Mixed Technology HV Switchgear and Substations:
Optimised Service Strategies

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1 Key Words
Mixed Technology Switchgear (MTS), Compact solutions, Modular Substations, Service concepts,
High voltage switchgear, Air-insulated switchgear (AIS), Gas-insulated switchgear (GIS), Highly-
integrated switchgear (HIS), New Segregated Ring (NSR)

2 Summary
Technical, economic, environmental and occasional drivers of the change in substation design call for
solutions which are not only economically competitive, but which also allow project managers and
operators to improve efficiency, flexibility, environmental integration and adaptability of installations
as well as faster commissioning and highest reliability guaranties. This requires standardised solutions
with proven and fabric tested reliability to minimize on-site mounting with its inherent risks of failure
and need for further testing.

Mixed Technology Switchgear (MTS) based on gas-insulated switchgear (GIS) is the reasonable an-
swer to today’s needs for high and very high voltage substations. Actually, the development of modu-
lar equipment and installations and the reconsideration of design for optimizing the integration of
these aspects offer a large range of solutions based on gas-insulated switchgear with modular and uni-
form characteristics. The combination of the high reliability of GIS technology and the high maintain-
ability based on good accessibility and quick replacement of defective devices of AIS results in modu-
lar solutions for switchgear and substations as presented in this paper. These modular solutions can be
applied for new substation, refurbishment or extension of existing ones, which are suitable for indoor
or outdoor application.

This paper summarizes design criteria as well as the implementation of new GIS equipment for a volt-
age range of 145 kV to 420 kV, giving a display of basic solutions that will help project planners and
operators. The following aspects are covered: economic factors, modularity, flexibility, reliability,
maintainability, environmental integration and reduced mounting space.

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### 3 Basic concepts of substation design

Substation design is an integration (TDL) of three different aspects:
- selection of technology (T)
- configuration of single line diagram (D)
- physical lay-out of substation (L)

The usually applied practice is to consider one or two aspects for engineering different alternatives of a substation. The only way to get a right solution is to consider all three aspects together. The most common mistake is to “copy and paste” single diagrams elaborated for AIS solutions to GIS switchgear. That concludes to too many equipment and devices which cause higher investment and failure cost by inherent failure rate.

Figure 1 shows the dependencies of availability and failure costs.

**Conventional approach:**
- High redundancy
- More devices
- Lower reliability for entire substation
- Higher failure costs

**Innovative approach:**
- Low redundancy, but reliable device
- Less devices
- Higher reliability for entire substation
- Low failure costs

**Fig. 1: How achieve high availability of substations**

The goal is to use reliable technology in order to achieve comparable availability with smaller amount of devices. The usage of MTS with GIS components is respecting the integrate consideration of the three aspects TDL, introduced in the beginning of this chapter, results in:
- higher reliability [1,2], consequently lower redundancy is required
- quick replacement by modular arrangement in unlikely event of failure, consequently lower redundancy is required
- direct connection of modules due to the modular system, consequently no busbar or other passive components are required (refer to Figure 2)

The lower redundancy results in less equipment which leads to reduced investment, maintenance and failure cost according to table 1.

<table>
<thead>
<tr>
<th></th>
<th>AIS</th>
<th>GIS-Convent.</th>
<th>GIS-Modules</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Major Failures</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failure rate per C.B.</td>
<td>1,00</td>
<td>0,52</td>
<td>0,52</td>
</tr>
<tr>
<td>Duration of downtime</td>
<td>36 h</td>
<td>90 h</td>
<td>6 h*</td>
</tr>
<tr>
<td><strong>Minor Failures</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failure rate per C.B.</td>
<td>7,08</td>
<td>3,95</td>
<td>3,95</td>
</tr>
</tbody>
</table>

**Tab. 1: Comparison of failure rates and duration of downtimes**

All the values are evaluated by Cigré [1,2], except (*), which is confirmed by tests.
4 Integrated MTS Solutions based on GIS

The recent past has witnessed a growing demand for compact solutions for indoor as well as outdoor applications. It has been noted that in addition to their small space requirement, many compact solutions offer standardised as well as interchangeable switchgear modules catering thereby to the clients’ needs for flexibility. The fact that different kinds of available solutions like the HIS (Highly Integrated Switchgear) are delivered as pre-fabricated modules, reduces the overall erection and installation time dramatically in comparison to a conventional (AIS) substation, where individual components have to be procured, handled, installed, commissioned and maintained separately. Another advantage of pre-fabrication is the reduced risk of faulty installation at site.

The MTS solutions are based on GIS technology taking advantage of consequent encapsulation of all switchgear devices. This achieves a significant higher reliability compared to AIS solutions and their derivates. As a matter of fact the AIS technology comprises a higher maintainability (refer to table 1). This article introduces new developed service concepts using MTS solutions allowing reducing the duration of downtime to only 6 hrs. This value is significantly lower than for AIS installations.

Actually, it is well known that a highly specialized skill level is needed to repair GIS and that access to primary elements (HV) is difficult (for example, mechanical actuators, switch devices, disconnectors, etc.). In traditionally designed GIS installations, this frequently necessitates the removal of adjacent elements in order to reach the element to be worked on.

Today, experience and an exhaustively proven technology combined with modular equipment specially designed to be maintained by medium-skilled staff allow the installation of HV substations which also offer ease of maintenance by unskilled personnel thus guaranteeing low outage times in case of failure. In case of refurbishments or extensions usually the lack of space makes the use of conventional (air-insulated) equipment difficult. The above mentioned MTS characteristics permit the use of the new modules in GIS technology as well as in conventional installations. When the TDL concept is considered consequently the overall cost of a substation using GIS components are comparable in investment cost but significantly lower in operating cost (refer to Figure 5).

The new solutions developed in cooperation of users and manufacturers are aimed on augmenting the advantages of GIS equipment with the flexibility and maintainability of AIS installations, while offering competitive costs. This is the main reason for making TDL solution so attractive for utility companies from asset management point of view.

As a result, the approach TDL has led REE (the main transmission company in Spain) to redesign its 400 kV substations.

REE has defined a number of solutions which are designated as NSR (New Segregated Ring). They comprise a uniform application for outdoor or indoor substations with the following characteristics according to the TDL approach:
**Modular GIS technology**

The advantageous characteristics of the selected GIS technology are as follows:

- GIS components are optimized for outdoor usage
- Moving parts are protected against environmental impact
- Single phase encapsulation (for EHV applications)
- Erection is enabled without assembly on site except mounting of air bushings
- Ease of installations and repair works by sliding contact systems, e.g. tulip type
- Interconnection of LV circuits by connector plugs
- Separate gas compartments on adjacent feeders
- Disconnector and current transformer comprise separate gas compartments each

These features result in quick exchangeability of circuit breaker (c.b.), disconnector or current transformer (C.T.) modules within 6 hrs. Depending on the module to be exchanged both feeders (c.b.) or only the adjacent one (disconnector, C.T.) can be kept energized.

![Separable GIS – Bay Module](image)

**Diagram: Meshed Ring**

The meshed ring concept provides the following advantages compared to conventional AIS single line lay out:

- Operating devices are less or equal compared with 1 ½ circuit breaker concept
- Due to simplicity no busbars are required
- Availability is higher or equal compared with 1 ½ circuit breaker arrangement
- Flexible extension of installation is achieved by uniform lay out of modules and their combinations, and with outages that affect only one node of the ring

**Physical layout**

The physical layout of the NSR concept is applicable to horizontal and vertical orientation of the meshed rings. In opposition to that the AIS arrangement for 1 ½ circuit breaker is characterized by strict physical lay out which is clearly different to the GIS approach.
Some of the possible layouts for NSR implementation with segregated phases are shown below:

**Hybrid Ring**

**GIS Ring**

**GIS Battery**

*Fig. 4:* Layouts which make up each single-line diagram phase with 6 I/O. Their triphasic implementation may be different leading to the NSR several possible solutions. Photographs of the installation will be presented in the contribution during the Cigré conference.

In Figure 5 two alternatives of NSR arrangements are presented for a meshed ring with six I/O (seven circuit breakers), where:

- 1,2 and 3 represents the three phases
- B₁, B₂ and B₃ contains the whole of bays that consists each phase as some of the previous presented arrangements (Hybrid ring, GIS ring, or GIS battery are all valid)
- Aᵢ and Cᵢ only contains the air insulated connections to allow the lateral outputs the access to the modules.

With this concept an extension as well as in horizontal as well as in vertical direction is facilitated.

*Fig. 5: Alternatives of NSR arrangements*
5 Life Cycle Cost Considerations

Evaluations of the life cycle cost of these arrangements (Fig. 6) demonstrate the economical advantages of GIS-modules: The investment cost of GIS modules based on GIS technology are lower than comparable GIS arrangements because the necessity of busbars is minimized and buildings are not required. Further on GIS-modules comprise similar operating cost compared to GIS due to usage of the same technology (= same reliability). The operating costs of AIS are higher in anyway: On the one hand a higher amount of components is necessary in order to achieve the same level of availability. On the other hand an equal amount of components causes higher outage costs because of the lower reliability of the AIS equipment.

![Fig. 6: Comparison of cost structure of LCC of GIS, GIS modules, AIS of a sample substation [3]](image)

6 Practical application

In the following some practical applications of existing installations are presented. The presented examples shall demonstrate the application of the basic ideas of GIS-modules.

One typical application for GIS modules is HIS from Siemens in single bay arrangement. As shown in Figure 7 numerous in/out HIS bays in wind parks have been installed so far.

![Fig. 7: GIS-module application 145kV “Windpark bay”](image)

The three phase encapsulated HIS bays used for wind parks for example are pre-assembled and pre-tested in the factory and located which reduces the activity on site to a minimum. By virtue of the compact bay structure only a few standardized foundations are necessary. In consequence the erection of one wind park bay is possible within only one or two days. Additionally HIS requires only a fraction of the ground area of an air insulated switchgear. In this way logistic expenses and the overall investment cost can be kept down.
The advantageous operation of HIS is mainly based on the complete encapsulation of the whole switchgear: the operating personnel are protected from contact with live parts and the reliability of this outdoor installation is comparable with the long experiences GIS technology. Integrated and encapsulated disconnectors and earthing switches permit risk-free isolation and earthing of any switchgear section. Release of conductor connections to establish isolating sections and the use of mobile earth rods can be avoided. The extremely effective sealing of the enclosure prevent any environmental contamination. The long service life and the minimal space requirement conserve resources and minimises the impact on environment.

![Fig. 8: 420/550kV HIS Single Pole](image)

The same principles are applied for the 420/550kV HIS which is an example for a mono phased GIS module system (Figure 8). The 420/550kV HIS is based on optimised outdoor proofed GIS modules so that the inherent advantages of this technology were kept. In comparison to GIS the investment cost are lower because no switchgear building is necessary and in comparison to AIS the need of ground area can be reduced up to 90% (e.g. for 1 ½ circuit breaker arrangement with encapsulated busbars). As for 145kV the poles are completed and routine tested in the factory. Therefore a high voltage test on site is superfluous. This keeps installation time short. Low space requirements, high reliability, low costs in maintenance are the main characteristics of this configuration. For customer’s benefit a markedly reduction of spare parts can be achieved. A second benefit is the reduced repair time: in case of emergency it is enabled that parts of the switchgear, such as the circuit breaker can be exchanged within 6 hrs. This is achieved through mobile steel supports which can be moved easily. An additional gas compartment keeps the outdoor terminations energised. The 420/550kV HIS can be used as an AIS extension module, in various arrangements, e. g. in series, in ring or in NSR (New Segregated Ring) lay out as preferred by REE.

Both types of HIS are good examples to illustrate the application of the presented principles of GIS modules as basis for NSR arrangements.
7 Conclusion

Modern Mixed Technology Switchgear (MTS) require adequate substation concepts for profiting from their extended possibilities. The application of common AIS based concepts leads to substations which are equipped with too much devices.

The NSR concepts based on fully encapsulated GIS modules as presented in this article allow decreasing the required devices without reducing the availability. A smaller amount of devices result in lower investment cost and in consequence in lower operating and failure cost. Additionally NSR provides improved maintainability by reducing the maximum outage time to only 6hrs. Extensions of existing NSR based substations are easy to realize.

These concepts require reliable and flexible GIS module devices. The HIS from Siemens as fully encapsulated switchgear is a representative for GIS modules. The compact high-voltage switchgear HIS enhance the availability and reliability in operation by benefiting from the decisive characteristics of GIS technology. Their characteristics including their flexible modular structure and the usage of pre-fabricated and pre-tested units facilitate project-planning and reduce erection & installation times.

Consequently, the design properties of an HIS system in NSR arrangement contribute to high life-cycle benefit, high operating safety, long service life and high reliability and availability of this technology.

8 References


