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**GIS STATE OF THE ART 2008**

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**WG B3.17**

# **GIS - State of the Art 2008**

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## **Synopsis**

Modern Gas Insulated Switchgear (GIS) technology has been undergoing continual development since its introduction in the 1960's when the use of SF6 as arc extinguishing and isolating medium was first introduced, and whilst many may consider this technology as mature, there have been continuous development driven changes in GIS design, manufacture, test and operation.

Some of the developments taking place are general to switchgear, some are specific to GIS technology and some general technology developments have particular implications on GIS. This brochure discusses some of the developments and trends that have occurred and that will continue to determine how GIS will evolve into the future.

SC B3 approved the scope of Task Force 04 of WG B3-02 in conjunction with WG B3-01 to identify those trends that have shaped the GIS of today and which will determine how GIS will further evolve into the 21<sup>st</sup> century. The implications of these trends in terms of GIS design, manufacture, test, operation through to end of life were all included within the scope of this work. The objective was to provide a framework of subjects that can be used to understand the evolution of GIS, and thus enable users and suppliers to optimize the future utilization of GIS, however this final document identifies more the trends that will determine the future rather than visions of what the future products might look like.

In order to identify the GIS trends for the future it is necessary to identify the current state of GIS technology as there are differences between users and indeed manufacturers in terms of normally accepted technologies. Therefore for some users this Brochure will be useful to assess their own position in relation to more recent developments offered by suppliers.

This brochure identifies the key primary market and technology drivers and the potential opportunities that these provide for the GIS solutions of the future.

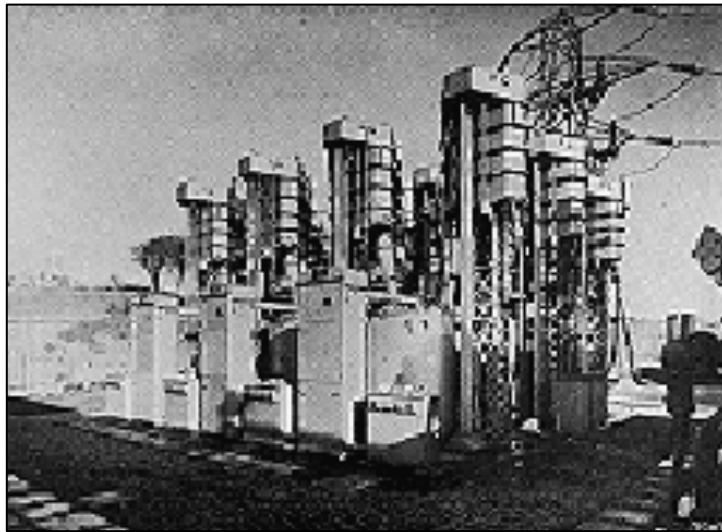
As with any work that looks to consider the future, there needs to be an associated "health warning". Whilst specific trends can be identified it is difficult to predict the impact that significant developments could have on the future direction of GIS. Looking back the most significant single development in the evolution of GIS was the adoption of SF6 as an insulating medium. It could well be that in the future the next most significant development also is dependent on the possible substitution of SF6 with alternative technologies. However as the technical substitution of SF6 with a direct equivalent is unlikely, the adoption of an alternative to SF6 will be driven by the Business and Environmental drivers that are discussed in the Brochure. It is in this area that prediction how business drivers will influence GIS evolution that opinion, guess work and uncertainty are the key issues.

# 1 Introduction

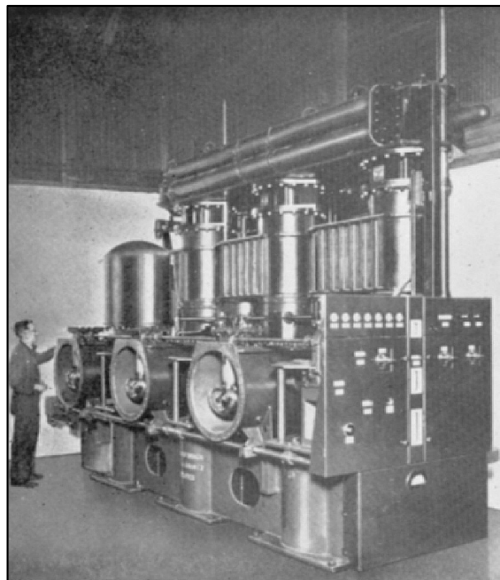
GIS using SF6 is now a well-established technology and many substations have been in service since the 1960's. The forerunners of today's GIS have their roots in the metal enclosed concept, first used at high voltage in the 1920's [1.1], using oil as the insulating medium. The first gas insulated metal enclosed switchgear used Freon as the insulating gas appeared as early as the 1930's.

With the advent of SF6, today's modern technology incorporating SF6 high-voltage gas-insulated switchgear was introduced into the market in 1968, using SF6 as the insulating and arc-quenching medium for the first time. Subsequent technological milestones include GIS switchgear installed in Canada in a 550kV substation with a 100kA rating as the highest breaking capacity ever achieved, 765kV GIS in South Africa and even more recently 1000kV GIS in Japan. Consistent research and development and innovative effort has led to the current third generation GIS technology applied nowadays, delivering compact dimensions and overall optimized switchgear.

GIS technology is typically of modular design and filled with a minimum quantity of SF6. It can have low Life Cycle Cost compared to AIS [1.2] and can be used for indoor and outdoor application.



**Figure 1.1 132kV Metalclad at Tongland (Scotland) 1926**



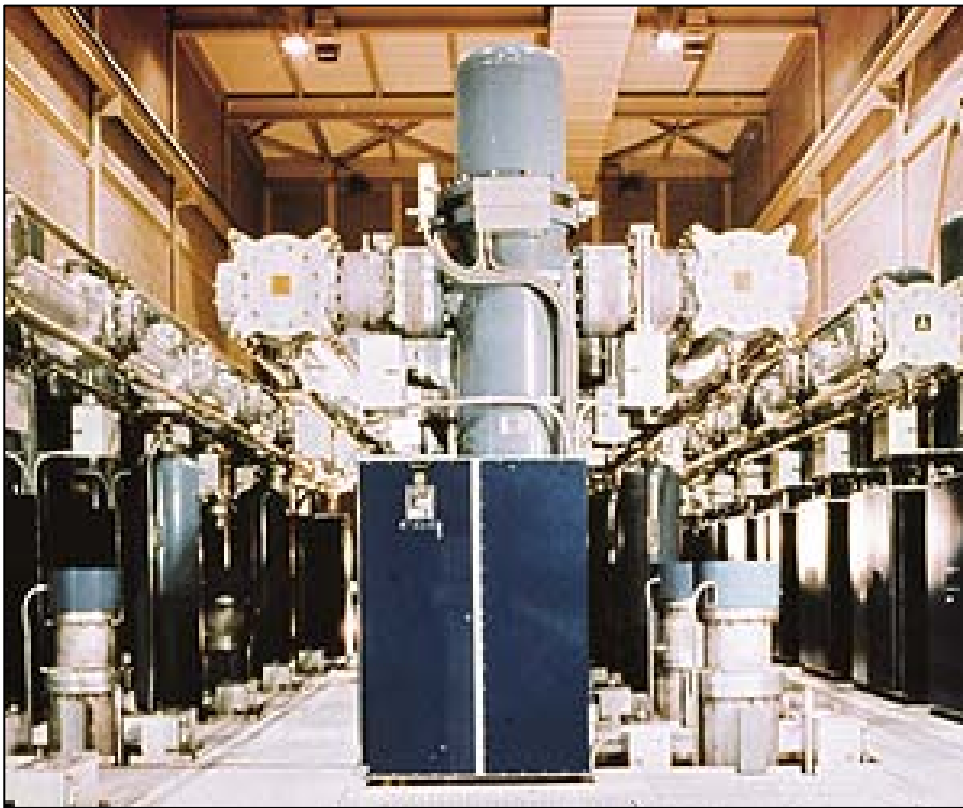
**Figure 1.2 1936 33kV GIS using Freon gas**



**Figure 1.3 145kV GIS using SF6 Sempersteig Zurich 1968 (basement)**



**Figure 1.4 145kV GIS using SF6 Sempersteig Zurich 1968 (upper level)**



**Figure 1.5 First GIS using SF<sub>6</sub> at 420kV Netherlands 1972**

Since these early examples of GIS there has been a rapid growth in the application of this technology with an estimated 80,000 bays now in service and increasing at a rate of over 6,000 bays per year.

Year	Status
1960	Start of fundamental studies in research and development of SF <sub>6</sub> technology
1964	Delivery of the first SF <sub>6</sub> single-pressure circuit-breaker
1968	Operation of first GIS delivered by major manufacturers
1974	Delivery of first GIS at 420 kV
1976	Delivery of first 550 kV GIS
1983	Delivery of the world's largest GIS for Itaipu, Brazil
1984	Delivery of 550 kV GIS for severe network conditions (rated current 8000 A, rated short circuit breaking current 100 kA,)
1986	Delivery of first 800 kV GIS
1996	Introduction of third generation ultra compact 123kV GIS
1997	Introduction of intelligent bay control, monitoring and diagnostics
1999	Introduction of third generation compact 145 kV and 245 kV GIS
2000	Introduction of new compact and hybrid solutions
2001	1000kV GIS commissioned in Japan.
	<ul style="list-style-type: none"> <li>• <b>More than 80000 bays installed worldwide</b></li> <li>• <b>More than 1,000,000 bay-years of in-service operation</b></li> </ul>

**Table 1 Milestones in the development of modern GIS technology**

The key advantages that GIS can offer of compactness, immunity from environmental conditions and reliability are well-understood and documented [1.3] [1.4] [1.5]. In today's environment where assessments of capital projects are made on a total lifetime basis then GIS can be the most cost-effective solution in comparison with AIS (Air Insulated Switchgear) or hybrid alternatives. Such Life Cycle Cost (LCC) assessments are enabling the one perceived disadvantage of GIS, namely its higher initial capital cost, to be overcome.

It is with this background that GIS technology can be expected to become the preferred choice of many users in the future. Many technological, business and environmental factors that will be discussed in the following sections of the brochure are accelerating this move toward GIS. These factors will of course influence the further development of GIS used in HV ( $\geq 52\text{kV}$ ) applications and several trends can be identified as to the characteristics the GIS of the future will have. It is this vision of the future GIS that this brochure will discuss. Perhaps not all of the ideas will be incorporated into future GIS together but the general trends will hopefully give a beneficial insight for users, specifiers and indeed manufacturers of GIS.

The common characteristic features of modern Gas Insulated Switchgear are as follows:

- Compact space-saving design with uncomplicated foundations, a wide range of options in the utilization of space and last but not least less space taken up by the switchgear.
- Minimal weight by lightweight construction through the use of aluminum housings and the exploitation of innovations in development such as computer-aided design tools to optimize shape and size
- Safe encapsulation providing an outstanding level of safety to the personnel under all operating and fault conditions based on new manufacturing methods and quality control procedures
- Environmental compatibility enables no restrictions on choice of location by means of minimum space requirement, extremely low noise emission and effective gas tightness with using sealing systems with guaranteed leakage rates less than 0.5% per year per gas compartment.
- Economical transport of several bays connected together as maximum possible shipping unit
- Minimal operating cost of practically maintenance-free equipment, designed for extremely long service life up to 50 years. This ensures that the first inspection will not be necessary until after 25 years of operation, however depending on the status of the switchgear.
- Highest reliability by a product concept which includes the most modern design tools as the use of finite element methods, three dimensional design programs, electrical field development programs and appropriate quality control measures in development and production
- Easy and efficient installation and commissioning with transport units already fully assembled and tested in the factory, pre-filled with SF<sub>6</sub> gas at reduced pressure.

A new area of GIS applications has appeared recently. New switchgear assemblies have been developed based either on AIS switchgear, GIS switchgear or on a combination of both technologies. Components of all kinds of different high voltage devices are being introduced into the high voltage market as a possible solution positioned between air insulated substations (AIS) and gas insulated substations (GIS). These solutions are often used to replace and upgrade air insulated substations in a smaller space. The evolution of deregulated energy markets is accelerating such opportunities due to the reduction of engineering and maintenance staff in the companies of power delivery. Environmental aspects, concerns due to electromagnetic fields and security of substations are additional drivers of this new technology, this will be discussed further in Section 2.3.

## References

- [1.1] Henry Clothier 1926, "Switchgear Stages"
- [1.2] "Functional Specification and Evaluation of Substations" CIGRE Technical Brochure No 252
- [1.3] H.Troger et al, CIGRE 1972, paper 23-04, "Compilation of International Experience on Installation and Operation with Metalclad Substations".
- [1.4] Kopejtkova, Molony, Kobayashi and Welch, "A Twenty-Five Year Review of Experience With GIS" CIGRE 1992 paper 23-101.
- [1.5] Kopejtkova D. at all. „Report on the 2<sup>nd</sup> international survey on high voltage gas insulated substations (GIS) service experience" CIGRE Technical Brochure No.150

## 2. Terminology of GIS Applications

### 2.1 Introduction

A significant number of new switchgear devices have been developed based either on air insulated switchgear, gas insulated switchgear or on a combination of both technologies. Components of all kinds of different high voltage devices and interconnections are being introduced into the high voltage market as a possible solution positioned between air insulated substations (AIS) and gas insulated substations (GIS). These solutions are often used to replace and upgrade air insulated substations in a smaller space. The evolution of deregulated energy markets is accelerating such opportunities due to the reduction of engineering and maintenance staff in the companies of power delivery. Environmental aspects, concerns due to electromagnetic fields and security of substations are additional drivers of this technology.

Examples of such mixed technology high voltage devices have now been in use for a number of years world-wide so that sufficient experience for standardization is available.

This section is intended to provide basic guidance for the terminology used for the implementation of switchgear technology into new and existing substation installations.

New (not yet standardized) terminology, which describes different substation technology concepts, used recently by utilities as well as by manufacturers in different ways can create possible confusion, concerning GIS, AIS and Hybrid Substations.

This brochure is focused on GIS equipment as defined hereafter but many of the trends and technologies discussed apply to hybrid devices as defined here, therefore it is useful to introduce and define both the GIS and Hybrid concepts.

### 2.2 Basic terminology

The definitions used in this brochure are based on terms of IEC 60050, if applicable, based on relevant IEC product standards, sometimes amended according to the relevance of this brochure.

#### 2.2.1 Switchgear:

A general term covering switching devices and their combination with associated control, measuring, protective and regulating equipment, also assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures, intended in principle for use in connection with generation, transmission, distribution and conversion of electric energy.

#### 2.2.2 Controlgear:

A general term covering switching devices and their combination with associated control, measuring, protective and regulating equipment, also assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures, intended in principle for the control of electric energy consuming equipment.

#### 2.2.3 Substation (of a power system) – IEC 60050-605

The part of a power system, concentrated in a given place, including mainly the terminations of transmission and distribution lines, switchgear and housing, which may also include transformers. It generally includes facilities necessary for system security and control (e.g. the protective devices).

Note. - According to the nature of the system within which the substation is included, a prefix may qualify it.

Examples: transmission substation (of a transmission system),  
distribution substation, 400kV substation, 20kV substation

Additional remarks:

Switchgear and controlgear at one voltage level is typically consisting of one or more bays.

Note: - The expression „substation“ in both AIS and GIS abbreviations is strictly speaking not correct but is commonly used slang.

#### **2.2.4 Bay (of a substation):**

(if a circuit breaker is installed in a bay then CB-bay)

The part of a substation within which the switchgear and controlgear relating to a given circuit is contained. Typically a three phase assembly consisting of one or more switchgear components at the same voltage level.

Note: - According to the type of circuit, a substation may include: feeder bays, transformer bays, bus coupler bays, etc.

#### **2.2.5 Switchgear component (bay component) (paraphrasing IEC 62271-203):**

A component is a part of a device which cannot be physically divided into smaller parts without losing its particular function. A switchgear component is any part of the main or earthing circuits of a switchgear which serves a specific function (for example circuit-breaker, disconnector, load switch, earthing switch, instrument transformer, bushing, busbar, bus duct, busbar, interconnecting conductors, post insulators, surge arrester, connection to line, transformer or cable, etc.)

#### **2.2.6 Switchgear component enclosure (paraphrasing IEC 62271-203)**

Part of a switchgear component retaining the insulating gas under the prescribed conditions necessary to maintain safely the rated insulation level and protecting the equipment against external influences.

#### **2.2.7 Gas-insulated switchgear enclosure (IEC 60517, 3.103):**

Part of gas-insulated metal-enclosed switchgear, retaining the insulating gas under the prescribed conditions necessary to maintain safely the rated insulation level, protecting the equipment against external influences and providing a high degree of protection to personnel. The enclosure can be single-phase or three-phase.

#### **2.2.8 Metal-enclosed switchgear and controlgear (IEC 60517, 3.101)**

Switchgear and controlgear assemblies with an external metal enclosure intended to be earthed, and complete except for external connections [IEV 441-12-04]

#### **2.2.9 Open-type substation (IEV dictionary chapter 605)**

A substation in which the insulation to earth and between phase conductors is mainly provided by air at atmospheric pressure and in which some live parts are not enclosed.

#### **2.2.10 External insulation (IEC 60694, 3.1.2) :**

The distances in atmosphere and the surfaces in contact with open air or solid insulation of the equipment, which are subjected to dielectric stresses and to the effects of atmospheric and other external conditions such as pollution, humidity, vermin, etc. Note: This definition corresponds to the commonly used "air insulation".

#### **2.2.11 Gas-insulated metal-enclosed switchgear (IEC 62271-203, 3.102)**

Metal-enclosed switchgear in which the insulation is obtained, at least partly, by an insulating gas other than air at atmospheric pressure.

Note 1: - This term generally applies to high voltage switchgear and controlgear

Note 2: - This gas is usually SF6 or SF6 mixtures.

### **2.3 Definitions**

The definition of a type of substations can be made according to two different aspects:

- insulation technology, which leads to the type of a AIS, GIS or Hybrid substations,
- or design features, which leads to the type of compact or combined bays or substations.

#### **2.3.1 AIS, GIS and Hybrid definitions**

**Substation (switchgear) – bay – component**

**The components are evaluated from their insulation and enclosure design point of views.**

Components, in this respect, can be either of gas-insulated metal enclosed switchgear technology design or of open-type substations with external insulation switchgear technology design.

The following abbreviations are introduced to simplify the text in definitions mentioned in chapter 2.2:

**GIS technology** - for gas-insulated metal enclosed switchgear components and their interconnections technology designs

**AIS technology**– for open-type substations with external insulation switchgear components and their interconnections technology designs

The principle technology designs for substations (their components and their interconnections) are as follows:

Technology design	Insulation	Insulating medium	Enclosure
AIS technology	external insulation	Air, SF6	live porcelain or composite insulators or no enclosure
GIS technology	gas insulation	SF6 or SF6 mixtures	metal enclosure effectively earthed
Hybrid technology	mixed insulation	SF6 or SF6 mixtures and Air	combination of all

Various layouts can be used for optimizing the operation, the space and the life cycle cost using AIS or GIS components and interconnections technologies or their mixtures. These layouts define **AIS, GIS and Hybrid**. All of them can be located outdoors or indoors.

**AIS (Air Insulated Switchgear) substation**

A substation of which the bays are fully made from AIS technology components and their interconnections.

Note:

Substations, where only dead tank type of circuit breakers are installed in its bays, are considered to be AIS substation. This is partly because of tradition and because the main insulation of dead tank breaker is external.

**GIS (Gas Insulated Switchgear) substation**

A substation of which the bays are fully made from GIS technology components and interconnections. Only external HV connections to overhead or cable lines or to transformers, reactors and capacitors can have an external insulation.

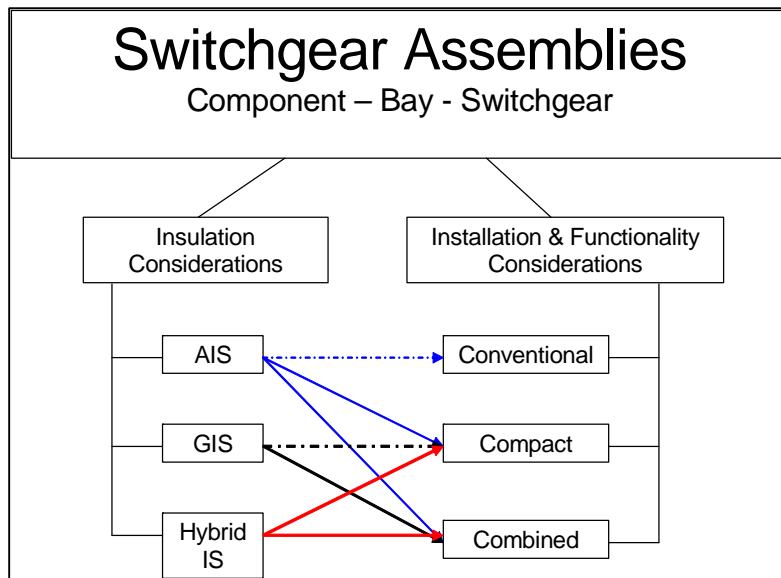
**Hybrid substation**

A substation of which the bays are made from a mix of GIS and AIS technology components and interconnections, i.e. a substation that consists of bays where some of the bays are made of AIS technology components only and some of bays are made of a mix of AIS and GIS technology components or some of bays are made of GIS technology components and their interconnections only are considered as Hybrid substations. In general: Elements of AIS and GIS technology are typically mixed.

There are two exceptions from this rule:

- If the only one component in AIS technology is the HV connection (bushing, box) to overhead line, cable or transformer the substation is considered as GIS substation.
- AIS where only one component is in GIS technology or where additional elements have a mixture of Air and Gas insulation but the primary insulation to earth is still air (as in dead tank) are still considered as AIS.

Any other combinations are considered as Hybrid substations (e.g. where only bus bars are SF6 insulated, or where an enclosed gas insulated circuit breaker contains additional equipment as instrument transformers, or earthing switches)



**Figure 2.3.1 Categories of Switchgear Assemblies**

**Component – Bay – Substation (switchgear)**

In contrary to the definitions above there are no definitions directly or for paraphrasing available in IEC to be used in this section.

**Components and their interconnections are evaluated from their functionality point of views.**

Components and their interconnections in this respect can be:

- either individually installed or installed in combination, i.e. installed in a compact form (placed in group sharing a common support construction and cannot be installed (placed) individually)
- either single-function or multi-function

Examples for multifunction components:

- disconnector-earthing switch in which its function depends on a position of one common main contact
- circuit breaker- disconnector switch – in which the main contact open position meets all requirements for the disconnector isolating function

**Introduced are the following definitions**

**Compact components** – for combined switchgear components

**Combined component** – for multi-function switchgear components

**Compact bays** - for bays containing at least one compact components group i.e. in which at least some components in a bay share common support structure and cannot be placed individually.

**Combined bays** – for bays containing at least one combined component

Various functionalities can be used for optimising the operation, the space and the life cycle cost using AIS, GIS or their combination components technologies. These functionalities of components define compact and combined substations.

**Compact substation**

A substation in which at least one or more bays are made from compact bays, i.e. in which at least some components share common support structure and cannot be placed individually.

**Combined substation**

A substation, of which the bays include at least one combined bay.

**Compact/combined substation**

A substation, of which the bays include at least one group of compact components and at least one combined component.



**Figure 2.1 Example of Mixed Technology Substation at 550kV**

**Mixtures of different kind of bays:**

- A substation that consists of bays where some of the bays are compact and some of them are not is considered as compact substation..
- A substation that consists of bays where some of the bays are combined and some of them are not is considered as combined substation..
- A substation that consists of bays where some of the bays are compact/combined and some of them are not is considered as compact/combined substation.

From these definitions it is evident that:

- All GIS and Hybrid IS substations always meet the characteristics of compact substations and can vary between combined or non-combined.
- AIS substations can vary between :
  - conventional = non-compact + non-combined components in bays
  - compact = compact + non-combined components in bays
  - combined = non-compact + combined components in bays
  - compact/combine = compact + combine components in bays
- **AIS substation:** all elements have air insulation, all functions are realised by individually placed apparatus
  - Compact: AIS substation where the apparatus in a bay share common support structures and can not be placed individually
  - Combined: AIS substations where apparatus share functionalities (e.g.: Circuit breaker and disconnector)
- **GIS substation:** all elements have metal enclosed and grounded enclosures except the connection to overhead lines or cables

Hybrid substation: mixed elements of AIS and GIS technology. Busbar is air insulated. Can vary between "GIS"combined solutions (apparatus share functionalities and gas compartments) and "GIS"compact solutions where all apparatus in a bay share common support structures or enclosures and can not be placed individually.

## References

- [2.1] IEC 60050 (1982) International Electrotechnical Vocabulary (IEV)
- [2.2] IEC 62271-203 (2004) High Voltage Switchgear and Controlgear – Gas Insulated metal-enclosed switchgear for rated voltages above 52kV.
- [2.3] IEC 60694 (1997) Common Specifications for high voltage switchgear and controlgear standards

### **3. Environment, Business and Technology Drivers**

A number of primary environment, business and technology drivers have provided opportunities and threats for the evolution of GIS. The development of electrical power markets is driven by increasing power demand, environmental constraints and new market conditions. Furthermore due to the strong competition advanced solutions will be required such as the use of power electronics and new technologies for switchgear.

The growing demands of customers can be summarized as follows:

- Minimum life cycle costs: Incorporating Investment, Operation and Maintenance
- High availability power systems
- High flexibility of solutions
- Compact solutions for existing areas
- Move towards competent system-providers instead of product-suppliers and the need for innovative solutions.

Substations are an important asset of the electrical power industry. Due to the fundamental changes of the structure of this industry in recent years, new developments can be seen. The deregulation of utilities puts a focus on the management of substations. In addition to asset management topics, all questions which have an impact from the development until the end of life of a substation, are relevant and discussed in this Section.

Some of the items that have determined the development GIS will now be discussed:

#### **3.1 Technology Drivers**

##### **3.1.1 Blurring of traditional technology boundaries**

The introduction of co-ordinated control techniques based on distributed system architecture and the rapidly increasing range of digital relays has permitted considerable simplification of control and protection schemes with increased flexibility.

Whilst the systems currently available “co-ordinate” the control and protection functions in the substation a greater degree of integration can be confidently expected to develop and the traditional separation of control, protection and monitoring function will disappear.

For example, the fault and other system data stored in modern digital protection relays will automatically be downloaded to the Station Management System processors to assist in analysis, post fault restoration etc. Relay based procedures such as synchronising, auto-reclosing, auto switching and the like will be more economically performed by the control function. Overall Station Management Systems will automatically reset relays, post operation, and re-configure the protection following automatic or manual switching operations.

In the substation the use of parallel conventional wiring will be dramatically reduced as digitally based control and protection systems are introduced utilising serial fibre optic connections. This change will lead to a dramatic reduction in the time spent during installation of conventional multi-cores on a GIS substation [3.1.1]

One item that will have to be evaluated carefully is the reliability in total system including HV component on primary circuit and secondary equipment. Since reliability of HV equipment has already been very high, reliability of secondary system should be the same level. From this viewpoint, integration of secondary system into primary component should be examined carefully and the position where microprocessor based equipment optimised.

Integration of secondary system into primary equipment has much possibility that leads GIS to become more compact and intelligent [3.1.2].

In the meantime, the puffer principle interrupter has been continuously used for HV Power Circuit Breakers during the past few decades and application of Power Electronics devices may be foreseen in the near future. Application of super-conducting technology to substation equipment is also predicted by some.

At any rate, new technology will be incorporated and most modern equipment will be realized to meet the substation and system requirement.

### 3.1.2 Implications of Transmission Systems Technology

Today's transmission systems are based on well running, mature technologies like AC currents and voltages; 50Hz and 60Hz frequencies, well established voltage levels, and sophisticated control and protection schemes. It is not expected that this basic architecture will fundamentally change in the near future. Nevertheless some ongoing developments may influence the evolution of GIS technology:

Circuit breakers:

- Fault current limiters based on super conducting or semi-conducting technologies may come up in the second half of this current decade. This could lead to a reduced number of breakers and reduced short circuit currents to clear. The consequences would be simpler breaker and simpler single line diagrams and finally lower costs. This would be valid also for AIS technology.
- Solid state breakers based on semi-conducting technologies would be easier to realise in GIS than in AIS: insulation, control via glass fibre cables... use of well controllable GIS disconnectors. Because of the elimination of mechanical drives and a much simpler geometry the GIS could be engineered in a much simpler and cost-effective way if these technologies were available.

Super-conducting cables

- Transmission systems based on this technology could be based on much lower voltages and probably replace the whole EHV systems. Ultimately it could lead to DC systems instead of AC. In this case GIS could be the right technology for substations: completely covered, no pollution and high current carrying capability.

Control and protection

- Highly sophisticated systems together with well placed surge arresting functions, perhaps even within conventional GIS spacer insulators, would reduce the dielectric stress in service and consequently allow to reduce the dielectric safety margin. The result would be lower BIL levels in the systems and lower GIS costs.

#### **Conclusions**

One clear trend is the incorporation of devices and technologies into integrated units within the GIS substation environment. Due to the inherent "integrated" nature of GIS this trend is to be expected but is nevertheless accelerating, particularly in the area of integration between primary and secondary technologies.

The integration of electronic/digital control into the primary components also includes the transfer of data and information by optical serial links. Perhaps the most significant changes in the way that utilities operate GIS substations will arise from the combination of the traditionally separated control and protection systems.

Independent from the technological development some main functions of a GIS will remain: current carrying, disconnecting of connections and grounding of sections. Based on the inherent advantages of a GIS (small size, safe due to encapsulation and independent from atmospheric stresses) GIS is likely to remain the preferred solution for most transmission systems applications independent of the future technologies that will impact on the transmission systems of the future.

#### **References**

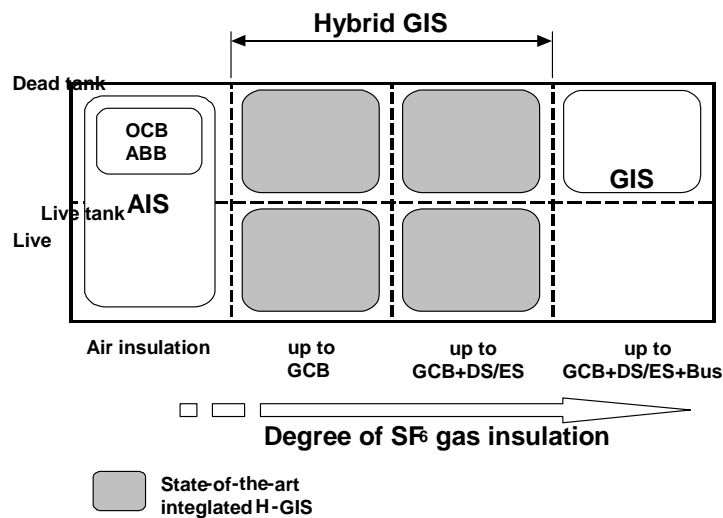
- [3.1.1] Pokarier, et al. 'First new integrated switchgear substation in service' CIGRE 2000 Session Paper 23-104
- [3.1.2] Bartlett, et al. 'Highly integrated switchgear – an innovative concept to reduce life cycle costs' CIGRE 2000 Session Paper 23-108

## 3.2 Business Drivers

### 3.2.1 Cost

In the future the need to reduce initial capital cost will continue to be critical, however increasingly Life Cycle Cost (LCC) evaluations will be used to assess the most appropriate solution for a particular system requirement. Whilst there can be no single methodology which can be applied to suit all circumstances, the following section describes some of the main factors which must be taken into account when performing a LCC assessment:

In recent years the cost difference between GIS and alternatives has become reduced. In addition, hybrid solutions are more often being proposed and becoming adopted. A Hybrid substation consists of bays where some of the bays are made of AIS technology components only and some of bays are made of a mix of AIS and GIS technology components or some of bays are made of GIS technology components only are considered as Hybrid substations. In general: Elements of AIS and GIS technology are typically mixed.



**Figure 3.2.1 Placement of Hybrid Equipment Between AIS and GIS Equipment**

The first Hybrid type 550kV GIS was put into operation at the beginning of 1980's in Japan. Since line side equipment such as disconnecting switches (DS), Voltage Transformer (PT) for voltage measurement and Surge Arrester (SA) are integrated together with circuit breakers (CB), the space for switchgear becomes approximately 30% less than for comparable dead tank type gas circuit breaker applications. As a result, there are reduced construction costs including that of civil portion. Grounding system and maintenance costs are reduced, additionally the outage time for maintenance purposes is reduced. In case of hybrid type GIS, the space required except for main busbars and busbar side DS becomes smaller. Application of full GIS can make the space required even smaller and the trend towards Hybrid and then to full GIS can be expected to increase. First Hybrid type 550kV GIS [3.2.1.1] has been operated satisfactorily since first installation with no major faults reported, thus supporting confidence in the application of this technology.

When Full GIS or Hybrid GIS is selected, LCC (Life cycle cost) consisting of initial cost for primary hardware, maintenance cost, operation cost, and outage cost, is normally taken into consideration. Initial cost consists of equipment cost, land cost and construction cost, commissioning cost and so on, for example. Typical example of cost comparison reported several times in CIGRE 2000 session [3.2.1.2], [3.2.1.3].

Life Cycle Cost (LCC) consists of the following items.

GIS Primary Hardware (Acquisition cost):

When comparing the equivalent primary HV components, GIS is more expensive than AIS. However, if the prices of the gantries, supports, conductors and earthing system for AIS substation are included in the comparison, the difference between GIS and AIS can be significantly reduced, because they are already included in the GIS system. Comparison including the cost of installation, land, building etc as well as the cost of secondary control, protection and monitoring equipment is also very important, and can lead to more cost attractive solutions for GIS in some circumstances [3.2.1.4].

Maintenance (Ownership cost):

In comparison of the failure rate, GIS has better features than AIS. In general, failure rate of GIS component such as circuit breaker (CB), disconnecting switch (DS) and Voltage transformer (VT) are one fourth (1/4) of that of AIS, especially one tenth (1/10) in case of Busbar. These figure show that GIS needs less repair maintenance cost throughout its lifetime. The cost of preventive maintenance and predictive maintenance shall be reduced as well, because of less possibility of failure.

Operation cost (Ownership cost):

Operating cost except the maintenance cost of GIS and AIS shall be equivalent. However, cost for training, spare holding for GIS may be higher, if GIS installation is newly applied.

Outage cost (Ownership cost):

As described in the above, failure rate of GIS components is lower that those of AIS and therefore, outage cost of AIS, including the possible loss of revenue by the outage shall be bigger.

However, it should be noted that outage time of GIS can be longer than that of AIS, in case of failure.

Disposal Costs

Cost of decommissioning and disposal after use and after subtracting earnings which can be received by selling the reusable materials like aluminum, copper etc. These costs have to be capitalized.

Life cycle cost for HV substations is calculated for a very long period of time, we assumed about 30 to 50 years dependent on the type of substation. So changes in the value of the money have to be respected. The calculation can apply the method of discounted cash flow in order to determine the net present value. In addition to the discounting of the value of future expenses the effects of inflation can be taken into account.

The basis of any life cycle cost evaluation is to select an appropriate cost break down structure, such as

$$LCC = Cost_{acquis.} + Cost_{ownership} + Cost_{disposal}$$

The cost breakdown structure is based on the recommendations of IEC 60300-3-3 [3.2.1.5] which is proposing a generic cost breakdown structure for high voltage applications.

**Conclusion**

Life Cycle Costing will play an increasingly important role in the evaluation of future substation projects. More extensive evaluations of Life Cycle costs will include not just the GIS hardware but also land, construction costs, maintenance, outage and even end of life decommissioning costs. How these costs are evaluated will vary from utility to utility and also by application but will nevertheless become part of the evaluation criteria.

- [3.2.1.1] Meguro, 'Application of Hybrid Gas Insulated Switchgear (GIS) for 550kV System', Contribution CIGRE 2000 SC23
- [3.2.1.2] Shimato, T et al "Evaluation of Total Life Cycle Cost of GIS Substation and Development of Portable Diagnosis Devices" CIGRE 2000 Session Paper 23-107
- [3.2.1.3] Bartlett, S et al. 'Highly integrated switchgear – an innovative concept to reduce life cycle costs' CIGRE 2000 Session Paper 23-108

- [3.2.1.4] Weltmann, 'GIS versus Non-GIS – a Value Based Comparison', Ninth International Symposium on Gaseous Dielectrics, 2001
- [3.2.1.5] IEC 60300-3-3 Dependability Management Part 3-3 Application Guide – Life Cycle Costing Second Edition 2004-07

### 3.2.2 Effects of Utility Privatisation

The climate of change in the 1990's encouraged the spread of privatization of public utilities in many parts of the world causing similar effects to those first experienced in the United Kingdom. One effect of privatization has been an emergence of Supply Industries with much greater commercial awareness as compared with the older Public Utilities that tended to be engineering driven. As well as the impact this has had on utility organizations, with significant reductions in engineering manpower, there is a growing demand to drive equipment and systems harder to ensure that maximum return is achieved on the assets.

The role and involvement of the Electricity Regulator in the new environment is critically important whereby investment decisions need to be even more focused on delivering end customer benefit.

These changes create significant challenges for transmission networks around the world:

- Reduction of planning time scales

The time available for planning of new connections is often severely constrained due to commercial confidentiality (clients are unwilling to disclose their plans in advance) and regulatory conditions imposing strict deadlines on Utilities to make connection offers. This severely limits the time available for assessment of potential sites and for discussion of planning/consent issues with the relevant authorities. Consequently, there are benefits in adopting GIS substation designs that simplify site selection (since the land area required is limited) and are less likely to encounter planning objections.

- Reduction of design and manufacture lead times

When making new connections to the network, Utilities are often under pressure from clients to minimize the time from agreeing the commercial terms of the connection to completion of the project. There are consequent benefits in having modularization/standard solutions.

- Reduction of Life Cycle Costs

There is an increasing emphasis in privatized Utilities on outsourcing of core functions. Costs of ownership throughout the equipment life cycle are thus more easily identifiable and are of greater significance in making purchasing decisions.

- GIS suited to user requirements

There is an increasing emphasis on purchase of 'standard' equipment rather than designs tailored to the requirements of specific users. Manufacturers must therefore ensure that these designs incorporate the core functionality required by Utilities, either as a standard feature or user-specifiable options

### **Conclusion**

- The economic view is becoming more and more the major selection criteria for the user
- Reduced lead times are required in planning, design, manufacturing and commissioning
- Utilities are moving towards increased outsourcing to specialised companies for design, maintenance, recycling and other services, many of which would have been considered as core within previous organisations
- The above changes are influencing the way that GIS is perceived by the user and also driving the GIS suppliers to exploit and develop certain features of the technology that reflect the needs of these "new" customer organisations.

### 3.2.3 Globalisation of markets and harmonisation of standards

The historic situation was that each user of GIS prepared its own GIS specifications based on its own company standards and interpretation of National/International standards. This resulted in a wide

variety of approaches and possible areas for confusion between users and suppliers of GIS (particularly for the first relationships between the parties).

The whole electric industry faces now dramatic changes that influence the GIS application and technology which have immediate impacts. As far as the standards are concerned, the most important issues are:

### **Utilities**

There is a tendency towards bigger user organisation by the acquisition of companies or mergers between them. This happens not only within the borders of countries, but globally acting transmission companies are becoming more and more common. The consequences are that not only the commercial but also the technical departments can merge. This leads inside such organisations to a more and more streamlined technical philosophy and ultimately to common company standards and common specifications where only basic national standards (e.g. safety) will be considered. In addition, utilities tend to outsource technical specifications to specialised consultants. Via such international acting consulting companies also national and company standards will be brought closer together, step by step.

### **Manufacturer**

A similar movement happens on the manufacturer's side. At least in the case of GIS only a few global acting manufacturers are becoming present on the market, most probably less than half those that existed compared to the recent past. As on the user side also here technical solutions and philosophies will be streamlined. GIS is a complicated technology especially if it comes to very large and complex substations. This has led to sometimes very close relations between companies and users with standards relying directly to specific technical solutions of the preferred manufacturer. Many of those connections will disappear in the future.

### **Commercial aspects**

It can be stated that the pressure on the economic result of both manufacturer and utilities has increased in the recent years and will continue. On the other hand GIS has been a "high end" technical product in the substation world, mainly technicians were involved in development, engineering and negotiations. Technical and quality aspects have been dominating aspects and some times even overruled economic arguments. Nowadays utilities and manufacturers check carefully the value of special requirements whether such specifications in addition to international standards improve their overall profitability.

The above mentioned trends and a sometimes rapid change of ownership of utilities and manufacturers can influence the close relationships between manufacturer and users. Therefore we see a clear tendency away from company or country related standards and specifications to international fixed requirements: one standard for one technology, but adaptation for different applications. This position relies on considerable effort by utilities and suppliers to ensure a complete communication of requirements is achieved

The international Standards like IEC and ANSI will become more and more important as a basis for well established technical descriptions and requirements; it is believed that they will be for many countries the only basis for national requirements. Unfortunately IEC and ANSI are different standards for the same products and the same applications, but there are now international technical working groups established to consider the harmonisation of switchgear standards, and in particular between IEC and ANSI. It is hoped that this work will proceed rapidly to ensure easier applicability of equipment in all world markets whilst at the same time safeguarding the particular requirements for safety of the system and operators of individual utilities. Parallel to that CIGRE and IEC began to streamline the standards for the interfaces between GIS and surrounding apparatus like transformers, bushings, cables, control and protection.

There is scope for a standardised user specification to be developed which could allow considerable improvement to be achieved in the effectiveness of the client/customer interface and tender preparation/evaluation. Such an activity is likely to be undertaken by a CIGRE working group in the near future.

### **Conclusion**

The international Standards like IEC and ANSI will become more and more important as a basis for well established technical descriptions and requirements; it is believed that they will be for many countries the only basis for national requirements.

### **3.2.4 Quality and availability of electricity supplies**

Availability of electricity supplies is becoming even more important than in the past. Blackouts which have occurred on a global basis have reinforced the importance to modern society of reliable and dependable power supplies. This trend is expected to continue as the demand for electricity grows and society becomes more and more dependent on the quality as well as availability of supplies. The de-regulation of markets where in many cases generation is separated from transmission and distribution increases the demand for network and equipment reliability.

Methods to improve Quality and availability are important for all utilities and they continually strive for internal operational improvements as well as possible technical solutions to improve quality and reliability performance. This trend is guaranteed to continue.

Fortunately one of the main “selling features” of GIS is a higher reliability compared to conventional solutions, mainly due to the enclosed nature of the GIS equipment and immunity from environmental and other external effects. These features deliver improved reliability which can either result in improved substation and network availability or substation simplification and resulting economic benefits. The choice of benefit is to some extent the choice of the user and whilst in most cases today it is reliability which is chosen, this may not always be the decision. What we can expect are more rigorous procedures in order to evaluate the commercial impact of the cost versus reliability trade off.

GIS technology can, and must, contribute to this by means of ever increasing equipment reliability reduced maintenance requirements and subsequent increased availability. Commercial arrangements between GIS suppliers and utilities to guarantee levels of availability and performance can be expected. With mutual benefits for improved performance and penalties for poor performance.

As previously indicated the elimination of the influence of atmospheric factors is important for GIS, however this also means that any repair time subsequent to some equipment problem can be significantly increased compared to conventional AIS technology. Therefore GIS designs which are modular and facilitate easy repair and replacement could be a strong element of the GIS of the future.

The actual quality of the electricity supply, as opposed to availability, is not a specific issue for GIS and GIS technology by itself does not influence quality issues.

#### **Conclusion**

- Availability is today an important issue and together with equipment reliability and definition of the single line diagram (see 4.16) to deliver the specified performance.
- GIS inherently has a higher reliability and lower failure rate compared to alternative technologies which should increase its application.
- Life Cycle Cost evaluation is required in order to ensure that the appropriate balance is achieved for availability taking into account the different contributions that factors such as single line arrangement can have.

### **3.2.5 Safety and Security Issues**

Whilst undoubtedly substation security has always been important it is believed that it will be even more important in the future. The importance of a secure and uninterrupted electricity supply continues to increase, and outages and failures due to insufficient substation security become less and less acceptable for customers.

Regardless of cause, utilities can be held responsible of damages and injuries to third parties.

Substation security is important to:

- maintain the availability of the power supply
- prevent public access to the plants, for the purpose of safety for general public, prevention of vandalism and inquisitive intruders
- protect other parts and components in a substation against violent deterioration of high voltage equipment caused by failures
- prevent and minimise the risk of sabotage and acts of war
- prevent financial risk due to occurrences mentioned above

All utilities must define their potential risks regarding substation security and from this implement sufficient measures. In addition to this, national authorities may define and set rules for minimum

protection levels for substations based on their importance. In the future more emphasis will be placed on the importance of these factors.

Protection measures to obtain an adequate security level include:

Protection against intruders.

- Outdoor substations: Fence design (height, shape, minimum clearance to ground, mechanical strength, reduction of height due to snow depth)
- Indoor substations: Building design (windows, doors, access control), access control (keys, locks, access control systems, camera supervision)

Protect other parts and components in a substation against violent deterioration of high voltage equipment caused by failures.

- Outdoor parts: Fence design (mechanical strength), passive protection of important components by concrete structures (bushings, surge arresters, instrument transformers).
- Indoor substations: Building design (quality of building materials (concrete), wall thickness)

Protection against sabotage and acts of war:

- Outdoor parts: Fence design, passive protection of important components by concrete structures (bushings, surge arresters, instrument transformers).
- Indoor substations: Building design (quality of building materials (concrete), wall thickness, EMP- issues)

GIS is inherently well placed to meet these demands and considerations in an excellent way, due to:

- Small space requirements are needed. The substation will be easier to protect, the more integrated nature of the substation also enhances the protection provided.
- The enclosure will give protection against access to live parts, this can prevent the ability to perform vandalism or accidental contact with live parts
- GIS are often located indoor which will give additional security compared to outdoor substations

Examples of how GIS delivers these requirements are presented in Chapter 4.6.

### **Conclusion**

Indoor GIS is inherently better protected from external effects and potential attack. With the increasing security issue GIS is expected to be used increasingly, particularly in densely populated areas.

### **3.2.6 System Fault and Normal Current Ratings**

#### **Network development:**

Generally there seems to be a slight trend for increasing fault levels and normal current ratings as specified on current GIS projects. This is partly due to the necessary demands on network design and also the fact that users are usually considering the future development of their network when defining the ratings of GIS projects. As the life expectancy of GIS is today at least 40 years considering normal use the envisaged development of networks may alter during the lifetime of the GIS and may exceed the originally expected and specified values. Upgrading of the equipment is one possibility to comply with new network conditions. An alternative approach may be to use fault limiting devices to keep system conditions within the performance limits of existing equipment. Nevertheless in the short term simply specifying the next standard short circuit current value resolves any doubts, however there is obviously a cost penalty for the unnecessary specification of high ratings.

How GIS as a technology can respond to the challenge of generally increasing fault and normal current requirements are discussed in Section 4.9.

### **Conclusion**

There is no particular impact of system fault and normal current ratings on the future development of GIS.

### **3.3 Environmental Drivers**

During the last few decades, man has become increasingly aware of the potential disadvantages, as well as the advantages of any aspect of technology. GIS is clearly no different to any other technology in this respect. Consequently the environmental advantages and disadvantages of GIS have to be evaluated to ensure that the overall best environmental solutions are developed for the future. This section talks about the specific environmental issues that have to be evaluated when considering GIS. Fortunately after such evaluations GIS can generally be shown to be of significant environmental benefit.

In recent years, global climate change, especially the threat of global warming of the surface of the earth, has been focused and the effects of green house gases such as SF<sub>6</sub> have been argued [3.3.1]. After COP3 in Kyoto in 1997, every effort to reduce the emission reduction of SF<sub>6</sub> into the atmosphere is being taken in the various industries using SF<sub>6</sub>, especially in the power industry, and the development of gas insulated equipment using less SF<sub>6</sub> gas including the potential for SF<sub>6</sub> gas mixtures are being conducted.

GIS provides some inherent benefits when compared to conventional AIS with regard to generation of EMF and susceptibility to EMC.

Similarly substations need to be blended into the environment to become as unobtrusive as possible from a visual, noise and electromagnetic field point of view.

#### **3.3.1 Advantages of GIS technology**

In response to the increase in electricity demand, substation equipment is required to be more reliable and compact coping with higher voltage and larger capacity ratings. By application of sulphur hexafluoride (SF<sub>6</sub>) to substation equipment like circuit breakers and switchgear, size reduction and less maintenance cost can be achieved to greater degrees compared to conventional air-insulated substation by virtue of the excellent performance of SF<sub>6</sub> gas. Therefore, Gas insulated equipment like gas circuit breakers (GCB), gas insulated switchgear (GIS) and gas insulated transformer (GIT) are being widely and commonly applied. Particularly in the locations where the land acquisition is extremely difficult, ambient conditions are severe and highly populated; there is a large demand for GIS. Since SF<sub>6</sub> is non flammable it has also been used to replace oil as an insulating medium in transformers. Gas insulated transformers can be applied in applications where the fire risk must be strictly controlled, such as in a substation installed beneath or within a public building.

#### **3.3.2 Awareness after COP3 in Kyoto in 1997**

Even before SF<sub>6</sub> gas was identified as a greenhouse gas at COP3 in Kyoto in 1997, electric power companies and equipment manufacturers have been jointly and independently studying countermeasures for limiting the emission of SF<sub>6</sub> into the atmosphere. Development of gas insulated equipment with less SF<sub>6</sub> gas including SF<sub>6</sub> gas mixture is being conducted. Since the alternative gas has not been found yet in spite of great efforts in the concerned fields, SF<sub>6</sub> has to be used and handled with special attention. Therefore, consideration should be taken to keep the SF<sub>6</sub> emission to a minimum so that we can make the best use of gas-insulated equipment.

#### **3.3.3 Emission from modern gas insulated equipment**

With the purpose of controlling emissions of SF<sub>6</sub>, joint activities have been conducted in many countries. The studies show that SF<sub>6</sub> emission from modern gas insulated equipment with up to date technology is less than 1% per year (experimentally 0.5%/year) and that most of emissions are from improper gas handling. In this sense, improvement relating to sealing performance does not have a priority.

#### **3.3.4 Other environmental issues**

In addition, high voltage substations tend to be constructed in populated areas, or visually sensitive areas and as a result, visual impact against the landscape and destruction of nature increasingly become one of the public issues. Furthermore, the risk of childhood leukaemia [3.3.2] due presumably to the effect of magnetic field strength and/or electric field strength from power transmission lines is also being surveyed and discussed. GIS benefits from low levels of magnetic field strength meeting guidelines on human exposure levels.

These situations provide challenges to reduce the environmental impact of overhead lines by reducing line and tower profile, extending the rating of existing circuits or perhaps replacing them altogether with low impact buried solutions such as cable or gas insulated lines. This tendency may affect the features of gas insulated equipment in 21<sup>st</sup> century.



**Figure 3.3.1 Gas Insulated Trunking in Tunnel**



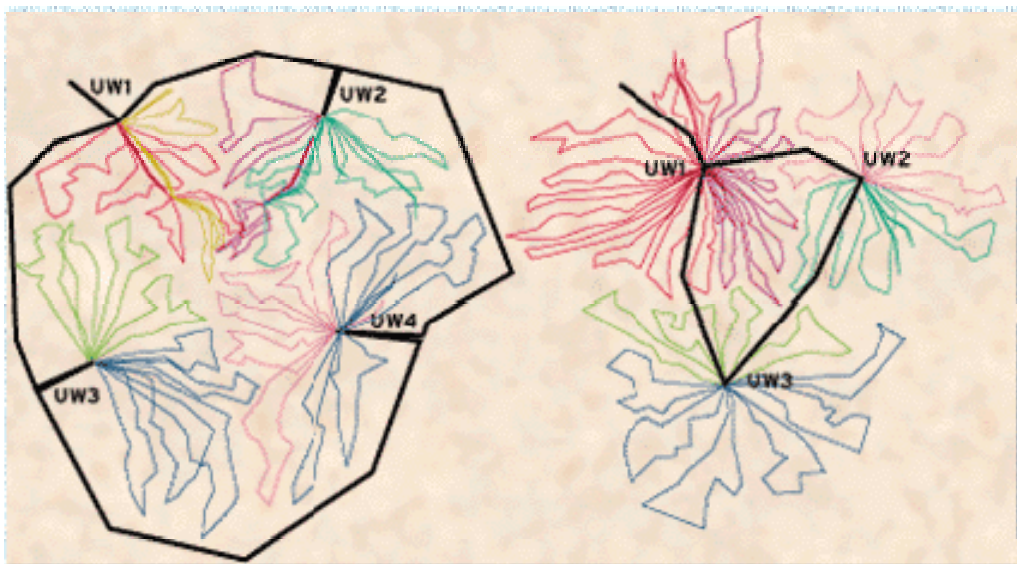
**Figure 3.3.2 Gas Insulated Line - Direct buried.**



**Figure 3.3.3 GIS used to By Pass Overhead Line Circuits**

### **3.3.5 Consideration for electricity supply using SF6 technology**

A joint study relating to 'Electricity supply using SF6 technology' [3.3.3] was conducted in Germany to establish the comparative environmental impacts of technology with and without SF6. At the system level, two alternative supply models are compared, based on the given load profile of a city about 40km<sup>2</sup> large, with about 130,000 inhabitants, a peak load of 120MW, and a consumption of 400GWh during the first year of the period and an annual increase in load of 1.5 percent. In two alternatives, electric power is fed into the city via GIS substation with underground cable and fed into the city via AIS substation with overhead transmission line.



**Fig.3.3.4 Electricity supply from GIS and AIS**

The results show that power supply network with GIS technology takes an advantage with respect to the following points:

- Primary energy consumption (Energy)
- The area required (Area)
- Acidification potential (AP)
- Greenhouse potential (GWP)
- Nutrication potential (NP)

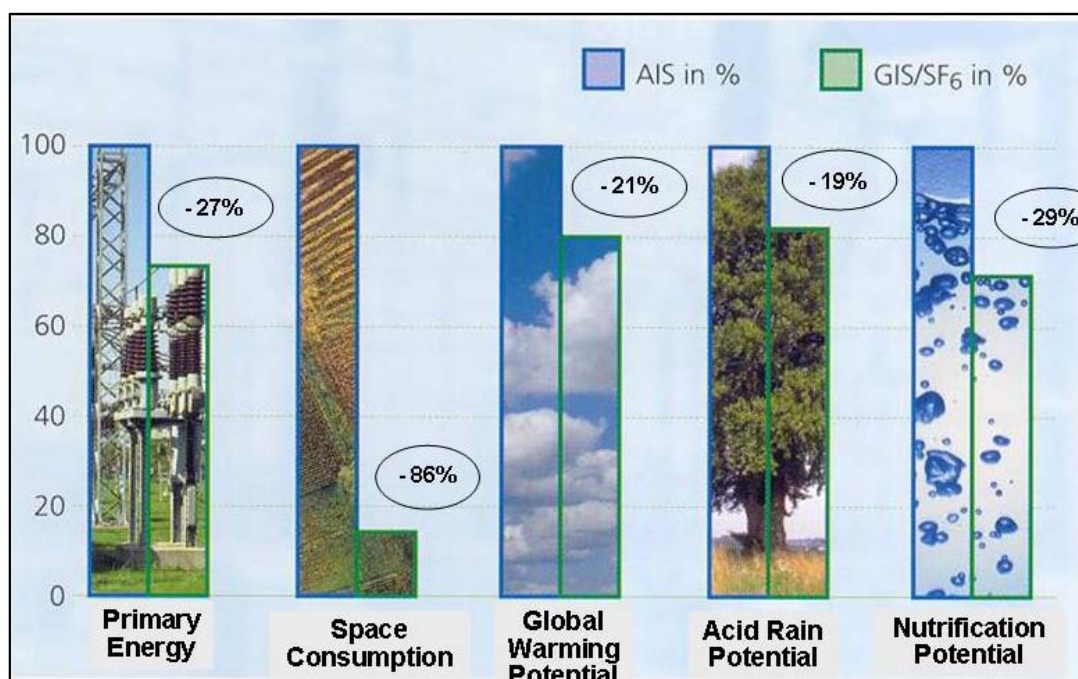


Figure 3.3.5 advantages of GIS technology in comparison with conventional technology

### Conclusion

In response to the environmental awareness, following should be taken into consideration for the future evolution of GIS.

- Since a viable alternative technology has not yet been found in spite of great efforts in the concerned fields, SF<sub>6</sub> has to be used and handled with special attention. SF<sub>6</sub> emission from equipment is relatively low and is from experience 0.5% per year [3.3.4] and therefore, such attention should be paid on SF<sub>6</sub> handling.
- Most emission occurs during the SF<sub>6</sub> handling work at maintenance works and at equipment disposal. In this sense, maintenance strategies should be carefully examined and time-based maintenance be reviewed as much as possible or postponed.

### References

- [3.3.1] Eliasson, 'Working together on Global Climate Problems', IEEE Power Engineering Review, P.3-5, March 2001
- [3.3.2] Ashley, 'Are Power lines unsafe?', IEEE Spectrum, p.21-23. July 2000
- [3.3.3] Project Group ABB, PreussenElektra, RWE, Siemens, and Solvay, Electricity supply using SF<sub>6</sub> technology. For MV see Solvay Management Support: SF<sub>6</sub>-GIS-Technologie in der Energieverteilung – Mittelspannung. Life Cycle Assessment study commissioned by ABB, Areva T&D, EnBW Regional, e.on Hanse, RWE, Siemens, and Solvay Fluor und Derivate. Solvay: Hannover/Germany, 2003 (in German, abstract and summary available in English)
- [3.3.4] Maruyama, et al, 'SF<sub>6</sub> Gas Emission Reduction from Gas Insulated Electrical Equipment in Japan', EPA Conference

## 4 GIS Solutions to Identified Business, Environment and Technology Drivers

In Chapter 3 the primary environmental, business and technology drivers for the electricity transmission business environment were discussed. The combination of these business drivers will determine the overall mix of GIS solutions that become available in the future.

The development of today's power markets faces as well as an increasing power demand much more environmental constraints. The new market conditions follow the strong increase in competition. So advanced solutions are required as the use of power electronics together with new technologies in switchgear.

The changing customer demands can be described as follows:

- Minimum life cycle costs: Investment, Operation and Maintenance
- High availability,
- High flexibility
- Compact solutions for existing areas
- Competent system-providers instead of product-suppliers

In this Chapter the specific GIS responses to these drivers are discussed to illustrate how GIS can be expected to evolve in the future. In order to provide a quick reference as to which GIS solutions are linked to which business drivers, Table 4.1 details the primary and secondary relationships between these two factors and also indicates upon which part of the GIS Life Cycle there is the major impact.

### 4.1 Integration of primary functional elements

Switchgear designers have already made considerable efforts to establish economical and space-saving combinations of primary devices. Even before the appearance of SF<sub>6</sub> gas-insulated switchgear, solutions had been developed with several integrated air-insulated devices, which were accepted by users. Application of these combined devices, for example disconnectors with earthing switches or bushing insulators with current transformer cores became commonplace. These accepted solutions have been adapted to gas-insulated switchgear since the very beginning of the technology. Of course in the meantime there have been further developed a number of new integrated technical solutions. Some of them are generally applicable in AIS and GIS as well; others are specifically for use in GIS.

The first gas-insulated switchgear was of the single-phase encapsulated design for all voltages. The individual devices were single phase as well. Later the integrated three-phase enclosed GIS became a further stage of the development. The use of the three-phase enclosed GIS began on the lower voltage levels, but it has been extended towards the higher voltages as well. Application of the common enclosures has made possible to reduce the overall dimensions, the volume, the weight and the number of constructional parts. Therefore it tends to be more economical, than the similar single-phase solution. One disadvantage is, that the common enclosure gives the possibility of a short-circuit between two or three phases, this being clearly impossible with the single-phase type enclosures. Due to the economic advantages and the positive working experience on the user side the three-phase enclosed technique has become more widespread and become almost the norm at the voltage levels below 200 kV.

After this general introduction we will try to summarize the technical solutions, which have been developed towards the multifunctional, integrated devices that we can see today and no doubt these will give us some ideas as to the further developments we will see in the future.

Specific Solution	GIS	Chapter Reference	Primary Business Drivers	Secondary Business Drivers	Life Cycle Period
Integration of Primary and Secondary Elements		4.1	- Cost - Technological Boundaries - Quality and Availability of supplies	- Environmental	Acquisition
Alternatives to SF6		4.2	- Environmental		Acquisition Ownership Disposal
Primary Equipment Interfaces		4.3	- Globalisation and Harmonisation	- Deregulation	Acquisition
Integration of Control, Protection and Monitoring		4.4	- Technological Boundaries - Quality and Availability of supplies	- Cost - Deregulation	Acquisition Ownership
Mobile substations		4.5	- Deregulation - Quality and Availability of supplies		Ownership
Increased Security and Safety Solutions		4.6	- Safety and security		Ownership
Reduction in BIL		4.7	- Cost		Acquisition
Developments in design and Materials		4.8	- Cost - Availability and security of supply - Technological barriers		Acquisition
Response to increasing fault and normal current ratings		4.9	- Increased ratings		Ownership
Urban Substations		4.10	- Environmental		Acquisition
Sealed for life designs		4.11	- Environmental	- cost	Ownership
Shorter design lives		4.12	- Technological boundaries	- Cost	Acquisition
Changes to Type and Routine Tests		4.13	- Globalisation and harmonisation	- Technological boundaries	Acquisition
Circuit breaker technology		4.14	- Cost - Availability and security		Acquisition Ownership
Simplified single line diagrams		4.15	- cost	- Security and availability	Acquisition Ownership
Changes to maintenance procedures		4.16	- Cost	- security and availability	Ownership
Standardised specifications		4.17	- Deregulation - Cost		Acquisition

Table 4.1 Linkage Between GIS Solutions and Business Drivers

#### 4.1.1 Circuit breaker and other devices

Usually the gas-insulated circuit breaker has relatively large outer dimensions and gas volumes. For this reason designers have tried to combine other devices within the same enclosure as well, examples being:

##### 4.1.1.1 Circuit breaker and disconnecting switch

Standards prescribe higher electrical requirements (higher withstand voltages) for disconnectors than all other switches, because they perform an important safety function. With a relatively small dimensional increase it is possible to provide circuit breakers, which can withstand all standard requirements for the disconnecting function as well. Some manufacturers offer these solutions as "disconnecting circuit breakers" or "circuit breaker disconnectors". Theoretically these new type devices can fulfill all the tasks of two different, series connected switches: a circuit breaker and a (line) disconnector. Up to recently the users were reluctant to accept this solution. System operators usually require a line disconnecting switch next to the circuit breaker as well.

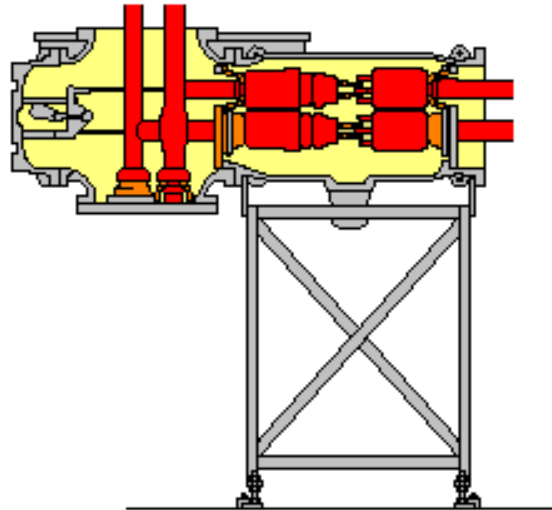


Figure 4.1.1 Circuit breaker disconnecting switch

##### 4.1.1.2 Circuit breaker and earthing switch(es)

There are several GIS designs on the market, which apply one or two maintenance earthing switches inside the housing of the circuit breaker. These earthing switches are usually hand or motor operated, and can be found on both sides of the arc quenching chambers.

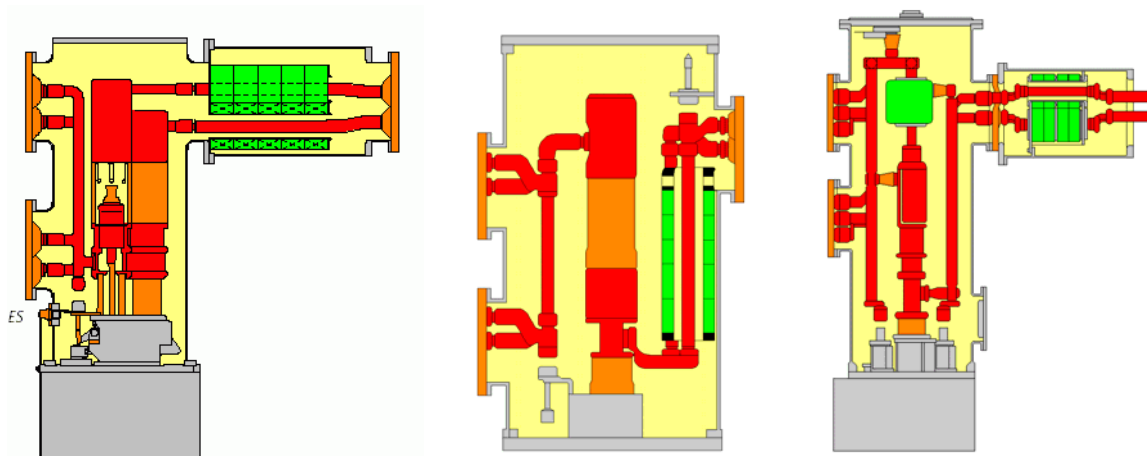


Figure 4.1.2. Circuit breakers with built-in earthing switch

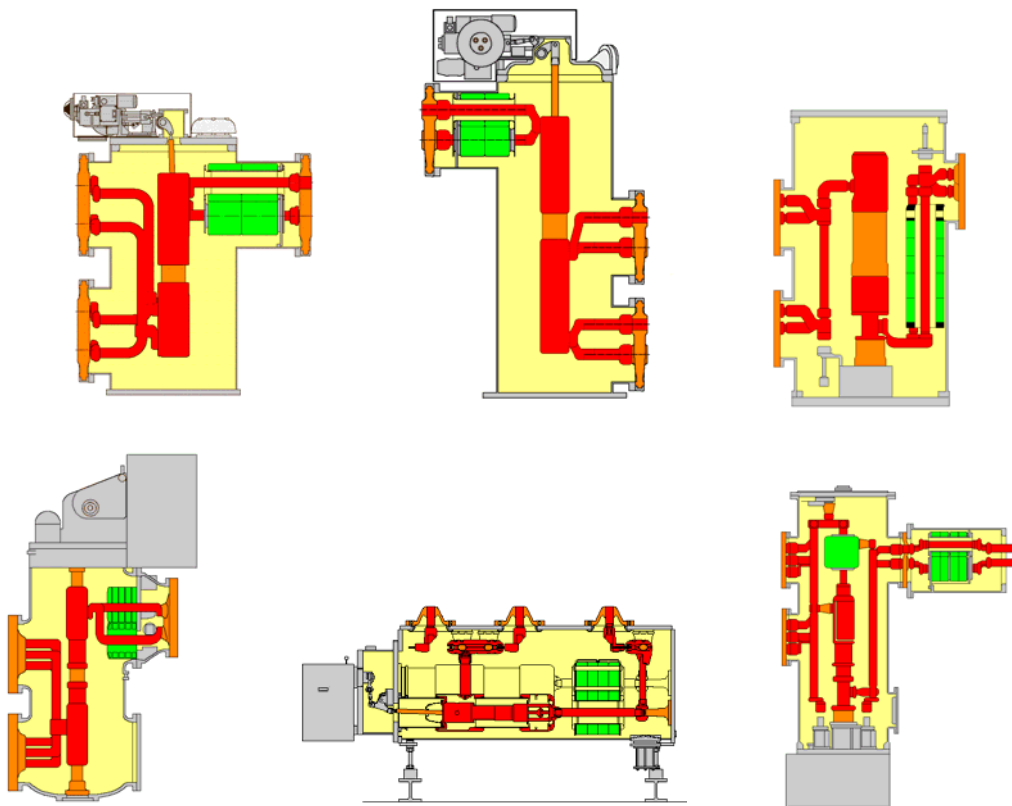
Frequently the Japanese manufacturers apply this switchgear combination. Users seem to readily accept these solutions.

#### 4.1.1.3 Circuit breaker and current transformers or sensors

Several (mainly three-phase enclosed) GIS circuit breakers include current transformer cores (or sensors) inside their common housing, in most cases on the line side connection. Usually on the other, busbar side, there is not any space for current sensing devices. They should be placed always on the line side of the circuit breaker. The integration of the current transformer cores gives possibility to reduce the space requirement of the bay, because the dimensions of the independent mounted current transformers are relative large.

#### 4.1.1.4 Circuit breaker and (internal) interconnections

For double busbar configurations the GIS has to provide connection between the busbar disconnectors and the circuit breaker. Mainly in the three-phase enclosed switchgears this connecting part can be integrated into the circuit breaker. This solution is usually combined with the built in current transformer cores, or sensors, and results further space saving. The busbar compartments, which include the line disconnectors and the earthing switch, are typically connected directly to the circuit-breaker enclosure. (See Figure 4.1.3) If the user requires current transformers on both sides of the circuit breaker, this arrangement becomes difficult to meet.



**Figure 4.1.3 Three phases enclosed circuit breakers with built-in current transformer cores and internal interconnections**

The opinions of users are not uniform about the above mentioned philosophies. The secondary protection designers like to have CT cores on both sides of the circuit breakers because the overlapping of the protection zones of the busbar and line protections. The system operators have to decide between application of the traditional protection methods and the potential economical advantages of the new designs. These decisions are different: There are countries where the CT cores on both sides of the circuit breakers are essential, and there are other countries where the change is accepted.

#### 4.1.2 Disconnecter and other devices

The first ideas concerning switch-combinations, which included the disconnector, were adopted from the air-insulated switchgears. Of course usually only the basic ideas are the same, the technical solutions can be totally different.

#### 4.1.2.1 Disconnecter and load break switch

Some manufacturers developed special "load break disconnectors", which cannot interrupt short-circuit current, only the load current of the switchgear, but can fulfill the functions of the disconnecter as well. (Similar to the disconnecting circuit breaker.)

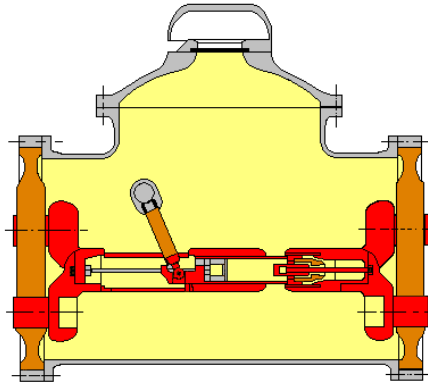


Figure 4.1.4 Load break disconnecter

Application of this type of switch is not common; they are generally used only in the supply circuits of non critical equipment.

#### 4.1.2.2 Disconnecter and earthing switch(es)

Figures 4.1.5 and 4.1.6 are showing examples of single-phase enclosed disconnecter and earthing switch combinations. All the presented units include independent disconnecting and earthing contacts, which are placed inside a common housing, and which have independent drives.

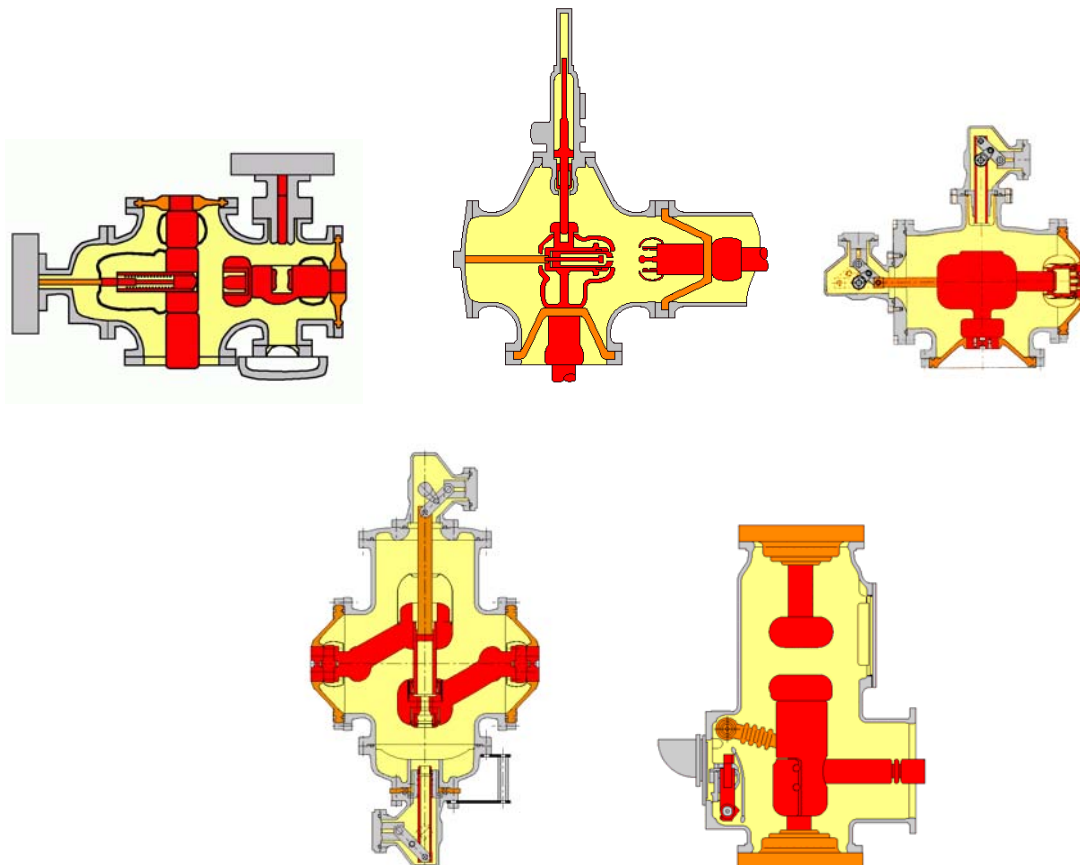
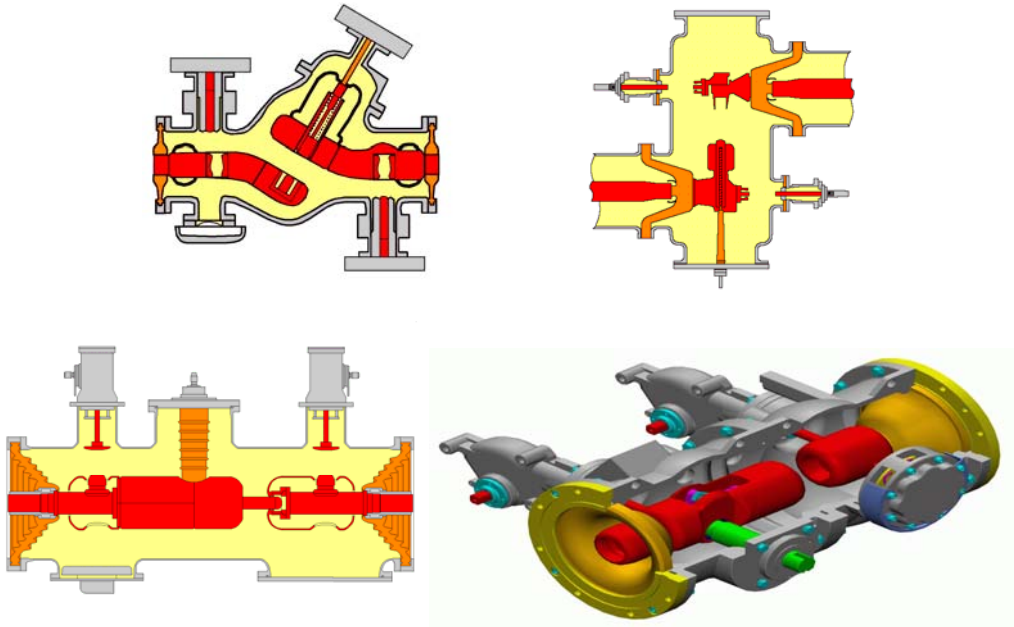


Figure 4.1.5 Single phase disconnecters with one (maintenance) earthing switch



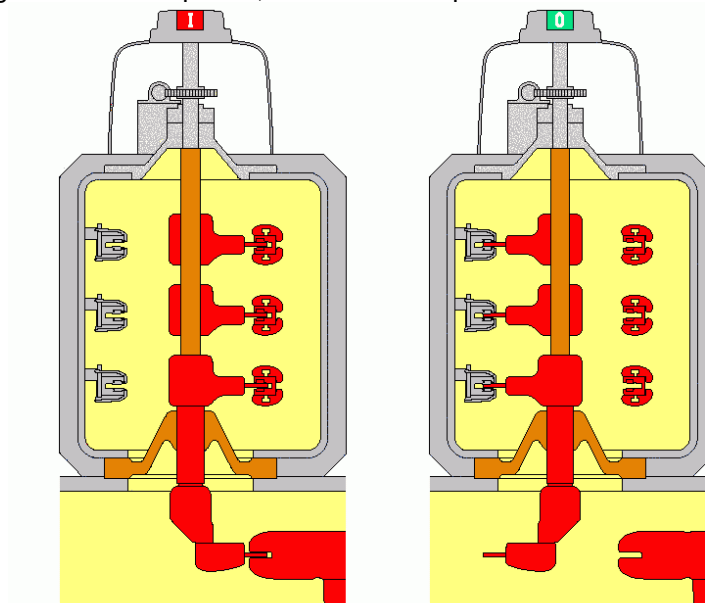
**Figure 4.1.6 Single phase disconnectors with two (maintenance) earthing switches**

In the Figures of 4.1.5 and 4.1.6 there are shown maintenance earthing switches only, but of course the application of high-speed earthing switches in similar combined constructions is very frequent as well.

Following the introduction of the three-phase enclosed gas-insulated equipment, all the three phases of the disconnecting and earthing switches were included into the common enclosure.

#### 4.1.2.3 Two-position disconnecting and earthing switches

As the next step of the integration of devices, the moving contacts of the disconnector and one earthing switch were merged together. The first version of these new type devices has two positions. In the first position the disconnector is closed (while the earthing switch is opened), in the second position the earthing switch is closed (while the disconnector is opened). The earthing point has to be isolated from the further current carrying parts, therefore the disconnector has two separate contacts. If the disconnecting contacts are opened, the connection part between them is earthed.



**Figure 4.1.7 Two-position three-phase enclosed disconnecting and earthing switch in closed and opened (earthed) positions**

This solution is very advantageous in safety point of view. But with duplicated disconnecting contacts, and a lot of special parts, it may not be very economical.

#### 4.1.2.4 Three-position disconnecting and earthing switches

The next generation of the integrated disconnecting and earthing switches has three positions. In the first position the disconnecter is closed (while the earthing switch is opened), in the second, neutral position both switches are opened, and in the third position the earthing switch is closed (while the disconnecter is opened). The number of the applied parts was reduced significantly (only one set of moving contacts and only one drive for two switches). See Figure 4.1.8 with several examples.

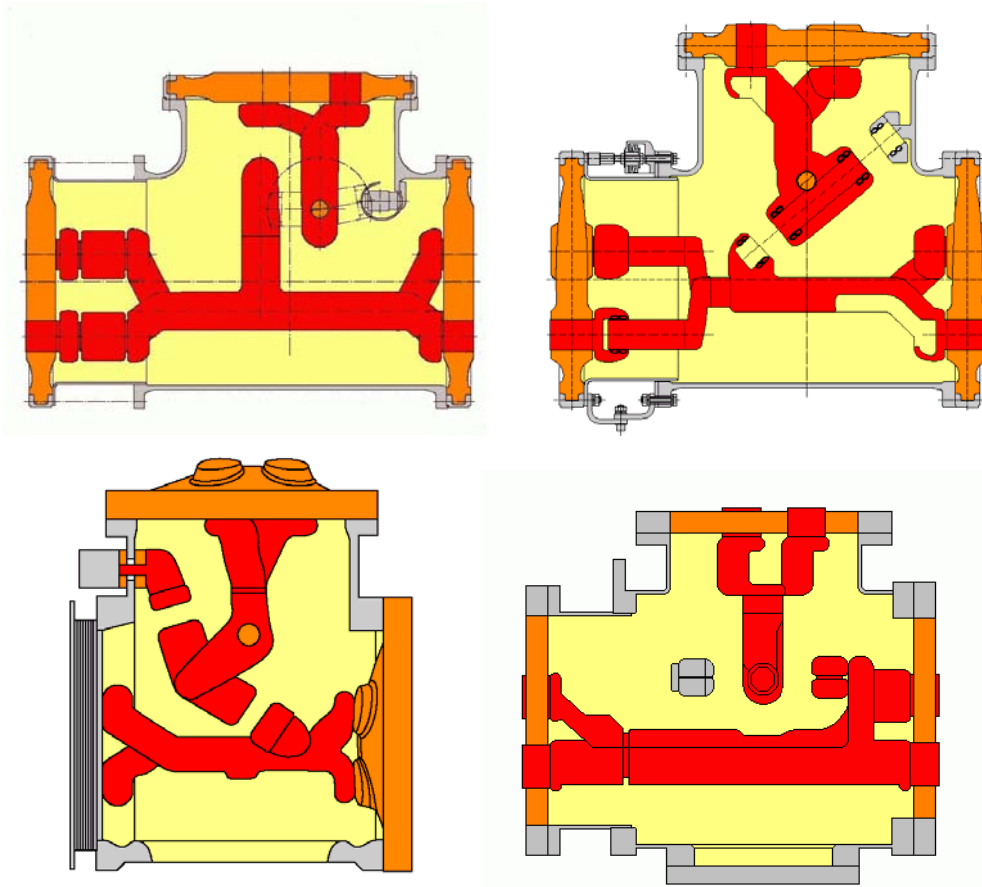


Figure 4.1.8 Three-position three-phase enclosed disconnecting and earthing switches

After a short time the new three-position type integrated disconnecting and earthing switch with the common moving contact was introduced among the single-phase enclosed constructions as well.

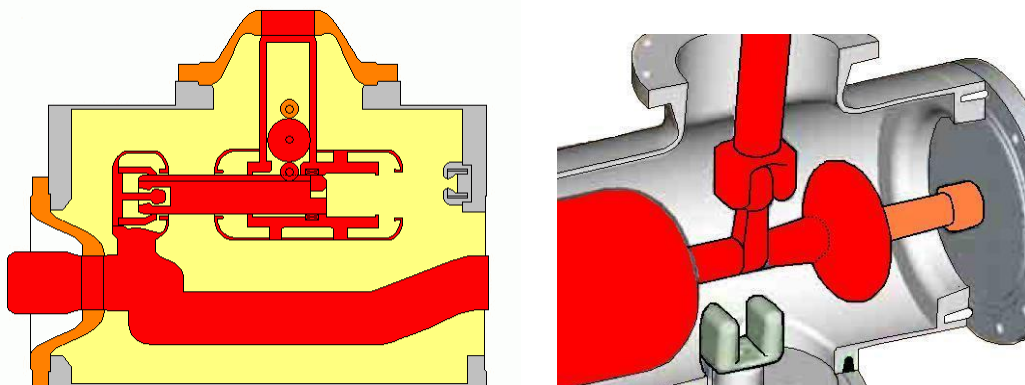


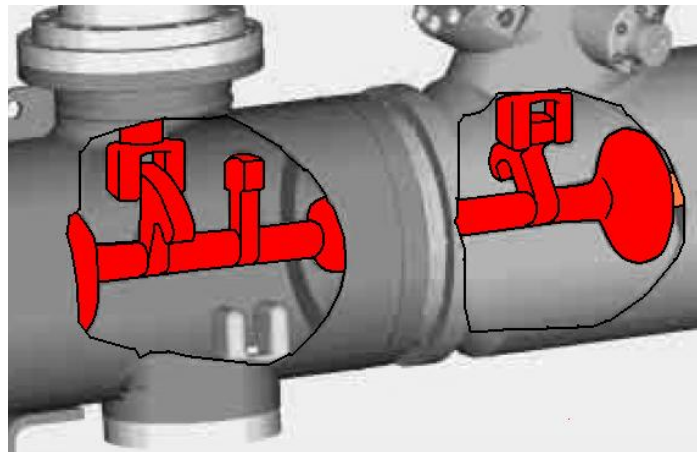
Figure 4.1.9 Three-position type single-phase enclosed disconnecting and earthing switches

For the users the disconnecter and earthing switch combinations are well-known and generally accepted. The only problem can be about the interlocking requirements: some users insist on mechanical interlocking in addition to the electrical one. It can be provided only by complicated (and

expensive) additional mechanical connections between independent driving boxes. The introduction of the new type three-position disconnecting and earthing switches can also provide solutions for this problem as well.

#### 4.1.2.5 Four-position double disconnector with earthing switch

The next step of the integration is a combined unit, which includes two disconnecting switches and one maintenance earthing switch. See Figure 4.1.10. This unit is operated with only one common drive. It is applied at single-phase enclosed gas insulated modules of hybrid switchgears in double busbar arrangement.



**Figure 4.1.10 Four-position type single-phase enclosed unit with two disconnecting and one earthing switches. The drive is common, rotating type.**

#### 4.1.2.6 Disconnecter and flexible elements

In the case of the three-phase enclosed busbar disconnectors further important functions can be added. (See Figure 4.1.8) The built-in flexible elements provide the following important features:

- Eliminates the mechanical effect of thermal expansion and contraction (it is important in the case of long busbars),
- Compensates the small inaccuracies of the manufacturing, and the relative higher mistakes of the civil constructions,
- Gives possibility to removing an element (a bay unit) from the busbar without dismantling of the neighboring parts.

#### 4.1.3 Instrument transformers or sensors and other devices

Instrument transformers practically haven't changed during the last thirty years, only improved materials have been incorporated. We can compare this stability for instance with the number of generation changes of the circuit breakers. But probably in the near future the situation will change dramatically. Modern electronic control and protection systems do not need the relative high power supply of the instrument transformers. Alternative sensor techniques offer much more accurate and economical solutions, for example new small-dimension sensors can replace the conventional iron-core transformers.



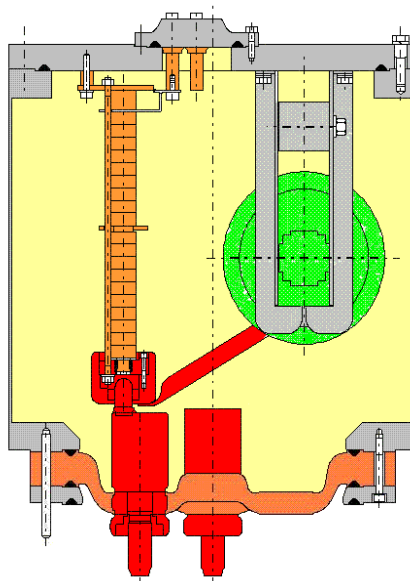
**Fig 4.1.11 Combined Current and Voltage Sensor**

#### **4.1.3.1 Voltage transformer and disconnecter**

Sometimes inside the voltage transformer enclosure can be found a special disconnecter as well. This switch conducts only very small working currents, but may be able to withstand any short-circuit current, and all the high voltage commissioning tests. The function of this device is the isolation of the voltage transformer, which can be important for the high voltage on-site test procedures. Application of this solution is very limited. It can be necessary only, if the user specifies, that the VT cannot be removed or physically disconnected for the duration of the high voltage tests of the GIS. In this case the VT has to remain on the GIS but have to be isolated for the critical period.

#### **4.1.3.2 Voltage transformer and surge arrester**

In Japan engineers have developed a three-phase enclosed, combined device, which includes three surge arrester units and one voltage transformer (in the centre phase). This solution is used at 72.5 kV voltage level at the moment. Task of the VT is the voltage detection only. The surge arrester units have extreme low dimensions because the applied special building elements. See Figure 4.1.12.



**Figure 4.1.12 Combined unit including one voltage transformer and three surge arrester**

#### 4.1.3.3 Current transformer and voltage transformer

The so-called combined measuring transformer, which included a current transformer and a capacitive type voltage transformer, was introduced more than twenty years ago. At that time it was not very successful, because the voltage transformer part couldn't provide high enough power supply for the electro-mechanical relay systems.

In recent years the device was reconsidered due to the changing requirements and formed to a combined sensor including a Rogowski-coil type current sensor instead of the current transformer, and a capacitive voltage sensor, which is similar to the earlier capacitive voltage transformer. Some applications of these devices have been implemented.

For the future there is the promise of optical devices based on the Faraday Effect (current) and Pockels Effect (voltage). Such optical devices have been applied for AIS applications and can offer advantages for GIS applications as well.

In a GIS configuration it is possible that a combined voltage transformer and current transformer could be even more compact than the Rogowski coil/Capacitive Voltage transformer devices described here. Such compactness would of course help further reduce GIS overall dimensions to even more compact solutions. A purely optical device also provides the same advantages of

- Elimination of problems with open circuits on CT's
- Elimination of problems of potential ferroresonance on electromagnetic VT's

As compared to Rogowski coils and capacitive divider devices.

Furthermore the introduction of digital communication protocols into the substation environment should facilitate the acceptance and adoption of such technologies in the future.

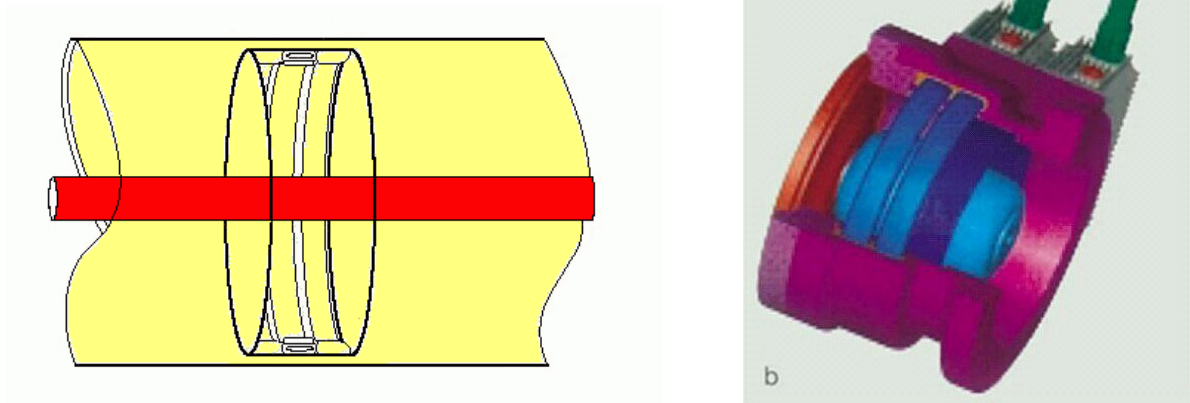
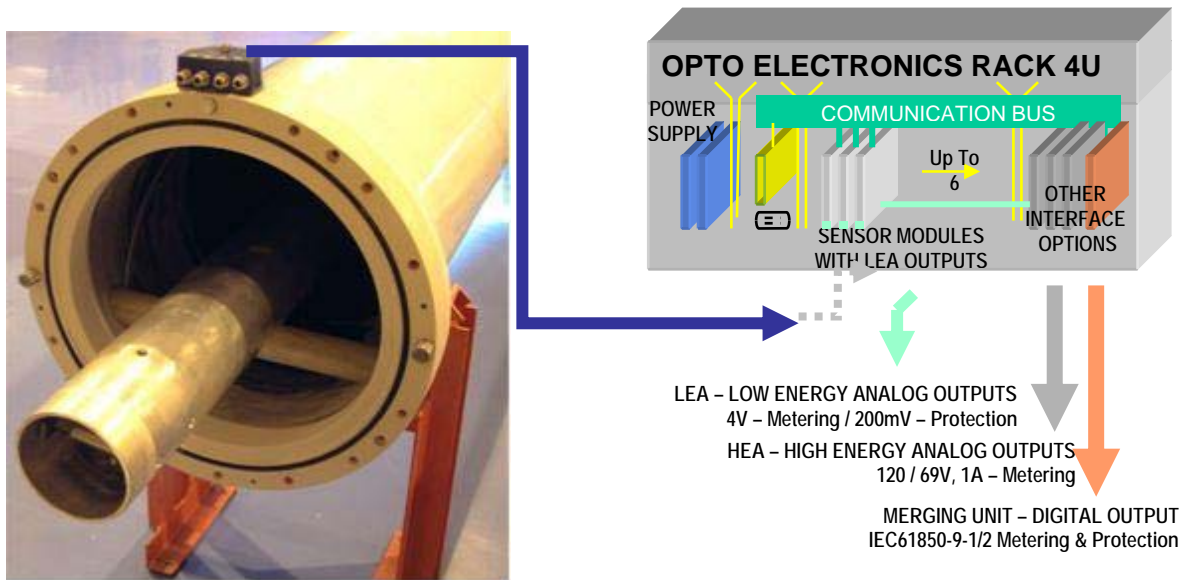


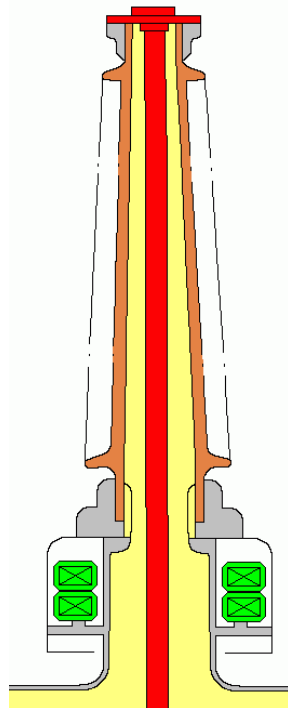
Figure 4.1.13 Combined sensor for current and voltage measuring



**Figure 4.1.14 Prototype combined optical sensor for current and voltage measuring**

#### 4.1.3.4 Current transformer and bushing insulator

This is one of the device-combinations that were adopted from the air-insulated switchgear. In the gas-insulated technique these are applied mainly in dead-tank circuit breakers and in hybrid type GIS units. The main characteristics are the same as at the oil-insulated bushings, only the insulating medium is changed to SF<sub>6</sub>. The CT cores can be placed inside or outside of the gas compartment of the bushing insulator.



**Figure 4.1.15 Current transformer and bushing insulator combination**

#### 4.1.3.5 Current transformer and cable sealing end

This is similar to the current transformer and bushing combination. The CT cores are placed inside the cable sealing end enclosure. This solution has not been very successful. This is probably because the slip over cable-type current transformers are more economical.

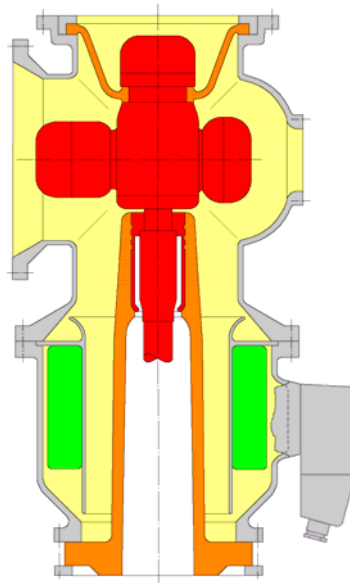


Figure 4.1.16 Current transformer and cable sealing end combination

#### 4.1.4 Surge arrester and bushing insulator

The concept has been suggested published of a new integrated solution, with a bushing insulator which includes in the hollow insulator of the bushing an integrated surge arrester. This seems to be a good idea, but there is no operational experience up to now. Probably the economic merits will determine if this solution will be adopted or not.

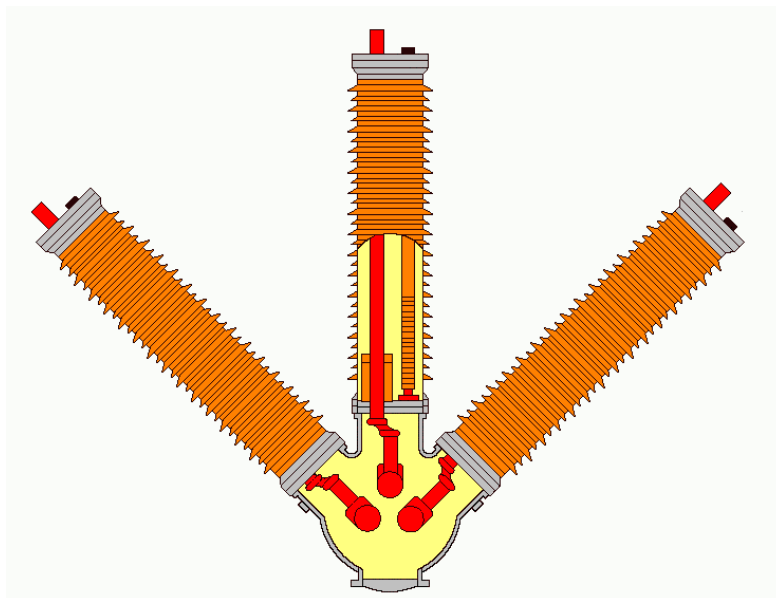
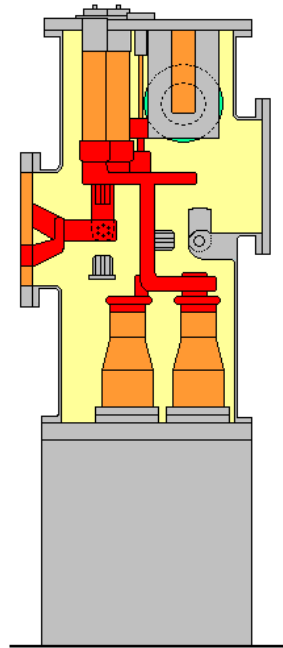


Figure 4.1.17 Surge arresters integrated into bushing insulators

#### 4.1.5 Complete load-side unit

Using the earlier introduced solutions, there is a possibility to include the load-side connection of a usual three phase enclosed bay into only one enclosure element. See Figure 4.1.16. This combined unit has the following building elements: three poles of a combined disconnecting and earthing switch,

three phase units of surge arrester, one voltage transformer unit in the centre phase, three poles of a further earthing switch, and three cable-sealing-end units. The applied current transformers are cable types, outside the switchgear.



**Figure 4.1.18. Complete load-side connection unit in one enclosure element**

#### **4.1.6 Further future possibilities**

It is hard to be precise about future integrated devices but the trend towards continued integration seems clear, hence the fast development of several technical areas shows future possibilities.

- Very probably the simplification processes will continue in future as well. Dimensions, weight, number of building elements will be reduced for each type of GIS. Application of three-phase enclosed equipment will spread towards the higher voltage levels, dependent on economic considerations. Development of multifunctional, combined or integrated elements will continue as well. Number of the different variations will increase. Application of new materials (insulators, conductors, contact materials, structural materials, etc.) and new constructions of the basic devices (new arc-quenching chambers, new drive solutions, etc.) will support the above mentioned trends.
- Appearance of new type switching devices is possible as well. Development of the power semiconductors and the semiconducting devices has a lot of significant results. Perhaps the semiconducting switches can be applied in the high voltage equipment as well as a very long term prospect.
- The prototype tests of the short-circuit current limiters for medium voltage equipment is in progress. According to the researchers they can become a standard product within approximately ten years. If the working experiences will be successful, the development can continue towards the higher voltages. A new device can be created, or a new function can be integrated into an existing device, most probably into the circuit breaker.

#### **Conclusion**

We can trace a continual development of GIS technology involving the integration of primary functions into single elements. The objectives of such developments have been to make the GIS:

- More compact
- Simpler, involving fewer components

- Increased performance and reliability
- Less costly

We can assume that such requirements will continue in the future therefore the continued integration of the primary GIS elements will continue providing that the same objectives are achieved. Whilst we can see that the harmonisation of standards and merging of different Utilities and reduction in numbers of manufacturers might limit the variety of GIS available, it is also the case that innovation in how GIS primary elements are integrated will also provide for variety in terms of GIS design solutions.

## 4.2 Reduction of Environmental Impact of SF6

Human activities have an effect on the environment. The impact of a given activity depends on its scale and on the materials involved. SF<sub>6</sub> has certain environmental characteristics and the Greenhouse gas effects of SF<sub>6</sub> are well documented [4.2.1]. Due to these characteristics, SF<sub>6</sub> has to be used avoiding any deliberate release into the atmosphere, and in an environmentally compatible way [4.2.2].

Nevertheless the real impact of SF<sub>6</sub> used in GIS should be considered by taking into account the entire functionality of the electrical equipment, which has to be evaluated from the global point of view, accounting for all components as well as the system design. The LCA (Life Cycle Assessment) methodology defined in ISO 14040 can be applied for this purpose.

The use of SF<sub>6</sub> technology in GIS can have a global benefit for the environment as discussed in the following paragraphs.

### 4.2.1 Present environmental impact of GIS

The use of SF<sub>6</sub> technology in GIS allows a much more compact design of the equipment. This results in transmitting and distributing electricity at HV level closer to the final users which is particularly important for big urban concentrations. A GIS can be placed in the basement of buildings but AIS (Air Insulated Switchgear) technology requires a large open air space. The physical layout of the transmission and distribution networks is therefore optimized with GIS and the network losses are considerably reduced. Loss savings translate directly into reduction of CO<sub>2</sub> emissions in the case of energy generated by fossil fuel combustion.

The increasing awareness of the environmental impact of SF<sub>6</sub> has led to major improvement of tightness of GIS equipment as documented by the relevant IEC Standards 60694 (future 62271-1) since the 1990s. In the same way, the adoption of state-of-the-art gas handling equipments and procedures for reclaiming, reuse and recycling of SF<sub>6</sub> [4.2.3] including training of personnel, during the whole life cycle of the equipment has led to substantial reduction of SF<sub>6</sub> emissions. However, a small proportion of older types of GIS equipment not fulfilling present requirements regarding tightness is still in service.

The contribution of SF<sub>6</sub> emissions from the electric industry to the global warming has been estimated to be less than 0.1% [4.2.4]

An LCA case study was carried out for a HV regional power supply [4.2.5]. The conclusion is that the use of SF<sub>6</sub> technology in GIS minimises the environmental impact of the network. It is therefore to be expected that the focus of concerns with the use of SF<sub>6</sub> is with the correct handling of SF<sub>6</sub> and the ongoing efforts to eliminate unnecessary emissions.

Other important aspects to consider when evaluating the environmental impact are the land occupation and visual impact. SF<sub>6</sub> technology in GIS allows more than 90% land savings compared to AIS solutions. Because of its low profile and the possibility of installation inside buildings, the visual impact of GIS is reduced.

### 4.2.2 Future trends in the environmental impact of GIS

The increasing commitment of society to sustainable development is raising environmental awareness [4.2.6]. This is a long term trend which is accompanied by environmental regulations and adoption of voluntary actions all over the world. As a consequence of that:

- The small proportion of older types of existing GIS equipment not fulfilling present requirements regarding tightness will be replaced by state-of-the-art GIS equipment;

- Even more, existing controlled pressure systems will also be replaced by tighter closed or sealed pressure systems;
- Future equipment will have an even more compact design with increased functionality;
- The need for SF<sub>6</sub> handling will be reduced due to continuous improvements in the equipment reliability and safety;
- The on-going widespread adoption of early leakage detection techniques, immediate leak repair, state-of-art gas handling equipment and procedures for reclaiming, reuse and recycling of SF<sub>6</sub>, including training of personnel, will contribute to achieve a further emission reduction.

A systematic search for environmental friendly alternatives to SF<sub>6</sub> started during the 1980s and is still ongoing within the International Scientific Community. For the time being, no green alternative gas exists with adequate dielectric and/or interruption capabilities. Substitutes with inferior performance have been identified (e.g. proposed CO<sub>2</sub> or vacuum for current interruption or nitrogen for insulation up to 145 kV) and all of them require a complete redesign of the power electric equipment. The operating pressure and the insulating distance must be increased to comply with IEC Standards in force. The additional cost, weight and dimensions result in an increase of the overall environmental impact. However, the research activity is a permanent process that will continue. Although no alternative substitute has been identified up to now, its existence should not be excluded "a priori".

A small market niche of electric equipment utilises SF<sub>6</sub> gas mixtures [4.2.7]. This is the case of equipment for arctic regions or latest developed GITLs (Gas Insulated Transmission Lines). In theory SF<sub>6</sub> gas mixtures could also be used in GIS, but, as stated above, the operating pressure or the insulating distance must be increased to comply with IEC Standards in force. In addition, state-of-the-art gas separation technology may need further improvements to become an industrial reality. For the time being and foreseeable future no further extension of the use of gas mixtures is expected.

### **Conclusion**

Voluntary programs for the reduction of SF<sub>6</sub> emissions from the electric industry were initiated shortly after the high global warming potential (GWP) of SF<sub>6</sub> had become known. These activities were organized by the electric industry (electrotechnical committees, OEM and utilities), SF<sub>6</sub> producers and manufacturers of SF<sub>6</sub> handling and recycling equipment resulting in:

- Establishment of global SF<sub>6</sub> inventories
- Promotion of conservative SF<sub>6</sub> handling by international committees

The equivalent functional replacement of SF<sub>6</sub> does not exist for arc interruption (at the moment) and there is no currently identified prospect of such a replacement being found which has less environmental impact for transmission voltage levels.

There is a possible vision of the GIS of the future is GIS with vacuum interrupter circuit breaker and N<sub>2</sub> insulation but considerably larger equipment would be needed and the overall environmental impact is yet to be evaluated for such equipment.

For purely insulating purposes, SF<sub>6</sub> and N<sub>2</sub> mixtures may be used mainly for large gas compartments such as gas insulated busbar connections but for widespread substitution such solutions are not viable.

### **References**

- [4.2.1] G Mauthe et al, "SF<sub>6</sub> and the Global Atmosphere" – ELECTRA No 164 1996.
- [4.2.2] G Mauthe et al, "SF<sub>6</sub> Recycling Guide, Re-use of SF<sub>6</sub> Gas in Electric Power Equipment and Final Disposal" – ELECTRA No 173 August 1997, pp 43-71.
- [4.2.3] P. Glaubitz, S. Stangherlin, D. Crawley, J. Henriot, A. Holm, P. Jannick, P. Justiz, M. Meguro, R. Probst, P. Sieber, S. Theoleyre, T. Yokota, L. Van der Zel, "Guide for the preparation of Customized SF<sub>6</sub> Handling Instructions" CIGRE Brochure No 276, Published 2005
- [4.2.4] P. O'Connell, F. Heil, J. Henriot, G. Mauthe, H. Morrison, L. Niemeyer, M. Pittroff, R. Probst, and J. P. Taillebois, SF<sub>6</sub> in the Electric Industry, Status 2000, *Electra* **200**, 16-25 2002.

- [4.2.5] Project Group ABB, PreussenElektra, RWE, Siemens, and Solvay, Electricity supply using SF<sub>6</sub> technology. For MV see Solvay Management Support: SF<sub>6</sub>-GIS-Technologie in der Energieverteilung – Mittelspannung. Life Cycle Assessment study commissioned by ABB, Areva T&D, EnBW Regional, e.on Hanse, RWE, Siemens, and Solvay Fluor und Derivate. Solvay: Hannover/Germany, 2003 (in German, abstract and summary available in English)
- [4.2.6] IPCC (Intergovernmental Panel on Climate Change), Climate Change 1995: The Science of Climate Change, edited by J. T. Houghton et al. (Cambridge University Press, Cambridge, 1996)
- [4.2.7] L. Niemeyer, H. D. Morrison, G. Mauthe, B. M. Pryor, H. Knobloch, J. Henriot, M. Pittroff, R. Probst, J. Poblitzki, B. Mazzoleni, J. Castonguay, W. Boeck, Y. Murayama, and P. Bolin, Guide for SF<sub>6</sub> Gas Mixtures, CIGRE Brochure N. 163, 2000

## 4.3 Primary Equipment Interfaces

### 4.3.2 Cable Connections

#### State of technology, standardization

IEC 60859 provides data and dimensions of cable connections for fluid-filled and extruded insulation cables – fluid filled and dry type cable-terminations. The limits of supply and responsibility of the cable and GIS supplier is well defined.

The assembly of fluid filled cables requires assembly of the cable end including insulator at site by the cable supplier or under its supervision to assure proper assembly. It always requires intervention of the cable installer into the connecting gas compartment of the GIS.

The assembly of dry type cable connections allows for assembly of the cone insulator into the GIS. At site the stress cone is assembled to the extruded insulation cable and the connection to the GIS is possible without opening the feeder gas compartment of the GIS and gas handling.

#### Voltage indication

Some manufacturers of dry type cable connections provide a capacitive low power voltage indication which can be used to indicate presence of voltage according to IEC 61958. With the trend towards functional integration already discussed, it is of course possible to integrate this signal into control if amplified for interlocking purposes or fed into a digital control system.

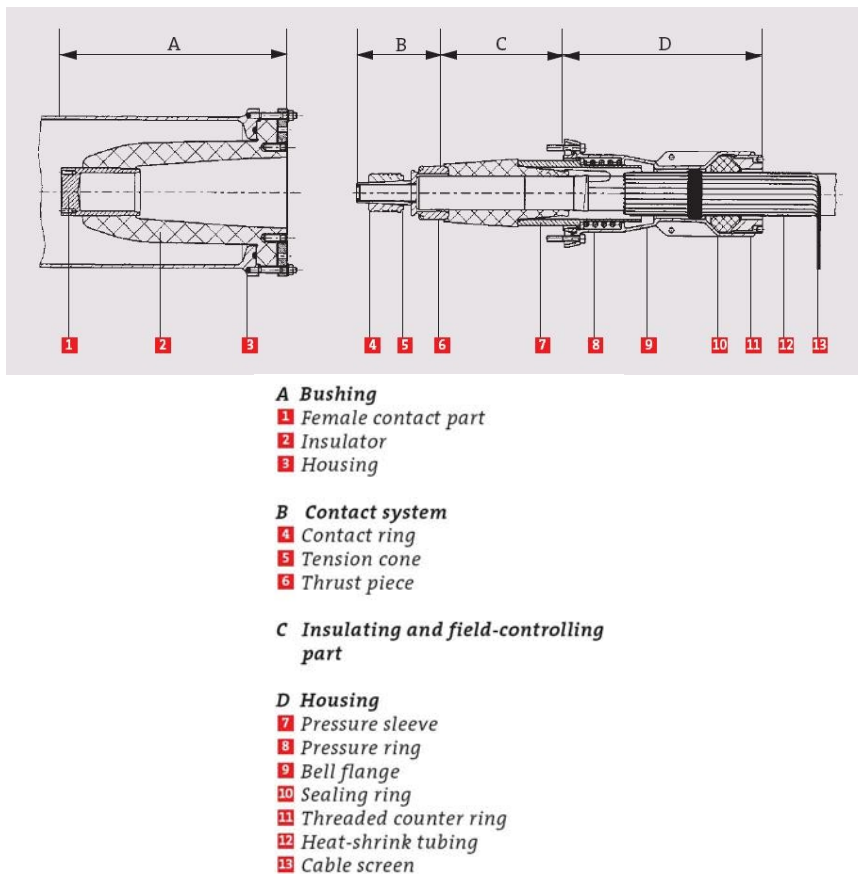
#### Current transformer cores on cables

Cores for protection, metering and control can be installed on the cables. The cores designs are either "slip on" type which have to be installed on the cable before assembly of the cable connection and split type which can be assembled independently of the cable connection.

As protection cores on cables are measuring the current in the cable. Any fault current between the core and the GIS is treated as a CB/busbar fault with the inherent consequences i.e. busbar tripping.

#### Overvoltage protection and Interface shielding

The protecting shields of HV cables have to be earthed. Depending on the earthing scheme of the user either both ends or only one end of the cable shield are connected to the station earthing system. If only one end of the shield is earthed the opposite end should be protected against induced overvoltages by adequately selected surge arresters. The GIS - cable interface presents a sudden change of impedance reflecting very fast transient switching surges producing high overvoltages and high frequency electromagnetic fields in the vicinity. This phenomenon can be suppressed or reduced by low inductance earthing connections of the GIS enclosures to the cable shield or surge arresters with low inductance connections to the cable shield. If the cable shield is connected directly to the station earthing system, the insulation between cable shield and GIS enclosure should be bridged by a low voltage surge-arrester. If sensitive equipment is located near the cable connection the inductance interface should be shielded by a sheet metal connected to the earth.



**Figure 4.3.1 Typical Plug in Cable Connection for GIS**

#### 4.3.2 Bushing connections to overhead lines

##### **Conventional gas insulated porcelain bushings**

From the beginning of GIS technology hollow porcelain insulators have been used to interface the gas insulated switchgear with air insulation for connections to lines and transformers. The transfer of the high dielectric field stress of the GIS to the low stress required for air insulation is achieved by electrodes of pure gas insulated bushings or by combined solid – gas insulation of bushings with capacitive field control. Porcelain bushings are well proven in service and have a very long life. The shortcomings of this type of bushing is its weight and sensitivity to mechanical and thermal shocks imposing danger of fracturing with high risk of personnel injury or damaging nearby equipment. This type of bushing is still used frequently today and is likely to continue in the future.

##### **Gas insulated composite bushings**

Composite gas insulated bushings have a structure comprising a fibre-reinforced and resin impregnated tube to support the pressure and terminal loads, protected by an insulating silicone rubber housing with sheds. This technology has been used for line support insulators with very satisfactory long-term experience. The dielectric stress interface between SF6 and air insulation is based on the same technology as for porcelain bushings. This type of bushing has the main advantages of less weight and of being insensitive to thermal and mechanical shocks. For this reason they have first been used on locations with high risk of mechanical damage or injury to personnel. In the meantime this type is used more frequently due to proven service experience and cost reduction of design and manufacturing with increasing tendency for the future. For GIS suppliers such technology has the added advantage that production times can be reduced in comparison with the long manufacturing lead times associated with large porcelain insulators.

##### **Incorporated voltage indication**

Voltage indication for control and interlocking is not normally included in this type of bushing but could be incorporated in the stress control electrodes or in adapter elements to the GIS.

### **Incorporated current transformers (bushing CT's as for dead tank CB's) for special application**

In the layout of GIS slip-on bushing cores are not yet used on a regular basis due to the normal location between circuit breaker and feeder disconnecter. For hybrid or GIS modules this arrangement is more appropriate since the bushing is part of the module and the location of the current transformer less strictly defined by the user.

### **Overvoltage protection (application of lightning arrestors)**

Surge arrestors are commonly placed near the entrance of lines or air insulated connections to transformers. This allows the application of low cost metal oxide outdoor lightning arrestors to limit atmospheric and switching overvoltages. The arrestors applied to the entrance bushings are normally sufficient for small to medium size GIS. For big GIS with long connections between bays and transformers the voltage coordination has to be investigated by calculations.

## **4.3.3 Transformer direct connections**

### **Direct Transformer Connections**

Such connections are very common and providing that the transformer connections are well designed there are no problems, connections using cables provide more damping of transients, although cost may be a factor at some voltage levels and connection lengths. There is some increased application of SF6 insulated transformers where fire risks are considered to be very critical; with such technologies direct connection of the two SF6 equipment is straightforward.

### **Single phase connections**

The interface of direct connections to power transformers is standardized by IEC 61639. This standard covers single phase connections only. Single phase direct connections are used for all rated voltage levels.

### **3-phase connections**

The connections of three phase enclosed GIS bus to power transformers normally uses 3 phase to single phase adapters. These adapters may be located immediately at the GIS feeder using single phase bus to connect the transformer or at the transformer connecting the 3 phase bus to the single phase entrance of the transformer. In particular for lower voltage levels ( $\leq 145$  kV) 3 phase direct connections to power transformers are available. This technology requires close co-operation and co-ordination between transformer and GIS manufacturer.

### **Interface treatment including earthing, current shunting, overvoltage protection of insulated interface**

The interface between GIS and power transformer imposes particular requirements.

The earthed enclosures of both equipment may be metallically connected. In this case the induced current in the GIS bus flows through the transformer enclosure (for 3 phase transformers only) and increase the ohmic and inductive losses in the steel enclosure of the transformer. As the induced current in the enclosures may reach approximately 80% of the current of the primary conductor it has to be considered for power transformers with high currents. Shunts between the single phase enclosures arranged near the transformer interface reduce the current flow in the steel parts of the transformer enclosure. No or negligibly low current is induced in 3-phase connections to the transformer.

For certain critical applications independent differential transformer protection is used. For this application the earthing circuit of transformers and GIS has to be separated by insulation between the transformer and GIS enclosure. This insulation reflects steep overvoltages induced by switching of disconnectors and circuit breakers. Adequate low voltage surge arrestors have to be placed at the insulation to avoid flashovers.

### **Overvoltage protection (lightning arrestors)**

Depending on the protection range of other lightning-arresters of the substation and based on overvoltage protection investigation arresters may be required at the transformer entrance to protect the transformer. In case of direct connection metal clad SF6 insulated arresters have to be connected to the GIS bus in the vicinity of the GIS-transformer interface.

#### **4.3.4 GIS to GIS Interfaces**

The expected service life of substations in GIS technology has increased in the past decades to 40 or 50 years. Changes in the demand of electric energy during this long life of GIS are to be expected, necessitating extensions and adaptations of the existing installations. Of course in many layouts space for extensions is planned for in the original GIS building or location. The timing of extension is usually related to the actual short or medium term planning of the network.

The normal procedure for extensions is to use the original type of GIS. This is possible when the GIS type is still in production. In particular for older GIS this may not be possible due to replacement of GIS by new generations or by phasing out of product lines in case of mergers.

Extensions of GIS usually concern adding of bays on one or both sides, less frequently adding of busbars in addition and / or replacing components e.g. metering transformers, cable connections etc.

Three types of extensions are described below:

- Extensions with GIS components of the original type
- Extensions with GIS components of a new generation of the original supplier
- Extensions with GIS components of a different supplier

The dimensions of different type of GIS have to be considered during planning of extensions.

##### **4.3.4.1 Extension of GIS with original GIS components**

This is the normal case for extensions of newer GIS. The connection to the existing GIS normally poses no problems and is usually possible with little or no intervention in the existing GIS. As the equipment is of the same type there are no issues for the user regarding operating procedures, training, spares etc.

##### **4.3.4.2 Extensions of GIS with different GIS type of the same supplier**

The extension of GIS being replaced by new type of GIS is usually considered by the manufacturer during the development of the new GIS generation. The interface of the busbars is designed considering the requirements of the existing and new generations.

To connect busbars of different GIS-generations usually requires additional space which in some cases may be partially or fully compensated by the smaller bay width of the new GIS. Extensions of single phase enclosed to three phase enclosed GIS or vice versa are possible and have been executed.

The in depth knowledge of the technical and quality details of the manufacturer of both GIS types provides the highest degree of service safety and dependability with GIS components of the same provenance. Philosophies with regard to operational practices, spares, training etc. will also be similar although differences will clearly exist that have to be addressed.

##### **4.3.4.3 Extensions of GIS with a GIS type of an other supplier**

Extensions of GIS of different manufacturers are technically possible and may be driven by economic or other reasons e.g. the original equipment supplier no longer exists in any form. The manufacturer of the extension has to design the interface of the busbars based on the available information of the existing GIS. This information may be difficult to obtain for various reasons. The service safety and dependability may be reduced due to unawareness of design facts of the original GIS. The manufacturer of the original GIS can be expected to decline any responsibility in case of problems or failures related to the interface. The user may be uncertain as to the full extent of responsibility that the supplier of the extension GIS will take if there are problems with the existing GIS.

##### **4.3.4.4 Open Interface for future extensions**

IEC 62271-203 item 5.107.4 describes the interfaces for future extensions. It is limited to the extension point of busbar or busduct only. The responsibility for testing the existing GIS is with the user.



**Figure 4.3.2 Extension of Existing GIS using new generation equipment from same original supplier**

### **Conclusion**

The trend towards dry type plug-in cable connections for higher rated voltages is continuing. The harmonization and standardization of connection / plug-in system of the cable side towards interchangeability is an open item and would certainly improve the independence of cable connections and GIS supply.

One future design innovation is the possible use of dry type / plug-in cable connection insulators being used to support GIS internal elements.

The trend of bushing application is clearly towards the use of composite insulators.

The design and testing of direct connections between GIS and power transformers strongly depends on the developments in possible future power transformer technology. The main trend of the interface is directed towards further optimization of the dimensions

### **References**

- [4.3.1] IEC 60859 (2000) Cable Connections for gas insulated metal enclosed switchgear for rated voltages above 52kV
- [4.3.2] IEC 61958 (2000) High Voltage prefabricated switchgear and controlgear assemblies – voltage presence indicating systems
- [4.3.3] IEC 6271-203 (2004) High Voltage Switchgear and Controlgear – Gas Insulated metal-enclosed switchgear for rated voltages above 52kV.

## **4.4 Integration of Control Protection and Monitoring and Secondary Systems into Primary Equipment**

### **4.4.1 Introduction**

Surveys [4.4.1] [4.4.2] have confirmed that GIS is generally more reliable than conventional or AIS and that this enhanced reliability is one of the main factors influencing users to install GIS equipment. The same surveys also indicate that the availability of GIS equipment is also improving as the technology matures and simpler, improved performance designs are introduced. With such highly reliable equipment the role of monitoring and diagnostic techniques will become more important as reliance on preventive maintenance carried out at predetermined time or operation intervals will reduce and maintenance will increasingly only be carried out when the condition of the GIS equipment warrants intervention. This will give the user financial benefits of reduced life cycle costs, improved availability due to fault prevention and the ability to plan for any outages necessary for maintenance. As important, monitoring, diagnostics and other new technologies offer users other advantages such as increased functionality (i.e. controlled switching) and performance enhancement (i.e. optimised utilisation of equipment at peak loads).

For the purposes of this Brochure a Diagnostic Test is a “comparative test of the characteristic parameters of equipment to verify that it performs its functions by measuring one or more of these parameters” [4.4.3] and monitoring is the “activity, performed either manually or automatically, intended to observe the state of an item”.

The success of such monitoring techniques will be determined by the development and implementation of diagnostic sensors and techniques that can be applied to GIS and allow either periodic or continuous monitoring of the equipment. Additional benefits, such as reduced project programmes, may also be possible by applying diagnostic sensors and techniques during the commissioning of GIS.

The development of monitoring and diagnostic techniques for GIS has been going on for a number of years. Working group B3-02 has closely followed this activity and produced "state of the art" review papers on the application of monitoring techniques in GIS [4.4.4] [4.4.5] as well as on the possibilities to apply new types of sensors for current and voltage measurement [4.4.6]. A great deal of experience on various sensors as stand alone devices has been collected during the last 10-15 years. The adaptation of sensors to the conventional electro-mechanical systems used for control and protection of substations has, however, been complicated and made such solutions rather expensive. Currently, digital microprocessor based systems for control and protection are being introduced on a broad basis. There is also considerable activity and progress being made in the development and application of diagnostic and monitoring tools for GIS. This intense development coupled with ever improving signal processing capabilities are providing interesting opportunities for new, cost effective monitoring techniques.

As well as providing a review of the diagnostic sensors which are becoming available including their properties, advantages and disadvantages this paper will give guidance on what factors should be taken into account when assessing the different sensors for use in fault location, fault prevention and maintenance prediction systems.

As well as developments in GIS equipment monitoring and diagnostics, parallel developments are taking place in the substation control and protection systems which are influencing the way equipment will be operated in the future. New digital based control and protection systems are capable of handling, monitoring and communication functions which open exciting opportunities for system integration and increased functionality. These opportunities create several possibilities for how monitoring functions can be integrated with implications in the structure of control and monitoring systems and indeed the design of the control equipment local to the GIS. Guidance is given on the factors which will determine the integration, location and communication methods for these monitoring, control and supervisory functions and hardware.

The introduction of new sensors into GIS equipment, whether for monitoring and diagnostics, enhanced functionality or to replace conventional type current and voltage transformers will influence the design of the GIS itself with sensors being integrated into the equipment design to ensure that the availability of the GIS is not reduced by the introduction of a sensor. Self checking for monitoring systems and circuits will also be necessary to safeguard equipment availability.

#### **4.4.2 Requirements for Monitoring**

As reported in [4.4.1], [4.4.2] the high number of respondents favouring monitoring and diagnostics who participated in this particular GIS survey indicates the level of interest of users in this subject. The monitoring of GIS, or any other type of switchgear, is not a new requirement or practice, however the extent to which monitoring is being applied, and the new opportunities available, does represent a change to traditional methods. Some of the ways in which monitoring can be applied are as follows;

##### **1. Equipment Status**

The most conventional and simplest form of monitoring covering the operational status of an element of GIS. A typical example would be circuit breaker position status monitored using a mechanically driven auxiliary switch.

##### **2. Primary Voltage and Current**

The most common devices used on GIS are iron cored ring type current transformers mounted either internally or externally to the GIS enclosure and electromagnetic voltage transformers. Coreless transducers are now being applied to GIS in the form of capacitively coupled voltage sensors and current transducers based on either optical fibre devices or Rogowski coils.

##### **3. Diagnostic to Predict Maintenance**

The use of a predictive maintenance (or condition based maintenance) philosophy based on diagnostic techniques gives the GIS user considerable advantages as maintenance is only done when necessary rather than at specific time or operation intervals, also the opening of equipment simply to check on the condition of parts can be avoided. An example is that by monitoring the number and duty of switching operations a continuous assessment can be made of the condition of circuit breaker contacts, thereby enabling planned maintenance to be undertaken.

##### **4. Diagnostic to Prevent Failure**

By analysis of failure statistics it will be possible to identify those causes of failure or components which represent the most significant risk of failure for a particular GIS installation. Monitoring can then be targeted to identify specific defects which may occur in-service which were not detectable at commissioning. Diagnostic techniques can be specific such as spring charging time on a circuit breaker drive mechanism or generic such as partial discharge detection.

##### **5. Operation and Maintenance Support**

Temperature detecting sensors can be used to determine if equipment can be utilised at optimum loading levels to cover possible peak overload conditions. Also in the unlikely event of an internal fault in GIS the early detection of the point of failure can be critical in ensuring the rapid restoration of supply. Sensors can be applied, based on detecting pressure rise, which can locate the faulted section. This information is then used to support the system which restores supply, whether this is by remote switching or automatically based on artificial intelligence technology.

##### **6. Active Control**

The use of controlled switching to mitigate over voltage, transient and switching problems is increasing [4.4.7]. Devices which control the precise moment of closing or opening of a circuit breaker dependent on equipment status and system conditions require inputs from many sensors e.g. voltage waveform, mechanism pressure, ambient temperature, battery voltage etc.

##### **7. Commissioning Tests**

Sensors and diagnostic techniques can be used during the commissioning of GIS to ensure that the equipment is put into service in good condition. Such techniques can also minimise the severity of tests required during commissioning.

##### **8. Life Assessment**

As the age of some GIS extends towards 40 years so end of life determination will become of increasing interest. Sensors which give information on gas seal and insulation integrity may be of particular benefit.

#### **4.4.3 Philosophy of Monitoring**

GIS monitoring covers both periodic and continuous monitoring systems where the sensors, monitoring equipment and opportunities for integration can be very different.

### **Periodic Monitoring**

Techniques are carried out at intervals (regular or irregular), requiring human intervention, during the life of the equipment. These range from simple techniques such as SF<sub>6</sub> density monitoring to techniques which would require circuit outages i.e. main circuit resistance.

### **Continuous Monitoring**

These techniques can be applied throughout the life of the equipment without the need to have outages. Data (continuous in the time domain) can be available to give alarm signals, remote interrogation or simply information on the trends of the state of the switchgear.

The philosophy of monitoring determines the applicability of the sensor, for example a simple SF<sub>6</sub> pressure/density gauge, even with alarm contacts is inappropriate for continuous monitoring where a gauge would have to be replaced by a pressure/density transducer giving a continuous analogue or digital signal corresponding to the actual chamber density.

Periodic monitoring can provide much useful diagnostic data on the condition of switchgear, however it does suffer from the disadvantages that an intermittent problem may be missed as may a sudden deterioration of the equipment. Continuous monitoring can overcome these deficiencies together with the advantage that monitoring can be done remotely without intervention at the substation, thus saving valuable human resources.

Periodic monitoring can also be invaluable at the commissioning stage of GIS where additional measures are justified to ensure that the equipment is correctly installed. An example of such a diagnostic procedure is the application of partial discharge detection methods, either conventional, UHF (Ultra High Frequency) or acoustic, during the normal site commissioning high voltage test.

#### **4.4.4 Transducers and Sensors for GIS**

Existing iron cored ring type current and electromagnetic voltage transformers have been used since the introduction of GIS with little development. However it is now possible to use coreless transducers which can offer benefits in space, cost and more appropriate interfacing with developing secondary equipment technologies. Examples of direct optical sensors, based on the Faraday or Pockels effects, are already available as well as hybrid devices which have proven experience on AIS applications. For GIS particular opportunities exist for combined current/voltage sensors based on capacitive field sensors and Rogowski coils. All of these new sensor devices offer the GIS designer the opportunity to integrate the sensors into the primary hardware thus making the GIS layout more compact and provide greater freedom for choosing the optimum location for the sensor. The main restriction in the application of such technologies is the power requirements of conventional control and protection devices. As digital technology dominates so the use of non-conventional Current Transformers (CT's) and Voltage Transformers (VT's) will expand rapidly.

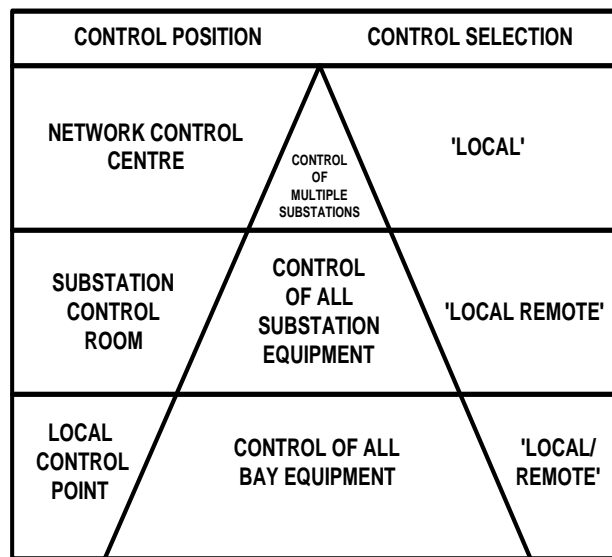
The trend towards the availability and use of a range of sensors based on modern technologies will continue and likely accelerate as the acceptance of new secondary equipment technologies becomes commonplace. Future sensors will offer even more opportunities for space saving, increased reliability and increased functionality. As sensors become readily available it will become imperative to develop a monitoring strategy which does not depend on the indiscriminate use of parameter specific sensors which generate vast amounts of information which requires processing. It is envisaged that sensors themselves will become "intelligent" and a hierarchy of parameter specific and general health checking sensors will develop. The parameter specific sensors will only become active, in terms of information generation, when the general sensors give the appropriate signals. This interactive use of sensors for monitoring will ensure that sensor application and information processing capabilities are optimised.

Users will require systems which provide simple information which is not subject to extensive interpretation, decision making for maintenance or operation needs to be based on information presented in a form which can be used at the operational level. Work is already being done on the use of expert systems in conjunction with maintenance and operation of GIS as reported in [4.4.8], this trend will continue with the emphasis being on providing the user with simple, unambiguous, but above all, usable information.

#### **4.4.5 GIS Control**

The current method of monitoring and controlling a GIS substation is generally through a hierarchical structure as represented in Figure 4.4.1. A range of possible architectures are given in [4.4.9]. Essential parameters are measured at plant level and will initially initiate alarms to warn of the problem and then initiate lockouts should dangerous levels occur. Alarms are arranged to be

progressively grouped the higher up in the hierarchical structure, thus an initiated alarm in the substation control room will give the general area of the problem but will require maintenance personnel to inspect the local position to establish the exact cause.



**Fig 4.4.1 Hierarchical Control Structure**

The control function of a substation is based on the hierarchical structure and is dependent on handing control up to the next level with the ability of "grabbing" control at a lower level. At the Local Control Point (LCP) all plant items for a particular bay can be operated if "local" has been selected at the LCP. Within the substation control room all plant items for a bay can be operated if control at the LCP has been selected for "remote" operation. Control at the "Network Control Centre" of a number of substations is possible if control selection at the lower levels are selected for "Remote" operation.

The current practice is for the Local Control Points to be placed adjacent to the primary equipment with one cubicle being allocated per bay of GIS. The LCP is also the interface between the primary and secondary equipment. The relays associated with the SF<sub>6</sub> gas density and mechanism pressure are housed within the LCP together with the control contactors for the primary equipment. In addition, the LCP is the secondary interface between adjacent bay LCP's and the substation control/protection room. Electrical connections between equipment/LCP/control and protection room are made with copper multi-core cables, however, progressive steps are being made to replace these cables with fibre optic cables. This has been achieved by the use of digital control equipment replacing some of the conventional equipment in the LCP and substation control room. The fibre optic cable enables serial transmission of information compared with the parallel transmission of multi-core cables. The fibre optic cables make connections between adjacent bay LCP's and bay LCP to substation control room.

The trend is for digital control and protection devices to become smaller and more powerful. At medium voltage technologies the integration of the complete set of control, supervision and protection functions in a single discrete unit has already been achieved.

At high voltage GIS it is not yet possible to rely on a single unit due to requirements for organisational redundancy; however the trend is in the same direction. A discrete hardware unit will contain interlocking, control and protection functions. There will only be a need for more than one device to satisfy safety and redundancy requirements, although perceptions of these requirements may change when very high reliability figures are achieved on such integrated units. The dedicated tasks of such devices will be determined by software systems.

On the other hand the nature of the control and supervision of the GIS will also change. Intelligent electronic subsystems, e.g. for the control of circuit breakers, SF<sub>6</sub> gas analysis and other diagnostic purposes, containing new sensor technologies promise many benefits in the future.

The flexibility of the controller units becomes increased and the variety of hardware is reduced as software solutions with parameter assignments replace hard wired functions. Today hundreds of copper wires connect the switchgear and sensing devices with the control and protection systems at

bay level. This copper wiring is prone to be replaced by digital serial links (process busses) as are already practised in many other process automation applications.

This lowers the costs for engineering, assembly and commissioning of the switchgear significantly. The communication paths are by necessity the subject of standardisation and has been addressed by the new standard IEC 61850. This trend is diagrammatically represented in Figure 4.4.2.

With the spread of IEC 61850 solutions this itself will help promote the integration of Control, Protection and Monitoring functions within GIS solutions.

Future power system control provides new features like telecontrol and teleservice by means of intelligent information management and data transfer. This allows those who are responsible for maintenance to use remote service features (dial in) and to establish new event driven maintenance strategies. Remote diagnostics and auto-resetting of alarms could offer attractive benefits with a much reduced reliance on "standby men" whether these are employed by a utility or some other organisation. The real time acquisition of data on the operation and performance of the GIS will also be of potential benefit to the manufacturer as well as the user.

In an intelligent system, as envisaged above, the primary and secondary equipment become closer together. Up to a rated voltage of 300kV it will be possible to assemble and test complete GIS bays including all primary and secondary equipment in the factory. Shipment, assembly and commissioning of complete bays will lead to shorter delivery lead times and significantly lower costs with higher quality.

In all new trends the demand for more cost effective solutions dominates and determines the success of an approach. Competition in the electricity market is becoming more intense for suppliers of power and equipment manufacturers, therefore expensive leading edge technologies such as expert systems are only acceptable when there is a quantifiable benefit of a return on investment. One example could be the optimised utilisation of equipment at peak loads by means of continuous data acquisition and relatively complex models in order to gain the required performance level with appropriate factor of safety.

The most challenging application of new sensors is the measurement of currents and voltages. Up to now a real breakthrough in technology has not been achieved, one of the reasons for this has been the lack of a suitable transportation network for the measured values that is now being provided by integrated systems.

#### **4.4.6 IEC 61850**

Today, for substation communications, there are a large variety of protocols. In order that devices running on different protocols may communicate, protocol converters are used. However, protocol converters can cause errors in the messages and introduce delay. The large number of protocols leads to high development expenditure on the part of the manufacturers and high operating and maintenance costs on the part of the utilities.

Since 1995 three IEC working groups have been addressing these issues. The response is the creation of the single, global and future-proof standard for substation communications, IEC 61850 [4.4.10]. The objectives for the standard being:

- To cover all the information in a substation.
- Openness for extension of the information to be communicated in the future according to the principle: All that are known are incorporated, and any future applications can be filled in according to the set rules.
- Openness for future high-efficiency data transfer.
- To promote the idea on interoperability in systems.

The standard is now ready. Utilities and manufacturers have been involved in the standardisation work since the beginning, and have taken part in pilot projects and interoperability tests. First orders of substation automation systems compliant with IEC 61850 are being implemented.

The advantages that IEC 61850 can deliver are:

- Defines one protocol for the entire substation
- Fully supports all substation automation functions comprising control, protection and monitoring
- The architecture is future-proof and facilitates future extensions, therefore it safeguards investments
- Is a worldwide applicable and accepted standard - the single key to interoperable solutions
- Defines the quality requirements (reliability, system availability, data integrity, security, etc.), environmental conditions, and the auxiliary services of the system
- Specifies the engineering processes and its supporting tools, system life-cycle and the quality assurance requirements and maintenance for the entire substation automation system
- States the conformance tests to be carried out on the products
- The flexibility allows optimisation of system architectures (scalable technology)
- Uses readily available industrial Ethernet and communication components
- Facilitates a utility-wide common communication infrastructure, from the control centre to the switchyard

The philosophy of a future-proof standard are based on

- Object-oriented communication
- Separation of application related functions from the communication methods
- Manufacturer-independent information exchange for configuration of the automation system.

Object oriented communication is the present trend in software and hardware. Each object is a function or part of a function, and the object exchanges data with other objects so that the function may be executed.

Substation automation has benefitted from the computer technology, particularly communication technology. While processor speed doubles every two or three years and when data transmission rate increases by a factor of ten, the underlying automation functions and the data involved hardly change. For example, for decades, an overcurrent function has had the current as input data and the trip signal as output data, accompanied by configuration data such as current and time settings. In order that substation automation may be able to take advantage of technological changes, the data are standardised in IEC 61850 and are independent of the communication method, which is separately standardised in IEC 61850.

Models have become an indispensable part in engineering but they take many forms. A model generally provides some information about a piece of equipment or a process. For a transformer, the equation. In substation communications, a model which lists the input and output data of the transformer is called the data model.

For each function, IEC 61850 has a data model. A data item has a name which comprises three standardised parts namely, the logical node, the data object and the attribute. There are approximately 90 logical nodes in IEC 61850.

In a substation automation system, some data are time-critical but some are not. Time-critical data include for example trip signals for circuit breakers and start signals for disturbance recorders. An example of non-time-critical data is the changes of device settings. Time-critical data need to be sent quickly while non-time-critical data have lower transmission priority. IEC 61850 defines a set of generic services which can meet the requirements of all kinds of anticipated data in a substation with regard to speed of transfer, accuracy and security.

Generic Object Oriented Substation Event (GOOSE) is a fast service. The high speed is achieved by means of connection-less communication and the security of data transfer is assured by repeating the message many times. File Transfer is a service for moving large data blocks such as programs and fault records.

The data models and services are mapped onto a real communication stack. The stack comprises now the Manufacturing Message Specification (MMS), Transmission Control Protocol/Internet Protocol (TCP/IP) and Ethernet. Data models and services models do not change much with time, but communication technology may. When communication technology changes, the data models and service models will be mapped on to a new real communication stack. This leads to the minimum changes not only in the standard but also in the substation automation system.

#### 4.4.7 Integration of Control, Monitoring and Protection

This section addresses the question of how to integrate monitoring, control and supervision functions in order to achieve benefits of increased reliability, reduced cost and increased functionality. Recent CIGRE failure and reliability surveys [4.4.1] and [4.4.2] amply demonstrate that new philosophies are required with a high proportion of all equipment failures being caused by conventional auxiliary and control circuits, unavailability of equipment due to such reasons is no longer tolerable.

The advanced systems comprise sensors for supervision of all important functions, as well as sufficient capacity for processing of the collected information. This offers a number of benefits, most of them contributing to an increased efficiency of in-service routines. In this subsection those blocks are identified where the biggest changes are to be expected and which options will be possible.

**Intelligent or smart circuit-breakers:** The heart of such devices is an intelligent breaker subsystem performing all control and supervision tasks. This intelligent subsystem is also an ideal platform for all monitoring and diagnostic tasks, including self supervision of the system. This intelligent breaker subsystem allows also the option of permanently available controlled switching which can easily be realised due to the available computational power. Synchronous closing has the potential of substantially reducing the cost of the circuit-breaker by means of eliminating the need for closing resistors in most cases. Furthermore, this technique will decrease the stresses on the breaker and, as a result, increase the reliability and maintenance intervals. Synchronous opening reduces the contact wear and the voltage stresses on breaker and network, a more detailed description is given in [4.4.6]. In providing such features one will have to consider the lifetime of equipment and as a result changes to the design might be appropriate.

**Current and Voltage Measurements:** Sensors for current and voltage measurement require very little space compared to conventional instrument transformers and are also potentially less costly. The voltage sensors have a very simple shape and are not likely to cause service problems as sometimes encountered with conventional voltage transformers. However the new sensor technologies provide measured values at very low signal level. Therefore new high speed communication systems are to be used for the transportation of these current and voltage values as discussed below.

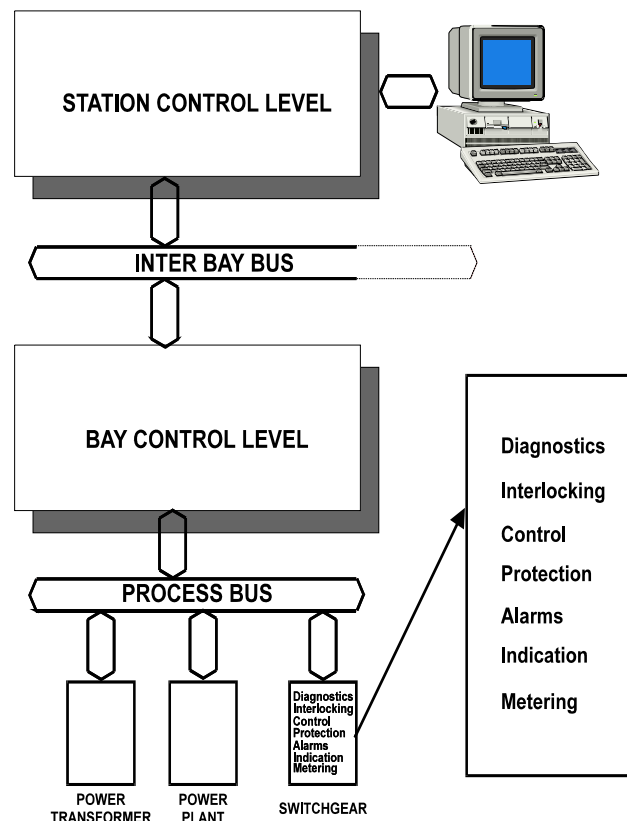
**Integration:** The primary as well as the secondary parts of the advanced GIS will be more compact thanks to the application of new technologies. In most cases complete bays can therefore be assembled and tested in the factory, including secondary functions.

The integrated system provides interesting possibilities to increase the functionality at limited extra cost. This comprises new functions related to the procedures for maintaining the installation as well as new functions performed by the installation, such as controlled switching. Intelligent station control and protection functions will also enable to strategically optimise the redundancy requirements for primary hardware in the network and to increase the effective use of power generation, transmission and distribution systems.

One main idea in the integrated system is to maximise the decentralisation of the intelligence. This idea will be realised in the form of intelligent units (circuit-breakers, disconnectors and so on) with built in sensors, actuators and microprocessor based sub-systems. Each intelligent unit is able to handle all the command, control, monitoring and diagnostic tasks as a stand alone unit. One important reason for the decentralised intelligent units is to avoid standardisation of functions distributed across the interfaces. The more complex calculations and processing required for trend prediction, statistical analysis etc. can be better done centrally, remote from the primary equipment. The integration of diagnostic features is now achievable with or without minimum additional hardware costs, with most diagnostic features being able to be pure software solutions. New algorithms can be easily added later with new software releases to the existing intelligent hardware units. The backbone of this integrated system will be a new process bus linking all the intelligent units of one bay, Figure 4.4.2 illustrates the process bus within the architecture of the overall system. The process bus is of course an area for standardisation.

High speed digital links are also needed for the communication of voltage and current signals. It may be desirable to combine these links with the process bus. However the data transfer rate for currents and voltages is necessarily high. Nevertheless at least low level solutions will need to be discussed that combine both interfaces within one physical medium.

**Self Testing Systems:** The availability of self checking electronic devices is considerably higher than the availability of periodically manually checked devices. This is due to the fact that in the case of self checking improper functions are detected immediately. Today both hardware checks by software (e.g. plausibility tests) and software checks by hardware (e.g. watchdogs) are achievable. This is demonstrated successfully in modern digital relays.



**Figure 4.4.2 Process and Substation Communication Buses**

**Conclusion**

As well as the described developments in GIS equipment monitoring and diagnostics, parallel developments are taking place in the substation control and protection systems which are influencing the way equipment will be operated in the future. New digital based control and protection systems are capable of handling, monitoring and communication functions which open exciting opportunities for system integration and increased functionality. These opportunities create several possibilities for how monitoring functions can be integrated with implications in the structure of control and monitoring systems and indeed the design of the control equipment local to the GIS.

As well as influencing the design and operation of GIS the changes which are occurring are having an impact on the organisation and operations of users together with the relationships between manufacturers and users.

Future opportunities for application of advanced technologies in GIS are likely to rapidly grow as the pace of technological advances continues to increase. The limiting factor in their application is likely to be the historical conservatism of the Electricity Transmission industry. It is envisaged that in some respects the development and increased application of more sophisticated sensors and monitoring systems will follow the type of route which has evolved on such areas as position indication on GIS Disconnectors and Earth Switches. Initially such provision was made with a system replicating AIS philosophy, i.e. viewing windows. Since then mechanical indication has now become favoured and electronic indication is becoming accepted as reliability concerns are overcome. In the same way

reluctance to apply sensors and other technologies to GIS will be reduced as reliability is proven and the benefits of the technology are demonstrated.

The real benefits to the user, which have been summarised in this section, will ensure that the application of advanced technologies to GIS continues. Many of the issues discussed apply to not only GIS but also AIS equipment, the developments involving these two substation technologies will therefore continue to be closely linked in terms of the further integration of secondary technologies.

## References

- [4.4.1] Kopejtkova, Molony, Kobayashi and Welch, "A Twenty-Five Year Review of Experience With GIS» CIGRE 1992 paper 23-101.
- [4.4.2] "Final Report On the Results of the Second International Inquiry Into Circuit Breaker Reliability" CIGRE Brochure No.83
- [4.4.3] IEC 60050 (1982) International Electrotechnical Vocabulary (IEV)
- [4.4.4] Vigreux et al, "Application of Condition Monitoring Techniques in GIS" ELECTRA No. 134, Feb 1991.
- [4.4.5] Jones et al, "Guidelines for Monitoring, Control and Supervision of GIS Incorporating Advanced Technologies" CIGRE 1996 paper 23-104
- [4.4.6] Holt, "New Principles for Current and Voltage Measurement and Aspects of Application in GIS" ELECTRA No 121.
- [4.4.7] Harner et al "Controlled Switching" ELECTRA No 162, 163
- [4.4.8] Dijk et al, "Advanced Control and Expert Systems for Substations" CIGRE 1994 paper 23/13-08.
- [4.4.9] Pederson et al on behalf of 23-05 "Possible Architectures of Future Control Systems Based on Computer Technique" paper 34-89 Bournemouth Symposium 1989.
- [4.4.10] IEC 61850 (2003) Part 1 Introduction and Overview

## 4.5 Mobile substations

### Application and Execution

Relocatable equipment is considered as GIS of variable layout which can be moved to new locations of use and service with little dismantling, assembly and commissioning effort.

Relocatable or moveable GIS are needed for temporary distribution of energy in cases when the planning and execution of substations is not able to follow the need for local energy supply, as a temporary means of supply during network upgrading, for rebuilding of substations or in cases of emergency.

Relocatable equipment consists of switchgear bay(s) consisting of standard or adapted GIS components equipped with bushings for overhead connections, cables, local control/metering/protection and optionally power transformers. High-output voltage transformers may be used as AC source for start-up procedures if the auxiliary voltage is dependent on the high voltage supply.

The control/metering/protection is adapted to the system needs of the user.

The GIS solution is normally mounted on trailers, platforms or structures that allow for road transportation. For railway application it can be mounted on special freight cars.

The single line diagram depends on the particular needs of the user and may be simplified as it usually consists of only one bay or few bays with a single busbar arrangement. The simplification

includes omission of switching components, reduced number of gas compartments and use of AIS components like dead-tank type current transformers.

The GIS is normally completely factory assembled and tested including control, metering and protection with the possible exception of bushings for reduced site commissioning testing. Usually relocatable GIS are designed for outdoor application.

**Relocation design measures:**

The design of relocatable GIS has to consider the requirements of easy disconnection and preparation for transport, the transport conditions and reconnection and re-commissioning at the new site:

- Transport profiles and dimensions of the area of intended use
- Transport accelerations
- Transport weather proofing
- Simplified transport preparations e.g. removal of bushings or cables (by the use of plug-in cable interfaces or fixed cables on drums) avoiding opening of gas compartments as much as possible.
- Optional facilities to store the SF6 gas of the compartments during the transport
- Plug-in type secondary connections for control, metering and protection

**Commissioning:**

Due to completely factory-tested delivery to site the commissioning tests can be reduced. They are aimed to locate transport damages and to assure safe function of the high voltage equipment including control, metering and protection:

- Gas tightness of seals reassembled at the new location
- Gas density of refilled compartments
- Humidity of opened gas compartments
- High voltage testing of opened gas compartments (normally omitted for simple static connection and with careful visual inspection)
- Functioning of reconnected control, metering and protection

**Maintenance:**

Due to the usually limited duration of service the maintenance is limited to the prescribed periodic inspections. Preventive maintenance can usually be planned for no service periods or during relocation.

**Conclusion**

This type of equipment has been used for a long time for very special applications. Due to changing needs of users initiated by the liberalization of the electric energy market increasing opportunities for such applications are expected.



**Figure 4.5.1 Mobile 145kV 40kA GIS Installation (4 bays)**



**Figure 4.5.2 245kV 50kA Mobile Installation (1 bay)**

#### **4.6 Solutions Providing Enhanced Substation Security and Personal Safety**

The solutions providing enhanced security and safety by GIS as well as some of the safety issues regarding the implementation of GIS solutions will be discussed in this section.

##### **4.6.1 GIS Solutions Delivering Enhanced safety and Security**

As discussed in Section 2.7 it will become increasingly important for substation solutions to provide even higher levels of security and safety in the future to:

- maintain the availability of the power supply

- prevent public access to the plants, for the purpose of safety for general public, vandalism and inquisitiveness
- protect other parts and components in a substation against violent deterioration of high voltage equipment caused by failures
- prevent and minimise the risk of sabotage and war actions
- prevent financial risk due to occurrences mentioned above

GIS is inherently suited to provide these higher levels of security due:

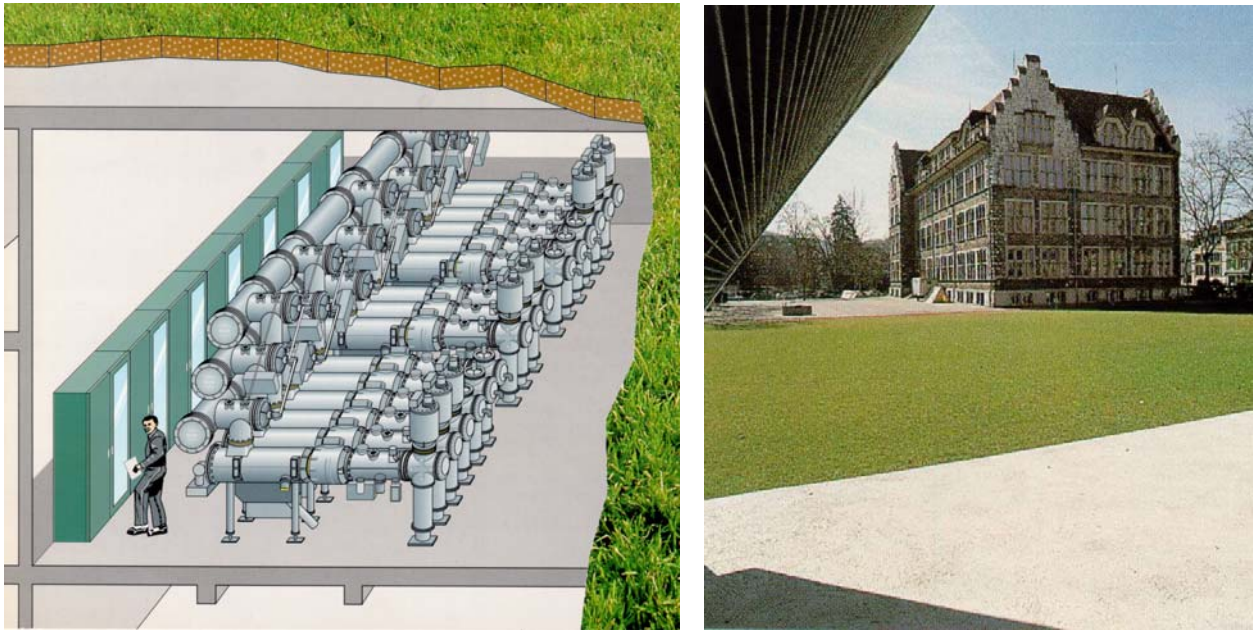
- Increased reliability and availability compared to AIS and other solutions which result in increased levels of availability of power supplies.
- As all conductors are enclosed in earthed metal enclosures it is impossible for casual intruders to accidentally come into contact with high voltage connections. This same design feature also means that the risk of accidental electric shock for employees is eliminated compared to conventional switchgear designs.
- Due to the compact nature of GIS it is easy to install the equipment completely inside a building. Particularly in urban environments this is useful to ensure:
  - The substation can be hidden from view and possible targeting for attack/vandalism
  - Unauthorised entry into the substation can be prevented and entry only allowed when all safety issues are completely satisfied.
  - A building is much easier to secure from intrusion or attack compared to an open substation
- No pressurised porcelain or other potential risk of explosion due to failure of insulation. With use of complete SF6 insulation risk of oil explosion/fire can also be eliminated.

One typical examples of a solution delivering enhanced safety and security is illustrated in Figure 4.6.1.

#### **4.6.2 GIS Safety**

Metal enclosed high voltage switchgear GIS (Gas Insulated Switchgear) in accordance with IEC 62271-203 offers a high level of safety with regard to external effects that might harm personnel, mainly because the high voltage parts are surrounded by a grounded metal enclosure. Nevertheless, GIS, like other high power equipment, has some potential risks that have to be taken into account:

- The enclosures are pressurised, containing a varying amount of SF6 gas.
- Although very rare, internal arcs may cause opening of pressure relief devices or, in extreme circumstances, burn through the enclosures — both result in the sudden release of hot gas.
- External sparks caused by VFT (Very Fast Transients), which are in them harmless to humans due to low energy content, may alarm personnel leading to accidents (e. g. a fall).
- The equipment may be complex and the active internal parts are mostly not visible. There may be increased risk during commissioning, maintenance and extensions — experience has shown that human error is an important factor that must be considered (e. g. closing a ground switch on an energised conductor or closing a live disconnecter on a grounded section).



**Figure 4.6.1 Underground Substation in School Grounds (below and above ground views)**

Some of the precautions implemented by manufacturers include:

- Design and test of pressurised enclosures, pressure relief devices and relevant switchgear elements to international electrical standards such as IEC, ANSI, CENELEC, and JIS.
- Provide adequate and easy to check interlocking systems (the most reasonable way to avoid human error).
- Explain safe operation of the switchgear clearly in instruction manuals. Explain precautions to prevent improper operation and the consequences of improper operation.
- Provide the user and/or contractor with appropriate information related to design of the surrounding area and, in the case of indoor GIS to building size, ventilation and gas detection information, to minimise personnel risks in case a failure occurs.

Measures and practices are also introduced by utilities:

- Limit access to the installation to people who are trained and authorised.
- Keep operators and other personnel instructed regarding risks and safety requirements.
- Keep switchgear maintained and up-to-date in terms of technical standards, especially interlocking and protection devices.
- Use remote control and have the interlocking system working as intended and forbid the use of interlock bypass keys on energised GIS.
- Select equipment that minimises the risk to personnel from improper operation (e.g. fast acting ground switches on lines, motor operated drives to allow remote operation).
- Co-ordinate the protection system with GIS properties (e.g. do not reclose on internal faults)
- Label equipment clearly for easy identification of individual devices and gas compartments.
- Prepare grounding procedures considering the difficulty of seeing and understanding the complex arrangement and operation of the GIS.

There are some particular risks during maintenance, repair or extension work that require special measures such as:

- Prepare a safety and protection plan for the work. Indicate clearly who is responsible for planning, implementing and enforcing safety and protection measures.
- Check interlocking and protection devices before starting.
- Pay special attention to gas handling and manual operations — especially when the GIS is energised.
- Inform personnel who may be near the GIS before operating the equipment (e. g. a horn or flashing light).

- Mark emergency exits, keep passages clear of obstructions and provide emergency equipment.
- Instruct the involved people how to work safely in a GIS environment and what to do in an emergency.

Further additional information can be found in the SF6 publications issued by Working Group B3-02 including User Guide for GIS [4.6.1] and SF6 Recycling Guide [4.6.2].

### Conclusion

- Indoor GIS is inherently better protected from external effects and attacks. With the increasing security issue GIS is expected to be used increasingly in densely populated areas.

### References

[4.6.1] "User Guide for GIS" CIGRE brochure 125 (1998)

[4.6.2] "SF6 Recycling Guide" CIGRE brochure 117 (1998)

### 4.7 Reduction in BIL Levels

For system voltages which are less than or equal to 420 kV and especially in the range below 300 kV there is a margin for substantial insulation reduction, as can be seen in Figure 4.7 below. This reduction should be possible without lowering the current reliability / availability of the network.

A survey was made by CIGRE WG 33-10 "Temporary overvoltages TOVs" concerning utilities' choice of arrester rated voltages and insulation levels (ELECTRA article Aug.99) the results of which are shown in the figure below. As TOVs are decisive for choosing the arrester rated voltage they will also be decisive to a large extent for the choice of insulation levels.



Figure 4.7 Quotient between LIWL and the highest voltage (HV) for equipment phase to earth

From Figure 4.7. it can be clearly seen that the standardised insulation levels for solidly earthed systems are extremely high even at the bottom end of the range and the utilities seem to avoid these lower levels.

It can also be seen from the fig. that the margins between the arrester protection level and chosen insulation level are also very generous making the lower standardised insulation levels perfectly viable. Still lower levels could be discussed for the lower end of the system voltages. However, when considering further reductions it must be borne in mind that for system voltages in the range  $\leq 245$  kV the IEC standard 71 Insulation co-ordination states the same insulation demands phase to phase as for phase to earth. It may be necessary to include special phase to phase impulse type testing if further reductions below the minimum currently recommended values are to be pursued. With regard to the impact of these changes on GIS it is not likely that this will lead to significant reduction of size but could allow the use of reduced gas pressures and hence less SF6 utilisation which could be a major benefit with the present environmental issues.

### **Conclusion**

Despite the fact of higher safety margin between LIWL and power frequency voltages at the lower rated voltage levels the trend towards a systematic reduction of the BIL is not visible at the moment but the potential for cost reduction may initiate activity in this area in the future.. It should be noted that the new IEC 62271-203 has eliminated the lower level options for BIL levels for GIS which may restrict any future movement in this direction.

## **4.8 Developments in Design, Materials and Manufacturing Technology**

### **4.8.1 Design Techniques - GIS Equipment**

In the past the development of switchgear, in particular circuit breakers, was a very empirical process. Ideas were analysed using the best techniques available but real progress was made during the development testing phase of a development. Increasingly the use of analytical techniques has increased as theoretical knowledge and computer processing power has increased. The result is that the old empirical approach is disappearing such that new GIS developments are developed on the CAD (Computer Aided design) workstation and only realized once extensive analysis has been completed. This results in a process which much better matches today's commercial needs, less time, less cost and less engineers.

Another implication is that the need for extensive development testing is reduced, however this reduction in development testing is being replaced with increased requirements for type testing. However one difference between the development tests and the type tests is in the objective of the tests. In a development test the objective is to verify a design by exploring the limit of performance, to actually take the equipment to the failure point and understand the consequences. On a type test the objective is to verify the design against a set of normalized criteria. The result is that the supplier and the user may have less knowledge about the performance of a design than was the case in the past, despite the improvements in analytical modeling.

Another set of tools that are enabling more rapid and "right first time" product development to be achieved is the use of rapid prototyping techniques. Here the CAD model of a component is brought directly to realization using a number of different techniques such as stereo-lithography. This enables aesthetic as well as ergonomic issues to very quickly assessed as well as the potential for rapid production of moulds and patterns for cast or formed components. Such techniques are invaluable to ensure that type tests are performed as early as possible, using components manufactured with the identical processes that will be used in production.

In the future the development of a new type of GIS is likely to become even more of a multi-disciplinary process than it has been. This is due to the increasing integration between primary and secondary equipment as well as the need for closer collaboration on other items of the GIS substation such as cables, transformers, civils etc.

Within these multi-disciplinary teams will also be an increased involvement of specialist suppliers. GIS producers now do less manufacture of components than they did in the past and rely on specialist suppliers for items such as GIS enclosures and cast resin insulation. This requires the GIS designer

and supplier to work very closely together if the full advantage is to be taken of the capabilities of the specialist supplier.

#### 4.8.2 Design Techniques - GIS Substations

As with the design and development of the GIS components themselves the process of substation design for particular customer application is also being changed by the availability of new design techniques. The shorter project timescales needed today demand that techniques are developed to maximize the use of standardized modules, automate certain design functions and improve visualization of final solutions so that designs can be optimized in a rapid way.

The design features of GIS are mainly driven by the use of SF6 within the power energy supply. The state of the art shows single phase and three phase encapsulated designs. For the distribution voltage level mainly three phase enclosures are used. For higher voltage levels single-phase encapsulation is a standard. In the last years the development of SF6 insulated switchgear was mainly driven by the aim to reduce the use of material and costs but still retaining extremely high reliability.

Main steps of the development were as follows:

- progress of circuit-breaker technology, which allows a reduction of the number of interrupter units despite increasing breaking capability
- progress of casting and machining technology of aluminum cast parts, which allow the use of minimized shapes and volumes
- use of computerized production and testing equipment with high quality standards
- design of integrated components with several functions like disconnections and grounding switches within one gas compartment
- use of intelligent monitoring and diagnostic tools to postpone maintenance activities and to avoid unnecessary tasks

As a result very compact substations designs are on the market with the following changes against older equipment:

- up to 98% of space reduction in comparison to air insulated switchgear
- up to 75% reduction of SF6 volume
- delivery of completely sealed and tested bay units up to 245 kV
- leakage rates down to less than 0.5% per compartment and year

A typical development of some of the GIS features can be seen in the next graph:

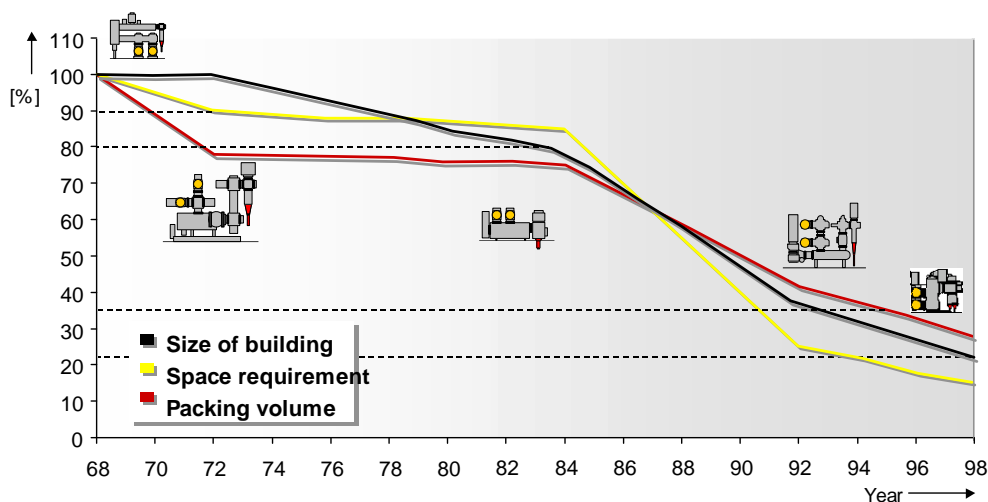


Fig 4.8. Progress of GIS Development (Example 145 kV)

The already reached mean time between failures according to international statistics [4.8.1] has reached levels of 400 to 1000 years dependant on the kind of switchgear and its voltage level.

The importance of quality and reliability of all kind of switchgear equipment has become an ever increasing topic over recent years. Quality and reliability is the result of a complex process which includes manufacturing, delivery and erection and after sales service.

However quality and reliability have to be already an integrated part of development activities. Reliability starts with the right design, followed by the choice of the suitable material, using the relevant testing procedures and the appropriate manufacturing techniques and all that accompanied by a stringent quality control. So future oriented methods of development e.g. by using the very latest procedures for computer aided design, optimization of parts and components and failure mode effective analysis (FMEA), dynamic calculations of arc extinction and drive behavior accompanied by quality checks are well known methods to achieve the customers expectations.

After the design stage, materials and components are subjected to thorough development tests. In this respect particular significance is given to long-term strength even at extremely high numbers of operations, as well as resistance to all kinds of environmental influences. Due to the dominance of mechanical failures, major components like drive mechanisms are tested on test rigs independently of the switchgear but using the previously measured loads given as stress level. Thousands of operating cycles will be performed in just a few hours. In this way the components can be subjected intentionally to a higher load than encountered in the switchgear itself in order to determine their safety reserves. This method of testing has been proven for contact systems, operating rods, drive components etc. and has enabled considerable improvement in their reliability.

These development tests will be followed by prototype testing comprising mechanical, power, dielectric, heat run and environmental tests even such as seismic testing, up to the limits, on several test objects in parallel.

Fortunately the continual development of software models and processing power suggests that the advances made will continue. The result for the user is not a standard solution but a customized solution that is composed of standard elements.

#### **4.8.3 Materials for GIS Equipment**

As far as GIS is concerned the key materials can be broken down in to a) Insulation, b) Enclosures c) Gas sealing d) Current carrying/contact. Briefly looking at each of these in turn:

##### **Insulation**

Other than SF<sub>6</sub> gas which is discussed in Section 4.2 the main insulation is the solid insulation system used for busbar support and gas zone segregation. Due to specialized and demanding requirements for such insulation (high mechanical as well as electrical strength) there has been relatively little development in the insulation systems used in high voltage GIS. Most developments have been in the adaptation of the insulation systems to allow improvements in the production process. Such developments are likely to continue but we should also expect a change in the basic formulation of the solid insulation systems used. The drive here will not be to reduce dimensions but to reduce costs and facilitate manufacture.

##### **Enclosures**

Materials for GIS enclosures have since the first designs been based on either steel or aluminum. The method of production has changed based on either fabricated vessels for steel or for aluminium cast, fabricated or a combination of the two. The choice of material has been driven by:

- The design of the GIS (single or three phase encapsulation)
- Size and complexity of enclosure
- Economics of production and relative costs of raw materials

Presently most GIS is based on aluminum enclosures with various combinations of cast and fabricated designs.

In the future, like the past, the economics of production which material and manufacturing technique is applied to enclosures. We should also anticipate that there may be some developments in the use of composite materials for enclosures and possibly the use of adhesive technology as an alternative to welding on fabricated vessels.

##### **Sealing technologies**

As discussed in previous sections there is a continual need to improve the performance of the sealing technology on GIS equipment. This applies to both static and dynamic SF<sub>6</sub> gas seals.

Whilst modern seal performance is excellent there is a need to improve this performance to meet growing expectations of lower and lower leakage rates on equipment. Also with the expected lifetime for the equipment and maintenance intervals increasing there is a need to improve seal performance.

It is likely that seal technologies and materials developed for other industries could be applied to GIS equipment to achieve static seals that are effectively "sealed for life" whilst at the same time providing flexibility if maintenance is necessary.

#### **Current Carrying/Contacts**

Already a wide variety of busbar materials and contact materials and designs are used on GIS. Alternative approaches to achieve high performance, minimum deterioration in a low cost and simple way to assemble are likely to be developed, limited only by the ingenuity and skill of the GIS designer.

#### **4.8.4 Manufacturing/Production of GIS**

The requirement for reduced project delivery timescales means that increasingly GIS suppliers are looking for ways to shorten the GIS process for engineering, procurement, assembly, test and site installation. One key way to achieve this is to have modular designs of GIS using standardized components that minimize stock holdings and allow a rapid response to customer needs.

Suppliers are moving to a production process that concentrates more on design, assembly and test rather than also including manufacture. It is not possible for a GIS supplier to maintain capital investment in all the machine tools necessary for low cost component production, hence the reliance on networks of specialist suppliers who each achieve excellence in their chosen specialist area. This philosophy will also allow the possible transfer of technologies from one industry into GIS without the need for the GIS supplier to invest in the manufacturing technology, the GIS supplier simply changes from one supplier to another.

It is clear that suppliers will explore other ways of reducing costs through joint collaborations in areas of R&D, production, procurement etc. The nature of such collaborations are impossible to predict but other industries e.g. the automotive platform concept provides an example that could be followed.

Finding suppliers of components now involves not just looking for suppliers close to the GIS production facility. Suppliers have to be sought on a global basis in order to achieve the right level of technology as well as competitive prices. Furthermore GIS production is becoming more widespread with facilities being established in certain key markets, close to the customer. A truly global base of component suppliers is needed to feed these GIS production facilities.

#### **Conclusion**

Developments in the use of new materials with reduced environmental impact including end of life treatment, design and manufacturing techniques will continue and no doubt accelerate as parallel developments enable the more rapid application of new technologies.

The adoption of these new technologies will of course still be driven by the need to deliver GIS solutions that are:

- More compact
- More reliable
- Safer
- Environmentally friendly
- Lower cost

#### **References**

- [4.8.1] Kopejtkova D. at all. „Report on the 2<sup>nd</sup> international survey on high voltage gas insulated substations (GIS) service experience” CIGRE Technical Brochure No.150

## 4.9 Fault and Normal Current Ratings

### **Introduction:**

The ratings of GIS are defined by the manufacturer during development and design mainly by market needs and expected quantities by selection from the standardized values of IEC or in some cases other standards e.g. ANSI. The type tests are then performed according to the same standards to prove the applicability.

Users usually define the ratings of GIS projects according to the network requirements normally selecting standardized values. These ratings are often at least partly lower than the design and tested ratings due to the fact that manufacturers intend to cover a defined market range using the maximum ratings.

### **Network development:**

Users are usually considering the future development of their network when defining the ratings of GIS projects. As the life expectancy of GIS is today at least 40 years considering normal use the envisaged development of networks may alter during the lifetime of the GIS and may exceed the originally expected and specified values. Upgrading of the equipment is one possibility to comply with new network conditions. An alternative approach may be to use fault limiting devices to keep system conditions within the performance limits of existing equipment.

### **Upgrading possibilities:**

In case of upgrading needs the ratings inherently available of the GIS should be investigated in cooperation with the manufacturer. An important factor to consider are modified or updated standards. If the GIS is older than 10 to 15 years the requirements for design and type-testing may have changed. The user has to investigate if necessary in cooperation with the manufacturer if the original design and tests are assuring safe service at the intended new rating.

If the required ratings exceed the original design ratings the adoption of part of the equipment may be investigated as an economic solution compared to replacement. Examples: Replacement of busbars or circuit breakers with designs of higher rating. Another possibility is for the user to accept non standardized values which the manufacturer considers safe for service. Example: Exceeding normal current may be safe for at least temporary application if the user accepts exceeding temperature rise and the manufacturer agrees based on experience, material used etc.

### **Overload possibilities:**

If the loads e.g. normal currents exceed the rated values temporary overloading may be the solution if the user is able to specify loads and duration and the manufacturer agrees to it. For short time currents designs may withstand higher ratings than originally type tested. For example 40 kA / 3 second designs may withstand 50 kA / 1 second including asymmetric component or intermediate non standard values required for the location. Type testing the higher values (with the user participating on the costs) may be an economic solution.

As the normal current ratings are always related to ambient temperature (usually 40 °C according to IEC) it is possible to exceed the current if the ambient temperature is lower. As there is no generally valid relation between allowed current and ambient temperature the manufacturer should be contacted to establish the loads at various temperatures.

From the technical perspective it is worth remembering that generally GIS has a greater capability for potential short term overload rating due the longer thermal time constant of GIS compared to equivalent AIS equipment.

### **Trends:**

Increasing loads, mainly short time and normal currents, are to be expected in developing networks during the lifetime of GIS. As an alternative to adapt the network to the ratings of switchgear upgrading possibilities as described above may be investigated.

### **Conclusion**

There seems to be a slight trend for the specification of higher ratings for GIS equipment and for the potential advantage of having equipment with short-term overload capability. However the increased loads seems to be specified within individual networks and there does not seem to be a trend towards higher and higher absolute ratings. E.g. most applications fall within the boundary of 4000A normal current and 63KA rated fault level.

For those applications where very high ratings may be needed there are also developments taking place in fault limiting and system control (e.g. FACTS) technologies that could limit the impact of network developments on the ratings of GIS.

**4.10 Urban Substations**

City centres are usually highly populated and it is very difficult to find out the space for a substation, which is the hub for electricity network. Stable supply of electricity essential for human society, and therefore, HV substation is strongly required even in city centre to comply with such demand for electricity.

Gas insulated equipment offers the following advantages, when introducing the HV substation in city centre.

**4.10.1 Advantages**

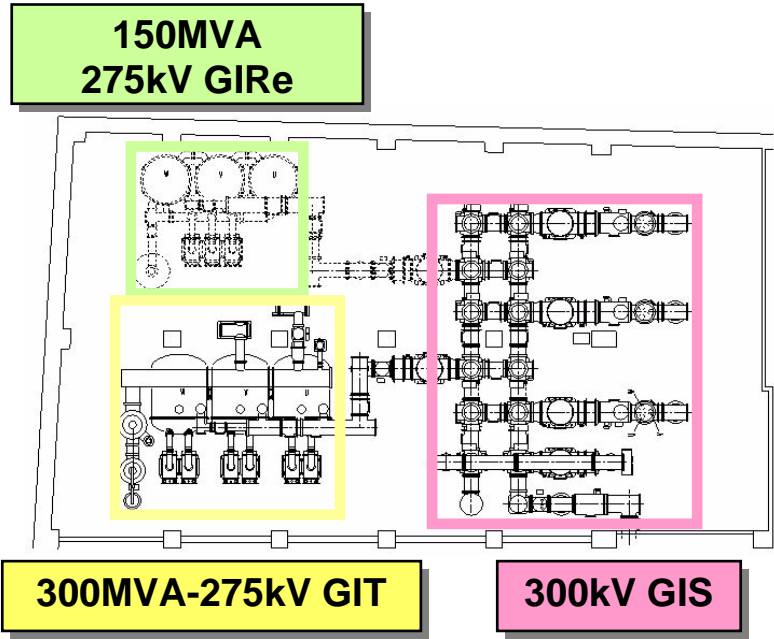
Gas insulated equipment, not only GIS but also Gas-insulated transformer (GIT) and gas-insulated reactor (GIRe) offers the following advantages, when introducing the HV substation in city center.

**Inflammability:**

GIS as well as GIT and GIRe, offers excellent performance of non-flammability. This performance makes it possible to construct the substation underground under a public space such as a park, garden, commercial complex, car park and so on. This solution also results in less cost for fire-fighting equipment in the substation, while it is not theoretically necessary.

It is quite usual practice that Oil insulated transformers (OIT) and Oil insulated reactors (OIRe) are installed in independent equipment cells due to safety reasons. However, GIT/GIRe can be installed in a same cell with GIS because GIT and GIRe are non-flammable and non-explosive.

Figure 4.10.1 shows a typical example of a 275kV substation by gas-insulated solution. In case of a conventional solution by OIT and GIS, a firewall or isolated cell is indispensable for the separation between OIT and GIS. In addition, transformers are usually installed separately on the bottom floor of the substation because it is heaviest equipment in the substation facility. However, 300kV GIS, 275kV 300MVA GIT and 275kV 150MVA GIRe are installed in the same equipment room without any partitions between them, as all of them are non-flammable. This results in a simple layout in the equipment room and also in a compact substation



**Fig 4.10.1 Layout of a 275kV underground substation in a metropolitan area**

### Simple interface to GIT/GIRe:

By the consistency of applied technology between GIS and GIT/GIRe, a simple interface measure can be applied between GIS and GIT/GIRe. Oil-Gas bushings are usually applied to the interface point, when OIT and GIS are directly connected. On the other hand, insulating spacers, which are equivalent to the ones for GIS, can be applied for the interface point, in the case of GIS and GIT/GIRe connection. In addition, power cable application needs some clearance between equipment due to the limitation of its bending radius and space for termination. Application of gas insulated solution results in a simple interface between GIS and GIT/GIRe and makes the equipment room compact. In addition, since the height of GIT is almost identical to that of GIS, height of ceiling in HV equipment room can be reduced. Both features result in the less construction cost.

Recently, feasibility study [4.10.1] relating to the utilization of very deep under ground (over 50m below the ground level) is being conducted in some leading countries, because it is very difficult to acquire the space for substation in the urban and the populated area. Compact profile of GIS is very nice countermeasure for such application.

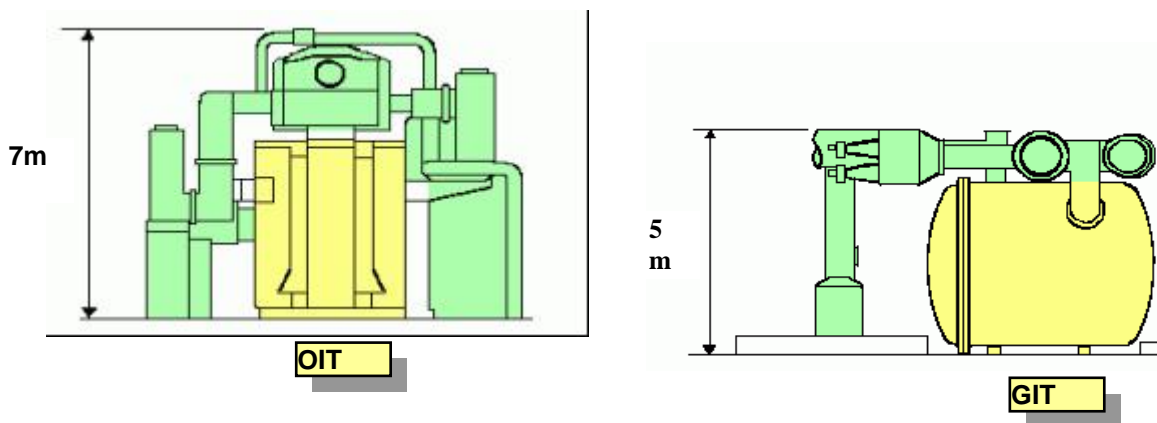
### Flexibility for substation layout:

Gas insulated technology has an excellent flexibility for substation layout. As mentioned in the previous section, it is not necessary to provide partition between the equipment. In addition, because of the nature of gas-insulated equipment, components such as heat exchangers, cable connection boxes, and conservators can be located where as necessary. In this sense, gas insulated solution has greater flexibility for substation layout. By this nature, substations can be constructed in sites with a more or less complicated shape.

### Less construction cost:

Since a 'Conservator' is not necessary for GIT and GIRe, the height of ceiling can be reduced by 2 to 2.5 meters, in case of 300kV-class equipment. In addition, since the heights of GIS and GIT become equivalent, space above the equipment can be utilized efficiently. Both result in less construction cost. It was once pointed out by a feasibility study that 30 % in volume of the substation and 15% of installation cost can be reduced by the application of gas insulated transformers. [4.10.2]

Figure 4.10.2 shows typical example of the height reduction of a 275kV 300MVA transformer, which leads to less construction cost of the substation.



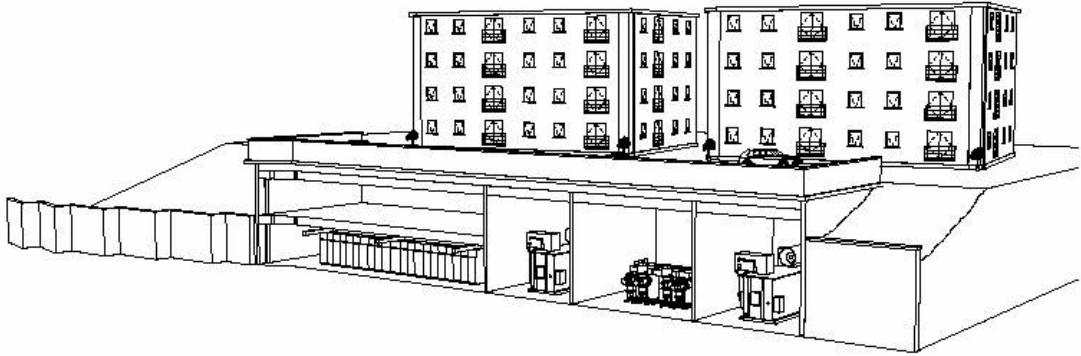
**Fig. 4.10.2 Reduction of height by application of gas insulated solution (275kV-300MVA)**

### Harmony with the surroundings:

In view of harmony with surroundings, indoor or underground substation is the most suitable solution. All active parts are encapsulated in the enclosure and all equipment can be installed in the small equipment room, when gas insulated equipment is applied. Cables are applied to the connection to the electrical networks and therefore, a gantry or tower for the transmission line is not necessary.

In addition, by the measures such that the machine hatch is covered by a flower garden and the intake and outlet of air for substation ventilation and cooling system are provided in a proper position, the visual impact to the city view by substation equipment and facilities can be neglected.

Furthermore, all substation equipment is installed in the building; audible noise and vibration by operation of equipment can be suppressed and minimized. This also meets the requirement for a substation in a highly populated area as shown in Figure 4.10.3.



a) Drawing of Completed Substation

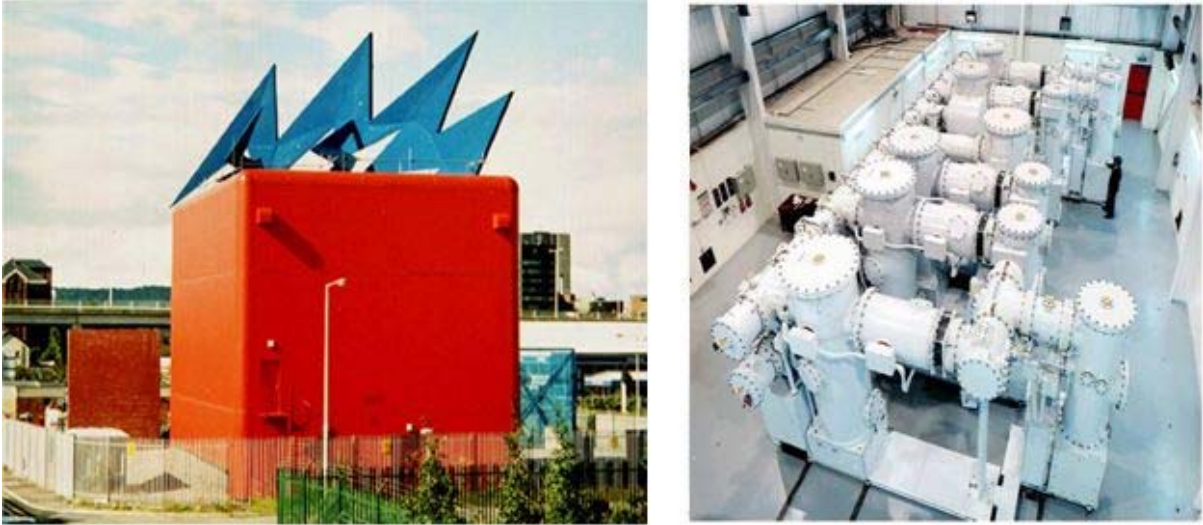


b) During Substation Construction

**Figure 4.10.3 110kV Urban Substation close to Housing Development**

It is also possible that the visual impact of the substation can be enhanced in order to make a statement consistent with the surrounding area. Figure 4.10.4 shows an example where the GIS

substation building is enhanced with a bright red colour and embellished with artwork so that the overall effect is to symbolize a welsh dragon. Whilst this will probably not be a common approach in the future, it does illustrate how we might expect the requirements of urban environments to influence substation design more and more.



**Figure 4.10.4 145kV GIS Urban Substation Building with enhanced appearance**

**Less installation period:**

Insulating oil needs a purifying process at site before oil filling. In this regard, some storage facility is temporarily required at site, which is troublesome considering getting a license from the fire authority. On the contrary, no purifying process is required in the case of gas-insulated equipment and the installation period becomes shorter. This also results in less installation cost.

**Upgrading the existing substation:**

Air insulated equipment is being provided in the existing substation, which was constructed in the past. Gas insulated equipment with the up-dated technology becomes very compact compared with the aged equipment and therefore, upgrading of substation, utilizing the available space by the application of compact equipment, can be realistic.

As far as weight is concerned, SF6 technology has a great advantage. From this viewpoint, aged OIT can be replaced by GIT with larger capacity, utilizing the existing base (footing) in the substation.

The above enhance the electrical network in the city without constructing new substations and obtain higher security and performance with a minimum of cost. We understand such a kind of study will be carrying out more frequently.

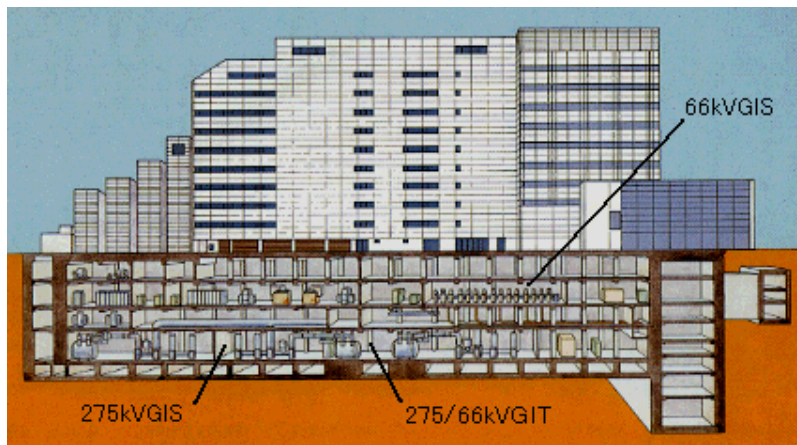
**4.10.2 Experience in Japan where applying gas insulated solution**

Making the most of advantages of gas insulated solution, five underground or indoor substations of 275kV with gas insulated solution have been constructed in the center of several cities in Japan and put into commercial operation with satisfactory service records.

The total capacity of those substations at the current stage is 3600MVA and all contribute to the stable supply of electricity for the populated area. As introduced above, gas insulated solution for substations offers a lot of advantages, especially in a populated area.

**i. Application to the basement of an office building**

In order meet the expanding demand at populated city center, a 275kV underground substation was constructed in the city center of downtown Tokyo and started commercial operation May 1995. Table



4.10.1 shows the list of main equipment in the substation and Table 4.10.2 shows the specification of GIT. Fig.4.10.5 shows the sectional view of 300kV underground substation in Tokyo area.

**Table 4.10.1: List of main equipment**

Equipment	May 1995	Future
275kV300MVA GIT	2	3
66kV 60MVA GIT	--	3
300kV GIS (3 phase type)	2	6
72kV GIS (3 phase type)	22	36
22kV Metal enclosed switchgear	--	36
Cooling Tower (On Roof floor)	3	4

**Table 4.10.2: Specification of 275kV GIT**

Items	Specification
Rated voltage (kV)	275/66/21
Rated capacity (MVA)	300/300/90
Rated LIWL (kV)	950/350/150
Rated Impedance (%IZ)	22 (at 300MVA)
Rated Gas pressure (Mpa)	0.53 (at 20deg.C)
Rated sound pressure (dB(A))	85
Type of cooling	GDWF
Insulation & cooling Media	SF6 only
Applied standard	JEC2200

**Fig. 4.10.5: Sectional view of 300kV underground substation in Tokyo Area**

In order to meet the requirement for the limitation of transportation, the maximum transportation unit, that is main tank of GIT, was designed as 60 ton and lifted off to the substation through machine hatch of 4.5 meter x 6 meter by crane. A sliding facility was temporarily provided on the equipment floor of Basement 5 during installation and main tanks were carried up to the designated positions by it. Accordingly, no crane for the transformer is provided in the substation.

Dissipated heat from the GIT is transferred to the water in the radiator beside the GIT and released through a cooling tower on the roof of the building. The capacity of the cooling tower is approximately 2550kW per unit. In addition, some part of the dissipated heat is utilized in the air conditioning system for the offices above the substation.

It should be noted that by the application of gas insulated solution, the space for substation could be reduced by 50%, comparing with the latest substation with OIT of identical ratings.

**ii. Application to the underground of a historic castle in city center**

In order to meet the electricity demand in central Japan, a 300kV class underground substation was constructed, utilizing the foundations of a historic castle in the city center. As Nagoya castle is designated as a national treasure, special attention was paid to the visual impact and audible noise from the facility. Table 4.10.3 shows the list of main equipment in the substation and table 4.10.4 shows the specification of GIT.

**Table 4.10.3: List of main equipment**

Equipment	Jun.1999	Future
275kV450MVA GIT	2	3
275kV400MVA GIT (Phase shifter)	--	3
275kV100MVA GIRe	2	3
300kV GIS (3 phase main bus)	4	12
168kV GIS (3 phase type)	6	15

**Table 4.10.4: Specification of 275kV GIT**

Items	Specification
Rated voltage (kV)	275/154/31.5
Rated capacity (MVA)	450/450/135
Rated LIWL (kV)	1050/750/200
Rated Impedance (%Iz)	22(at 450MVA)
Rated sound pressure (dB(A))	80
Type of cooling	LDWF(PFC)
Insulation & cooling Media	SF6+ PFC

Figure 4.10.6 shows the sectional view of this substation. In this substation, transformers are located on basement 5 floor and 300kV/77kV GIS are located on basement 3 floor. Between them, a cable floor is provided. In this substation, a 4.5meter height reduction of the building was achieved by application of gas-insulated solution, which corresponded to approx. 12% of the total depth of the substation.



**Fig. 4.10.6: Sectional view of substation under a historic Castle**



**Fig. 4.10.7: Elevator tower for underground SS**



**Fig. 4.10.8: Night view of castle tower and buildings of substation**

Fig.4.10.7 & Fig.4.10.8 show the typical view for the buildings of the substation, which are in harmony with the view of the national treasure.

The weight of transport of the main transformer for this substation was approximately 90 ton. Since the transportation unit can slide on the floor of equipment room by utilizing the air castor system, no special transportation facility or crane inside the substation building was required. Since this substation is located in the area where a special attention should be paid to the visual impact and audible noise from the facility, some measures are taken. For example, parking space is integrated into the substation building and the visual impact by the facility is minimized.

### **iii. Application to commercial complex**

In order to meet the electricity demand in Kobe City, a 300kV class underground substation was constructed, utilizing the basement floors of a commercial complex including offices and museum. Table 4.10.5 shows the list of main equipment in the substation and table 4.10.6 shows the specification of GIT.

**Table 4.10.5: List of main equipment**

Equipment	Mar.1999	Future
275kV300MVA GIT	2	3
77/33kV 30MVA GIT	2	3
77/6.6kV 30MVAGIT	2	3
77kV 40MVA GIRE	--	3
300kV GIS (3 phase type)	2	6
84kV GIS (3 phase type)	6	21

**Table 4.10.6: Specification of 275kV GIT**

Items	Specification
Rated voltage (kV)	275/77/--(*)
Rated capacity (MVA)	300/300/--(*)
Rated LIWL (kV)	1050/400/--(*)
Rated Impedance (%IZ)	24 (at 300MVA)
Rated sound pressure (dB(A))	87
Type of cooling	LDWF(PFC)
Insulation & cooling Media	SF6+PFC

\*: Stabilizing winding application

In this substation, mobile telephones are utilized in communication within the substation. In addition, Industrial-usage Television cameras (ITV) are applied to the supervision system inside the substation, which results in a higher security level of an unmanned substation.

Furthermore, an opening and a closing operation of the machine hatch for the substation can be completed within 3 minutes and an interruption of the traffic for commercial complex during its operation shall be minimized.

#### 4.10.3 SF6 handling with great care

It is understood that the electric power industry has to continue to use SF6 with special attention and in this sense, every action should be taken to keep SF6 emission to minimum. Since the amount of SF6 within the substation becomes larger in the case of GIT and GIRE application, it should be noted that SF6 should be handled with great care.

Installation of higher performance SF6 reclaimers, which can be utilized within narrower substations, is typical countermeasure for intensive gas handling and the provisions of Oxygen density monitors are that for safety of operating personnel. Taking convenient maneuvering within substation into consideration, reclaimers are required to be of a unit basis, so that an elevator can be used instead of lifting crane.

#### **Conclusion**

The requirement to build substations in urban environments is going to continue and indeed increase in the future. The application of GIS technology in such environments is ideally suited to such an extent that we will see GIS applied in more and more innovative ways within different urban environments. In well developed countries we may also see the replacement of existing substations with GIS technologies due to the space saving potential of GIS. The reclamation of the substation land being sufficient incentive for the substation equipment to be replaced.

## References

- [4.10.1] Yamazaki, et al, 'Compact GIS in harmony with environment and CAD evaluation system for 550kV substation Design' CIGRE Session paper 23-202, 1998
- [4.10.2] Shimato, et al, 'Evaluation of total life cycle cost of GIS substation and development of portable diagnosis device' CIGRE Session paper 23-107, 2000
- [4.10.3] Meguro, et al, 'Solution for underground substation by gas insulated equipment' CIGRE paper 23-101, 2002

## 4.11 Sealed for Life Designs

### Definition of 'sealed for life'

According to IEC 60694 'Gas and Vacuum Tightness' a sealed system is defined as one where no further gas or vacuum processing is required during its expected operating life where expected operating life has standard values of 20 and 30 years.

This implies that for the specified service life the sealing system for the SF<sub>6</sub> gas is designed and tested for a leakage rate assuring at least the minimum operating density for the whole life.

It also implies that a sealed system is operated without constant gas density supervision and requires no service access by gas connections.

For high voltage GIS these implications are feasible only for parts of the equipment requiring no maintenance during the specified life time. In practice this limits its application to static components. For today's switching equipment the maintenance cycles depend mostly on the use in service i.e. number of switching operations at load or no load (condition based maintenance)

Usually the service safety of high voltage GIS is too important to rely on sealing systems without gas density supervision.

The leakage of modern GIS is in the range of 0.2 % per year according to accessible service experience.

These facts and the relatively low cost of density supervision equipment allow the conclusion that sealed for life systems as defined above provide no significant advantage for the user of high voltage GIS and impose unnecessary risks in case of unnoticed leakage.

### Conclusions

There appears to be no visible trend towards use of sealed for life, based on the definition given, HV GIS systems in the future, however the need to minimize leakage, maintenance and gas handling will dictate that the same features as needed for "sealed for life" equipment will be introduced into the GIS of the future.

## 4.12 Implications of Shorter Design Lives

GIS has become a mature technology and in general gives a better performance than it was originally conceived would be the case by users and manufacturers. GIS of the second and subsequent generations may have a lifetime of 40 years or even more. Low service stress compared to type test requirements in combination with the advantages of encapsulation resulted in refurbishment cycles which are mostly much longer than foreseen in the manuals of the manufacturers (10 years or more).

On the other hand the technological progress and economic pressures can lead to more frequent redesign cycles with in some cases general shorter design lives e.g.

- Primary and secondary technique become more and more integrated resulting in redesigned or even new apparatus
- Falling price levels and competition on the world market forces the manufacturer to rationalise their GIS design resulting again in redesigned apparatus

- The upcoming Hybrid substations merge GIS and AIS technologies. Apparatus used in GIS and Hybrid's will be of the same design which may result again in some redesigned equipment

Users and manufacturers therefore face the following situations

- More variants of switchgear will be in service. The variants will be in service for a very long time
- Less well updated experts will be available on both sides at users and manufacturers

The consequences could be that:

- A proper documentation system becomes very important considering the lifetime of the used data handling system.
- Spare parts: The philosophy may change from exchanging pieces to replacement of complete kits, apparatus or even bays. It enables to implement the latest technical solution for the required function. In addition to that users, manufacturers or even independent companies will built up together global stocks in order to combine availability and economics
- Maintenance: Especially users with smaller GIS population are not anymore able to hold up trained service organisation. Manufacturers or even specialised companies will provide the users with experienced crews for maintenance. In addition to that different revision cycles of electronic and not electronic devices have to be handled
- Equipment of different design models could be required at a single installation if extensions are implemented. This raises issues in terms of operational familiarity for users in order to ensure safety is maintained.
- Education, training: Manufacturer will train the users organisation in proper operation of GIS substations and not anymore in deep knowledge of product and maintenance. Training is only needed for the above mentioned specialists.

### **Conclusions**

Equipment designs have been changed at shorter and shorter intervals whilst at the same time in-service lifetimes are likely to increase, this has significant implications on spares, training and maintenance for users in order to balance technical progress with economic constraints.

## **4.13 Type, Routine and Site Test Methods**

This section reviews how tests will develop and the implications for GIS design including:

- Existing IEC standards are updated on a regular basis and new standards are created by specialist of users, manufacturers and of other bodies like universities, international and national test institutions and government or non government organizations. Updates and new standards are based on service experience, new developments, new technologies or new conditions like environmental issues.
- In addition to the updating and harmonization between different IEC standards new requirements are being established for electrical endurance and for combined switchgear like circuit breaker-disconnectors or hybrid switchgear.

### **4.13.1 Type Tests**

The target of mandatory and optional type tests is to prove the intended function of GIS and its components under given service and exceptional conditions.

The type tests procedures and test conditions are described in the relevant IEC standards. Type tests are conducted on test samples complying to the manufactured equipment.

The future evolution in this field is mainly related to new and updated IEC standards

Some aspects that may see development in the future include

## **Environmental**

Where greater importance will be placed on environmental performance (e.g. SF6 leakage and EMC) that may generate new type test requirements.

## **Reduced maintenance**

As designs start to achieve real maintenance free capability the need for updated type tests to better represent lifetime stresses on multiple production samples may develop.

### **4.13.2 Routine Tests**

Mandatory and optional routine tests are part of the quality assurance procedures of manufacturing to assure the compliance of the equipment with the type tested and proven design. The relevant IEC standards describe the test procedures and conditions.

Routine tests are usually carried out on all assembled GIS components with components defined as single apparatus or combinations thereof for transportation or further assembly including single or multiple bays depending on size and design.

The same evolution will occur in this area as for type tests.

### **4.13.3 Site Tests**

The target of mandatory and optional site tests is to prove that the GIS and its components are fulfilling the intended functions after transport and assembly at site. The procedures and conditions are defined by the relevant IEC standards with some additional requirements specified by particular customers. Site tests are carried out on components, GIS parts of full GIS after site erection and are concentrated on assuring the quality of site erection activities and possible effects of the transport to site.

In the future as extensions and refurbishment of existing GIS become more commonplace as the population continues to increase, the complexity of site tests on an existing installation might evolve.

### **4.13.4 Validity of Type Tests**

The type tests are carried out on the final execution of equipment as manufactured. During the production life of equipment it is periodically or continuously adapted to changing suppliers and manufacturing procedures. As it is the responsibility of the manufacturer to assure the function of the switchgear according to the standards the manufacturer has to judge the influence of adaptations and to repeat type tests if necessary or to prove that the adaptations are of no influence to the function. There is no validity time of type test results stated in the standards. Updated standards may lead to the repetition of type tests if the conditions change. This is normally applicable for new GIS projects, for extensions of existing GIS the application of new requirements of standards has to be related to the existing switchgear.

Although the capability to perform simulation studies with more confidence will improve it is still envisaged that type tests in their current form will still be required.

## **Conclusions**

The future evolution in the field of type routine and site testing is mainly related to new and updated IEC standards. There is no strong driver to radically change the nature of standards. However there will be some evolution of standards to accommodate the changes in technology that are envisaged such as the integration of monitoring systems. These changes will have to be reflected in type testing as well as production and site testing procedures.

Harmonization trend between IEC, ANSI, IEEE etc. will continue. Also as participants in standards development activities become harder to find the role of harmonized standards will become increasingly important.

#### 4.14 Circuit breaker Technology

For GIS for transmission voltages the use of SF6 circuit breaker interrupters has been standard since the first introduction of SF6 insulated GIS in the late 1960's. The vast majority of these SF6 circuit breakers that have been installed are based on the SF6 puffer principle that very quickly replaced the dual pressure technology that was used in the very first GIS applications. SF6 puffer circuit breakers have excellent interruption capabilities and are particularly well suited to application in a GIS environment that also uses SF6 for the main dielectric medium.

The main disadvantage with such SF6 puffer circuit breakers is the relatively high drive energy required. The flow of high pressure gas necessary to travel axially over the length of the arc drawn between the contacts is generated by the mechanical compression of SF6 gas in the puffer interrupter cylinder. The energy requirement for this operation can be considerable and additionally a high energy mechanism leads to high reaction forces on the GIS support framework and foundations.

The advantage in using a current interruption method that requires less energy was realised many years ago and led to the development of second and more recently third-generation puffer circuit breakers.

So called thermal, auto-expansion or self-blast interrupters were developed to overcome the high operational energy requirements of conventional puffer devices. In a self-blast or auto expansion device the arc energy is utilised to produce a pressure rise in a gas enclosure immediately upstream of the nozzle throat. By trapping the arc within a relatively small volume during the arcing period the pressure within the volume can rise rapidly. The pressure is further increased by wall ablation of the nozzle due to the intense radiation from the arc. This high pressure is used to generate the flow of clean, relatively cool SF6 over the arc to facilitate the interruption process. For the interruption of low currents a small puffer device is incorporated together with a system of pressure relief valves. Such devices have been able to reduce by approximately 50% the drive energy necessary. This has a dramatic impact on the complexity and technology of the circuit breaker operating mechanism.

Simple spring operating mechanisms can therefore be used in applications where previously high power pneumatic or hydraulic drives were necessary.

The application of self blast or auto-expansion interrupters has been widespread for the last 10 years and now the next generation of technology is becoming common. In the so called third generation technology the self blast principle is modified such that both fixed and moving contacts have a relative movement. This doubling of the effective speed of contact separation means that the operating drive energy can be reduced significantly (Energy being proportional to square of speed). This technology enables even higher ratings to be possible with simple low energy drive mechanisms.

The impact on the GIS equipment of these technology improvements is to make the GIS more compact and simpler. This trend has been seen first at voltages up to 145kV, has now extended to 245kV and is becoming evident at even 420/550kV levels.

The other significant change that developments in circuit breaking technology have delivered is a reduction in the number of circuit breaking elements for a particular voltage rating. Whilst single element circuit breakers at 420kV have been available since the mid 1980's these now extend up to 550kV and can also achieve the highest fault levels that are normally specified (up to 63kA). Single break circuit breakers can be less complex than comparable multi-break circuit breakers and can also provide advantages in terms of GIS layouts. Single break designs can be applied in compact vertical arrangements giving advantages compared to two-element vertical or horizontal designs.

The elimination of voltage grading capacitors necessary on multi-break circuit breakers helps to simplify the circuit breaker design and eliminates a potential weakness i.e. the need for solid insulation across the interrupting gap. The additional benefit of the elimination of grading capacitors is that the potential risk of resonance phenomena with electromagnetic voltage transformers or power transformers is eliminated.

The further advancement of circuit breaker technology to reduce operating energies and device complexity will continue such that these benefits will also become standard at the highest voltages for GIS equipment.

At the lower range of GIS voltages we can also predict possible changes due to the implementation of alternative interrupting technologies. The use of vacuum interrupters is well known for equipment up to



Figure 4.14.1 420kV Single Break Circuit Breaker with Spring Operating Mechanism

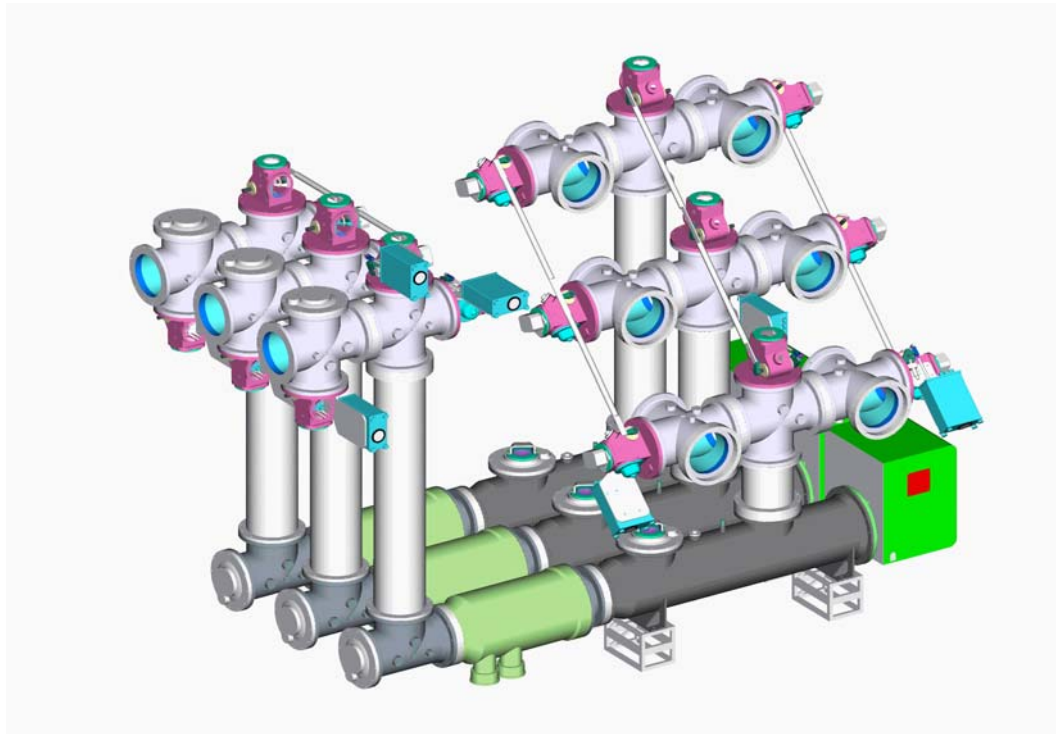
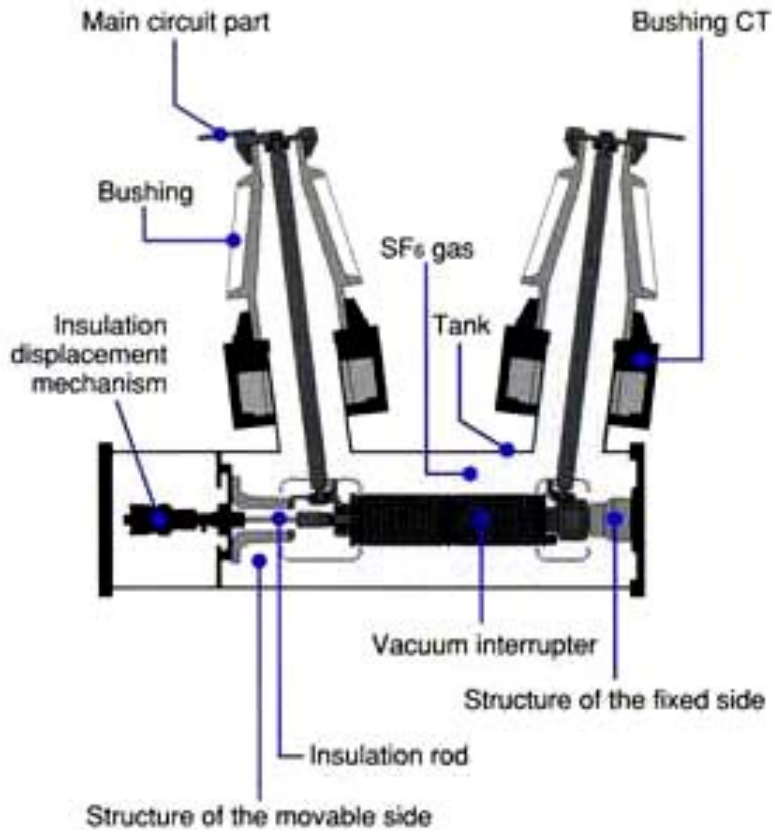


Figure 4.14.2 Very Compact 420kV GIS Layout Using Single Break Circuit Breaker

36kV but devices are now also available for 72,5kV and even up to 145kV. Potentially vacuum interrupters offer the advantage that they could eliminate the need to use SF6 as an arc extinguishing medium, possible benefits in terms of the durability of contact life and need for maintenance might also be expected. Whilst applications have already been seen for equipment with a rated voltage of 72,5kV it is not expected that there will be a significant move towards vacuum circuit breakers in the foreseeable future.

Application of controlled switching for transient reduction is well established, opportunity also exists for wear reduction in circuit breakers



**Fig. 4.14.3 Sectional drawing of a 120 kV single-break vacuum circuit breaker**

**Conclusions**

Significant developments have taken place in the technology used within circuit breakers for transmission applications and this has been reflected in the associated GIS equipment. As interrupter performance has increased and the number of interrupting elements for a given rating has reduced so the GIS can become more compact driving developments in other areas of the equipment.

The current trend towards auto-expansion/self blast designs for all ratings will continue and this will impact of the overall GIS solution. The next major interrupter development which would impact on GIS may be at the lower voltages (72,5 - 145kV) where the application of vacuum interrupter technology may be seen. This could drive the development of GIS solutions using alternative gases to 100% SF6.

#### 4.15 Simplified single line arrangements taking into account GIS availability

Transmission substation plant is becoming increasingly more reliable. As discussed above this is particularly the case with EHV circuit breakers using only one or two interrupters per phase compared with the earlier designs.

The changes to circuit breaker design yielding significantly increased reliability with commensurate reduction in maintenance requirements will lead to simplification of the electrical diagram of the substation. For example in AIS the practice of providing circuit breaker by-pass facilities will surely completely disappear. Whilst in GIS where additionally the primary insulation is protected from the polluting and aging effects of the atmosphere the use of simpler busbar systems forecast in successive CIGRE GIS Service Experience Review Reports [4.15.1] must inevitably take place.

This section discusses these issues:

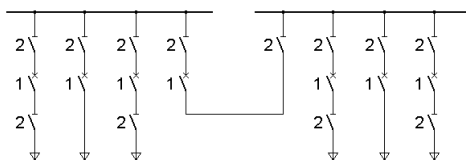
The single line diagram can provide a simplified representation of any electrical project. It shows the connections among the different elements of the switchgear only in one phase, because the other two phases are equivalent (or the differences can be neglected). The usual symbols of the single line diagrams - the symbols of different equipment and measuring devices - are standardised. (See IEC 617: Graphical symbols for diagrams.). The engineers can use the single line diagrams at study of the energy system as well as the substations.

The single line arrangement of a substation is the basic starting point of the switchgear design. The single line diagram defines the number and connection of the busbars and the bays. In the past a lot of different substation arrangements have been developed in order to improve the quality parameters (mainly the availability) of the energy supply system and the maintainability of the substation. The main goals of these developments were the minimisation of those parts, which have to be switched off in the case of any trouble or fault, and safe maintenance of any part of the equipment without any danger of the continuous energy supply for the consumers. Obviously these goals were based on the switchgear technologies and characteristics available at the time.

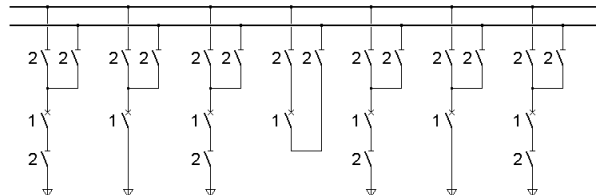
Number and arrangement of the busbars and the circuit breakers can distinguish the different solutions. The more common and relative frequently used versions according to the complexity of the systems are the followings [4.15.2, 4.15.3]:

- 1.) Single busbar
- 2.) Double busbar
- 3.) Single busbar with transfer bus
- 4.) Double busbar with double circuit breaker
- 5.) One and a half circuit breaker scheme
- 6.) Ring busbar

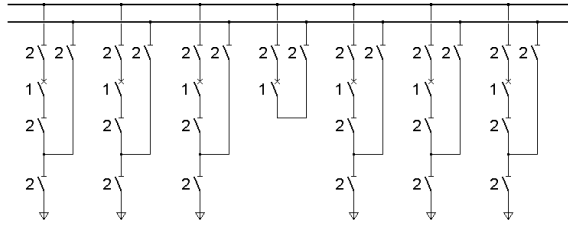
Figure 1 gives a brief summary of the above-mentioned arrangements. The represented diagrams are typical and simplified ones. They show only the arrangement of the main switches, the circuit breakers (marked:1) and the disconnectors (marked:2), because only they are determining. Details about measuring transformers, earthing switches and terminations can be different types, but they have no effect to the category.



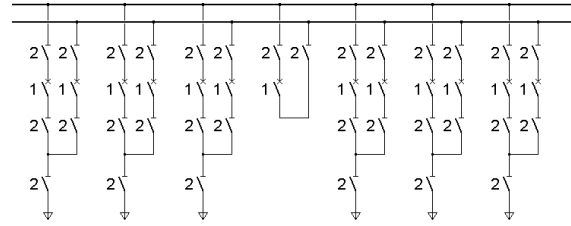
**FIGURE 4.15.1-A**  
Single busbar system



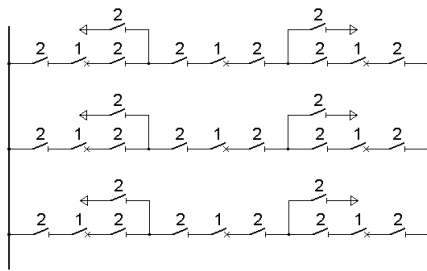
**FIGURE 4.15.1-B**  
Double busbar system



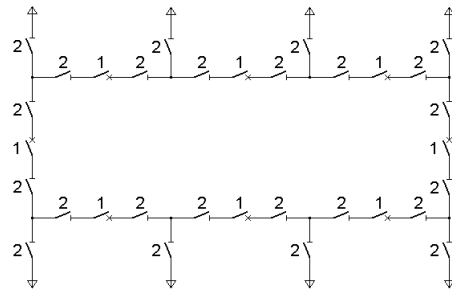
**FIGURE 4.15.1-C**  
Single busbar system with transfer bus



**FIGURE 4.15.1-D**  
Double busbar system with double circuit breaker



**FIGURE 4.15.1-E**  
One and a half circuit breaker scheme



**FIGURE 4.15.1-F**  
Ring busbar arrangement

**FIGURE 4.15.1: Single line schemes of gas insulated substations**  
Legend: 1-Circuit breaker; 2-Disconnector

According to the results of the wide-ranging international surveys in recent years [4.15.4, 4.15.5], the significant majority of the existing gas-insulated substations are single or double busbar systems. The population of these types of systems is between 92 and 94 percent. Within these populations in the lower voltage classes (below 200 kV) the single busbar system prevails, in the higher voltage classes (above 300 kV) the double busbar arrangement is the more frequent.

In recent years some new considerations have begun concerning these issues:

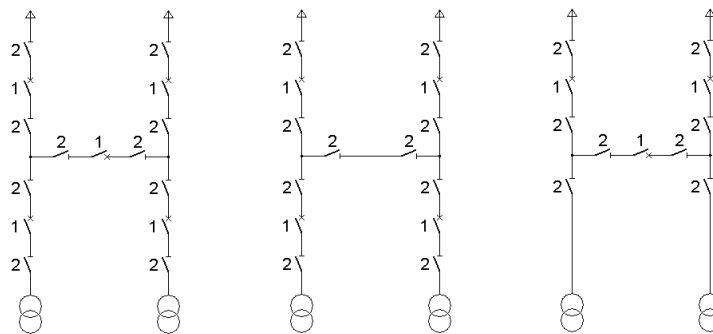
- The interest and sensitivity of the society increased very much about all projects and activities, which have any impact to the environment. Real and only supposed effects of the electrical equipment are controlled and strictly limited. The public opinion about any impact of the substations has great importance.
- The privatisation of the energy supply companies has a basic influence to the substations, and to all activities (development, design, operating, maintenance, etc.) connecting with them. The role of the economic points of view (cost efficiency, profitability) is increasing continuously.
- The international surveys conducted by CIGRE and other organisations [4.15.4, 4.15.5, 4.15.6] resulted in new statistical databases, which are suitable to support the economic and availability analysis and comparison of the different technical alternatives.
- The technical development of the switchgear and controlgear made possible the substantial reduction of the outline dimensions and simplification of structures and arrangements. At the same time the reliability was improved too much higher level and the need of maintenance was practically eliminated.

The above-mentioned effects do not work exactly the same way and intensity in all countries and areas. Two extremities can be defined: the densely populated urban areas of the industrialised countries, and the

under-populated rural areas of the developing countries. All other possibilities can be situated between these extreme ones.

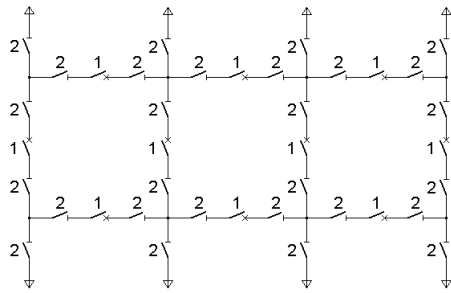
In the recent years several detailed studies have been dealing with the future substation trends of the industrialised countries [4.15.7, 4.15.8]. They pointed out, that the future substations will be established as close to the load centres as possible, in order to reduce the energy losses of the distribution system. The number of the substations will be higher, but their dimensions will be much smaller than present ones, with only a few bays. In the urban areas, in the cities they will be placed inside multifunctional buildings or under the ground level. In the industrial areas they will be arranged in independent parts of factory buildings, in containers, or outdoors. GIS will be preferred because its relative low space requirements.

The main goals at the design of these new gas insulated substations will be not the same than earlier. The simple fact of the energy supply is not enough any more. The life cycle costs of the GIS and the energy system will be thoroughly analysed and minimised. That means that the new priority is not the best technical solution and the highest possible availability, but the minimisation of the resultant cost. New economic calculations show, that in the case of new type highly reliable switchgears the earlier developed complex single line schemes have only limited effect to the availability of the GIS. Under the new circumstances their application is not so economical and not so advantageous technically as in the past. Thus the single line diagrams can become simplified in the next future. The single busbar arrangements, for example different forms of the „H” scheme can provide lower life cycle costs and higher availability, than earlier the more complex busbar arrangements. (See Figure 4.15.2.)

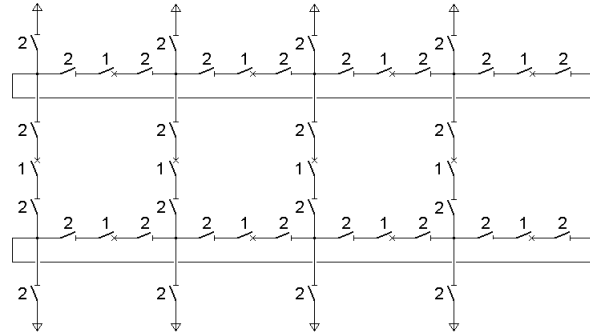


**FIGURE 4.15.2: Complete and simplified forms of "H" connection**  
**Legend: 1-Circuit breaker; 2-Disconnector**

An other way of the development, which can be spread at outdoor type substations of the rural areas, goes towards different types of the ring busbar arrangement. They are very advantageous in the case of hybrid substations, if the high voltage switchgear is built up from uniform gas-insulated modules. For example in Spain the ring busbar was improved to the "meshed ring" arrangement (Figure 3-A). Similar way in Italy the "crossed-ring" was developed (Figure 3-B). In normal everyday work the elements of the basic ring are used (see Figure 1-D). The "cross-links" play role in failure modes. The basic units of both solutions are usually gas-insulated modules (including one circuit breaker, two combined disconnecting and earthing switches, two current transformers and two SF6-air terminations). Any module of the arrangements can be exchanged with a spare unit very quickly, during approximately six hours. This work is very simple, none of the gas compartments have to be opened, only the connecting overhead conductors have to be removed, and after exchange of the units these connections have to be put back. The on-site maintenance activity of these types of switchgears is practically eliminated. The failed gas-insulated modules are transported to the manufacturer for reconstruction.



**FIGURE 4.15.3-A**  
**Meshed ring arrangement**

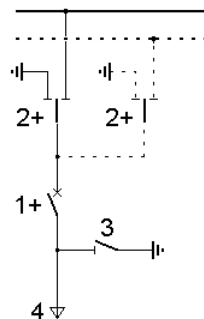


**FIGURE 4.15.3-B**  
**Cross ring arrangement**

**FIGURE 4.15.3: New versions of ring busbar arrangement**  
**Legend: 1-Circuit breaker; 2-Disconnector**

The simplicity and compactness of the gas-insulated switchgear can be increased using the results of the new technical developments as well [4.15.9, 4.15.10]. Some of them can have considerable effect to the single line diagram (See Figure 4.15.4):

- 1.) The circuit breaker and the neighbouring line disconnector can be integrated to a new type switching device which has to satisfy the requirements against both switches. (The single line diagram includes one switch only instead of the circuit breaker and the line disconnector.)
- 2.) The disconnector and the neighbouring earthing switch can be integrated. They work with a common blade, which can move from the closed disconnector position through a neutral position up to the earthing switch position. (The single line diagram includes one „selector switch” instead of the disconnector and the earthing switch.)
- 3.) Measuring transformers (current and voltage transformers) can be replaced by new type sensors, or transducers. These ones do not have any galvanic contact with the high voltage primary current carrying parts. (The single line diagram does not include the sensors, because they do not have any „active” primary current carrying parts.)
- 4.) The plug-in type cable terminations make possible the connection or disconnection of the cables, and the performance of the site tests without the opening of any gas compartment. (The removable elements of the primary current conductor, which were necessary only to provide the possibility of the site tests, can be eliminated.)



**FIGURE 4.15.4: Single line diagram of a simplified cable bay**  
**Legend: 1+: Combined disconnecting circuit breaker,**  
**2+: Combined disconnecting and earthing switch,**  
**3: High-speed earthing switch, 4: Plug-in type cable sealing end**

The advantages of the here mentioned new technical solutions are obviously: They give possibility to the reduction of the number of switches, and to the elimination of the measuring transformers. But the application of them can get in conflict with the traditional thinking of the substation operators. They need new philosophies about the safety rules and regulations and about the protection systems, which should be supported by the international standards and recommendations as well. Probably the new ideas will spread only very slowly and they will become general only after a long time period.

### **Conclusions**

In rural areas of the industrialised countries the price of the land is not as high as in the cities. The constraint of the compactness is not so strong. In these areas the only partly gas-insulated, hybrid substations can be very competitive [4.15.11, 4.15.12, 4.15.13, 4.15.14, 4.15.15]. In this case the busbars are air insulated ones, the bays are gas insulated and the line connections are usually air insulated as well. The simplifications about the switchgears (integrated circuit breaker and line disconnecter, disconnecter and earthing switch) and the measuring transformers (sensors instead of traditional ones) are possible in this case as well.

In the developing countries the situation is more difficult. There are large differences in the state of technical, social and economic development compared to the industrialised countries or to each other. The new constraints, which are typical in the industrialised countries, here are much weaker or can be missing. In this point of view these countries are in an earlier period of the development. But at the same time they usually apply the same products of the same manufacturers in their new substation projects as the highly developed countries. Thus the differences in the technical level and in the new technical solutions in the future will be decreased.

Emphasise the point that different utilities will evaluate their own circumstances and may arrive at different optimum solutions for choice of layout.

### **References**

- [4.15.1] Fink D.G., Beaty H.W.: Standard Handbook for Electrical Engineers. McGraw-Hill Book Company 1987.
- [4.15.2] Boehle B., Guthmann O., Haneke K., Hügin K.-H., Tettenborn W., Voss G., Wittwer H.: Schaltanlagen. Brown Boveri Taschenbuch. BBC Brown Boveri AG, Mannheim 1987.
- [4.15.3] Kopejtkova D., Molony T., Kobayashi S., Welch I.M.: "A Twenty-five-year Review of Experience with SF6 Gas Insulated Substations (GIS)". CIGRE Paris 1992, paper SC23 No. 23-101.
- [4.15.4] Balzer G., Becker J., Dzieia M., Strnad A., Neumann C.: Erfahrungen mit gasisolierten Schaltanlagen (GIS). Elektrizitätswirtschaft, Jg. 99. (2000), Heft 7, 24-32
- [4.15.5] Kopejtkova D. at all.: Report on the 2<sup>nd</sup> international survey on high voltage gas insulated substations (GIS) service experience. CIGRE Technical Brochure No.150
- [4.15.6] Wahlström B., Aoshima Y., Mino Y., Lajoie-Mazenc C., Torgerson D.R., Zomers A.N.: "The Future Substation: A reflective approach". CIGRE Paris 1996, paper SC23 No. 23-207.
- [4.15.7] Wahlström B. et al."Simplified Concepts for Future Substations – Some Case Studies. CIGRE Paris 1998, paper SC23 No. 23-107"
- [4.15.8] Norberg P., Tapper M., Lord W., Engqvist A.: "The Future Substation – Reflection About Design" CIGRE Paris, 1998, Paper SC23 No. 23-105.
- [4.15.9] Schett G., Engler F., Petterson K., Kaczkowski A., Frei K.: The Integration of Secondary Technology and Novel Sensors into GIS. CIGRE Paris 1994, paper SC23 No. 23/13-01.

- [4.15.10] Doin Y., Durant-Laurent M., Gens S., Leroy J.C., Triay G., Thomasset G.: "Compact Substation: A Comprehensive Solution" CIGRE Paris, 2000, Paper SC23 No. 23-103
- [4.15.11] Högg P., Fuchsle D., Kara A. „PASS für Retrofit, Erweiterung und Neubau von ` Hochspannungs-Schaltanlagen“ ABB Technik 1998, Heft 2, 12-20.
- [4.15.12] Pokarier B., Petersen A., Högg P., Staiblin J.“First New Integrated Switchgear Substation in Service” CIGRE Paris 2000, paper SC23 No. 23-104.
- [4.15.13] Carvalho A., Bosshart P., Christianse, U., Guerra G., Tang L., Olovsson H.-E.: Functional Specification as Driver for Technical / Economical Optimisation of Substation. CIGRE Paris 2000, paper SC23 No. 23-101.
- [4.15.14] Helbig D., Meinherz M.“HIS – ein hochintegriertes innovatives Schaltanlagenkonzept“ ETZ, 2000, Heft 6, 68-70.
- [4.15.15] Bartlett S., Moller I., Helbig D., Schütte A.“Highly Integrated Switchgear – An Innovative Concept to Reduce Life Cycle Costs” CIGRE Paris 2000, paper SC23 No. 23-108.

## 4.16 Maintenance Strategies

The increased use of Condition Monitoring and Predictive Maintenance is covered to a certain extent in Section 4.4 what is covered here are the more general trends with respect to maintenance that can be identified for GIS. These trends are relevant in an environment where utilities are under increasing pressure to reduce costs and asset replacement tends to be deferred. This environment as much as GIS technology will determine the evolution of maintenance strategies.

Since the introduction of GIS into the market at 1968 progress has been made on the need of inspections and maintenance. The modern generations of GIS need less maintenance and allow longer service periods due to the excellent experiences of more than 35 years of service [4.16.1], [4.16.2], as Figure 4.16.1 shows. It is expected that this change in the way that maintenance is applied to GIS will continue in the future with less and less maintenance being required.

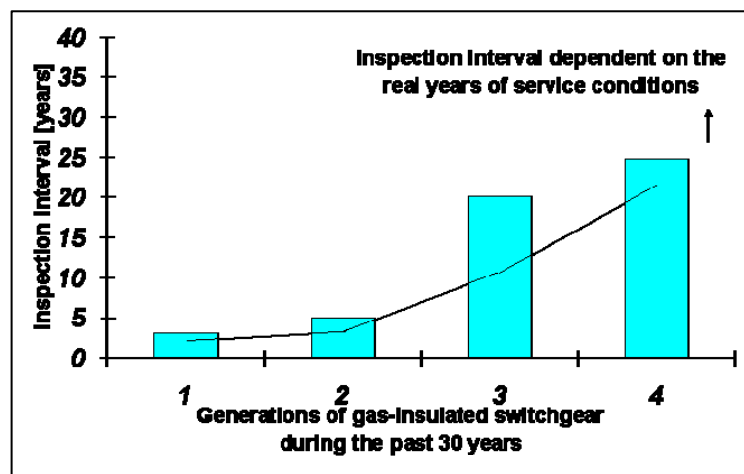


Figure 4.16.1 Development of Inspection Intervals

The effectiveness of maintenance depends mainly on the way manufacturers and users work together. Maintenance in general is by definition a required action on switchgear in order to sustain the availability of the equipment. The maintenance activity should

- replace specially stressed parts in time and prevent failures
- determine the wear of parts and assess their state
- ensure that parts are still in good shape and can be kept in place

Maintenance can be done on the basis of the manufacturers experience – time based maintenance TBM - as it is still done commonly today, on basis of monitoring and the use of diagnostic systems - condition based maintenance CBM - and as reliability centered maintenance RCM (in some way a scheduled maintenance). As an effect of the deregulation another maintenance strategy, which can be called risk based maintenance, is introduced. By all of these activities the maintenance costs should be minimized, the intervals between maintenance enlarged and the availability of the equipment increased.

Recent maintenance practices give increased focus upon achieving greater efficiency. Business profitability, availability, reliability, revenue and customer satisfaction are all identified as key drivers. In the following Sections the most common possibilities for maintenance philosophy presented in detail and commented upon:

### 4.16.1 Time Based Maintenance TBM

Typically the time based maintenance activity is following a maintenance schedule according to the recommendations of the manufacturer. Following this approach the maintenance has to be done after reaching special limit values of

- number of operations
- interrupting current
- years of service (age)

Due to the effects related to the service stresses. The limit values were specified by the manufacturer according to his experiences in development, manufacturing and service. All this is based on product reliability statistics of the manufacturer, which include the complete number of delivered units in service under all conditions, and will be adapted to changes if necessary.

The advantage of this method is a planned and organized procedure, harmonized for all elements of the equipment and substations and optimized for the effectiveness of maintenance effort [4.16.3]. The disadvantage is that the activities are carried out independently if necessary or not. Failures might occur between the maintenance intervals. However the costs for labor and spare parts are predictable.

An example of the structure of this maintenance method can be seen in the following table:

Description of inspection and maintenance services (due after time or wear)		Remarks
time	wear	
Visual check (VK) after 8 years		Switchgear remains in service; the bays must be isolated one after the other. The compartments need not be opened.
Visual check (VK) after 16 years	Circuit-breaker: after 3.000 mechanical operating cycles	Switchgear remains in service; the bays must be isolated one after the other. The compartments need not be opened.
Major inspection (MI) after 24 years	Circuit-breaker after 6.000 mechanical operating cycles  High-speed earthing switches and Work-in-progress earthing switches: after 2.000 mechanical operating cycles Disconnecter and earthing switch module: after 2.000 mechanical operating cycles	Switchgear is taken out of service, either completely or in sections, depending on the amount of work involved.  <b>Gas compartments need be opened.</b>
Contact system check (CC)	Circuit-breaker:  if the maximum allowable number of fault current operations according to digit 4.1 has been reached. After a maximum of 6.000 fault current operations! High-speed earthing switch: after the second closing operation onto live conductors	Module must be isolated.  <b>Gas compartment is opened.</b>
Visual check (VK) after 32 years	The inspection and maintenance schedule is repeated.	

**Table 4.16.1 Typical Inspection and Maintenance Activities of TBM**

Whilst specified by GIS manufacturers in the past, this approach will become less common in the future and experience and other philosophies dictate changes in approach.

#### **4.16.2 Condition Based Maintenance CBM**

This kind of maintenance will be done on the basis of the results of diagnostic and monitoring devices for special parameters as there are e.g.

- drive characteristics/operating characteristics/timing
- density
- gas leakage/gas moisture/decomposition products
- partial discharges
- conductive particles
- breaking current
- local overheating
- wear/condition of contacts
- position of operating systems a.s.o.

The data gathered by sensors can be processed and used for the determination of trends, which indicate what activity might be necessary at which time.

Advantageous for this method is the knowledge about the actual state of the equipment, the prevention of predictable failures and the reduction of not necessary work. The disadvantage is that additional effort around the equipment (investment and labor) has to be done, that the overall reliability might be decreased and that possible actions cannot be planned. For example as the result of the diagnosis the maintenance of the circuit-breaker might be necessary at different times than that for disconnectors, so compromise decisions have to be taken as to the optimum maintenance interval.

#### **4.16.3 Reliability Centered Maintenance RCM**

RCM is a structured method of maintenance activity that establishes the maintenance requirements for the equipment based on the experiences and consequences of failure, as it is also done by the scheduled maintenance method. However the failure consequences are not determined by the manufacturer but by the (limited) experiences of the user with only his equipment in an operating system. The failure causes and failure modes for each component in this system have to be identified and than to be subjected to a failure mode effective analyses (FMEA).

The advantage of this method is expected to have cost savings in preventive maintenance and that the costs of implementation will provide a rapid pay back. However it is difficult to judge correctly the failures and to proceed with FMEA without the knowledge and experience of the manufacturer. Failure statistics require big numbers of units to be representative. If only small units will be considered, the conclusions might be misleading.

#### **4.16.4 Corrective Maintenance CM**

In case of corrective maintenance no preventive maintenance at all is carried out, maintenance is only performed when a failure occurs. This has an influence on the failure rate and consequently on the availability of the switchgear. Reducing the time based maintenance will as well result in a higher failure rate as the variation of the maintenance interval in case of TBM.

It has to be considered that this method has an impact on the overall life cycle cost, depending on the reliability of the equipment and the financial losses in case of outage.

#### **4.16.5 Risk Based Maintenance RBM**

This maintenance procedure can be considered as a special form of CM, which includes additional a risk assessment when to decide, on which parts of the substation equipment RBM should be applied. Of course on more important switchgear, where severe consequences of an outage have to be expected including penalties, the risk has to be kept lower as on not so important switchgear.

#### **4.16.6 Implications on Utilities of GIS Maintenance**

As described in other sections of this brochure, GIS equipment is becoming simpler and therefore requires less maintenance than earlier designs of equipment. The maintenance intervals for the equipment is also increasing.

This raises issues for utilities when it comes to planning for maintenance.

Firstly a larger proportion of the maintenance activity becomes more difficult to plan for on a long term basis, i.e. a GIS substation will not be subjected to a defined 15 year maintenance programme. However there will also be less need for failure and short-term maintenance responses due to the application of diagnostic techniques that will predict equipment deterioration, ideally this will happen before failure occurs.

Secondly the normal practice of training for a know maintenance programme becomes difficult and indeed as maintenance intervals reach 20 years it becomes pointless training today's staff when knowledge may not be required for a long time.

Hence utilities are taking many different approaches to this problem, and in some cases are outsourcing the maintenance of the equipment or sub-contracting the responsibility back to the original GIS supplier. This gives benefits in terms of training and also potentially with the holding of spares, dependent on whether or not the utility wishes to retain responsibility for spares itself.

Some of these issues for Utilities are now discussed.

#### **Assignment of personnel**

The inspection and maintenance services may only be carried out by qualified personnel. The advantage of calling in manufacturers personnel is that the work is carried out in accordance with the latest information and experience gained with a large number of metal-enclosed gas-insulated switchgear installations. This is then reflected in the switchgear having a higher reliability standard. Experienced personnel guarantee that the work is quickly completed. This means that when switchgear operation must be limited or interrupted, the duration will be kept as short as possible.

Assignment of personnel also means that tools and measuring instruments etc. that are usually not worth buying have to be provided on a hire basis.

In general it can be said, that the choice of the right maintenance method has a major impact on the economic situation of the equipment and even on decisions of its replacement. Therefore this issue is subjected to all kind of cost saving investigations and as a result the outsourcing of maintenance will become an important issue in the future.

#### **Outsourcing of Maintenance**

An "International Survey of Maintenance Trends and Policies" has been published [4.16.4]. This reported the results of a questionnaire conducted during 1998 and was coordinated by a joint working group (WG 23/39) of CIGRE study committees 23 and 39 and reflected the recent, and ongoing, dramatic changes occurring in the maintenance policies of the electricity supply industry worldwide.

For many utilities the tradition has been for internal staff to undertake all operation and maintenance activities - and to achieve this at the same high technical standard at all points in the transmission system. This situation has changed, and many utilities now report outsourcing of activities that are judged to be non longer core-business like tower painting and substation building repairs. Such activities are traditionally defined as non-core work while technical work, for example, primary plant or protection maintenance, is considered to be core work since it has direct consequences for the power supply. The typical level of outsourcing reported in the survey was that in 1998 utilities were reporting 30-35% of their operation and maintenance activity was being outsourced. In general this activity related to non-core activity. The exceptions were in some countries where there was not a strong technical capability and there was greater reliance upon external technical support for activities usually conceived to be "core". This result shows an increase compared to a survey in 1991, which reported an average of 26% outsourcing. More surprising is that 25% of respondents outsourced more than 50% of their maintenance, and of these 15% outsourced more than 90%. Asia and the Middle East had the highest average of 57% and North America the lowest at

5%. While this North American result has increased substantially since 1998, there remains evidence that many of the large U.S. utilities still have little exposure to outsourcing.

Without doubt this strategy includes a certain risk is for transmission utilities. Beside the operational risk there are other equally significant categories of risk associated with outsourcing which should be regularly reviewed to ensure that they are fully understood and managed. The risks include:

- Inadequate training and loss of technological skills base
- Business failure or pull out by contractor
- The level and availability of skilled resources, especially if the utility does not have its own field resources
- Domination of the utility by the contractor

Whilst the above risks are significant they are normal business risks that can be overcome provided that the market is sufficiently mature to allow choice of suppliers. Appropriate forms of contract and ensuring that an asset manager retains sufficient expertise and resources to adequately manage suppliers can also offset such risks. This latter capability is defined in the CIGRE Guidelines as a realization capability.

The use of external service providers does enable risk to be shared. However, it is unreasonable to expect a contractor to carry large risks on behalf of a utility if the work to be undertaken is low cost and low margin. The allocation of risk is a key issue and it should be recognized that it is generally more practical to accept greater rather than less risk.

#### **Selection of Service Providers**

Maintenance contracts for transmission assets tend to be long lasting, it is therefore important that contractors are carefully selected. Important considerations are the alignment of the utility's and contractor's business objectives, and the fit of the contractor with the current, or desired culture of the utility. Whenever possible the contractor should enhance the utility's business.

A rigorous and formal approach to selection is necessary to avoid risk of failure downstream. This requires that a set of selection criteria be developed and thoroughly applied to all supplier candidates. The CIGRE Guidelines 4.16.5] describe a process based on the ranking of the business drivers behind the outsourcing initiative and an assessment of the potential utility/supplier relationships. The proposed selection criteria also make use of "gateway" questions. These are high level questions covering, for example, the financial health and health and safety standards of the contractor.

#### **4.16.7 End of life of the gas insulated switchgear and disposal**

The average service life of gas insulated switchgear is nowadays between 20 to 30 years old. It has to be considered, that the average age of end of life is between 35 to 50 years and as a result of good experiences it can be estimated, that a service period of about 50 years can be economically completed. However there are a lot of other facts beside the equipment itself, which can influence the service life like

- change of technical requirements,
- change of legal conditions,
- change of network conditions,

The use and operation of switchgear needs qualified staff due to federal regulation not only for operation but also for disposal. Disposal of equipment will be done typically for HV equipment on site and mainly the by users themselves, with assistance of manufacturer only if requested. For MV a system has to be installed, until now however, there is no recycling association or network installed.

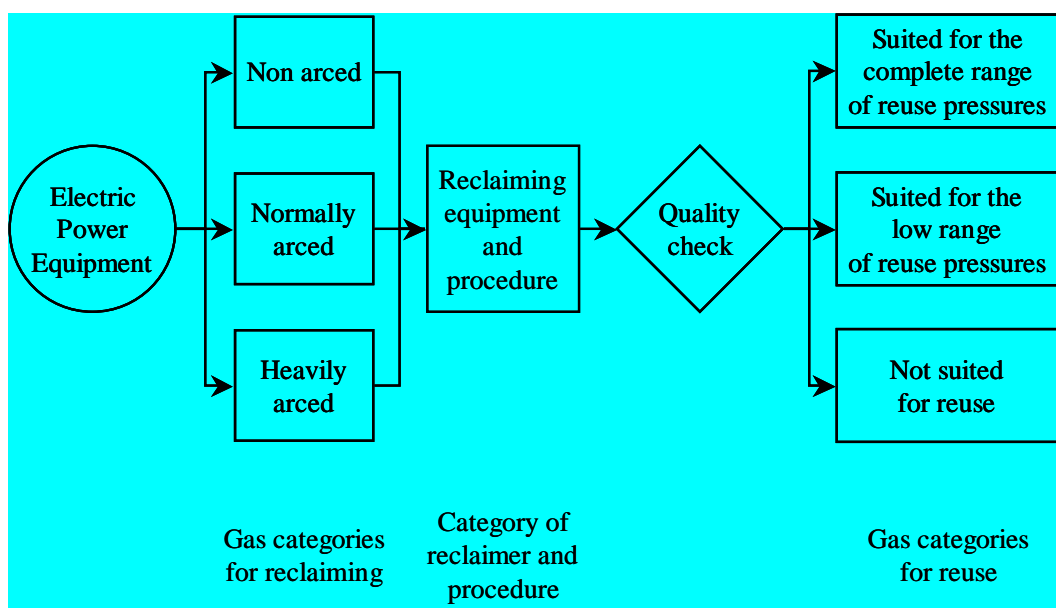
The end of life procedures of a gas insulated substation must be defined. For decommissioning in general the equipment will be disassembled down to its material components, which are typically metallic material – aluminum, copper, aluminum casting components, low voltage waste, hydraulic fluid and grease. Almost 90% of all materials can be reused. Each material has a waste processing number, which indicates what has to be done. Materials and equipment must be cleaned or disposed of so that the decomposition products they contain are not released. The materials have to be assorted on site before delivery to the waste collector. Switch dust, absorption agents and filters from gas compartments, respiratory equipment, cleaning and maintenance gear, disposable protective clothing and other materials which have been in contact with the decomposition products, must be deposited in sealed containers and disposed of in

compliance with local regulations, stating refuse code ASN 59304 (materials contaminated with chemicals) as necessary.

The owner is always responsible for cleaning and disposal tasks. Due to the environmental impact of SF6 special procedures how to handle e.g. used SF6 and SF6 contaminated materials have to be followed. General considerations of recovering SF6 and a basic structure of the SF6 reclaiming from electrical power equipment were described in several papers of the CIGRE B3-02 working group [4.16.6].

Before the gas is recovered from the electric power equipment it has to be assigned a gas category for reclaiming. This category is based on the severity of contamination with the levels non-arc'd, normally arc'd and heavily arc'd. Based on this category an adequate reclaimer and reclaiming procedure are chosen. After the gas has passed the reclaiming process it has to undergo a quality check by which it is assigned one of the following three categories:

The basic structure of the SF6 reclaiming process can be seen in the following picture:



**Figure 4.16.2 Basic structure of the SF6 reclaiming process.**

The higher gas category for reuse is “suited for the complete range of reuse pressures”. This gas can be reused in electric power equipment without any limitations.

The lower gas category for reuse is “suited for the low range of reuse pressures”. This gas can only be reused in equipment with filling pressures up to 200 kPa.

The lowest gas category is “not suited for reuse”. This gas requires further treatment, usually off-site.

Normally arc'd gas may contain, in addition to air and moisture:

- The inert gas CF4 generated by arc erosion of polymers;
- Corrosive gaseous SF6 decomposition products up to about a few 100 ppmv as residues which have not been removed by adsorbers;
- Solid decomposition products, mainly metal fluorides and tungsten oxifluorides, usually referred to as "switching dust".

Heavily arc'd gas is to be expected from equipment in which failures have occurred:

- Circuit breakers after interruption failure;
- Insulation compartments after internal arcing failure;
- Any kind of arcing failure.

In this case, high levels of solid and gaseous contaminants have to be expected. The gaseous contaminants may reach levels of several % vol, of which a substantial fraction can be highly reactive and toxic and/or corrosive. The solid contaminants will generally be charged with adsorbed reactive gaseous contaminants.

Gas reclaimers have been used successfully since the introduction of SF6 technology. Standard reclaimers are commercially available in a variety of sizes, processing speeds and storage capacities and range from small portable to large trailer mounted systems. The appropriate type and size of the reclaimer should be chosen according to the gas quantity to be handled. The choice should also consider whether the reclaimer has to operate as a stationary or transportable device. Among the transportable devices, low cost portable versions operating at low pressure levels without SF6 liquefaction are of particular interest to enable reuse also under conditions where general purpose reclaimers are not available.

The next figure shows the basic functional scheme of a general purpose SF6 reclaimer.

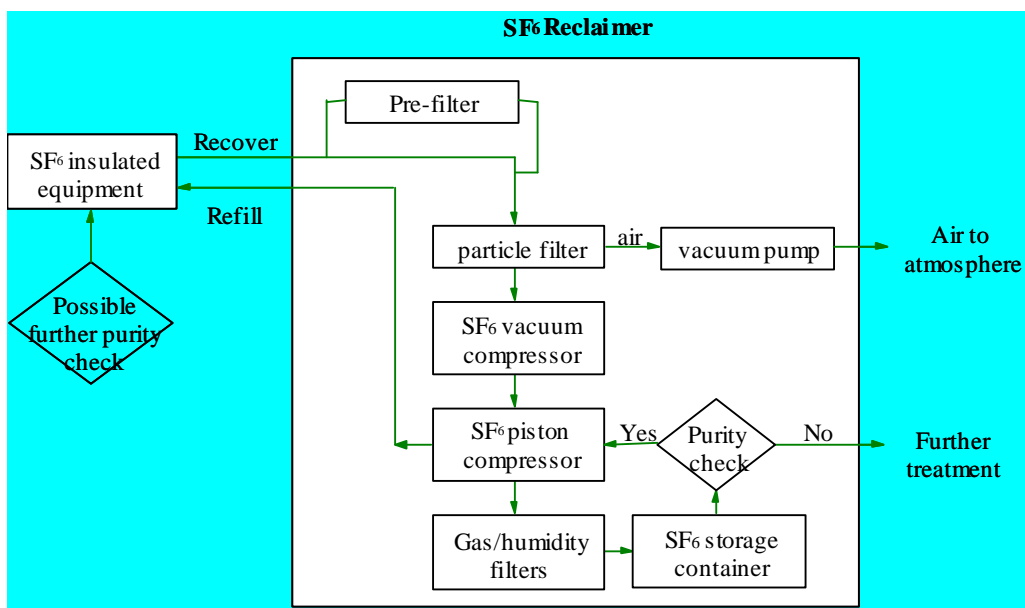


Figure 4.16.3 Functional scheme of a general purpose SF6 reclaimer.

The main elements of the gas reclaiming procedures are:

- Determination of the gas category;
- Selection of filters;
- Gas purification by filtering;
- Quality checks;
- Handling of gas that results non-reusable.

For final waste high voltage equipment manufacturers are offering their services to switchgear users in parallel to switchgear users (mainly utilities) who work under own responsibility. Individual and small installations especially in the medium voltage sector are not covered by existing de-commissioning companies besides the manufacturers.

Documentation about de-commissioning is indirectly documented in the overall SF6 inventory by the recycled and re-used SF6 quantities. For decommissioning especially the SF6 balance will be evaluated and reported by the acting parties.

## **Conclusions**

When the first GIS installations were applied the maintenance requirements were based on the then practices for conventional switchgear with preventive or time based maintenance programmes. Fixed intervals of time were given for the opening of equipment simply to check that everything was in good condition. Diagnostic checks would be limited to items such periodic resistance measurements and SF6 gas quality checks.

Based on early operational experience the maintenance philosophies for GIS are changing so that for passive primary parts (busbars and connections) no preventive maintenance tends to be prescribed at all. Any maintenance is based on some need that is preferably identified through some diagnostic technique e.g.

- Partial discharge measurement
- Gas quality
- Gas leakage detection
- Resistance measurement

For active primary parts (circuit breakers, disconnectors and earthing switches) the maintenance needs are based on predictive maintenance with diagnostic techniques or a specific knowledge of the operational duty (number of operations and duty switched) of the equipment. Thus again maintenance is only performed when the equipment requires attention.

By not carrying out needless maintenance the operational performance of the utility is improved as:

- Availability of the equipment improves as there is no need to take equipment out of service unnecessarily.
- Reliability improves as defects introduced through unnecessary maintenance are eliminated.
- As unnecessary maintenance is not being done the labour costs of maintenance and spare parts is reduced.

In addition to the active and passive primary parts of the GIS there is also the secondary equipment including the control and protection equipment. This equipment is generally the subject of the closest scrutiny during routine operation of the GIS and is also the equipment that requires the most frequent maintenance. Also this type of equipment can have shorter a life-time than the primary equipment and may require replacement or updating during the life of the GIS. However the requirements for the secondary equipment apply to any type of substation and issues are not specific to GIS equipment.

This trend is set to continue with less and less maintenance being done on equipment which raises key questions for utilities concerning their maintenance strategies and the utilisation of their own staff. We will surely see many different approaches to these issues in the future as the importance of asset management grows within the GIS environment.

## **References**

- [4.16.1] [4.16.1] Welch IM, Jones CJ, Kopejtkova D et al "GIS In Service - Experience and Recommendations" Paper 23-104 CIGRE Paris 1994
- [4.16.2] CIGRE WG 23-10 Kopejtkova, D., et al.: Report on the second international survey on high voltage gas-insulated substations (GIS) service experience, CIGRE 23-102, 2000
- [4.16.3] CIGRE Report 176: "Ageing of the System - Impact on Planning" of the Working Group 37-27, December 2000
- [4.16.4] CIGRE JWG 23/39 brochure N°152 "International Survey of Maintenance Policies and Trends ", published February 2000
- [4.16.5] CIGRE JWG 23/39 brochure N°201 "Maintenance Outsourcing Guidelines", published in 2002
- [4.16.6] CIGRE Brochure No 276 "Practical SF6 Handling Instructions", published in 2005.

## 4.17 Functional/Standardised Specifications

The trend towards functional specifications is likely to continue. This allows suppliers to offer alternative solutions that may offer users particular advantages, however users need to be aware that such choices would require evaluation.

### 4.17.1 Background

Over the last few years manufacturers, contractors and engineering companies (solution providers) have developed a number of innovative solutions for substation design. Presently the asset owner or asset manager predetermines the availability, maintainability, flexibility and extendibility aspects of a substation. This is done, for example, by requiring a certain type of primary single line diagram and by positioning accurately the different parts of the substation and even different high voltage equipment in layout drawings. In order to standardise his substation solutions, the asset owner also defines many of other requirements in detailed specifications for the specific plant (Refer to Figure. 4.17.1). One reason for using a detailed specification is the fact that this way the asset owner can be sure that he will get what he wants.

This approach inherently preserves the old designs and effectively slows the introduction of innovative substation solutions. However, it is also in the asset owners' interest to get better solutions together with minimised life cycle costs. In order to achieve the significant cost benefits of innovation [4.17.1] it is necessary to change from detailed specifications to functional specifications (As indicated in Figure. 4.17.2).

Functional specifications seem to be most powerful if projects are ordered on a turnkey basis. Only then can the solution providers do the whole cost optimisation including engineering, installation and construction work. Turnkey substation projects have in fact become more common even when using detailed specifications. A bid competition for a complete turnkey substation project has very often meant lower investment costs and shorter implementation time. These savings are expected to be achieved by reducing contract administration to a single substation supplier rather than managing several individual contracts for procurement of discrete components and other services. Furthermore, this outsourcing of engineering design and construction services has led to a dramatic reduction in the population of the grid asset owners' internal engineering resources.

In many countries the deregulation of electricity markets has also meant that there are new factors in the market. The independent power producers, who often have very little internal expertise in transmission assets, have frequently introduced very tight time schedules for the projects. In these cases turnkey projects are virtually the only possibility. Also the deregulation process has forced short planning and construction times in almost all substation projects. In some cases consumers and producers do not disclose their investment proposals until a final investment decision has been reached.

There are also some problems with the principle of a functional specification, which must be solved before this kind of specification can be utilised. One concern lies with defining a method for the evaluation of the different solutions derived from the functional specification. This evaluation of very different solutions employing new technologies, is more complicated than in the conventional case. A second concern is the lack of sufficient time for complex studies into the availability and flexibility of alternative solutions when the project evaluation and execution lead times are considerably reduced. To help to speed up this process some guidelines are essential. Most conventional busbar systems have been developed over many years and asset owners are well aware of the extendibility and availability. Furthermore, the standardisation of busbar schemes and switchgear layouts has contributed to reducing the risk of human error during maintenance and switching operations. To incorporate these requirements considerable rethinking of the specification of the substation availability and flexibility is necessary. Also, the substation requirements often change over the lifetime of the station and it is difficult to predict these future needs at the time the specification is written. Nevertheless, it is important to define the required flexibility in design within the functional specification.

With the implementation of "functional specifications" asset owners must rely more heavily on "solution providers" for technical substation solutions and consider new concepts with an open mind. The functional specification should also include long term penalty/bonus schemes for the substations performance against guaranteed availability measures. The functional specification should also be flexible in that implementation of future substation extensions are not restricted to the designs and protocols of the

original solution provider. In essence this philosophy enables/facilitates competition for future extension works.

#### 4.17.2 Scope

The functional specification should include all the necessary information for the solution provider to supply the optimum substation, which meets the customers' present and future requirements. The objective is to produce a standard format for such a specification, which can be used as a guide for asset owners, when specifying their requirements for a specific substation.

As a first step the functional specification will be made only for a turnkey substation on a "green field" site. This is to minimise the interfaces to existing installations enabling attention to be concentrated on the basic principle of a functional specification. The functional specification is divided into four parts: Boundaries, functional requirements, evaluation criteria and commercial conditions.

Although most of the technical solutions are left open in functional specifications, it is not possible that solution providers can make all technical decisions independently of the asset owner. Certain predetermined requirements, such as interfacing with the existing high voltage network as well as the environmental and legal aspects, may be regarded as boundaries. For example, boundaries may include high voltage terminal points, environmental aspects, spatial constraints, civil information, the laws, grid code and standards to be followed, safety regulations and other basic system parameters.

Functional requirements of a particular substation define the actual and future needs of the asset owner. These needs include the guaranteed capacity and availability, which will be subject to penalty/bonus schemes together with requirements for flexibility and future extendibility.

When solution providers are allowed more freedom in their tender preparation, the asset owners must state clearly in the functional specification how the tenders will be evaluated, as is frequently required by the competition legislation of public procurement. The evaluation of tenders based on functional requirements is also made more complicated as the solutions differ from each other more than with the previous detailed conventional designs. In order to evaluate each solution, evaluation criteria and weighting factors need to take into account the running, operating and maintenance costs. This is most likely to be achieved in financial terms by considering the Life Cycle Cost (LCC) together with weighting factors for flexibility, extendibility and availability. The factors to be used in the LCC for evaluating the bids shall be defined by the asset owner.

#### 4.17.3 Evaluation formula and rules

The first step of the evaluation process is to check the compliance of the solution with the "boundaries" requirements.

A common and predefined evaluation formula, with associated costs, is necessary:

- for the solution provider, to provide the most adapted substation to the asset owner,
- for the asset owner, to evaluate the bids of the solution providers.

A number of factors have to be incorporated into the evaluation formula including.....

**AOC** : asset owner cost for installation

This category includes such items as cost of installation supervision, of testing and of training (in-house or contracted).

**PMC** : capitalised costs for planned preventive maintenance

This category includes such items as level of required maintenance for the new equipment, cost of spare parts, rental or purchase of special equipment to perform preventive maintenance, cost per man-hour of in-house labour, of contracted labour.

**CMC**: capitalised costs for corrective maintenance

This category includes such items as level of reliability of the new equipment, cost of spare parts, rental or purchase of special equipment to perform corrective maintenance, cost per man-hour of in-house labour, of contracted labour.

**COC:** capitalised operation costs

This category includes such items as cost for running losses.

**PUC:** capitalised costs for planned unavailability

This category includes such items as loss of revenue from planned downtime (cost for power, cost for energy), outage planning administration costs. Network constraints e.g. customer/generation constraint penalties should also be detailed if relevant.

**UUC:** capitalised costs for unplanned unavailability

This category includes such items as loss of revenue from forced unplanned downtime (cost for power, cost for energy).

**DC :** capitalised costs for decommissioning

This category includes such items as salvage value of old equipment.

#### **4.17.4 Commercial Conditions**

The commercial conditions in a functional specification should include all of the normal general conditions applicable to conventional specifications plus those requirements specific to a functional specification. These include the penalty and bonus clauses for availability and losses, short and long term warranty and rules for the case when specific functionality requirements are not fulfilled.

#### **Conclusions**

The trend towards functional specifications is likely to continue. This allows suppliers to offer alternative solutions that may offer users particular advantages, however users need to be aware that such choices would require evaluation.

Conversely standardised specifications may reduce engineering effort required within a user which is certainly attractive in today's market liberalisation atmosphere. The disadvantage of standardisation is that choice will be reduced.

Perhaps the conclusion is that we will see increased functional and standardised specifications dependent on the utility, the type of project and the relationships with suppliers.

#### **References**

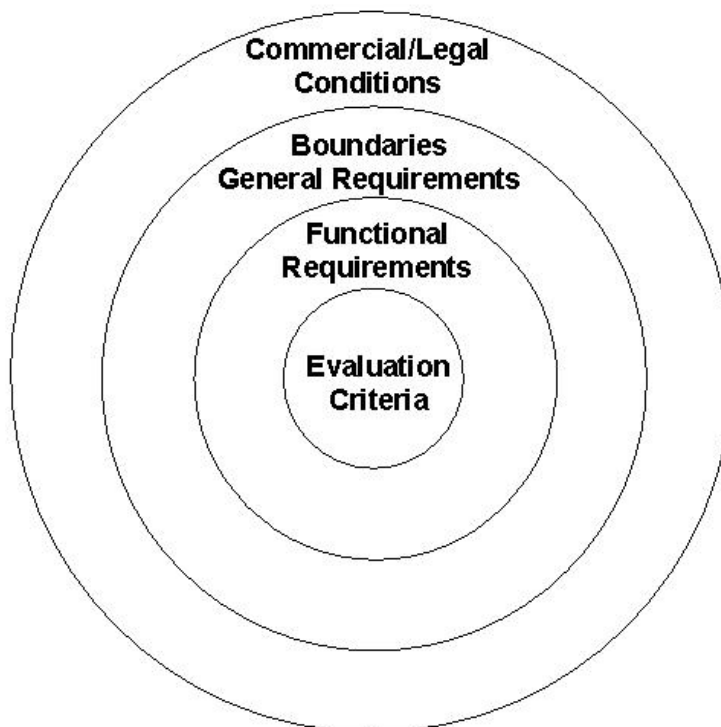
4.17.1 "Functional Specification and Evaluation of Substations" CIGRE Technical Brochure No 252

<b>Flexibility/Extendability 1)</b>			<b>Commercial/ Legal 2)</b>
<b>Availability/Reliability 1)</b>			
<b>Maintenance 1)</b>			
<b>Primary Equipment2)</b>	<b>Secondary Equipment2)</b>	<b>Ancillary Equipment2)</b>	
<b>Civil Works 2)</b>			
<b>Environmental aspects</b>			
<b>Substation on environment 2)</b>	<b>Environment on substation 1)</b>		

1) Pre-determined aspects (shown with red colour)

2) Detailed specified (shown with blue colour)

**Fig. 1 Existing principles for specifying S/S**



**Fig. 2 Proposed functional specification**

## 5 Conclusion

The work of Task Force 04 of Working Group B3-02 shows that many of the developments that have taken place in the area of GIS are driven not by GIS technology itself but by general economic, environmental and business drivers. Whilst perhaps not surprising, it is nevertheless reassuring that those involved in GIS technology seem to be very aware of the needs of customers and indeed the needs of society.

The business drivers, including particularly economic and environmental aspects are discussed at length in the brochure but they can be summarised as;

- Need to reduce costs
- Changing nature of utilities due to market liberalisation and industry privatisation
- Globalisation of markets, further reduction of number of suppliers/utilities and harmonisation of standards
- Ever increasing environmental awareness
- Security and quality of electrical supplies
- Global recognition of security and personnel safety

The future development of GIS is already being determined by these factors and in many cases this has been visible for many years. Some of these factors will however become even more important in the future.

Fortunately for those interested in the development, application and operation of GIS equipment, the fundamental attributes of GIS are ideally placed to respond to these challenges.

- GIS is often the most cost effective solution, particularly when full Life Cycle Costs are considered including land costs, cost of maintenance and costs of lack of availability of equipment and consequently electricity supplies are evaluated.
- Generally GIS solutions minimise environmental impacts giving the preferred solution for an increasing number of customers. This is still the case despite concerns regarding the use of SF6 gas and this is supported by the proactive approach taken by the industry in the responsible usage of SF6 technology.
- GIS continues to demonstrate performance and reliability improvements and inherent advantages over alternative AIS solutions.
- GIS is also able to offer flexible solutions in switchgear with mixed technologies

It is further concluded that GIS will continue to respond to the needs of its users and society generally in the future.

As far as the specific features of the GIS of the future are concerned, these are expected to show continued evolution of this mature technology rather than a revolutionary step.

In terms of a vision of the GIS of the future, certain general characteristics can be expected:

- Even more compactness
- Simpler designs and therefore inherently more reliable and requiring less maintenance with longer expected lifetime
- Even closer cost evaluations between solutions resulting in decisions being taken on investment on a substation by substation basis rather than a common philosophy across an utility. Hence methodologies for Life Cycle Cost evaluation of different options will become very sophisticated in the future.

- The acceptance by users of functional specification for GIS with fewer variations of requirements between different users. This will tend to bring the equipment design philosophies of suppliers closer together with innovation being restricted to ancillary equipment and application engineering.
- The development of Intelligent GIS with full condition assessment capability with integration of control, monitoring and protection functions and communication directly to utility centralised IT functions.
- GIS supply will continue to be centred with key business processes of
  - New Product Introduction
  - Outsourcing of component and system manufacture
  - Application engineering
  - Assembly and test
  - Project management, site installation and commissioning

Suppliers will establish global supply chains with central R&D teams and local assembly and test capabilities where territory volumes justify a facility. Capability for application engineering and project execution will evolve to be close to the customer in order to match customer requirements and deliver solutions in shorter timescales.

- More integration of functions and primary/secondary devices. Also solutions which are more integrated into urban communities within buildings and other developments.
- More flexibility to satisfy wider customer needs but reliant on common modules applied in more and more innovative ways.
- Utilising less SF6 gas by design techniques (designs requiring less gas) and improved equipment reliability (less need to handle gas).
- Equipment designs will be modified more frequently leading to more complexity for users of equipment. This may result in more outsourcing by utilities of responsibilities for operational duties as well as maintenance and spares logistics.
- Single line diagrams will continue to change allowing more diversity taking full advantage of the increased flexibility that can be satisfied more easily by the GIS of the future.

The considerable overall economical and environmental benefit in utilising SF6 gas will continue to dominate HV technology. Whilst alternatives for SF6 cannot be ignored it does not seem very likely in the foreseeable future. Using alternatives is likely to introduce economical and environmental disadvantages.

## 6 Bibliography

- [1.1] Henry Clothier 1926, "Switchgear Stages"
- [1.2] "Functional Specification and Evaluation of Substations" CIGRE Technical Brochure No 252
- [1.3] H.Troger et al, CIGRE 1972, paper 23-04, "Compilation of International Experience on Installation and Operation with Metalclad Substations".
- [1.4] Kopejtkova, Molony, Kobayashi and Welch, "A Twenty-Five Year Review of Experience With GIS" CIGRE 1992 paper 23-101.
- [1.5] Kopejtkova D. at all. „Report on the 2<sup>nd</sup> international survey on high voltage gas insulated substations (GIS) service experience" CIGRE Technical Brochure No.150
- [2.1] IEC 60050 (1982) International Electrotechnical Vocabulary (IEV)
- [2.2] IEC 62271-203 (2004) High Voltage Switchgear and Controlgear – Gas Insulated metal-enclosed switchgear for rated voltages above 52kV.
- [2.3] IEC 60694 (1997) Common Specifications for high voltage switchgear and controlgear standards
- [3.1.1] Pokarier, et al. 'First new integrated switchgear substation in service' CIGRE 2000 Session Paper 23-104
- [3.1.2] Bartlett, et al. 'Highly integrated switchgear – an innovative concept to reduce life cycle costs' CIGRE 2000 Session Paper 23-108
- [3.2.1.1] Meguro, 'Application of Hybrid Gas Insulated Switchgear (GIS) for 550kV System', Contribution CIGRE 2000 SC23
- [3.2.1.2] Shimato,T et al "Evaluation of Total Life Cycle Cost of GIS Substation and Development of Portable Diagnosis Devices" CIGRE 2000 Session Paper 23-107
- [3.2.1.3] Bartlett,S et al. 'Highly integrated switchgear – an innovative concept to reduce life cycle costs' CIGRE 2000 Session Paper 23-108
- [3.2.1.4] Weltmann, 'GIS versus Non-GIS – a Value Based Comparison', Ninth International Symposium on Gaseous Dielectrics, 2001
- [3.2.1.5] IEC 60300-3-3 Dependability Management Part 3-3 Application Guide – Life Cycle Costing Second Edition 2004-07
- [3.3.1] Eliasson, 'Working together on Global Climate Problems', IEEE Power Engineering Review, P.3-5, March 2001
- [3.3.2] Ashley, 'Are Power lines unsafe?', IEEE Spectrum, p.21-23. July 2000
- [3.3.3] Project Group ABB, PreussenElektra, RWE, Siemens, and Solvay, Electricity supply using SF<sub>6</sub> technology. For MV see Solvay Management Support: SF<sub>6</sub>-GIS-Technologie in der Energieverteilung – Mittelspannung. Life Cycle Assessment study commissioned by ABB, Areva T&D, EnBW Regional, e.on Hanse, RWE, Siemens, and Solvay Fluor und Derivate. Solvay: Hannover/Germany, 2003 (in German, abstract and summary available in English)
- [3.3.4] Maruyama, et al, 'SF<sub>6</sub> Gas Emission Reduction from Gas Insulated Electrical Equipment in Japan', EPA Conference
- [4.2.1] G Mauthe et al, "SF<sub>6</sub> and the Global Atmosphere" – ELECTRA No 164 1996.
- [4.2.2] G Mauthe et al, "SF<sub>6</sub> Recycling Guide, Re-use of SF<sub>6</sub> Gas in Electric Power Equipment and Final Disposal" – ELECTRA No 173 August 1997, pp 43-71.

- [4.2.3] P. Glaubitz, S. Stangherlin, D. Crawley, J. Henriot, A. Holm, P. Jannick, P. Justiz, M. Meguro, R. Probst, P. Sieber, S. Theoleyre, T. Yokota, L. Van der Zel, Guide for the preparation of "Customized SF<sub>6</sub> Handling Instructions", to be issued as CIGRE Brochure, 2005
- [4.2.4] P. O'Connell, F. Heil, J. Henriot, G. Mauthe, H. Morrison, L. Niemeyer, M. Pittroff, R. Probst, and J. P. Taillebois, SF<sub>6</sub> in the Electric Industry, Status 2000, *Electra* 200, 16-25 2002.
- [4.2.5] Project Group ABB, PreussenElektra, RWE, Siemens, and Solvay, Electricity supply using SF<sub>6</sub> technology. For MV see Solvay Management Support: SF<sub>6</sub>-GIS-Technologie in der Energieverteilung – Mittelspannung. Life Cycle Assessment study commissioned by ABB, Areva T&D, EnBW Regional, e.on Hanse, RWE, Siemens, and Solvay Fluor und Derivate. Solvay: Hannover/Germany, 2003 (in German, abstract and summary available in English)
- [4.2.6] IPCC (Intergovernmental Panel on Climate Change), Climate Change 1995: The Science of Climate Change, edited by J. T. Houghton et al. (Cambridge University Press, Cambridge, 1996)
- [4.2.7] L. Niemeyer, H. D. Morrison, G. Mauthe, B. M. Pryor, H. Knobloch, J. Henriot, M. Pittroff, R. Probst, J. Poblitzki, B. Mazzoleni, J. Castonguay, W. Boeck, Y. Murayama, and P. Bolin, Guide for SF<sub>6</sub> Gas Mixtures, CIGRE Brochure N. 163, 2000
- [4.3.1] IEC 60859 (2000) Cable Connections for gas insulated metal enclosed switchgear for rated voltages above 52kV
- [4.3.2] IEC 61958 (2000) High Voltage prefabricated switchgear and controlgear assemblies – voltage presence indicating systems
- [4.3.3] IEC 6271-203 (2004) High Voltage Switchgear and Controlgear – Gas Insulated metal-enclosed switchgear for rated voltages above 52kV.
- [4.4.1] Kopejtkova, Molony, Kobayashi and Welch, "A Twenty-Five Year Review of Experience With GIS" CIGRE 1992 paper 23-101.
- [4.4.2] "Final Report On the Results of the Second International Inquiry Into Circuit Breaker Reliability" CIGRE Brochure No.83
- [4.4.3] IEC 60050 (1982) International Electrotechnical Vocabulary (IEV)
- [4.4.4] Vigreux et al, "Application of Condition Monitoring Techniques in GIS" ELECTRA No. 134, Feb 1991.
- [4.4.5] Jones et al, "Guidelines for Monitoring, Control and Supervision of GIS Incorporating Advanced Technologies" CIGRE 1990 paper 23-104
- [4.4.6] Holt, "New Principles for Current and Voltage Measurement and Aspects of Application in GIS" ELECTRA No 121.
- [4.4.7] Harner et al "Controlled Switching" ELECTRA No 162, 163
- [4.4.8] Dijk et al, "Advanced Control and Expert Systems for Substations" CIGRE 1994 paper 23/13-08.
- [4.4.9] Pederson et al on behalf of 23-05 "Possible Architectures of Future Control Systems Based on Computer Technique" paper 34-89 Bournemouth Symposium 1989.
- [4.4.10] IEC 61850 (2003) Part 1 Introduction and Overview
- [4.6.1] "User Guide for GIS" CIGRE brochure 125 (1998)
- [4.6.2] "SF<sub>6</sub> Recycling Guide" CIGRE brochure 117 (1998)

- [4.8.1] Kopejtkova D. at all. „Report on the 2<sup>nd</sup> international survey on high voltage gas insulated substations (GIS) service experience” CIGRE Technical Brochure No.150
- [4.10.1] Yamazaki, et al, 'Compact GIS in harmony with environment and CAD evaluation system for 550kV substation Design' CIGRE Session paper 23-202, 1998
- [4.10.2] Shimato, et al, 'Evaluation of total life cycle cost of GIS substation and development of portable diagnosis device' CIGRE Session paper 23-107, 2000
- [4.10.3] Meguro, et al, 'Solution for underground substation by gas insulated equipment' CIGRE paper 23-101, 2002
- [4.15.1] Fink D.G., Beaty H.W.: Standard Handbook for Electrical Engineers. McGraw-Hill Book Company 1987.
- [4.15.2] Boehle B., Guthmann O., Haneke K., Hügin K.-H., Tettenborn W., Voss G., Wittwer H.: Schaltanlagen. Brown Boveri Taschenbuch. BBC Brown Boveri AG, Mannheim 1987.
- [4.15.3] Kopejtkova D., Molony T., Kobayashi S., Welch I.M.: "A Twenty-five-year Review of Experience with SF6 Gas Insulated Substations (GIS)". CIGRE Paris 1992, paper SC23 No. 23-101.
- [4.15.4] Balzer G., Becker J., Dzieia M., Strnad A., Neumann C.: Erfahrungen mit gasisolierten Schaltanlagen (GIS). Elektrizitätswirtschaft, Jg. 99. (2000), Heft 7, 24-32
- [4.15.5] Kopejtkova D. at all.: Report on the 2<sup>nd</sup> international survey on high voltage gas insulated substations (GIS) service experience. CIGRE Technical Brochure No.150
- [4.15.6] Wahlström B., Aoshima Y., Mino Y., Lajoie-Mazenc C., Torgerson D.R., Zomers A.N.: "The Future Substation: A reflective approach". CIGRE Paris 1996, paper SC23 No. 23-207.
- [4.15.7] Wahlström B. et al."Simplified Concepts for Future Substations – Some Case Studies. CIGRE Paris 1998, paper SC23 No. 23-107"
- [4.15.8] Norberg P., Tapper M., Lord W., Engqvist A.: "The Future Substation – Reflection About Design" CIGRE Paris, 1998, Paper SC23 No. 23-105.
- [4.15.9] Schett G., Engler F., Petterson K., Kaczkowski A., Frei K.: The Integration of Secondary Technology and Novel Sensors into GIS. CIGRE Paris 1994, paper SC23 No. 23/13-01.
- [4.15.10] Doin Y., Durant-Laurent M., Gens S., Leroy J.C., Triay G., Thomasset G.: "Compact Substation: A Comprehensive Solution" CIGRE Paris, 2000, Paper SC23 No. 23-103
- [4.15.11] Högg P., Fuchsle D., Kara A „PASS für Retrofit, Erweiterung und Neubau von ` Hochspannungs-Schaltanlagen“ ABB Technik 1998, Heft 2, 12-20.
- [4.15.12] Pokarier B., Petersen A., Högg P., Staiblin J."First New Integrated Switchgear Substation in Service" CIGRE Paris 2000, paper SC23 No. 23-104.
- [4.15.13] Carvalho A., Bosshart P., Christianse, U., Guerra G., Tang L., Olovsson H.-E.: Functional Specification as Driver for Technical / Economical Optimisation of Substation. CIGRE Paris 2000, paper SC23 No. 23-101.
- [4.15.14] Helbig D., Meinherz M."HIS – ein hochintegriertes innovatives Schaltanlagenkonzept“ ETZ, 2000, Heft 6, 68-70.
- [4.15.15] Bartlett S., Moller I., Helbig D., Schütte A."Highly Integrated Switchgear – An Innovative Concept to Reduce Life Cycle Costs" CIGRE Paris 2000, paper SC23 No. 23-108.
- [4.16.1] [4.16.1] Welch IM, Jones CJ, Kopejtkova D et al "GIS In Service - Experience and Recommendations" Paper 23-104 CIGRE Paris 1994

- [4.16.2] CIGRE WG 23-10 Kopejtkova, D., et al.: Report on the second international survey on high voltage gas-insulated substations (GIS) service experience, CIGRE 23-102, 2000
- [4.16.3] CIGRE Report 176: "Ageing of the System - Impact on Planning" of the Working Group 37-27, December 2000
- [4.16.4] CIGRE JWG 23/39 brochure N°152 "International Survey of Maintenance Policies and Trends", published February 2000
- [4.16.5] CIGRE JWG 23/39 brochure N°201 "Maintenance Outsourcing Guidelines", published in 2002
- [4.16.6] Guide for the preparation of customised "Practical SF6 Handling Instructions", Draft 3rd February 2004, of WG B3-02 TF1
- [4.17.1] "Functional Specification and Evaluation of Substations" CIGRE Technical Brochure No 252

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