greasing, checking oil level of pump unit, exchange of operating oil.</td>
<td></td>
</tr>
<tr>
<td>Measuring Test</td>
<td>Measurement of Insulation resistance, measuring initial oil charging time, checking accumulator gas (N2) pressure.</td>
<td></td>
</tr>
</tbody>
</table>
**Inspection** | **Description** | **Brief Details**
--- | --- | ---
Disassembling Inspection | To be carried out under supervision of manufacturer’s representative | Checking condition of main contacts, nozzle, cleaning of interrupting chamber and gas tank, replacement of adsorbent, greasing, checking resistance across terminals of each pole.

Special Inspection | To be carried out under supervision of manufacturer’s representative | To be carried out as and when the conditions indicated above are observed. The inspection content is same in case of a detailed and disassembling inspections. During O&M, parts may be exchanged, greasing, cleaning of all ports done.

Besides the above, certain novel modifications in GIS architecture, incorporated due to operating experience were carried out by Tata Power while procuring new GIS substations. The advantages and disadvantages of modifications in GIS architecture are indicated below:

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Modifications</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Reduction in number of gas chambers in a bay by combing CT.</td>
<td>New GIS is much more compact.</td>
<td>Volume of gas handled at a time is more.</td>
</tr>
<tr>
<td>2.</td>
<td>Three position switch i.e. isolator, and earth switch</td>
<td>Space required for mounting isolator / earth switch reduced and hence further reduction in space requirement</td>
<td>Mechanical interlock thereby avoiding mal operation isolator / earth switch.</td>
</tr>
<tr>
<td>3.</td>
<td>Cable side earth switch and cable compartment in single gas compartment</td>
<td>Reduction in size of GIS</td>
<td>Quantity of gas at the time of evacuation of gas from cable chamber is more.</td>
</tr>
</tbody>
</table>

**4. INNOVATIVE SOLUTIONS**

In today’s changing market, the substation is becoming more and more a key element to meet end users requirements successfully and economically. Many existing substations have outlived their operational life and a one-to-one replacement of conventional AIS components like circuit breakers and disconnectors is not economically advisable. Completely new substations have to meet tough requirements of in terms of occupied space, environment and availability. Also, extension of existing substations require high availability of primary circuit components, to cope with already existing control systems, lack of availability of space, limited down time.

Taking into consideration all the above factors, to expand existing substation, Tata Power has introduced new concept of “Hybrid Switchgear” in HV/EHV switchyards. Hybrid Switchgear is a combination of AIS and GIS and it can be thought as “Performance and Save Space” and it can meet any substation layout requirement while making efficient use of available space. Hybrid GIS bay consists of breaker, isolator, earthing switch enclosed in an enclosure filled up with SF6 gas. The interface with the existing switchyard can be through air bushings if it is to be connected to busbars or through cable if the bay is located away from busbars. Sometimes, based on the customer’s requirement, the hybrid GIS bay can be equipped with conventional current transformers.

In one of Tata Power’s Generating Station at Lodhivli, three 110 kV outdoor bays were to be created for Generator Transformer and two outgoing lines in a very limited space (Trapezoidal plot 10M x 23M x 20M x 25M) for evacuation of power. It was not possible to install conventional outdoor bay within space available. Also, it was not economically advisable for installation of complete GIS. Hence a midway solution of installation of Hybrid GIS was considered and commissioned. Figure 5 shows Hybrid GIS by installed at Tata Power’s Lodhivli Station.
5. **CONCLUSION**

The paper highlights the experience of Tata Power on High Voltage GIS indicating some minor problems, operation and maintenance philosophy of GIS including quality control aspects of GIS and innovative modifications in the switchyard to meet the exceptionally growing load requirement from existing substations. GIS are now exhibiting an excellent in service performance in terms of availability, compactness and reliability, which was made possible only through more integrated approach to quality control by both users and manufacturers during design, manufacture, testing, shipping, assembly, operation and maintenance.

GIS has resulted in widespread use over the years and has helped in optimally using the space available. (Refer Figures 6 & 7)

References:

1. “Site Investigations and study of VFTO in 245 kV GIS of Tata Electric Companies by A M Sahni etal”, CIGRE 1996 session (15/21/33-01)