390

EVALUATION OF DIFFERENT SWITCHGEAR TECHNOLOGIES (AIS, MTS, GIS) FOR RATED VOLTAGES OF 52 V AND ABOVE

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Evaluation of Different Switchgear Technologies (AIS, MTS, GIS) for Rated Voltages of 52 kV and above

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0 Scope

The intention of this brochure is to provide comparative information to aid in the selection of the most effective equipment solution for a new or existing transmission or distribution substation. A comparison between Air Insulated Switchgear (AIS), Mixed Technologies Switchgear (MTS), and Gas Insulated Switchgear (GIS) solutions applied to 52 kV and above, partially or totally, can also impact the site selection and help determine the most effective means of developing the substation project with respect to the user, the public, and applicable government regulations. Not all factors considered herein may have a direct impact on investment or life cycle costs, but some can still be critical factors in the selection of the substation location and construction planning.

This brochure was developed to provide a balanced approach in determining whether a substation should use AIS, MTS or GIS technologies to provide the best overall value to the utility (or other owner) and its customers.

In appendix A, there is detailed information provided about the specific features of Mixed Technologies Switchgear MTS, which consists of high-voltage switchgear assemblies for operation at voltages rated above 52 kV according to standard IEC 62271-205.

1 Introduction

Gas Insulated Switchgear (GIS) and Air Insulated Switchgear (AIS) use proven technologies to provide safe and reliable power to the public.

New high voltage switchgear components have been developed based either on air insulated technology (AIS) or on gas insulated technology (GIS) or on a combination of both of them. Mixed Technologies Switchgear MTS are switchgear assemblies combining various high voltage components and were introduced into the high voltage market as a possible solution between AIS and GIS. These solutions are often used to replace and/or upgrade open type substations (air insulated) or older gas insulated substations (GIS) because of their smaller space requirements and reduced outage time demand. These assemblies have now been in use world-wide for several years; therefore a fair amount of experience is available and can be offered to potential users.

Various manufacturers have developed switchgear components derived from AIS or GIS, which can be assembled in a variety of configurations to perform switchgear and control gear functions as a Mixed Technology Switchgear (MTS). Numerous arrangements are possible and in this guide they are identified and considered to form one assembly unit.

CIGRE WG B3-03 has published general guidelines for the design of outdoor AC substations [1]. Apart from some minor comments the scope was limited to air-insulated switchgear (AIS). B3-02 published another guide covering all points which are specific for gas-insulated switchgear (GIS) for rated voltages of 52 kV and above [2].

The general chapters of the previous guides concerning system requirements, network considerations, and the need for a substation cover AIS and GIS substations as well as MTS (as MTS modules were derived from AIS and/or GIS components). The following evaluation will provide help to decide which technology will be the optimal solution.

In general, there is a trend of switchgear solutions towards more compact and integrated gas insulated solutions for the outdoor use.

The different design technologies for high voltage switchgear can be clustered into three groups (see Appendix A for definitions and details):

- Conventional AIS solutions
- Conventional GIS solutions (for indoor as well as for outdoor applications)
- Compact AIS or GIS or hybrid switchgear solutions (mainly for outdoor use)

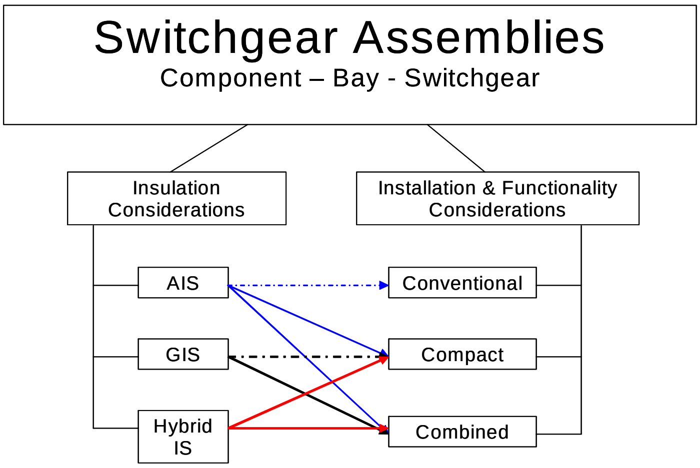

Fig. 1: Mixed Technologies Substations (full line connections) built with switchgear assemblies

These different technologies differ in their approaches: One solution is driven by the need to optimize the investment cost, another by limited space requirements, a third by the need for redundancy and higher reliability of the single line layout.

Since the introduction of GIS into the market in 1968 the substation layout for GIS design followed almost identically the AIS design layout. With the development of compact outdoor solutions, a lot of different substation layouts were built to take advantage of compact switchgear or of switchgear with combined functions. One appropriate method to distinguish between the different high voltage substation technologies is based on the degree of metal encapsulation, whereas the type of encapsulation of the circuit breaker and the disconnector is decisive for classification.

The drivers for the development of MTS are strictly the demands of the changing world of energy supply. The economic pressures on utilities under the conditions of deregulation demand equipment with minimum life cycle cost, high availability (which will be achieved by highly reliable products with high flexibility for installation and replacement), and compact solutions to extend as effectively as possible the already existing substations. Last but not least the suppliers of switchgear have to change from equipment suppliers to solution providers.

Switchgear layout nowadays can be based on insulation technology or on design and functionality. The different substation technology concepts, which are not yet standardized, have recently been used by utilities as well as by manufacturers in quite different ways - a fact that can create confusion.

This brochure provides illustrative and qualitative comparisons of GIS, MTS, and AIS when evaluating the installation of a new or expansion of an existing substation. Evaluation factors are provided in a table format that may be useful to compare various GIS, MTS, and AIS design alternatives, which later on are explained in detail. Direct cost comparisons between various items of equipment or between GIS manufacturers are not provided, but the comparison can be used to help to develop spreadsheets to analyze cost data and provide an economic analysis. (For more details see appendix A).

2 Summary Table

The table contains a summarized evaluation of the applicability of the various characteristics to the three types of technologies AIS, MTS, GIS for a rated voltage level of 52 kV and above. In the referred chapters more details will be found, explaining the evaluation of the different types of switchgear.

Chapter No. and Title	**page**	AIS	MTS	GIS
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• Underground	9	--	+	++
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• Material (*combined equipment)	11	+	+ (-)*	+
• Manufacturing process and quality control of manufacturing (only manufacturing point of view)	11	++	+	-
• Manufacturing process and quality control of manufacturing and assembling (from on-site commissioning point of view)	11	-	+	++
3.3 Engineering	**12**			
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• Single line diagram	13	0	0	0
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Chapter No. and Title	page	AIS	MTS	GIS
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• Preparation of site	18	++	+	-
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• Work crew	19	+	+	-
• Erection	20	-	+	0
• Impact on existing service	20	+	+	-
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3.5 Impact on Environment	**21**			
• Aesthetics	21	-	0	+
• Nature	22	-	0	++
• Noise	22	0	0	+
• Leakages	22	-	0	-
• EMF/EMC	22	0	0	++
3.6 Impact of Environment	**23**			
• Climatic conditions (* Indoor application)	23	0	+(++)*	+ (++)*
• Pollution (* Indoor application)	23	0	0 (++)*	0 (++)*
• Corrosion (** Climatically controlled building)	23	0	0	+**
• Seismic conditions	23	0	+	++
3.7 On-Site Time Efforts	**24**	0		
• Preparation time	24	-	+	0
• Transportation time	24	-	+	++
• Erection time	24	++	++	0
• Commissioning time	25	++	+	0
• Repair time	25	++	+	0
• Maintenance time	25		+	0
3.8 Operation and Service	**25**			
• Control (* for multifunctional MTS)	26	+	0 (-)*	0
• Condition monitoring	26	-	0	+
• Expected life time	27	+	+	+
• Decommissioning and disposal	27	0	0	-
• Replacement of components	27	++	+	-
• Dependence on manufacturer (OEM)	28	++	+	-
• Dependence on special know-how	28	++	+	-
3.9 Availability	**28**			
• Maintainability	28	-	+	++
• Meantime of maintenance	29	+	++	0
• Reliability (*indoor applications)	30	0	+	+ (++)*
• Mean time of repair	30	+	++	0
• Tools, gas handling	30	+	0	0

Chapter No. and Title	page	AIS	MTS	GIS
3.10 Testing	**30**			
• Type tests	31	+	0	++
• Routine tests	32	+	0	++
• On-site tests	32	++	+	0
• Test equipment	33	++	+	0
3.11 Flexibility	**33**			
• Extendibility of existing substations	34	++	++	0
• Use for extension of existing substations	34	0	++	+
• Upgrading /refurbishment of existing substations (*for voltages up to 245 kV)	34	-	++	+*
• Use for upgrading/refurbishment of existing substations	34	+	++	- -
• Mobile and/or temporary installations	34	+	++	
• New substation	34	+	+	+
3.12 Personnel Safety	**35**			
• Injury risk during service	35	0	+	++
• Injury risk during maintenance	36	++	+	0
• Injury risk in case of major "violent" failure	37	0	+	++
3.13 Physical Security	**38**			
• Security against terrorist attack	38	0	+	++
• Security against vandalism	38	0	+	++
• Security against metal theft	38	0	+	++
3.14 Life Cycle Cost	**38**			
• Cost of acquisition	39	++	0	-
• Cost of ownership (* heavily influenced by individual utility 's conditions)	39	0*	++*	+*
• Cost of disposal	39	-	0	0

Interpretation of symbols:

"++" denotes this technology confers **Definite Advantage**
"+" denotes this technology confers **Advantage**
"0" represents **Neutral Status**
"- " denotes **Disadvantage**
"- -" denotes **Definite Disadvantage**

3 Details

3.1 Location

Title	AIS	MTS	GIS
Location • Outdoor rural • Outdoor urban • Indoor • Underground • Container	 ++ 0 - -- --	 + ++ + + ++	 -- + ++ ++ ++

Switchgear rated voltage considerations: The evaluation and the below mentioned explanation depend significantly on the rated voltage of the switchgear. The differences among technologies increase with the rated voltage.

Outdoor rural and outdoor urban

Location is one of the key aspects considered in the selection of the switchgear technology. The location criterion includes two main considerations that need to be evaluated – the space available and the ambient environment, especially for indoor or outdoor installations in rural or urban environment (for impact on and of the environment see chapters 3.5 and 3.6).
The availability of space speaks with exception of outdoor rural areas for MTS and GIS substation designs and therefore simplifies the site selection since the real estate required is typically limited. Due to their compact design and/or their combination of different functions in one module, the space requirements are limited to the dimensions of the switchgear itself.

The following figure (Fig. 2) exemplifies how the required space for the same arrangement of 420 kV switchgear with the same single line, using AIS, GIS, and MTS, leads to a footprint reduction of up to 90% in comparison to AIS. This results in space necessary for building new substations or the possibility of adding three or even more bays instead of one when retrofitting/extending the existing substations.

In general MTS offers in addition a higher flexibility of layout compared to AIS or GIS equipment due to the modular arrangement. A single line diagram can be easily improved or the number of bays can even be increased, while using the same space, to extend the already existing substations efficiently without exceeding the space limitations.

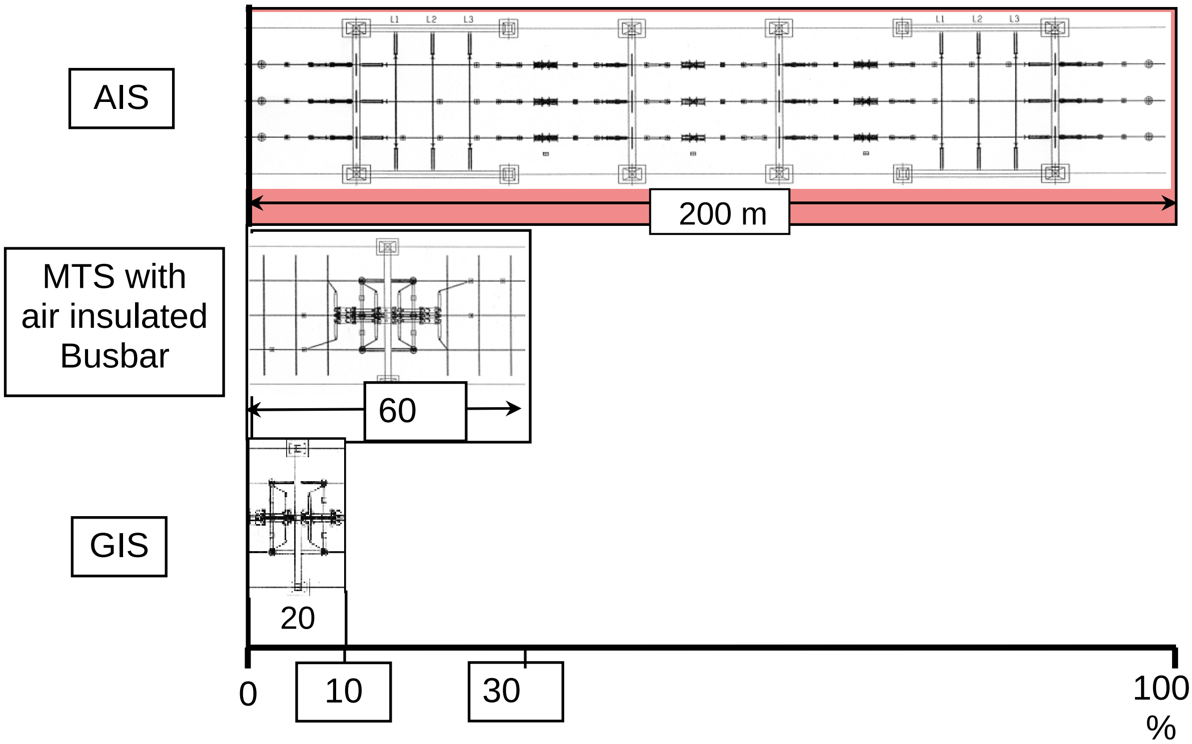


Fig. 2: Space comparison of AIS, GIS, and MTS solution at two CB-bays 420 kV level

Indoor

The more compact the switchgear is and the less space it occupies, the better are the chance that the installation will fit within the existing indoor available space. . Moreover, there are applications such as underground or urban localities, where there are practically no other options than indoor installation. In such cases GIS or highly compact MTS are usually the only possible solutions.

Underground

Even if underground switchgear has got the same ratings as indoor switchgear it is considered separately since additional aspects as installation, interconnection, ventilation, etc. have to be addressed.

Container

A further possibility of saving space is the installation of the switchgear module within a container for easy transportation, whether it is used as a mobile or permanent installation. Containerized switchgear solutions represent special indoor applications protected from some of the environmental factors (such as rain, ice & snow, wind, strong solar radiation, extreme pollution). As the volume of a container is limited it can be used for full GIS only for rated voltages up to 245 kV or very small switchgear (simplified single line diagrams)

3.2 Equipment Design and Manufacturing

Title	AIS	MTS	GIS
Equipment Design and Manufacturing			
• Conceptual design and its evaluation	++	0	+
• Material (*combined equipment)	+	+(-)*	+
• Manufacturing process and quality control of manufacturing (only manufacturing point of view)	++	+	-
• Manufacturing process and quality control of manufacturing and assembling (from on-site commissioning point of view)	-	+	++

Switchgear rated voltage considerations: The evaluation and the below mentioned explanation depend significantly on the rated voltage of the switchgear. The differences among technologies decrease with the rated voltage.

Conceptual design and its evaluation

GIS and AIS designs are considered well established and have been proven by long term service. Both AIS and GIS installations are covered by existing international engineering standards. Hence there are only relatively small changes that are applicable to their designs.

The manufacturer's tasks thus include:

1) Re-designing with existing technologies to simplify them (compact and hybrid MTS)
The re-designing implies application (adoption) of older technologies using the same equipment, but in a different, improved arrangement. The process does not require radical innovations, just re-designing the configuration using the same components, and can be achieved:

- in AIS – via compactness,
- in GIS – via simplification of arrangement (e.g. less gas compartments, transport units).

No special methods for modelling are usually necessary. Standards usually exist and cover most of the design.

2) Using a completely new design (combined MTS)
For combined equipment (MTS) the application of past technologies is somewhat limited. The combined equipment represents a new challenge for the manufacturers**.** Their design has to pass all steps starting with mathematical calculations, PC modelling, development tests, new type tests, etc.
As usually, there is only limited service experience available (based on feedback from utilities) and that is why close collaboration with selected users is necessary. Special design and manufacturing methods are necessary and existing standards might not cover all needs.

An overview of special design aspects to be considered:
There are not many specific aspects that are uniquely valid for MTS only, however, they exist and thus the designer has to deal with few specific topics that cover both electrical and mechanical aspects, such as:

- interconnections/interface design,
- mutual influence between AIS and GIS parts,
- mutual influence between compact modules (namely switchgear assemblies),
- mutual influence of components within compact modules,
- functionality of combined devices,
- secondary systems consideration,
- optimization of SF_6 volume,
- reduction of the total weight,
- optimization of SF_6 monitoring (reduction – where possible – in the number of separate gas compartments),
- accessibility, maintainability, and reparability after installation,
- combined functions,
- withstand ability to seismic events.

Material

Materials used in AIS and GIS are well-known (though research and development on new materials continues). MTS units (compact and hybrid) generally use the same materials but in an optimized manner. However, as with other equipment, research continues to find and develop better materials and to integrate them in optimal ways in the modular applications. New materials and new treatment technologies, and/or restrictions in material usage may be needed in particular for MTS combined equipment, e.g.:

- selection of materials which share physical elements which were originally separated in AIS or GIS,
- selection of materials to be used now for outdoor installations instead of their originally-intended indoor application,
- requirements to use composite insulators,
- the use and application of new technologies such as nano technology, ...

Manufacturing process and quality control of manufacturing and assembly (manufacturing point of view)

All modern power equipment, regardless of their use in AIS, GIS or MTS requires very good control of the manufacturing process.
The more compact the application is, the higher the complexity of switchgear is likely to be and the more demanding the manufacturing and factory testing is required.
Factories usually offer excellent conditions for each individual manufacturing step and production control (including detailed written instructions and check procedures), manufacturing environment control (cleanliness, controlled temperature, organized production flow) and partial and complete testing. Such conditions cannot be fully met on-site during the switchgear assembly.
More of assembly work and testing is commonly done in the factory under optimal working conditions the more compact the switchgear is.

Manufacturing process and quality control of manufacturing and assembly (on-site point of view)

The manufacturing process and quality control of manufacturing can be thus evaluated from two different points of view – from manufacturer's and from final user's points of view. MTS and GIS require higher manufacturer's care in a factory (manufacturing, assembly, and testing) that leads to lower efforts on-site (assembly and testing). For AIS this ratio is just opposite.

3.3 Engineering

Title	AIS	MTS	GIS
Engineering			
Project complexity	++	+	0
Planning schedule	0	0	0
Contracting schedule	0	+	++
Single line diagram	0	0	0
Specification	+	0	+
Basic layout	-	+	++
Civil works layout and earthing	+	-	+
Secondary scheme	++	+	0

Switchgear rated voltage consideration: The evaluation and the below-mentioned explanation do not depend significantly on switchgear rated voltage.

The engineering and contracting includes the following steps:

1. User's decision on construction.
2. Feasibility study (selection of basic technology – may include alternatives), evaluation of alternatives, and selection.
3. Project specification (only one well-defined alternative).
4. Project work – includes obtaining permits (environmental assessment and approval where necessary, construction permits, building permits, and/or approvals, etc.), general and detailed project deliverables, engineering schedule, construction schedule, commissioning schedule.
5. Tendering for the selected technologies/equipment suppliers.
6. Tendering for construction work.
7. Evaluation of tenders – technical and commercial.
8. Contract preparation and release (for equipment and construction).

If a user opts for a turnkey project, only items 1, 7, and 8 may be applicable, depending on the degree of contracting-out. Generally (in most cases), the demands (time schedule and complexity) on turnkey projects are independent on the technology selected.

If a user decides against using the turnkey approach for a project, the project and contracting schedule and complexity may differ for AIS, GIS, and MTS. All steps mentioned above depend considerably on whether the user employs standardized layouts (repeatable designs) or not and on how many "actors" are involved in the tendering and contracting processes.

There are various important project considerations that include location, impact on/of environment, operation, construction, safety, flexibility, availability, maintainability, etc.

Project complexity

The more compact the installation is the higher coordination of activities among all the project’s responsible parties and higher accuracy is necessary on the project. The more compact the installation is, the more difficult it will be to implement changes to the originally planned project. In some cases changes may even be impossible. Future extensions have to be considered in advance in the first stages of the project.

In this respect AIS has advantages against MTS and MTS against GIS (especially with higher voltage levels).

Planning schedule

The following aspects have to be considered:

- Non-standardized non-turnkey projects may require longer lead times to permit coordination between user's engineering efforts and manufacturer's efforts, especially the closer coordination required between the user's civil design and the manufacturer's civil requirements.
- The smaller footprint of GIS and MTS may increase public acceptance of the substation and reduce the time for meeting all regulatory and permitting requirements.
- The more compact the installation is the more coordination of activities among all the planning's responsible parties is necessary (especially with regard to the interface with the HV transformer and HV cable connections).
- Extended lead times may also be required to permit design coordination between different equipment (from different manufacturers) purchased by the user.
- The type of construction selected may affect what permits are required and the lead-time to obtain them.
- Within AIS, there are normally many more different suppliers involved than in GIS and MTS. Large numbers of different suppliers may lead to more time consumed for planning and further for coordination of the project.

Contracting schedule

When connecting new elements to the network, utilities are often under pressure from clients to minimize the time elapsed from the moment of agreeing on the commercial terms of the contract to the completion of the project. Here, having modularized/standardized solutions like MTS provide considerable benefits.

Single line diagram

The main technical aspects which influence single-line diagram selection of any technology, i.e. busbar scheme, switching arrangement, and individual components used, are generally valid for GIS as well as for MTS and AIS. They are as follows:

a) operational flexibility (impact of system operator requirements),
b) system reliability (impact of substation maintenance requirements and/or failures and their repairs on system service),
c) availability (expected planned and unplanned outages of individual substation components and their impact on the substation to the extent which it has to be reenergized, impact of further substation extension),
d) substation control (simple and efficient performance of operational duties),
e) substation reliability (impact of primary and secondary equipment on substation protection systems),
f) other considerations, such as:
   - future development of the supply system, including ultimate single line diagram requirements,
   - facilitating future switchgear extensions,
   - national regulations and user's standardization policy,
   - level of skill and experience of operating and maintaining staff.

Comparing different technologies within the above-mentioned main aspects it is possible to say the following:

a) All technologies are able to meet the requirements. There are no significant differences. However, the simplification can be supported by the use of compact design and combined functions (example circuit breaker with disconnector performance).

b) Even though the equipment reliability of the new technology (MTS) is very high and comparable with all other technologies, there are some aspects that can influence the overall installation reliability and create differences between technologies. These aspects concern e.g. compactness (the higher the compactness, the higher the reliability – the most reliable is the case of non-existence of component) or service conditions (indoor installations are less influenced by environment). Higher reliability enables to simplify single line diagrams (e.g. by avoiding transfer busbar). In that respect GIS and MTS show certain advantages prior to AIS.

c) Compact and specifically metal-enclosed technologies require additional measures (like additional earthing switches, more busbar sectionalisers, or transversally dismountable pieces with disconnecting links) to be introduced into single line diagrams to allow the same level of availability and safety as in AIS solution.

d) One specific difference between technologies concerns GIS (because of the wide variety of GIS with different designs, dimensions and interfaces typical for different manufacturers or different generations of GIS). This can cause some difficulties for further GIS extension. Incorporating certain measures into the first stage of construction reduces future constraints. The single-line diagram design must allow for the assumed final GIS extension from a network viewpoint (busbar and switching schemes) as well as from a configuration related viewpoint (the order and connection type of all bays). In some cases it is useful to accept an early investment (e.g. busbar disconnectors and earthing switches, simple removable joints, extension tubes or busbars) to facilitate change at a future stage.

e) Given all the above considerations, under certain conditions MTS offers specific advantages compared to both AIS and GIS, in particular for replacement of existing AIS. Using GIS would allow considerably more real estate savings than using MTS, the higher cost of GIS may be a deterrent. On the other hand, when replacing existing AIS with MTS, its modularity and compactness offer sufficient space saving at a more reasonable cost, to allow for a reconfiguration of the bus system that offers a higher degree of reliability.

Specification

If specifying the different types of equipment, it has to be considered that the qualification of components might be different and has to be adapted to the application (e.g. using GIS disconnectors for air insulated bus transfer switching).

Whatever the user is employing (compact, combined AIS or GIS, or GIS modules in hybrid installations), the AIS equipment specification is governed by mature AIS standards. Similarly, the GIS equipment specifications fall under mature GIS standards.

A new international standard for MTS (IEC 62271-205) is applicable to compact switchgear assemblies consisting of at least one switching device directly connected to, or sharing subcomponents with, one or more other devices, provided that there is an interaction between the functions of the individual devices.

Such assemblies are made up of separate components that are designed, tested, and supplied for use as a single unit according to their appropriate standard. The interaction between these devices may be due to proximity, sharing of subcomponents or a combination of both.

The assemblies may contain components of Air Insulated Switchgear (AIS) only or a combination of AIS and Gas Insulated Switchgear (GIS), so-called Mixed Technology Switchgear (MTS), and may be delivered entirely prefabricated or partially assembled.

For overview of relevant valid and developed standards see chapter 4.

The selection of an MTS suitable for a given service duty is best done by considering first the combination of device functions required according to the single line diagram and then, as with circuit-breakers, by considering the individually rated values required by load and fault conditions.
The user, together with the supplier(s) should confirm that the combination, functions and ratings of the elements within a specific switchgear assembly are adequate for this application.

When such review is not performed by a manufacturer (see Design chapter) the user shall pay special attention to influences and interactions between the different components to be mixed and their parameters to be considered. Special consideration should be given to:

- insulation coordination,
- interconnection/ interface design,
- mutual influence between AIS and GIS parts,
- mutual influence between compact modules (namely switchgear assemblies),
- secondary systems consideration,
- accessibility, maintainability, and reparability,
- special considerations, such as seismic withstand for high seismic zones, or low temperature conditions (below -30°C).

Basic layout

The basic layout has to meet:

- single line diagram requirements for current development and future extensions,
- specific site conditions, i.e. size and shape, transportation access roads,
- specific interconnection requirements to other substation equipment (e.g. transformers, reactors, other switchgear location, etc.) and line connections (OHL, cables, etc.), i.e. HV interface considerations,
- operational and service requirements similar to single line diagram requirements (see above),
- specific regional/site conditions, such as seismic requirements, temperature requirements, exposure to local pollution or marine environments.

Higher modularity and higher independence on maintaining air clearances enable higher flexibility in basic layout. From this point of view GIS offers the best options. MTS comes next with fewer options (in dependence to an extent on AIS portion of the installation) and AIS is the least flexible solution.
Regarding basic layout, the GIS earthed modular system with its compactness and minimal dimensions offers, in comparison with AIS layouts, a wider range of different combinations. These may be, depending on a manufacturer’s design and specific conditions, characterized by the following:

- three- or single-phase encapsulation or combinations thereof,
- mixed, separated or coupled phases of busbars and/or bay arrangements,
- single-, two- or more-line arrangement of circuit-breakers,
- horizontal or vertical circuit-breaker designs and "U" or "Z" current passes CB arrangements,
- vertical, horizontal, triangle or upper or lower flange connected busbar arrangements.

To insist on GIS bays being arranged in a similar way to AIS arrangements might represent a substantial cost increase and unnecessary bus duct length, with possible negative impact on GIS reliability.

Nevertheless, in order to enable a manufacturer to design an optimised solution, it is necessary for a user to provide a manufacturer with a detailed description of input conditions in the technical specification of an inquiry. At the same time, a user should avoid over determination and should be ready to cooperate with a manufacturer and/or be prepared to consider the manufacturer's proposals for change, so that the optimisation process will be effective. Conversely, the manufacturer should attempt to provide comprehensive solutions rather than just equipment.

Civil works layout and earthing

Civil design that can diverge for different technologies includes supporting structures, foundations, facilities (access roads, rails, site surface, internal fencing), and buildings.
Regarding other considerations (such as acoustic noise protection, external fencing, energy efficiency in substation, substation security, direct lightning stroke shielding) there are no significant differences as they concern only the size of installation.

Supporting structures in AIS include terminal gantries and support structures for each individual equipment such as circuit-breakers, disconnectors, instrument transformers, and post insulators. Structures may be delivered by another supplier than the equipment manufacturers.

Many GIS components are self-supporting. If steel structures are required as support elements or due to seismic specifications, the planning and approval must be performed by the GIS manufacturer. This will avoid interference and mismatching problems during installation. Requirements for high-level access to perform normal operational functions generally depend on whether or not inspection windows are considered necessary. As far as MTS are concerned, both options are available (separate support structures, self-supporting elements or a combination of both).

Dimensioning of **foundations** is carried out according to the loads on the structures and additional forces such as the dynamic stresses imposed by circuit-breaker operation as well as applicable seismic conditions. Foundation designs for AIS (small, separated independent foundations) and GIS (one large common foundation/floor) are simple and depend on the specific location (e.g. type of soil, type of building, seismicity).

Generally the civil aspects to be considered for detailed design include:

- Horizontal and vertical (dynamic and static) loading.
- Seismic loading due to latent ground and location conditions.
- Existing soil conditions at the substation location including groundwater level and type of soil (rock, sand, fill-in, etc.).
- Type of foundation to be applied (piled foundation of raft footing foundation).
- Points and position of loading.

In case of replacing AIS equipment with MTS, sometimes existing foundations can be re-used, particularly with the older generation circuit breakers that were installed on huge foundations, to withstand the massive loads involved.

Site facilities for maintenance and operational needs must be taken into account in all substation designs. Where access by trucks, crane and transportable platforms has to be provided for installation, maintenance or replacement operations, roads or tracks have to be constructed. The surface of the site will also influence access. Usually stone chippings or grass are used to reduce dust levels at outdoor installations (usually AIS and MTS). Regarding indoor installations (usually GIS) corridors and access ways must be properly dimensioned and must be smooth and easy to clean. For GIS and MTS an adequate space for performing commissioning work (e.g. work on the gas system, high-voltage test) and inspection work (e.g. dismantling of an interrupter unit) must be provided. In indoor installations a portal (under a ceiling) crane is usually required.

The main role of **buildings** at outdoor switchgear installation is to house protection relays, SCADA equipment, auxiliary equipment, battery systems, fire protection pumps etc. At indoor installations the building contains all primary and secondary equipment. Indoor GIS design requires special measures against dust penetration into GIS room, SF_6 ventilation systems, and direct connection of switchgear earthing grid with the building reinforcement.

The use of **fire protection** systems and/or measures in all technologies is mainly based on minimizing the hazard for the operators and the public and protecting the environment and assets by limiting the damage to power transformers and to adjacent apparatus, equipment, buildings, and other single elements and minimizing the loss of customer's service.

Indoor GIS installations as well as GIS outdoor installations do not require any specific fire precautions except special interface applications such as oil cable terminations. In general and independently on used technology, any indoor installation requires more considerations than outdoor installations. That concerns namely appropriate material for walls, ceilings, and fire barriers, escape routes, rescue routes, and emergency exits.

Secondary scheme

The definition of secondary equipment generally covers all individual components which form part of the switchgear protection, control, and monitoring systems, i.e. devices needed to operate, supervise, protect, control, and monitor the primary equipment. These devices are similar regardless if used on AIS, MTS or GIS equipment.

The trend towards introducing digital control and protection systems and the move towards so called "integrated systems" are bringing major changes and benefits to the architecture of secondary systems in HV substations and in particular GIS. Modern digital devices dispense with the need for discrete devices for each function, therefore allowing multiple functions to be handled on the same hardware platform but using specific software modules. This allows the opportunity to locate all the compact bay related functions at the local bay cubicle close to the bay. This affords considerable advantages to GIS (and to a lesser extent to MTS) in terms of the drastic reduction in length of wiring necessary as well as a reduction in the quantity of secondary equipment required. The introduction of GIS and MTS with GIS parts also provides an opportunity for the introduction of enhanced monitoring and diagnostic facilities.

On the other hand some special aspects (not widely applicable in AIS) have to be considered in GIS and GIS parts of MTS:

- Careful design of gas monitoring systems.
- Partial discharge monitoring systems or internal measures (coupling capacitors) that enable PD diagnostic measurement.
- Introduction of fault location systems.
- Protection system timing - A rapid fault clearance should be obtained in order to minimize the damage to the equipment and the risk of release of contaminated SF_6 into the atmosphere in the unlikely case of an internal fault. The insulation in GIS is not self-restoring and the longer a fault persists, the higher the resulting damage will be, and consequently longer outage duration is probable.
- Auto-reclosing design - In addition to clearing faults of external circuits, the protection used on GIS must ensure that automatic reclosing does not occur in the event of an internal GIS fault.
- Busbar and bay protection design - Busbar protection should be applied. In order to minimize the fault clearing time it should be designed in such a way that only the faulted section is cleared, leaving the maximum number of circuits still energized.

- Inter-tripping design - For faults on GIS connections to external circuits, protection must be coordinated with the circuit remote end protection, and rapid fault clearance should be obtained by the use of inter-tripping circuits.
- Earth fault protection design - In GIS with single-phase enclosures used on systems without a solidly earthed neutral, conventional protection might be unsuitable for detecting an earth fault. Therefore systems able to detect the earth current are required.

3.4 Construction

Title	AIS	MTS	GIS
Construction			
Preparation of site	++	+	-
Transport and storage	-	+	++
Civil work (foundation)	+	0	-
Work crew	+	+	-
Erection	-	+	0
Impact on existing service	+	+	-
Commissioning	+	++	-

Switchgear rated voltage consideration: The evaluation and the below-mentioned explanation do not depend significantly on switchgear rated voltage.

Preparation of site

The more compact the installation is the more important is the requirement to complete all civil works before the equipment erection starts. This strict requirement, i.e. all platforms or buildings must be complete and all preparations must be in place prior to the start of erection, is particularly applicable for GIS and GIS technology parts of MTS. GIS and MTS project scheduling should ensure that non-immediate work related tasks (e.g. civil works modifications) do not overlap with tasks planned for the GIS technology installation period. For construction in "separate" bays (MTS modules and AIS) there is sometimes possible to complete the civil work step by step in coordination with the various construction stages.

When using GIS technology (in GIS or in MTS), if that includes parts which have to be assembled on-site, the key requirement is cleanliness. The long-term reliability of the final product depends greatly on the level of cleanliness maintained during the erection process. This can be achieved by the provision of a defined clean working area. Additional measures that might be adopted for the future erection include:

- Temporary measures in the form of shelters, barriers or heaters in particular for outdoor installation.
- Availability of the contractually agreed installation tools and accessories (e.g. lifting equipment, tools, power supply) throughout the full installation period.
- Availability of the contractually agreed special test equipment and special platforms for the test equipment installation if required.
- The foundation (floor) should be cleared and the concrete sealed to prevent unnecessary dust.
- Space for unpacking must be provided and if necessary general cleaning of the components should be performed away from the final clean assembly area.
- The crane capacity should be double-checked and the revolution range calculated from the weight of the transportation packing lists. The crane position should be chosen such that there are firm foundations for the outrigger of the crane. If there are space limitations for lifting, it may be necessary to consider special arrangements such as installation by using rollers.

Transport and storage

A shipment unit can be more compact the more compact the installation is. This is a significant advantage for compact and combined designs (GIS and MTS), as the shipment units are fully assembled and tested by the technology manufacturer. Moreover the compact design thus enables easier transportation to and on-site. The storage method utilized (i.e. indoor, outdoor, covered, etc.) should be consistent with the storage method specified by the technology manufacturer and provided by the user. There are no essential differences among the different technologies.

Civil work (foundation)

The civil work requirements and other different considerations must be already implemented at the stage of engineering. The differences for AIS, GIS, and MTS are already described in the chapter "Engineering".

From the construction point a view the following items are applicable:

- The more compact the equipment is (GIS, compact MTS), the more compact and complex foundations are necessary and the demand for precise building (materials, dimensions, smaller vertical and horizontal tolerances, more complex anchoring layout ...) is more important.
- Modern technologies, if assembled on-site, require defined ambient conditions for civil work.
- Accuracy of MTS and GIS positions and tolerance level of foundation must be maintained and checked in order to allow the connection of gas insulated busbars (if used) between circuit breaker and other components.
- In case a single foundation is adopted, the time required for constructing the unit foundation is much less than the time required for separate equipment foundations. This may (depending on such factors as size of the installation, layout of the substation, etc.) result in time and cost saving for the civil works.

Work crew

At the contract stage the manufacturer of the selected technology shall specify, if necessary, the number and qualifications of personnel needed to complete the erection. This is particularly applicable for GIS installations.

When using GIS technology (in GIS or in MTS), if the switchgear includes parts which have to be assembled on-site, it is strongly recommended to perform the erection under the supervision of the manufacturer's erection technician. If the actual erection is performed by a third party, it is essential that this party possess the basic knowledge regarding the assembly procedures and quality standards. This can be achieved by the following:

- ➢ detailed and precise manufacturer's instructions manual must be available,
- ➢ the crew must be trained by the equipment manufacturer,
- ➢ correct and properly calibrated tools, accessories and special clothing must be available and their proper use must be understood by the erection crew.

It is generally accepted that erection activities which require direct manufacturer's supervision are firmly established between all parties at the contract stage.

Erection

Specific tailored erection procedures may be applied when using GIS technology (in GIS or in MTS), if that includes parts which must be assembled on-site. On the other hand AIS erection procedures and erection procedures of compact modules may be very simple and do not require any extraordinary measures.

The most important advantage of MTS assemblies regarding erection is their compact design that allows them to be completely assembled and tested within the factory. For higher voltage levels single pole units are typically shipped, where at least the bushings have to be installed on site The work to be done on site is thus only remaining assembly, bolting of the supporting structure to the foundation and interconnection to the AIS parts of the substation.

The more complicated the erection procedure is, the more important is to follow manufacturer's recommendations. Before starting the manufacturer shall specify any local working condition limitations on the erection of the gas insulated switchgear parts that must be open during the erection. This is to avoid contamination by particles, dust, water or ice. Temporary measures in the form of shelters, barriers or heaters may be necessary to achieve this condition, especially during outdoor installation.
Note: For testing considerations see chapter 3.10.

Impact on existing service

For the projects which consist of extension or replacement of existing equipment, there are many situations where the MTS technology offers the best solution.

As the size and loading is usually different from that applicable to existing equipment, the following points must be checked at the design stage to prevent potential problems during transportation, erection and commissioning stages:

- actual site conditions for access and transportation into the substation site,
- width of access roads and the existence of any obstacles such as conductors, walls, etc.,
- allowable weights for roads, bridges along the transportation route,
- suitable storage space with consideration to drainage, site work constraints, insulation distance from existing equipment, etc.,
- crane loading – see above (site preparation),
- locations for special test equipment installation.

There is no standard erection sequence related to an extension of a substation. Each case must be looked at separately by the manufacturer who can advise what must be done and the user will have to be consulted as to how it can be achieved with minimum disruption to the existing operational plant. During the extension process the end user and plant operator will have to play an active role in order to ensure that the working practices of the installation contractor meet the minimum safety standards applicable to their operating practices. GIS installations are more difficult to extend than AIS if no special provisions have been provided for such extension at the GIS initial installation stage.

Commissioning

The testing and commissioning on-site shall be performed according to the agreed testing procedures.
General commissioning activities such as visual checking, documentation checks and completion, energizing tests, tightness tests, etc. do not differ significantly for different technologies.
The differences concern only specific tests. Generally it can be stated that, no additional tests on-site beyond normal commissioning tests are required, if the pressurized gas compartments were not opened during assembly work.

3.5 Impact on Environment

Title	AIS	MTS	GIS
Impact on Environment			
Aesthetics	-	0	+
Nature	-	0	++
Noise	0	0	+
Leakage	-	0	-
EMF/EMC	0	0	++

Switchgear rated voltage consideration: The evaluation and the below mentioned explanation depend significantly on the rated voltage of the switchgear. The differences among technologies increase with the increasing rated voltage.

A new term has been in current use for the past few years: Eco Design. This term is considered an evolutionary design, as new solutions are ecologically improved in regard to relevant design parameters such as sizing, material and technologies used. Even Life Cycle Assessment studies (LCA) are conducted to demonstrate the overall impact of switchgear on the environment.

However there is no doubt that to accomplish such a solution, it has to be economically and ecologically balanced. Presently the performance evaluation of the advanced equipment on the market is slanted more in favour of economic rather than ecologic attributes, as it is driven by the tough competition in the markets. However in the medium to long term the importance of the environment is expected to increase.

New criteria for evaluation and optimization of the assets [8] are needed, to provide the optimum solution for the individual substation. In addition to the evaluation of economic benefits, environmental aspects also need to be considered. The design of the future substations should use materials, equipment and technical solutions which are compatible with socio/environmental aspects.

A comparison of AIS, GIS and MTS from an environmental point of view, must consider a number of factors, both in regard to the influence of the substation on the environment as well as the influence of the environment on the substation. The impact on environment includes the following factors:

Aesthetics

An AIS substation, depending of its location may require appropriate aesthetic treatment, usually at its boundary/fence line, to blend into surroundings. An outdoor GIS installation presents a considerably smaller footprint and can be made to look more like an industrial installation. If aesthetic treatment is required, this will have to conceal a much smaller area. While from a distance MTS looks more like an AIS, the area occupied is closer to a GIS installation; thus the potential cost of any aesthetic treatment will definitely be less than for an AIS and closer to GIS. Where GIS is installed in a building, the building itself will provide the aesthetic treatment.

Nature

Due to the compact design of MTS and GIS the following impact on their natural surrounding can be reduced:

- construction site dimensions – minimize :
- excavations and backfills,
- impact on flora and fauna,
- loss of top soil,
- erosion process,
- impact on surface and groundwater sources.

Noise

Some air-insulated circuit breakers and load break switches may produce a high level momentary noise when operated. Other noise sources from switching equipment in a substation include corona discharges, arcing during operation of switches, etc. Noise alteration treatment is mostly not required. GIS and MTS installations produce lower levels of noise due to the fact that equipment is completely enclosed, and the SF_6 gas in the enclosures is a very efficient sound absorber. New arc interruption technologies in SF_6 gas that require lower energy levels, have resulted in the development of smaller, spring-operated mechanisms that generate lower levels of noise.

Leakage

The fluid employed in all three technologies (SF_6 gas or a combination and oils used in hydraulic mechanisms or as lubricants) can under certain circumstances leak into the environment. SF_6 is deemed as a greenhouse gas (SF_6 having the greenhouse effect 22200 times higher than that of the same mass of CO2) and all necessary precautions are taken by both manufacturers and users to restrict design and handling leaks.

All technologies are designed to minimize gas leaks. However, when comparing among the technologies, the length of sealed surfaces might differ within AIS, MTS, and GIS. The total length of SF_6 seals is the greatest within GIS, whereas in AIS and MTS some oil filled equipment might be installed. However, consideration should be given to the fact that GIS equipment can be installed indoor, thus minimizing exposure to environment and extending the life of the sealing systems.

In addition to the above, detailed procedures of installation, service, maintenance, repair and proper disposal are described by the manufacturer in order to minimize handlings losses as well. Also several CIGRE guides give information about the use and handling of SF_6 [5], [9] and [11].

National guidelines on reporting of greenhouse gas emissions, which include design related leakage as well as service-related handling emissions, are already installed in a lot of countries [17], [18].

Electro-magnetic fields (EMF)/Electromagnetic Compatibility (EMC)

In GIS and the enclosed parts of MTS the electric field levels in the immediate vicinity of the substation are negligible due to the shielding effect of the earthed enclosure. In AIS the electric field levels inside the substation fence are more or less of the same intensity as the electric fields associated with the incoming and outgoing transmission lines. Magnetic fields are mainly related to the nominal current and the physical arrangement (distances, enclosures and phase arrangements), but not significantly influenced by the technology. The impact of EMC outside the substation is independent of the technology.

3.6 Impact of Environment

Title	AIS	MTS	GIS
Impact of Environment			
Climatic conditions (* Indoor application)	0	+(++)*	+(++)*
Pollution (* Indoor application)	0	0(++)*	0(++)*
Corrosion (** Climatically controlled building)	0	0	+**
Seismic conditions	0	+	++

Switchgear rated voltage consideration: The evaluation and the below mentioned explanation do not depend significantly on switchgear rated voltage.

A comparison of AIS, GIS and MTS from an environmental point of view, must consider a number of factors, both in regard to the influence of the substation on the environment as well as the influence of the environment on the substation. The impact of environment includes the following factors:

Climatic conditions

All technologies must be designed to cope with the specific climatic conditions (temperatures, humidity, ice, rain or snow, wind, solar radiation etc.) at the place of installation. There is no significant difference between technologies in this respect. However compact MTS and GIS solutions allow indoor installations where the influence of climatic conditions can be limited only to outdoor parts (bushings and bus ducts).

Pollution

The influence of pollution on switchgear is proportional with the number of insulators and bushings in that particular switchgear. Consequently, more compact arrangements like MTS and in particular GIS present some distinct advantages. Naturally, indoor GIS offers greater advantages compared to outdoor equipment (AIS, MTS or GIS).

Corrosion

All outdoor-installed equipment is subject to environmental factors, including even an exposure to extreme conditions such as acid rain, marine environments or man-made pollution (chemical releases from nearby industries), that can lead to corrosion of apparatus elements and premature failures. Naturally, indoor GIS presents significant advantages against outdoor equipment (AIS, MTS or GIS) when using such criteria.

Seismic conditions

Regardless of the technology, if the substation is installed in an area with seismic activities, proper engineering design and seismic testing in accordance with the relevant standards must be used. However, a statement may be made that an AIS is likely more vulnerable to damage during an earthquake due to individually installed structures and foundations, while the GIS due to its structure may behave more robustly. Depending on its design and testing (including foundations), MTS behaviour under seismic conditions may be better than AIS; however GIS installations have the best performance due to the compactness and low centre of gravity.

3.7 On-Site Time Efforts

Title	AIS	MTS	GIS
Time efforts			
• Preparation time	0	+	0
• Transportation time	-	+	++
• Erection time	-	++	0
• Commissioning time	++	+	0
• Repair time	++	+	0
• Maintenance time	++	+	0

Switchgear rated voltage consideration: The evaluation and the below mentioned explanation depend on switchgear rated voltage. Time savings in general are higher for the lower voltage levels and for single pole units on higher voltage levels.

The deregulation in the 1990's has encouraged the spread of privatisation of public utilities in many parts, opened the energy market and put much more emphasis on new construction speed and/or on much less reduced outage time when working in an existing substation. This impact can be seen on the time frame of all stages of handling with the equipment, i.e. also on on-site time efforts.

Preparation time

When making new connections to the network, utilities are often under pressure from clients to minimise the time from agreeing the commercial terms of the connection to completion of the project. There are consequent benefits in having modularisation/standard solutions like MTS.

In general, the smaller the construction site is the less preparation work is needed that bring advantages to MTS and GIS. However AIS requires sometimes less sophisticated approach to building design and construction, temporary assembly protection areas, etc., however more individual foundations.

Transportation time

The most important advantages of MTS and GIS assemblies regarding transportation are the compact design and its integrated functionality due to GIS technology, which leads normally to a smaller number of transportation units. That represents a smaller demand on logistic activities (less separated transport items, less number of different suppliers) and left smaller room for deviations in construction scheduling.

Erection time

The more compact and complete the transportation units are and the less the number of separated transported parts are the shorter the erection time is. From this respects MTS and even more GIS have advantages to AIS. However, it is important to emphasize that MTS and namely GIS technology require that all civil works must be completed before the start of the erection. The erection work requires moreover special skills and should be done according to the recommendations of the supplier. The supplier should at least supervise the work and ensure that appropriate site qualities prevail.

Commissioning time

The commissioning time is mainly influenced by on-site commissioning test extent and duration (see chapter 3.10 - testing). Therefore the evaluation of different technologies is the same as for the testing itself.

Repair time

AIS consist typically of individual units, so the access is easier and the repair time less than of the other types of switchgear. However due to the compactness of MTS the exchange of units in case of repair is possible which means a different approach to its repair comparable with demands on AIS repair extent and outage time. GIS requires sometimes disassembly of many of its parts to reach the failed one and has got thus significant disadvantages to AIS and MTS.

The repair time has an impact on a more general aspect – availability (see chapter 3.9).

Maintenance time

Maintenance in general is per 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.

However due to the compactness of MTS replacing complete units in time and preventing failures can be used for maintenance and/or repair and will reduce the maintenance time.

Because of their intrinsic complexity, depending of their design, both GIS and MTS may require specific maintenance tasks with impact on the maintenance time that are seldom required by AIS equipment. Such special maintenance practices usually target the circuit breakers (as the most complex equipment within the GIS/MTS) and may be more time-intensive than for equivalent AIS equipment. This, to some extent, is due to the somewhat more difficult access to the breaker interrupters and closing resistors (if the breaker is equipped with resistors). Other special requirements may address the SF_6/oil interfaces (in case of cable connections, or specific requirements when removing bellows, etc.

In general, the basic maintenance aspects of MTS design are the same to those for AIS and GIS.

The maintenance time has an impact on a more general aspect – availability (see chapter 3.9).

3.8 Operation and Service

Title	AIS	MTS	GIS
Operation and Service			
• Control (* for multifunctional MTS)	+	0 (-)*	0
• Condition monitoring	-	0	+
• Expected life time	+	+	+
• Decommissioning and disposal	0	0	-
• Replacement of components	++	+	-
• Dependence on manufacturer (OEM)	++	+	-
• Dependence on special know-how	++	+	-

Switchgear rated voltage consideration: The evaluation and below mentioned explanation do not depend significantly on switchgear rated voltage.

As any switchgear construction is based on the specific network requirements the service and operation are the key issues. All technologies have to cope with the network service and operation requirements. There is no difference among technologies from this basic point of view.

The way how they cope with this basic task is actually described in various chapters of this guide. Chapter 3.8 focuses only on those considerations not described in other chapters.

As far as the switchgear control is concerned the following conditions should be considered separately:

a) standard control conditions, i.e. either remote control or control from substation control room,
b) non-standard control conditions, e.g. local emergency control.

Control

Standard control conditions do not present any significant differences between technologies. Special attention shall be paid only to proper setting of switching sequences and interlocking conditions (for preparation to service and for service switching) in MTS where multifunctional switching equipment (such as combined disconnectors and earthing switches) is installed. Following proper engineering procedures (see chapter 3.3.) is the key to avoid standard control conditions problems.

In regard to **non-standard control conditions** AIS offers a higher flexibility than the other technologies. In case of control weakness (such as loss of supply or impossibility to control, for any reason, some of the switching equipment) AIS and MTS with a significant part build in AIS technology usually enable the use of a wider variety of emergency means such as separate manual local operation of disconnectors or earthing switches, portable earthing rods or temporary bypasses installations. It is fare to say that the more compact and multifunctional the switchgear is the less it provides the possibility for non-standard, "improvised" measures.

Condition monitoring

Monitoring is the simply periodic or continuous measurement of one (or more) characteristic parameter(s) applied permanently to primary or secondary equipment. Condition monitoring is continuous measurement using devices permanently installed on primary or secondary equipment to measure, collect and evaluate one or more characteristic parameters with the intention of automatically determining and reporting the status of the monitored subject at a certain moment in time.
There are two basic sources of monitored data available in a substation:

a) data collected at substation level, i.e. data collected by substation control (data from SCADA – loading currents and voltages, outputs, temperature, etc.) and protection systems (data from fault recorders or from advanced digital relays – records of transient phenomena),
b) data collect at equipment level, i.e. data collected by specialized equipment monitors designed to collect and evaluate conditions that are specific for a specific equipment type (CB, DS, IT, etc.) or even to a specific equipment design.

Whereas data collected at substation level is independent on the technology used, the compact and combined solutions (namely GIS and MTS with a significant GIS design) offer more options for condition monitoring at equipment level. They usually do not contain equipment from different sources (from different manufactures) and of different vintages, but rather all or most components from the same source and of the same vintage. That facilitates the development of "tailor made" equipment monitors, which are usually installed and delivered by the switchgear manufacturer. That same fact allows the manufacturer to develop a representative evaluation method to interpret measured values and their trends.

GIS also offers an option to monitor important parameters such as on-line partial discharges or precise fault location detection. It's important to emphasize that condition monitoring is one of the most effective sources of information about actual service conditions that allows the application of condition based maintenance.

Expected life time

All manufacturers of modern switchgear, regardless of the technology offered, claim a very long life expectancy (more than 40 years) for their equipment. There is no significant difference among technologies in this respect except for the differentiation between the indoor or outdoor installations.
In spite of such claims, certain differences can be found. GIS as well as MTS based on GIS technology are usually designed, manufactured and tested by one manufacturer who designs all switchgear parts for more or less the same life expectancy (controlled ageing). Therefore it is expected that most components will age at the same rate.

On the other hand, if some parts in AIS are deemed to be at the end of their life whereas others are not, it is usually much easier (because of their individual status) to refurbish or replace only the aged items. These advantages and disadvantages may however change, subject of the utility refurbishment strategy, i.e. either to refurbish the whole switchgear when it has aged or to refurbish the switchgear partially, based on individual components service conditions.

Decommissioning and disposal

Regardless of the technologies employed, all switchgear must be disposed in an ecological way. There are no significant differences among technologies regarding decommissioning and disposal. The only difference can be found in the extent of dangerous materials separation from ordinary metal and non-metal materials. In general it is necessary to pay special attention on used SF_6, whereas the GIS gas containment is higher than that of AIS. Beside SF_6, which can be kept in a closed cycle and be reused after recycling, a similar attention has to be paid to oil separation and oil disposal.

Replacement of components

The more compact the arrangement is the more complicated it is to replace one of its components by a component of a different design. A comparison between the technologies provides the following:

- Within conventional AIS with free standing equipment interchange ability of components of different design or manufacturing origin does not constitute any problem.
- In AIS with combined equipment, specific combined equipment has to be replaced by other similar (if not identical) combined equipment – a difficult task if the space does not allow for space expansion of the switchgear. That typically concerns combined equipment such as combined current and voltage transformers or CB’s with disconnecting features. If the combined equipment is a part of compact module, that may not possible.
- Within compact modules (AIS or GIS) it is practically impossible to change one single equipment component with another component of different design, namely with a component produced by another than original manufacturer. Normally, only the original manufacturer will be able to supply replacements for such a requirement.
- Within GIS it is practically impossible to change one single component with another of different design or produced by another manufacturer. In extreme cases customized parts can be designed and produced by specialized suppliers if original detail drawings exist; however that requires additional significant development efforts. Such a specific requirement can be better addressed by dismantling or isolating the particular component and extending the GIS. The extension can be obtained from another manufacturer, using transition bus connections.

Taking into account the above, it is fare to say that utilities that use primarily AIS equipment and have a well established operating and/or engineering spare strategy, may want to reconsider these strategies in light of these considerations if they decide to employ GIS or MTS.

Dependence on manufacturer (OEM) and on special know-how

The above overview also addresses the question on dependence on specific manufacturers and the need for specific know-how. Usually, the more compact the switchgear design and the more functions are combined, the more dependent on the OEM and specific know-how for proper operation and service the user is.

Note: Maintainability and reparability are usually considered as parts of "operation and service" issues, too. As they are also parts of "availability" issue they are described in details in chapter 3.9.

3.9 Availability

Title	AIS	MTS	GIS
Availability			
• Maintainability	-	+	++
• Meantime of maintenance	+	++	0
• Reliability (*indoor applications)	0	+	+ (++)*
• Mean time of repair	+	++	0
• Tools, gas handling	+	0	0

Switchgear rated voltage consideration: The evaluation and below mentioned explanation do not depend significantly on switchgear rated voltage.

Maintainability

Modern switchgear, regardless on whether it is AIS, GIS or MTS, is presently presented by manufacturers as practically maintenance free for the first 20 to 25 years after delivery. Such statements must be clarified as meaning:

a) no specific time-based activities are necessary except periodic visual inspections such as corrosion checks or various indicator position checks,
b) maintenance needs to be focused on the important equipment functions (applying RCM principles = Reliability Centred Maintenance),
c) maintenance needs to be performed only if the service condition of the equipment indicates a deteriorated state (application of CBM = Condition Based Maintenance),
d) maintenance is to be prioritized, i.e. carried on the most important equipment (using PBM = Performance Based maintenance or RBM = Risk based maintenance principles).

When evaluating maintainability for different technologies it is essential to understand the major differences that exist between the above mentioned a) to d) categories, and to evaluate how these technologies enable the application of modern maintenance strategies/philosophies such as RCM, CBM, PFM and RBM. The following is a summary of these differences:

a) - The extent, depth, and time required to perform periodic visual inspections depends on the number of components to be inspected. Compact and combined solutions include fewer items to be inspected. Hence advantages offered by GIS, MTS equipment.

b) - As the basic functions of the three technologies being discussed are the same, maintenance activities based on functions (failure modes, switching applications, number of operations, etc.) are also the same. Hence no particular advantage from RCM perspective flows to any of the three technologies.

c) - Compact and combined solutions offer more options for condition monitoring of critical components. Condition monitoring is one of the most effective sources of information about actual service conditions that may trigger condition based maintenance. Hence GIS and MTS offer distinct advantages if CBM is the selected maintenance philosophy.

d) - The function of the equipment as part of the network is independent of the technology selected, hence no distinct advantage can be assigned to either technology.

e) Individual maintenance requirements (routine inspections, diagnostics and major maintenance work) depend on the switchgear (equipment) designs. Each technology and each design needs a specific approach. For example : SF_6 and GIS technology in general require more effort to check SF_6 conditions, oil immersed air insulated instrument transformers require oil analysis, air insulated joints require frequent infrared thermovision, etc. Individual maintenance tasks and diagnostic methods that available are described e.g. in [2], [6], [7], [12], [19].

Meantime of Maintenance

Meantime required to perform maintenance basically depends on the extent of visual inspection required and on accessibility to the components that needs to be maintained during minor or major maintenance.

AIS equipment is normally accessible for both visual and hands-on maintenance with no major constrains. The more compact the switchgear is, the more restricted the access may be. Conventional GIS requires some special precautions such as:

- careful gas segregation design,
- implementation of special enclosure parts that can be easily removed transversally (removable links incl.) to allow access for maintenance to other GIS compartments,
- proper design of the earthing system (location of earthing switches in the installation),
- availability of fixed or portable mechanisms,
- availability of trained and knowledgeable personnel.

However, as important as it may be, the meantime for maintenance is not the main issue facing the utilities. The utilities are presently focusing on minimizing the outage time necessary for equipment maintenance. This minimum outage time can be influenced by the utility policy, particularly in cases where major maintenance is necessary.

From this perspective, modular MTS offers an advantage with the option to replace a module that has failed or requires major maintenance by a similar spare module and thus reduce the outage time to the time required for this replacement. The maintenance of the respective module can be thus performed separately and under controlled conditions, without any further influence on switchgear operation (availability).

The time for repair is not the only one aspect which has got an impact on repair unavailability. As AIS are normally delivered by many different main component suppliers, the organization of the troubleshooting may be more complicated and time consuming.

Reliability

Based on various studies performed on all three technologies, [3], [4], [13], [14], [15], [16] it can be stated that reliability of modern switchgear equipment, regardless of which technology is selected, is approximately the same. However, there can be differences between these technologies based on their installation type (indoor or outdoor) and their physical size. It has also to be mentioned that with increasing voltage level the reliability is decreasing, however it is valid for all technologies.

Mean time of repair

The same considerations are applicable as for the mean time for maintenance.

The time for maintenance itself (prevailing advantages for AIS) is not the only one aspect which has got an impact on maintenance unavailability. As AIS are normally delivered by many different main component suppliers the organization of the maintenance (namely major maintenance at old equipment) may be more complicated and time consuming.

Tools, gas handling

GIS and GIS modules at MTS may need specialised "tailor made" tools and larger volumes for gas handling accessories. Gas handling needs special attention, the CIGRE Handling Guide for the Use of SF_6 [11] gives advice.

3.10 Testing

Title	AIS	MTS	GIS
Testing			
• Type tests	+	0	++
• Routine tests	+	0	++
• On-site tests	++	+	0
• Test equipment	++	+	0

Switchgear rated voltage consideration: The evaluation and the below mentioned explanation do not depend significantly on switchgear rated voltage in type tests and routine tests categories. For on-site tests and test equipment evaluations, the higher the rated voltage of the switchgear, the higher the differences between technologies.

GIS and AIS equipment testing methods are well established, proven by long term service and covered by existing standards that have been issued long ago and revised periodically.

The MTS assemblies (either in AIS or GIS technology) are assemblies of individual devices and components intended to be directly installed and connected together and able to operate only in this manner. Therefore the components of MTS assemblies have to be type tested in such a configuration, so that possible interaction between the devices is detected and anticipated. That same principle is, of course, also valid for routine testing. The testing procedures for either type testing or routine testing have to cover the possible interferences between the various components of these switchgear assemblies such as circuit breakers, disconnectors, earthing switches, busbars, current and voltage transformers, surge arresters and local controls, which may influence the performance.

To design and build an MTS it is recommended to use only devices which are approved in the appropriate IEC standards applicable to MTS. However, each individual component (each switching device, other devices and controlgear) must comply concurrently with its specific relevant individual standard.

Each switching device, other devices and their controlgear forming part of a compact switchgear assembly shall comply with the relevant individual standard. If part of the compact switchgear assembly is formed by metal enclosed switchgear devices the requirements of IEC 62271-203 apply.

However, as there are potential interactions between devices within such assemblies, it is necessary to consider the standardisation requirements for the assembly in its entirety.

A new standard IEC 62271-205, High-voltage switchgear and controlgear – Compact switchgear assemblies for operation at rated voltages above 52 kV, covers this aspect. Compact switchgear assemblies, as defined in this standard, are considered to be a single product with a single serial number and one set of documentation.

The objective of the MTS standard is to respond to the increasing use of compact switchgear assemblies that perform the functions of a number of separate devices and their controlgear. Numerous arrangements are possible and this standard provides guidance on basic types of assemblies which might be envisaged.

From the user's point of view there is a slight disadvantage in using AIS due to the variety of manufacturing sources for individual equipment. Even if all suppliers comply with standard requirements, the manner in which they prove the compliance with standards can differ. These differences make the orientation and cross checking sometimes more difficult than the situation where all test protocols are provided by one manufacturer only (MTS and particularly GIS).

Type test

The supplier must be able to demonstrate, with test reports or test certificates, that all the type tests have been performed on subassemblies of the same design supplied to the customer. Type tests are not part of a quality assurance system applicable to each supply consignment, and should be performed only once for a given design.

Once performed successfully on a MTS basic design, all MTS based on the same basic design are expected to present very similar service behaviour.

Subclause 6.1 of IEC 62271-1 is applicable with the following addition: The characteristics of a complete switchgear assembly, and those of all components, shall be proven during the same type test series. However, for practical purposes other test procedures may be used in accordance with the relevant standards.

Switchgear assemblies may consist of various devices in numerous configurations. Therefore, it is not possible to define the test conditions for each arrangement. The typical arrangements are to be specified by the supplier.

When testing of a complete switchgear assembly is not practical due to plant test equipment limitations, single components only or a combination of devices can be tested, provided that the potential interaction between all components is also tested.

When tests are performed on a single component, the manufacturer shall prove that the stresses on the components during the tests are not lower than those applied to the same component when the full switchgear assembly is tested.

Component tests must cover all the different types of components making up the switchgear assembly, provided that the particular test is applicable to the component. The conditions for the component type tests must be the same as those which could be employed for the full switchgear assembly.

If one switching (active) component is mechanically integrated with another, e.g. a combination in which a circuit-breaker is mechanically interlocked with the disconnector, the test shall be performed on the complete combination.

The parts of auxiliary and control equipment which have been manufactured in accordance with relevant standards, shall comply with these standards. The proper function of such parts in connection with the function of the other parts of the combination shall be verified.

Routine tests

Routine tests are part of the quality assurance process and should prove the functionality of the MTS. They are carried out during manufacturing on each item of equipment, at least on each transportation unit, with the purpose of uncovering faults in material or assembly of individual units.

The MTS advantage consists in the fact that the units are delivered as a prefabricated and pretested bay fully or partially assembled.

If a device or a combination of devices including its connections is routinely tested in the factory, then the dielectric tests need not be repeated on site. This is applicable only if the re-assembly of these devices can be checked and confirmed as correct by dimensional measurements provided by the supplier.

On-site tests

Commissioning testing on-site shall be performed according to the agreed testing procedures and relevant standards (individually as well as for MTS assemblies). This rule is valid for all types of technologies.

The on-site tests are carried out in order to detect possible damage suffered during transportation, storage, exposure to the environment, or final assembly. It is important to point out that on-site testing is neither a repetition of the type tests nor of the routine tests. The aim is to prove the integrity of the system before it is energized. It is the final step in the process of quality control and quality assurance.
The commissioning tests are also necessary to obtain “the fingerprint”: a set of test results that become the reference data to which results from future maintenance tests are compared, to determine the operational capability of the equipment at a given moment.

The difference among the three technologies discussed concerns only special tests performed specifically to prove insulation (SF_6) integrity, electrical and mechanical interconnection integrity (mechanical strength and gas tightness) and interconnections integrity with control, protection and auxiliary systems. The more compact the equipment is, the more sensitive it is against defects and the higher consequences are necessary in event of a failure.

Generally, when compared to AIS, it can be stated that for MTS and GIS no additional tests on-site are required, if the gas compartments will not be opened for internal assembly work. If gas compartments will be opened, or bushings shipped separately need to be installed, dielectric tests will need to be performed (specifically for GIS), and they require special attention. Dielectric tests on-site on GIS are considered to be the final quality control of proper transport and erection. Therefore they are recommended for all GIS.

While all other commissioning tests can be performed quite easily and do not require expensive test equipment, dielectric tests may pose special problems concerning:

- the optimal test procedure to be chosen,
- the actual possibility of performing the tests,
- the cost of the tests,
- for equipment at higher voltage ratings, securing and transporting to site the test equipment that can achieve the required test voltages (e.g. mobile resonant test sets), and qualified personnel that can man such test sets.

<u>Test equipment</u>

Test equipment as well as provisions for test equipment connection to the equipment and necessary space for its installation must be selected and arrangements made for at the contracting stage of MTS and GIS.

The technical specification must include the following information:

- requirements for site testing and the test equipment and qualified personnel to be provided by the manufacturer,
- requirements for on site testing procedures and mutually acceptable passing criteria,
- information about and provisions for equipment connected to the MTS and GIS during testing (e.g. cable or directly connected power or instrument transformers or reactors),
- accessibility and space for test equipment on site,
- availability at site of lifting and handling equipment.

3.11 Flexibility

Title	AIS	MTS	GIS
Flexibility			
• Extendibility of existing substations	++	++	0
• Use for extension of existing substations	0	++	+
• Upgrading /refurbishment of existing substations (*for voltages up to 245 kV)	-	++	+*
• Use for upgrading/refurbishment of existing substations	+	++	-
• Mobile and/or temporary installations	+	++	-
• New substation	+	+	+

Switchgear rated voltage consideration: The evaluation and the below mentioned explanation do not depend significantly on switchgear rated voltage with exception of mobile and temporary installations. (*) For voltages up to 245kV and very simple single line diagrams the use of mobile GIS is also possible (e.g. in rural areas).

Switchgear configuration, i.e. type of construction, service conditions, single line diagram, and layout design, is primarily dictated by system requirements and is determined by the applied technology features. The different technical solutions have to be evaluated either whether they are able to be upgraded/extended or whether they can be used for upgrading/extension of existing equipment.

Extendibility of existing substations / Use for extension of existing substations

Originally, the development of MTS was triggered by the need to obtain efficient answers to questions such as "How to economically extend AIS substations?". On such specific projects (determined by environmental restrictions, limited space and time for construction), the MTS fit very well within the requirements for reliable equipment, compactness, uncomplicated construction, easy maintenance, relatively simple transportation. Depending on the single line diagram outage during the extension might become a problem.

While AIS can only be used for the extension of AIS substations, GIS can be used for AIS and GIS extensions. MTS offers the higher flexibility to extend/upgrading of all existing substations.
MTS offers the following possible solutions:

- the use of compact or combined AIS equipment and, in case that solution does not fully meet the requirements (e.g. not enough space for three phases), then:
- the use of GIS or hybrid IS components (more suitable because of limited space and time) as another option.

The experience feedback indicates that the application of standardized modules of GIS equipment to resolve connection problems (with air or gas insulated equipment) between the existing and new equipment, as well as between different types of equipment technologies, is very effective and relatively easy to achieve.

Extension of existing GIS substations

Extensions of existing GIS substations may cause problems, if not previously considered (see chapter 3.3) or if the original manufacturer of the equipment doesn't exist anymore. Indoor solutions may cause even more additional limitations.

Upgrading/refurbishment/ use for upgrading/refurbishment of existing substations

Upgrading of existing switchgear (e.g. upgrading of switching capability, insulation coordination, one-line reconfiguration for higher system reliability) is easier due to the singular components with AIS than with GIS. However MTS have proven that it is the most flexible solution for all possible applications except of some highest current ratings (for the time being).

Mobile and/or temporary installations

Compact switchgear is prevailing a solution to accommodate temporary requirements (temporary installations) in substations for it allows high flexibility.

New substation

The natural progression to the second step followed, prompted by questions such as: "Why not use similar solutions for new or under renovation (refurbishment) indoor or outdoor AIS or GIS? Why not specify the MTS technology for new or renovation projects?"

As the technical requirements are the same for extensions as for new installations, compact/combined AIS or GIS equipment modules (up to full bay arrangement) offer very effective solutions for such applications also. However for new substations additional advantages, such as

- simplified single line diagrams,
- more economical lay-outs,
- less dependence on one manufacturer,
- possibility to combine indoor and outdoor equipment, and
- possibility of designing mobile units for temporary installations (compact AIS or GIS modules)

can and should be considered.

The most flexible solution for all possible applications will be found from two perspectives: The right evaluation of the appropriate equipment in combination with the utilities individual conditions and necessities. A general solution doesn't exist.

3. 12 Personnel Safety

Title	AIS	MTS	GIS
Personnel safety			
• injury risk during service	0	+	++
• injury risk during maintenance	++	+	0
• injury risk in case of major "violent" failure	0	+	++

Switchgear rated voltage consideration: The evaluation and the below mentioned explanation do not depend significantly on switchgear rated voltage

The major concerns regarding personnel safety in all technology applications are as follows:

- injury risk during service (step voltage, touch voltage, electromagnetic field exposure),
- injury risk during maintenance (safety in the work place),
- injury risk in case of a major "violent" failure (explosion, fire, mechanical damage).

Injury risk during service

The aspects to be evaluated are: step voltage, touch voltage, accessibility of parts at service voltage, and electromagnetic field exposure.

Step voltage and touch voltage are controlled by a proper substation earthing network design and construction. The basic rules are the same for all technologies. The only difference consists in the number of vertical earthing conductors connected to the horizontal earthing grid. In addition to that, in AIS (AIS part of MTS) it may be necessary to increase the earthing grid density in places where a person can stand and operate the equipment or in any other places where personnel access is more frequent.

Regarding **accessibility of parts at service voltage** there is an essential difference between AIS and GIS technologies. GIS and GIS parts of MTS haves considerably lower risk of injury to personnel than AIS, mainly due to enclosure of the live parts. Special attention must be paid to proper earthing of this enclosure. To prevent or reduce the flow of induced current in the earthing system, all enclosures of each phase must be connected by bonding circuits designed to withstand circulating currents. These circuits, connected to the earthing system, are best located near the connection of GIS with other items (bushings, cables and transformer connections) and at the ends of the busbars. Additional non-linear resistors are sometimes installed across enclosure flanges to prevent sparking due to very fast transient overvoltages caused by operation of the disconnectors.

All technologies are considered safe with regards to **EMF** but exposure in AIS is higher. Electric fields are shielded by grounded GIS enclosures, whereas there is generally no shielding of electric fields by AIS equipment. Magnetic fields due to conductor currents are reduced by GIS enclosure currents. That however, does not apply to AIS. Workers are exposed to both electric and magnetic fields throughout AIS. Worker exposure to electric and magnetic fields in GIS substations is generally limited to the vicinity of GIS interfaces to AIS parts.

Injury risk during maintenance

The risk during maintenance is mainly covered by the safety in the work place. The aspects to be evaluated are: earthing provisions, work place safety considerations, accessibility of parts to be maintained, ventilation, and personnel safety devices (such as respirators, protective clothing, gloves, portable grounds, etc.).

For AIS as well as GIS it is necessary to have a proper **earth connection of the work place**. In AIS it is possible to use portable grounds almost anywhere if there is no free standing earthing switch installed in the substation.

In GIS and GIS parts of MTS it is necessary to pay special attention to this issue. Several options are available to achieve primary earthing by the user during maintenance or fault repair outages.

- The main option is to provide at the design stage for sufficient numbers of permanently installed, electrically (as well as mechanically) interlocked, earthing switches at all possible locations where they may be required within the GIS and MTS, to allow appropriate maintenance earthing.
- GIS and GIS parts of MTS with directly connected overhead lines or those connected by air-insulated conductors offer the possibility of bay earthing by means of conventional air-insulated earthing switches or portable grounds.
- Another option for earthing during repair and/or major maintenance within GIS is represented by portable earthing devices which can be connected onto specially designed locations on primary conductors. This method necessitates degassing, removal of access covers and usually requires the development of special rules describing conditions for installation. Portable maintenance earthing devices are recommended in most cases only as additional (emergency) tools.

There are differences between AIS and GIS technologies in respect of **work place safety considerations**, such as:

- **Visual checking of the isolating gap** and/or earthing connection for maintenance work: Whereas in AIS the isolating gap is always visible, in GIS or GIS parts of MTS this is not possible if the enclosure is not equipped with special viewports. The absence of visible isolating gaps on disconnectors has already led to changes in maintenance safety rules required by most users in comparison with rules prescribed for AIS. If GIS enclosures are not equipped with viewports, it is not possible, before starting any maintenance work, to insist on visual checking ("own eyes") of a disconnector´s isolating gap and its earthing switch closed position. Viewports can help in this respect, however, they can affect the overall integrity of GIS and introduce additional leakage. The user should be aware that an isolating gap in GIS provides its functional integrity if the SF_6 gas pressure is within allowed limits. Many users nowadays accept the principle of external position indication providing that it always truly represents the state of the internal contacts, and mechanical interlocking of disconnector and earthing switch in case they serve for safety requirements for work. Some users accept special provisions, such as video cams, that allow viewing the isolating gap.
- **Work close to pressurized components**: At GIS and MTS it is necessary to decrease the SF_6 pressure at the adjacent gas compartment to a certain level (usually atmospheric pressure) to avoid accidental rupturing of insulating spacers.
- Clear identification and **marking the work place area** and access to the place: This requirement can be easily achieved in AIS and AIS parts of MTS using e.g. plastic strips.

Regarding the **accessibility of parts to be maintained** there are also significant differences between technologies. The more compact the equipment is the more provisions (e.g. walk paths, access of lifting mechanisms, etc.) and the more attention to precise instructions needs to be paid.

Differences between technologies with respect to **ventilation and personnel safety devices** concern only whether SF_6 insulated equipment is used in the switchgear or not. Ventilation needs to be considered only for indoor installations.

Handling of SF_6 gas and use of personnel protection devices are the same in GIS, MTS, and AIS and are well described by several CIGRE guides [9], [11].

Indoor switchgear with SF_6 insulation must be ventilated adequately. Natural ventilation is preferred. This also applies to rooms, ducts etc. located below rooms containing SF_6 equipment. Locally applicable regulations must be complied with. A fixed or mobile fume extraction unit may need to be provided to assist in the removal of SF_6 decomposition products.

Injury risk in case of major failure

The aspects of a risk of a “violent” major failure can be evaluated as: explosion, fire, mechanical damage.

On the issue of **explosion-prevention**, GIS and GIS parts of MTS provide better protection than AIS. Every GIS gas compartment must be equipped with a pressure relief device. Such devices are not always used at live tank and dead tank CBs or oil immersed instrument transformers. (There is a different practice in different parts of the world.)

Additional measures must however be applied on GIS and GIS components of MTS:

- The pressure relief devices must be installed at locations where operational personnel do not normally have access to, and the pressure relief device venting should be directed away to avoid injury to personnel.
- The design philosophy used in engineering the pressure relief devices is to delay the operation of a pressure-relief device, if possible, until after the operation of the main protection, thus limiting the exposure of the substation to pollution and contamination.
- Gas zone barriers should be capable of withstanding pressure differentials in both directions of stressing, to allow for repair and maintenance work in an adjacent zone of a pressurized spacer if necessary. The barriers should also be able to withstand the pressures generated by an internal fault in any gas compartment, thus preventing contamination of adjacent compartments by arc by-products.

Regarding **fire risk**, GIS and GIS components of MTS offer certain advantages compared to AIS, because they do not contain any oil-filled equipment. SF_6 is a non-combustive gas. However, in all three technologies discussed there may be combustible materials such as cable insulation, oil (insulating or hydraulic), thermal insulation, even epoxy or composite components that under intense temperature will burn. However if a fire has ignited the more compact the switchgear is the more the damage to its components will be.

Local fire codes must be taken into consideration. These factors are applicable to AIS as well as GIS and MTS, however, the reduced size of the facilities allows smaller systems to meet the applicable fire codes. Specific areas of indoor substations may require additional fire protection, especially where oil-filled equipment is part of the installation. Indoor substations require in general measures, which are not necessary for outdoor installations, such as zoning, emergency exits, escape routes, etc.

Regarding **mechanical damage** the AIS also presents more risk, as people have access under various parts of the substation, and may be subjected to falling objects.

3.13 Physical Security

Title	AIS	MTS	GIS
Physical security			
• Security against terrorist attack	0	+	++
• Security against vandalism	0	+	++
• Security against metal theft	0	+	++

Switchgear rated voltage consideration: The evaluation and the below-mentioned explanation do not depend significantly on switchgear rated voltage.

Maintaining the security of substation physical assets has become increasingly important in recent years. Inadequate security of a substation property can result in a loss in asset value, decreased asset reliability and increased company liability.

Security against terrorist attack

While GIS in general is better protected against terrorist attacks particularly if indoors installations, once damaged such damage is much more severe.

If GIS is installed in a building, trespassing by unauthorized personnel becomes more difficult. However, should penetration occur, and in case of terrorism intent, the damage to GIS would obviously be worse and more difficult to repair that in the case of AIS and MTS. From the physical security point of view, the MTS is closer by its nature to an AIS installation and needs to be protected similarly, however because of its compactness (smaller size and partly encapsulated) it can be protected easier than AIS .

Security against vandalism and/or against metal theft

From the results of the survey conducted both by CIGRE [10] and by IEEE Std. #1402 respectively, it is obvious that the most important physical security issues to be addressed are: theft and vandalism.
For AIS, protective measures need to be applied at the fence line. Stealing copper from a substation grounding system is an issue that almost all utilities are currently facing, especially due to increases in the price of the commodity. This poses a serious safety issue for the maintenance personnel of the substation.
Penetration of AIS by unauthorized personnel represents a real liability for the asset owner.
GIS, by its construction, is more protected against theft and vandalism.

3.14 Life Cycle Cost

Title	AIS	MTS	GIS
Life cycle cost			
• cost of acquisition	++	0	-
• cost of ownership (* heavily influenced by individual utility's conditions)	0*	++*	+*
• cost of disposal	-	0	0

Switchgear rated voltage consideration: The evaluation and the below mentioned explanation do not depend significantly on switchgear rated voltage.

The wide diversity of high voltage switchgear technologies lead to many approaches for evaluation of the customer's benefits. While in the past the investment costs were the most important consideration in the evaluation of different alternatives, nowadays the investigation of the life cycle cost (LCC) has become more important.

The goal to minimize the life cycle costs can only be achieved by using detailed knowledge about the specific parameters and their influence on the LCC. Sensitivity analysis will indicate which cost element and which configuration have the largest impact.

In addition to the conventional solutions for high voltage substations (GIS and AIS), several innovative concepts, such as MTS, have entered into the market recently. The main drivers for this development are the rapid changes in the ownership of utilities and the stronger focus on asset management in the liberalized power transmission and distribution market. Criteria for evaluation and optimization of the assets need to be considered in the selection of the optimum solution for the individual substation.

The MTS is based on the service experience of AIS and GIS equipment and designed and manufactured to ensure the best possible relationship between system planning design, materials utilised in fabrication, equipment service performance and maintenance effort. The result is optimized utilization of equipment for a service life expectancy of up to 50 years with appropriate maintenance. The MTS switchgear therefore offers a high degree of reliability and availability, even if the limits of wear (contact erosion, aging, corrosion etc.) are approached.

Electric utilities are placing increasing emphasis on cost-effectively extending the life of existing substations while maintaining adequate levels of reliability and availability. To maintain high levels of power quality and reliability requires appropriate switchgear performance. However the long-term switchgear integrity is often compromised nowadays with continuous budget cuts in investment spending as well as maintenance. Utilities are not willing to invest in switchgear improvements unless they are deemed critical or if there is an immediate or near future return of revenues. Deregulation processes are supporting these asset management attitudes.

Comprehensive life cycle cost investigations and a tight asset management reduces the overall cost of a high voltage substation and contributes to the economical benefit of the operating utility.

The life cycle cost can only be evaluated if the cost breakdown structure for the overall service life of the equipment has been worked properly. IEC 60300-3-3 is proposing a general cost breakdown structure for high voltage applications which shall be applied here.

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

with the following cost elements:

Cost of acquisition:	cost of the equipment (system cost) and the cost of installation
Cost of ownership:	operation cost
	maintenance cost (planned preventive maintenance cost + corrective maintenance cost)
	cost of unplanned unavailability
Cost of disposal:	all cost of decommissioning and disposal after use

The calculation however is so heavily influenced by the individual parameters of the user, that no general recommendation can be given. Calculations exist which suggest that MTS has some life cycle cost advantages against AIS and GIS.

4 Standards

Regardless of what type of equipment the user is using (compact, combined AIS or GIS, or GIS modules in hybrid installations), the AIS portion is covered by mature AIS standards, while the GIS portion is subject to mature GIS standards.

The use of compact switchgear design flows from requirements for limited availability of space and the limited budgets for new investments. In mixed technologies the advantages of Air Insulated Switchgear (AIS) and Gas Insulated Switchgear (GIS) are combined to yield a large variety of technical solutions.
Two years ago, the IEC SC 17C committee has started work on new standards that will close the gap between already existing devices and equipment standards, like Circuit Breakers, Disconnectors, or Switchers, on one side and the GIS standards on the other side.

The new standard which deals directly with MTS was completed in 2007 and assigned the number IEC 62271-205. The scope of this international standard applies to AC switchgear and controlgear that is an assembly of switching devices in close/compact formation with other switching devices or other devices, defined in IEC standards and which are designed, tested and supplied for single use as an indivisible unit. Such assemblies may contain components of Air Insulated Switchgear (AIS) or a combination of Air Insulated Switchgear and Gas Insulated Switchgear (GIS), and are designated as Mixed Technology Switchgear (MTS).

Due to their compact nature, interaction between the various devices making up the assemblies is anticipated and has to be type-tested. The new standard should provide the regulations on how such compact switchgear assemblies have to be designed, tested and specified.

The objective of this new IEC standard is to respond to the increasing use of compact switchgear assemblies that perform the functions of a number of separate devices and their controlgear. Numerous arrangements are possible and this standard will provide guidance on basic types of assemblies which might be envisaged. Interactions between the different devices within such assemblies have to be considered and it is necessary, to consider the standardization requirements for the switchgear assembly in its entirety.

When designing and producing an MTS it is recommended to use only devices which are defined in the appropriate IEC/IEEE standards. However each individual switching device, other devices and controlgear shall comply simultaneously with its specific relevant individual standard.

Relevant Standards (end of 2008 status)

Common clauses :

MTS, GIS, AIS	IEC 62271-1 High-voltage switchgear and controlgear – Part 1 Common Specifications
MTS	IEC 62271-205, High-voltage switchgear and controlgear – Compact switchgear assemblies for operation at rated voltages above 52 kV
GIS	IEC 62271-203, Gas-insulated metal-enclosed switchgear for voltages of equipment of 52 kV and above

Additional to the standards of the common characteristics, defined by IEC standards above, there are other standards that are applicable for individual devices as listed below:

Switching devices:

Circuit breakers	IEC 62271-100
Disconnectors/earthing switches	IEC 62271-102
Switches	IEC 60265-2
Disconnecting circuit-breakers	IEC 62271-108

Other Devices:

Instrument transformers	IEC 61896-1(common clauses)
Current transformers	IEC 60044-1, IEC 60044-8
Voltage transformers	IEC 60044-2, IEC 60044-5, IEC 60044-7
Combined transformers	IEC 60044-3
Surge arresters	IEC 60099-4
Bushings	IEC 60137
Insulators	IEC 61462, IEC 62155
Cable connections	IEC 62271-209
Transformer connections	IEC 61639

IEC 60480 Guide to the checking of SF_6 taken from electrical equipment
IEC 60050- Chapter 605: "Generation, transmission and distribution of electricity – substations"

IEC Technical Reports

IEC TR-113933 Practical Guide to SF_6 Handling Practices
IEC TR-62271-303 Use and Handling of Sulphur Hexafluoride (SF6)

Other standards

IEEE Std.1127 - Guide for Design, Construction, and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility
IEEE Std. 980 - Guide for Containment and Control of Oil Spills in Substations
IEEE Std. 693 - Recommended Practices for Seismic Design of Substations
IEEE Std. 1402, "Physical Security of Power Electric Substations"
IEEE Std. C37.122 (1983) Standard for High Voltage Gas-Insulated Substations, rated above 52 kV (under revision)

5 Conclusions

All used technologies have their advantages that are described in detail in this brochure. The comparison of technologies indicates that MTS combines a lot of advantages of AIS and GIS and leads to a good compromise.

The following table shows a summary of main MTS benefits.

<table>
<tr><th>MTS type</th><th>Benefits</th></tr>
<tr><td>AIS in compact design</td><td>▪ Less space required for the same single line diagram
▪ Extend single line diagram within the same space
▪ Easier engineering
▪ Easier integration of secondary systems</td></tr>
<tr><td>Hybrid in compact design</td><td>▪ Less space required for the same single line diagram
▪ Higher flexibility of layout versus AIS
▪ Extend single line diagram with the same space
▪ Allows bus reconfiguration for increased system reliability
▪ Easier engineering
▪ Reduced maintenance efforts and costs
▪ Easier integration of secondary systems</td></tr>
<tr><td>AIS in combined design</td><td rowspan="2">▪ Extend single line diagram with the same space
▪ Less space required for the same single line diagram
▪ Allows bus reconfiguration for increased system reliability
▪ Easier engineering
▪ Easier maintenance
▪ Easier integration of secondary systems</td></tr>
<tr><td>GIS in combined design</td></tr>
</table>

The aim of this brochure was to show all aspects to be considered when making a decision about a technology to be used. The consequent evaluation of all parameters of the use of switchgear and its comparison will help to find the right solution. However there is no recommended general solution for all users possible, the individual conditions of every case have a strong impact on the evaluation and can lead to different conclusions.

References

[1] CIGRE Brochure No. 161 “*Guidelines for the Design of Outdoor AC Substations*” 2nd version, August 2000

[2] CIGRE Brochure No. 125 “*User Guide for the Application of Gas-insulated Switchgear (GIS) for Rated Voltages of 72.5 kV and above*“, 1998

[3] CIGRE Brochure No. 83 “*Final Report of the Second International Enquiry on High Voltage Circuit-Breaker Failures and Defects in Service*“, June 1994

[4] CIGRE Paper "*The First International Enquiry on High Voltage Circuit-Breaker Failures and Defects in Service*“, ELECTRA No. 79, December 1981

[5] CIGRE Guide No. 163 “*SF_6-Gas Mixtures*”, March 2000

[6] CIGRE Guide No. 165 “*Life Management of Circuit-Breakers*”, August 2000

[7] CIGRE Brochure No.167 “*User Guide for the Application of Monitoring and Diagnostics Techniques for Switching Equipment for Rated Voltages of 72.5kV and above*”, 2000

[8] CIGRE Brochure No. 221 "*Improving the Impact of Existing Substations on the Environment*”, 2003

[9] CIGRE Guide No. 234 SF_6-Recycling Guide “*Re-use of SF_6 Gas in Electrical Power Equipment and Final Disposal*”, August 2003

[10] CIGRE Brochure No. 253 “*Substations Physical Security Trends*”, 2004

[11] CIGRE Brochure No. 276 *"Guide for the Preparation of Customized Practical SF_6 Handling Instructions”*, August 2005

[12] CIGRE Brochure No. 309 “*Asset Management of Transmission Systems and Associated Cigre Activities*”, Dec 2006

[13] CIGRE Publications “*First International GIS Experience Survey and Database*“, 1992, 1994

[14] CIGRE Paper No. 500-05 “*Report on the Second International Survey on High Voltage Gas Insulated Substation (GIS) - Experience in Life Expectancy, Maintenance, and Environmental Issues*” (CIGRE London Conference 1999)

[15] CIGRE Paper SC 23 No. 23-102 “*Report on the Second International Survey on High Voltage Gas Insulated Substation (GIS) Service Experience*”, (CIGRE Paris 1998)

[16] CIGRE Brochure No.150 “*Report on the Second International Survey on HV Gas Insulated Substations (GIS) Service Experience*”, 2000

[17] "Voluntary Agreement on the Use of SF_6 and on Measures for SF_6 Emission Reduction in the Atmosphere", national or regional electric industry agreements

[18] The EPA’s SF_6 Emissions Reduction Partnership for Electric Power Systems

[19] IEEE C37.10.1-2000 *"Guide for the Selection of Monitoring for Circuit Breakers"*

Appendix A:

Joint Task Force B3-02/03

Introduction to Mixed Technologies Switchgear

(High-Voltage Switchgear Assemblies built for operation at rated Voltages above 52 kV acc. IEC 62271-205)

1. Objective:

High voltage switchgear components have been developed using either air insulated technology (AIS) or gas insulated technology (GIS) or a combination of both of them. Assemblies of various high voltage components are introduced into the high voltage market as a possible solution between AIS and GIS. These solutions are often used to replace and upgrade open type substations (air insulated) to utilize less space and reduce the outage time demand. These assemblies have now been in use for several years' world-wide, generating sufficient experience to allow for standardization.

Switchgear layout nowadays can be based on insulation technology or on design and functionality. The different substation technology concepts, which have not yet been standardized, are being used lately by utilities as well as by manufacturers in many different ways, a fact that can lead to confusion.

This paper should introduce the mixed technologies switchgear namely using the following terms:
Insulation technology

air insulated switchgear (AIS)
gas insulated switchgear (GIS)
hybrid insulated switchgear (Hybrid IS)

Note: In the abbreviations GIS and AIS the "S" is often read as "substation". In this paper the IEC definition is used, where the "S" is read as switchgear.

Design and Functionality

conventional
compact
combined function

Mixed technologies switchgear (MTS) as described in the paper thus concerns the following combinations:

AIS in compact and/or combined design
GIS in combined design
Hybrid IS in compact and/or combined design

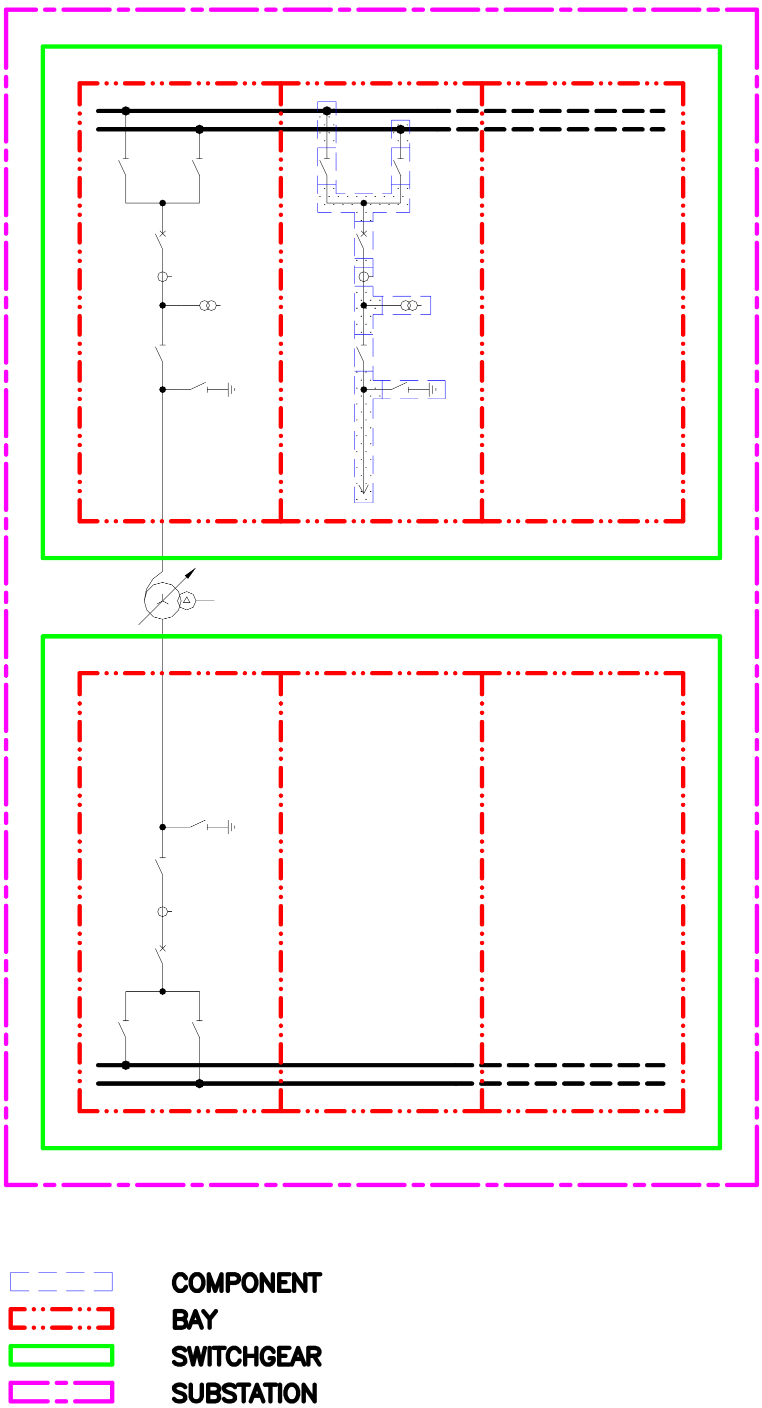
The aim of JTF B3-02/03 is to provide proposals to make the terminology clear and precise and to prepare a base for its introduction into standardization documents. Therefore and to avoid misunderstanding the suggested definitions are split into two parts, one according to the insulation technology (chapter 3.1.) and the other according to the functionality (chapter 3.2.).

2. Basic terminology used in the paper

The terminology used in this paper is based on terms of IEC 60050, if applicable, or on relevant IEC product standards, sometimes amended according to the specific use in this paper, and on previous CIGRE publications. The definitions of the terminology are given in appendix A.

This paper is based on the following logical structure of high voltage installations description, starting with the single component and ending with a complete substation:

Component - Bay = assembly of components - Switchgear = assembly of bays - Substation



3. Mixed Technologies Switchgear

This type of switchgear can be described according to two different aspects:

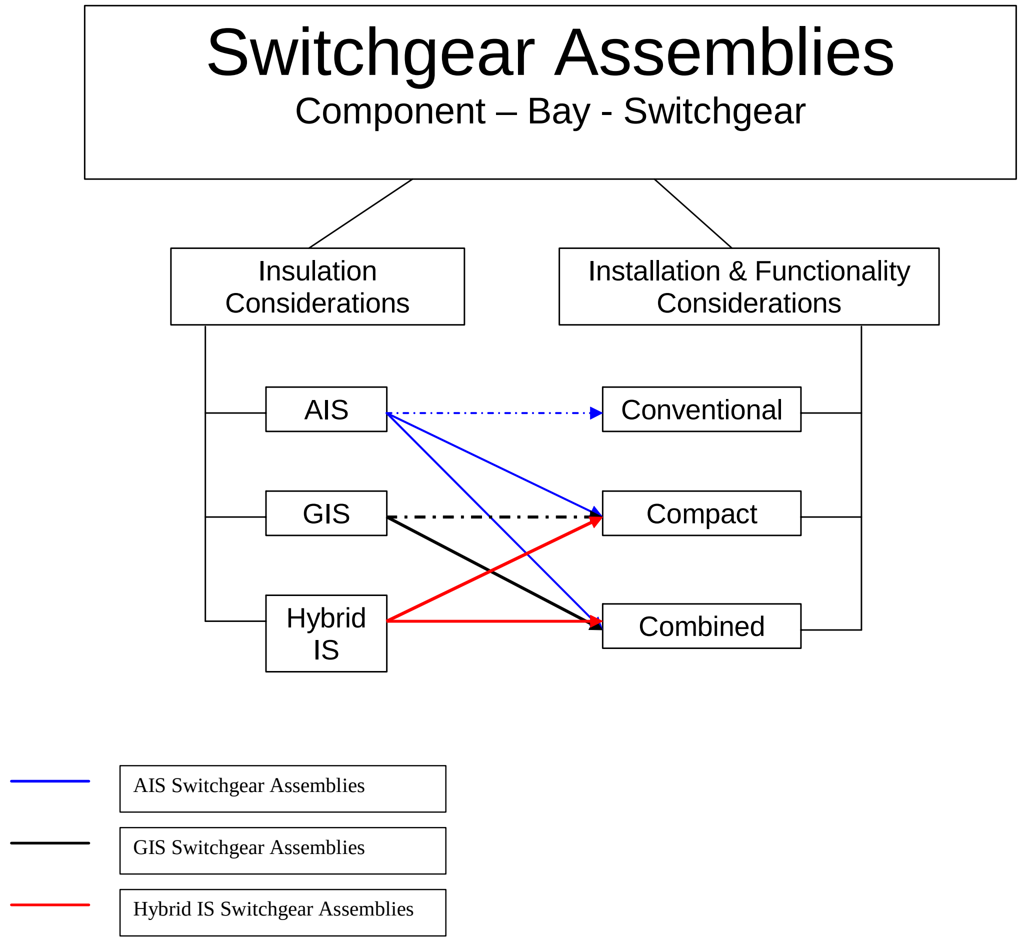
- insulation technology, which leads to the type of a AIS, GIS or Hybrid switchgear (chapter 3.1), or
- installation and functionality features, which leads to the type of compact or combined switchgear (chapter 3.2)

Both features can be mixed as seen from the graph above, which leads to the mixed technologies switchgear.
Mixed technologies switchgear as described in the paper thus concerns the following combinations:

- AIS in compact and/or combined design
- GIS in combined design
- Hybrid IS in compact and/or combined design

3.1 AIS, GIS and Hybrid IS

3.1.1 Insulation technology considerations



The features mentioned in chapter 3.1.2 are based on their insulation technology, using the following terms as defined in chapter 2:

component – bay - switchgear

The components are evaluated from their insulation and enclosure designs point of views. Components, in this respect, can be either of gas-insulated metal enclosed switchgear technology design or of external insulation switchgear technology design.

The following abbreviations are introduced to simplify the text in definitions mentioned in chapter 3.1.2:

GIS technology - for gas-insulated metal enclosed switchgear components technology designs
AIS technology– for open-type substations with external insulation switchgear components technology designs

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

Technology design	Insulation	Insulating medium	Enclosure
AIS technology	external insulation*	Air,	no enclosure or enclosure (porcelain or composite insulators) under high voltage
GIS technology	internal and external insulation	SF6 or SF6 mixtures	metal enclosure effectively earthed
Hybrid IS technology	external insulation*	SF6 or SF6 mixtures and Air	combination of all

* internal insulation can be air, SF6, oil, resin or all other kind of insulating media

Various assemblies (single line diagram arrangements and layouts) can be used for optimizing the installation, operation, space and the life cycle cost using AIS or GIS components technologies or their mixtures. All of them can be located outdoor or indoor.

3.1.2 AIS, GIS and Hybrid IS definitions

AIS (Air Insulated Switchgear)
Switchgear of which the bays are fully made from AIS technology components.
Note:
Substation, where only dead tank types of circuit breakers are installed in its bays, is also considered to be AIS substation.

GIS (Gas Insulated Switchgear)
Switchgear of which the bays are fully made from GIS technology components.
Only external HV connections to overhead or cable lines or to transformers, reactors and capacitors can have an external insulation.

Hybrid IS (Hybrid Insulated Switchgear)
Switchgear of which the bays are made from a mix of GIS and AIS technology components,
Switchgear, that consists of bays where some of the bays are made of AIS technology components and some of the bays are made either of GIS technology components only or of a mix of AIS and GIS technology components.

In general: Elements of AIS and GIS technology are mixed. There are two exceptions from this rule:

If the only one component in AIS technology is the HV connection to overhead line, cable or transformer the switchgear is considered as GIS.
If the only one component in GIS technology is a dead tank breaker the switchgear is considered as AIS.
Any other combinations are considered as Hybrid IS (e.g. where only bus bars are SF6 insulated, or where a metal enclosed gas insulated circuit breaker contains additional equipment as instrument transformers, or earthing switches).

Conventional, compact and combined switchgear

3.2.1 Installation and functionality consideration
The definitions mentioned in chapter 3.2.2 are based on their kind of technical solution like installation and functionality, using the following terms as defined in chapter 2:

Component – Bay –Switchgear

Contrary to 3.2.1 there are no direct or paraphrased definitions available in IEC to be used in this section.

The components are evaluated from their installation and functionality point of view.
Components in this respect can be:
either individually installed or multi-installed, i.e. installed in a compact form (placed in group sharing a common support construction and cannot be installed (placed) individually)
either single-functional or multi-functional

Technology design	Installation	Functionality
Conventional	Single (independent) installation	Single (independent)
Compact	Common support construction – interaction among components	Single (independent)
Combined	Single (independent) installation	Multifunctional (dependent)
Compact + combined	Common support construction – interaction among components	Multifunctional (dependent)

Examples for multifunctional components:
disconnector-earthing switch (ground switch) in which its function depends on the position of one common moving main contact
circuit breaker- disconnector switch – in which the open position of the circuit-breaker meets all requirements for disconnector isolating function*
*In their simplest form these combined function devices are required to satisfy the basic combination of a circuit-breaker (or switch) and one or more disconnectors. In general this applies to AC switchgear and controlgear that is a switching device combination, as being under standardization in IEC 17A. The new standard will have the number IEC 62271-108 and the title “Switchgear having combined functions”.

The following terms are introduced to simplify the text in definitions mentioned in chapter 3.2.2

Conventional components – for individually installed and single functional components

Compact components - for single function switchgear components installed in such a close formation, that thermal, electrical and mechanical interaction between the devices can be anticipated

Combined components – for multi-functional switchgear components

Conventional bays – for bays containing only conventional 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 optimizing the operation, the space and the life cycle cost using AIS, GIS or their combination components technologies. These functionalities of components define conventional, compact and combined switchgear.

3.2.2 Conventional , compact, and combined switchgear definition

Conventional switchgear
Switchgear of which the bays include only conventional components.

Compact switchgear
Switchgear of which at least one or more bays are compact bays, i.e. in which at least some components share common support structure and cannot be placed individually.

Combined switchgear
Switchgear of which at least one or more bays are combined bays, i.e. in which at least some components are multifunctional.

Compact/combined switchgear
Switchgear of which the bays include at least one group of compact components and at least one combined component.

Mixtures of different kind of bays:
Switchgear that consists of bays where some of the bays are compact and some of them are conventional is considered as compact switchgear.
Switchgear that consists of bays where some of the bays are combined and some of them are conventional is considered as combined switchgear.
Switchgear that consists of bays where some of the bays are compact/combined and some of them are conventional is considered as compact/combined switchgear.

3.3 Common considerations of insulation and installation + functionality

In chapters 3.1 the insulation considerations and in 3.2 the design and functionality considerations were discussed separately. In reality switchgear has always got both characteristics. The resulting mixtures can contain the following features:

GIS and Hybrid IS always meet the characteristics of compact switchgear and may be also combined.

AIS can vary between:
- conventional
- compact
- combined
- compact + combined

4. Relevant IEC activities

An IEC 17C MT17 had been given the task to check whether and how a new standard can cover the new possible arrangements. The new standard will have the number IEC 62271-205 and the title "High-voltage switchgear assemblies for operation at rated voltages above 52 kV".

5. Conclusions

New technology – either insulation technology or compact or combined design technology, which describes different substation technology concepts and which is not yet standardized -, used recently by utilities as well as by manufacturers in different ways, can create confusions.

This paper offers basic terminology for the use of new switchgear technology in order to avoid confusions caused by different meanings of the same expressions used by utilities and manufacturers. This terminology could be used as a base for further standardization and guidance for such kind of assemblies.

A CIGRE guide will be prepared by the end of 2005 to include information on substation layouts, specification and commissioning procedures, advantages and disadvantages of AIS, GIS and MTS. Comparisons of the of the different approaches will be made and LCC considerations will also be addressed.

To summarize the features of MTS:

Mixed Technologies Switchgear as described in the paper is defined by the following combinations:
AIS in compact and/or combined design,
GIS in combined design
Hybrid IS in compact and/or combined design

6. Definitions (as used in this document)

6.1 Switchgear component (bay component) (paraphrasing IEC 62271-203, 3.106):

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.)

6.2 Switchgear component enclosure (paraphrasing IEC 62271-203, 3.103)

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

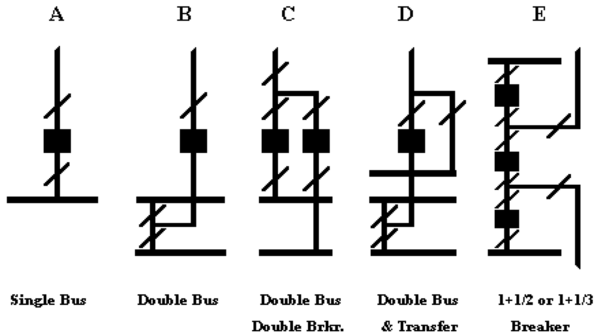
6.3.1 Bay (of switchgear components - common use in CIGRE Papers)

A three phase assembly consisting usually of one circuit breaker or switch, its associated disconnectors, instrument transformers interconnecting bus up to and including the line disconnect switch (if applicable), and the section of main bus (if applicable).

TYPE

BUS ARRANGEMENT/
CONNECTION

DESCRIPTION



6.3.2 Circuit Breaker Bay
A three phase assembly consisting of one circuit breaker, its associated disconnect switches, instrument transformers, interconnecting bus up to and including the line disconnect switch (if applicable), and the section of main bus (if applicable). [For example the number of Circuit Breaker Bays shown in Bus Arrangement/Connection is A=1, B=1, C=2, D=1, E=3.]

Note: Do not mix bay with exit; Exit is a conductor duct directly interconnecting the bay(s) to other system elements such as overhead lines, underground cables, transformers, reactors and generators. [For example the number of exits shown in Bus Arrangement/Connection is A=1, B=1, C=1, D=1, E=2.]

6.4 Switchgear:
A general term covering assemblies of one or several bays at one voltage level

6.5 Metal-enclosed switchgear and controlgear (IEC 62271-203, 3.101)

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

6.6 Gas-insulated switchgear enclosure (IEC 62271-203, 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.

Note: The enclosure can be single-phase or three-phase.

6.7 Gas-insulated metal-enclosed switchgear (paraphrasing 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. [IEV 441-12-05]

Note 1: This term generally applies to high voltage switchgear and controlgear
Note 2: Three-phase enclosed gas-insulated switchgear applies to switchgear with the three phases enclosed in a common enclosure.
Note 3: Single-phase enclosed gas-insulated switchgear applies to switchgear with each phase enclosed in a single independent enclosure.
Note 4: This gas is usually SF6 or SF6 mixtures.

6.8 Substation (of a power system) – IEC 60050-605-01-01
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

Note: - The expression „substation" in both AIS and GIS abbreviations is a slang, as normally any substation (switchgear and control gear installation) will almost always have more than one voltage level

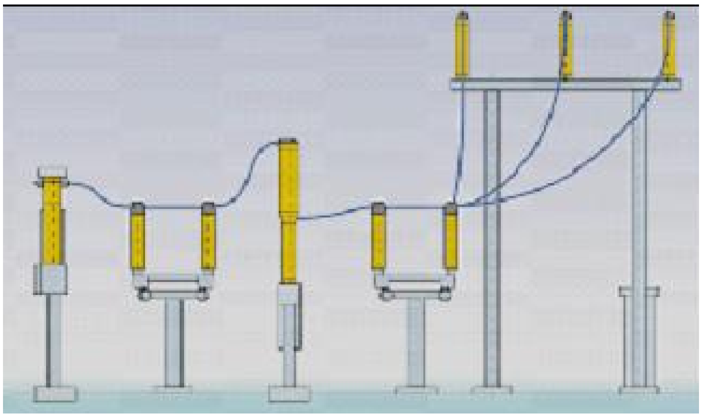
6.9 Open-type substation (IEC 60050- 605-02-13)
A substation in which the insulation to earth and between phase conductors is mainly provided by air at atmospheric pressure and in which some live parts are not enclosed.

Note: An open-type substation maybe indoor or outdoor

6.10 External insulation (IEC 62271-1, 3.1.2):
Distances in atmosphere and the surfaces in contact with open air or solid insulation of the equipment, which are subject to dielectric stresses and to the effects of atmospheric and other external conditions such as pollution, humidity, vermin, etc.

Note: This definition corresponds to commonly use "air insulation".

4. SPECIFIC BAY EXAMPLES



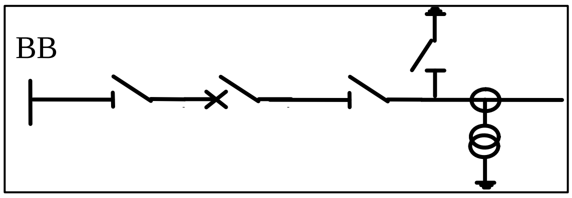
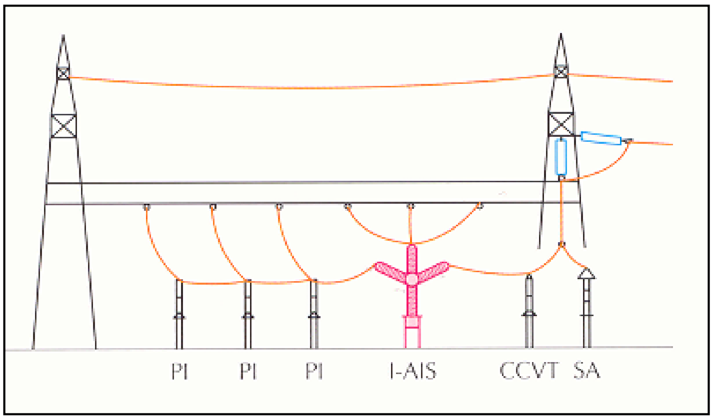


Fig. 1: part of conventional AIS bay



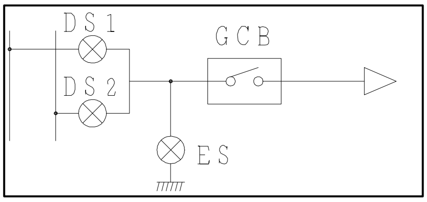


Fig 2: Combined AIS bay (Circuit Breaker/Disconnector Switch)

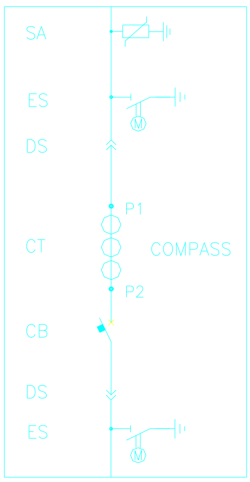
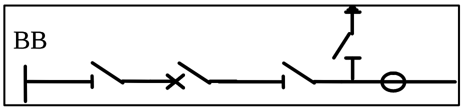


Fig 3: Compact AIS bay

Fig 4: part of compact AIS Bay



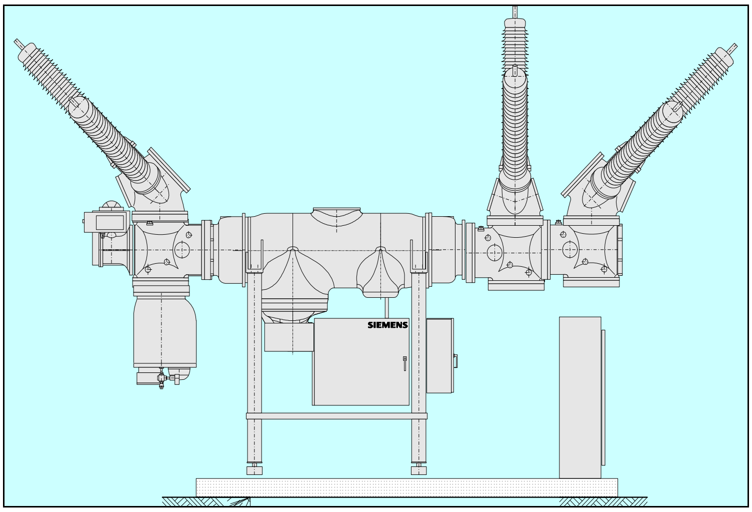


Fig 5: part of Hybrid IS Bay

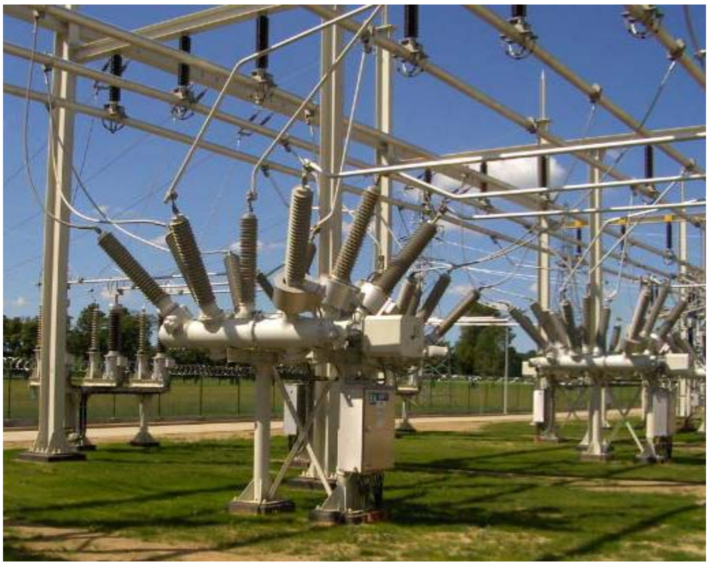
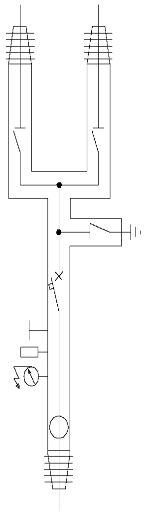


Fig 6: part of Hybrid IS Bay



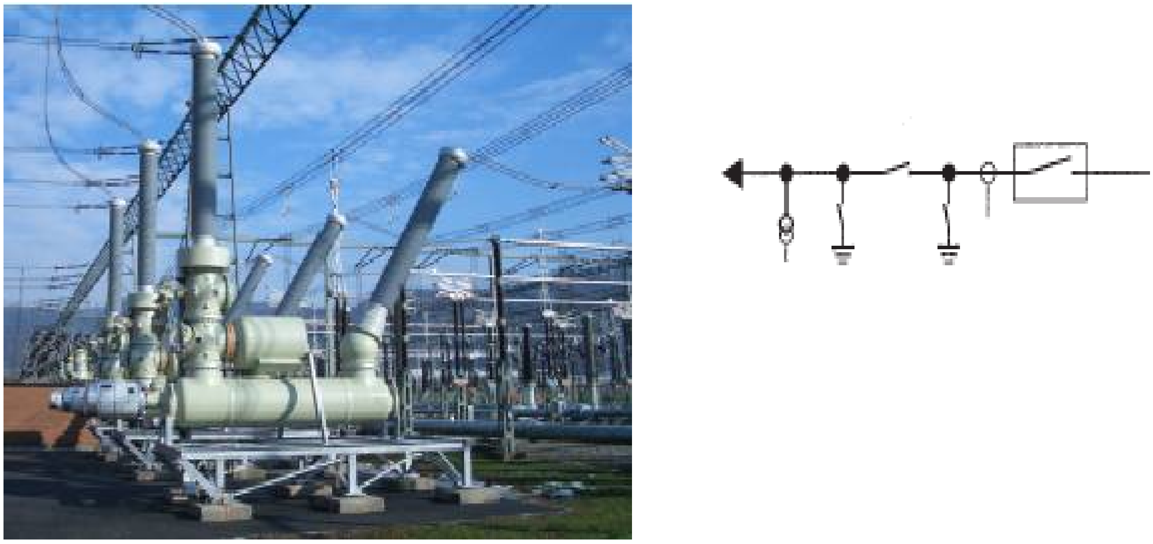


Fig 7: part of Hybrid IS

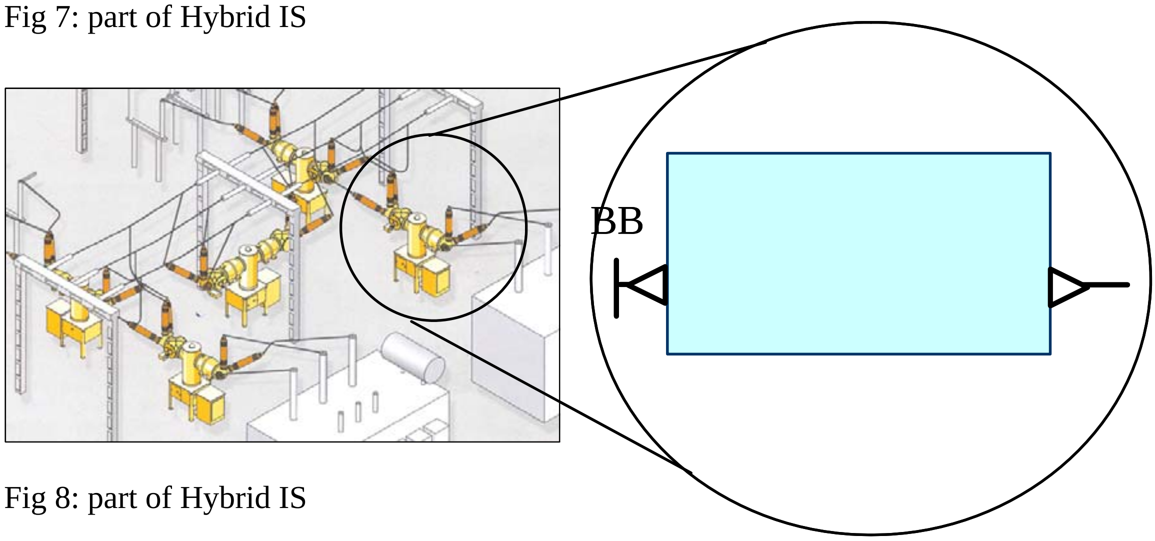


Fig 8: part of Hybrid IS

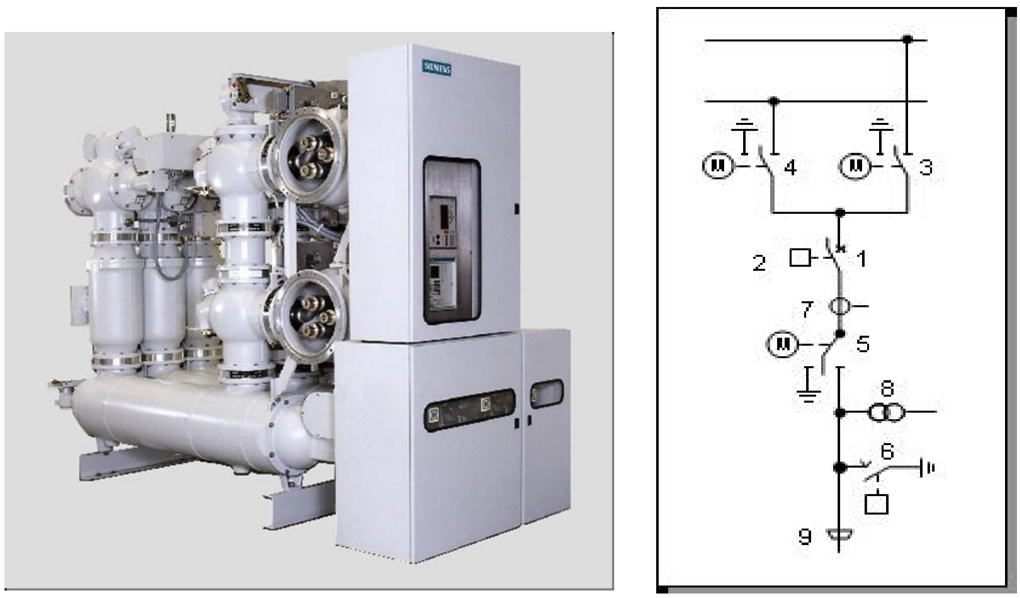


Fig. 9 conventional GIS bay

Appendix B: Case studies

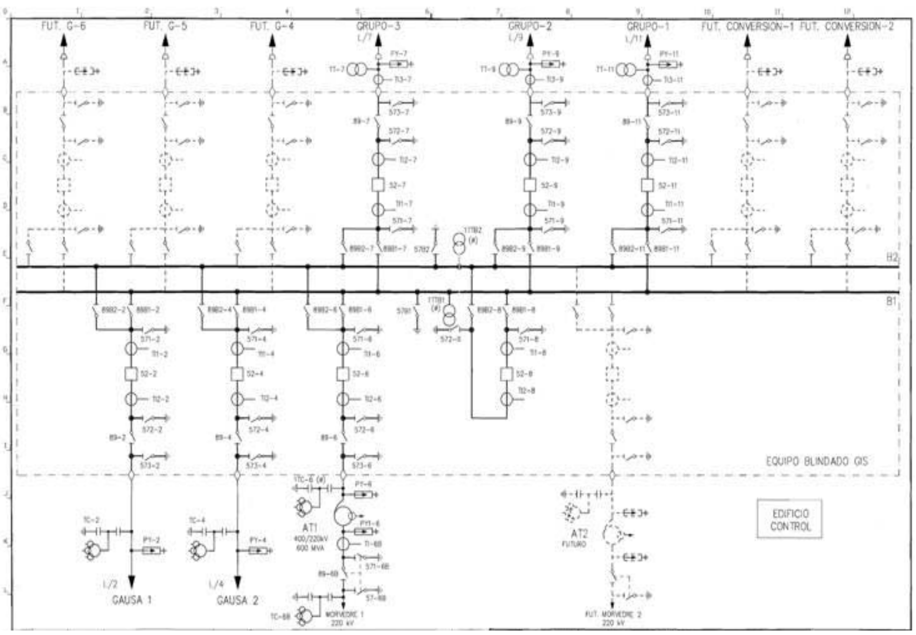
B.1 New Substations

B 1.1 Outdoor GIS: Red Electrica (REE), Spain, Valencia, Substation Morvedre

Ratings

	U_r	420 kV
	I_r	4000 A
	U_p	1425 kV
	I_K	63 kA

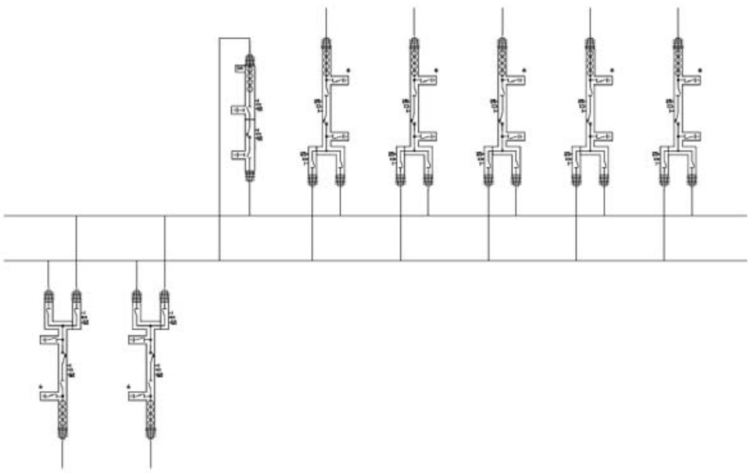
Single line diagram



B 1.2   New Substation with MTS (GIS Technology): Endesa, Spain, Barcelona, Substation Garraf

Ratings		
	U_r	145 kV
	I_r	2500 A
	U_p	650 kV
	I_S	40 kA

Single line diagram

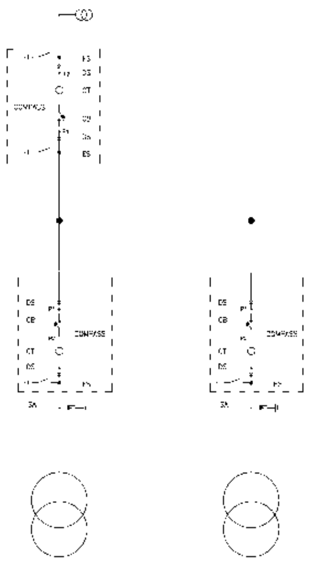


B 1.3 New Substation with MTS (Compact AIS Technology): Fiera di Primiero (BZ), Italy, Substation Fiera di Primiero

Ratings

U_r	145 kV
I_r	2000 A
U_{BIL}	650 kV
I_S	40 kA

Single line diagram

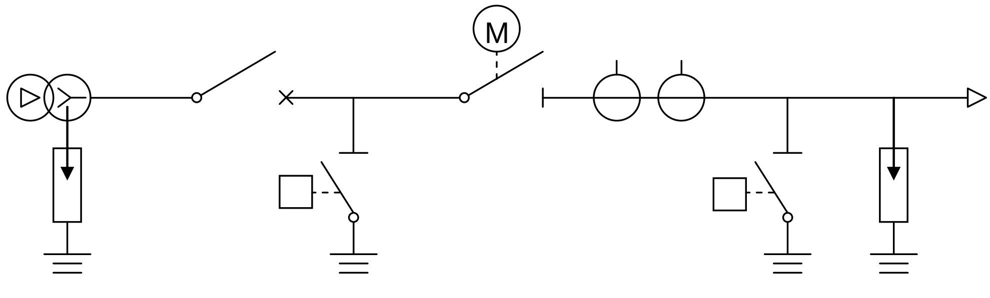


B 1.4 New Substation with MTS (Compact and combined AIS technology): Noheji Substation (Noheji wind farm Utility) Japan

Ratings :

U_r	168 kV
I_r	1200 A
U_P	750 kV
I_S	25 kA

Single line diagram

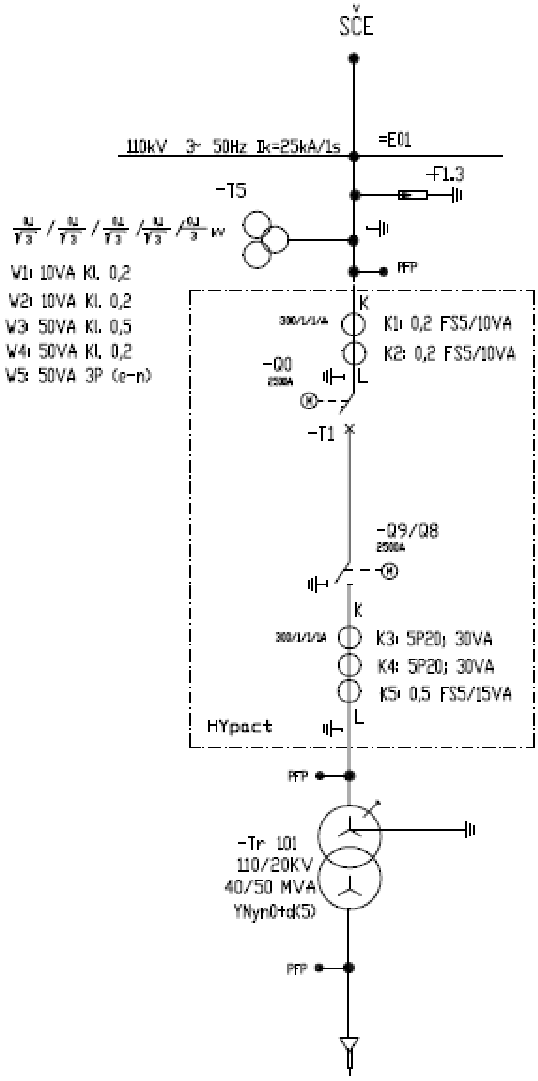


B 1.5 New Substation with MTS (Compact AIS Technology): Utility Ecoenerg s.r.o. , Czech Republic, Medenec, Substation Medenec

Ratings

Ur	123 kV
Ir	2500 A
Up	550 kV
Is	25 kA

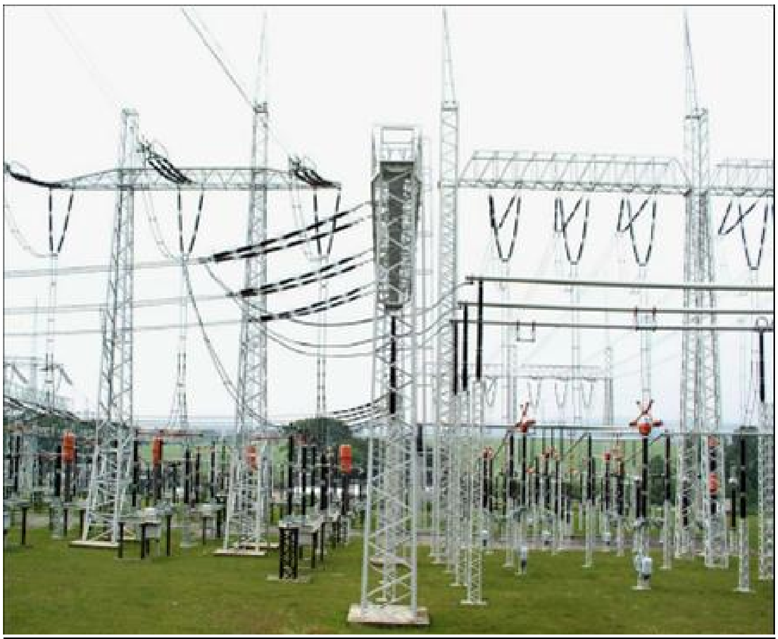
Single line diagram



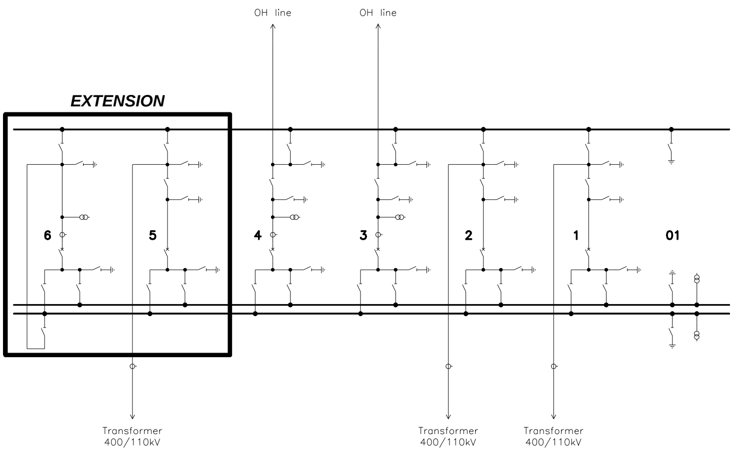
B.2 Extension of Existing AIS Substations

B 2.1 Extension of AIS Substation with AIS (Conventional AIS): CEPS, Czech Republic, Otrokovice, Substation Otrokovice

Ratings	**old**	U_r	420 kV	**new**	U_r	420 kV
		I_r	2500 A		I_r	3150 A
		U_P	1550 kV		U_P	1425 kV
		I_S	40 kA		I_S	50 kA



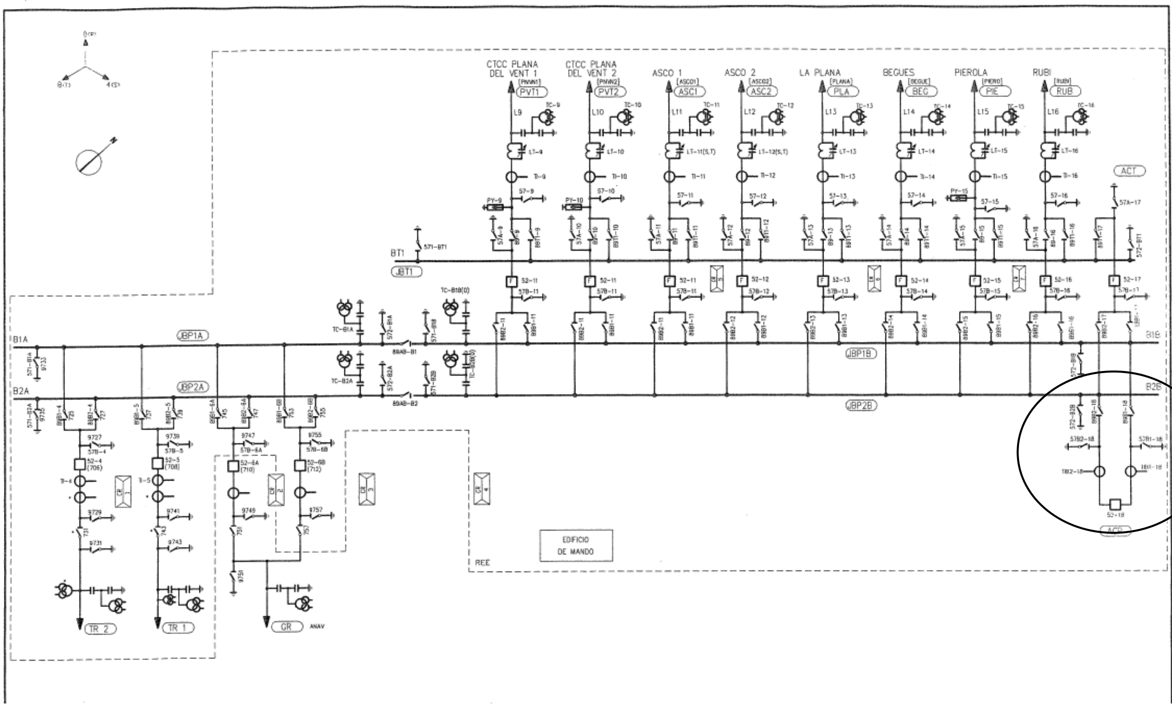
Single line diagram



B 2.2 AIS Extension by MTS (GIS Technology): Red Electrica (REE), Spain, Vandellos, Substation Vandellos

Ratings	**old**	U_r	420 kV	**new**	U_r	420 kV
		I_r	2500 A		I_r	4000 A
		U_{BIL}	1425 kV		U_{BIL}	1425 kV
		I_S	50 kA		I_S	63 kA

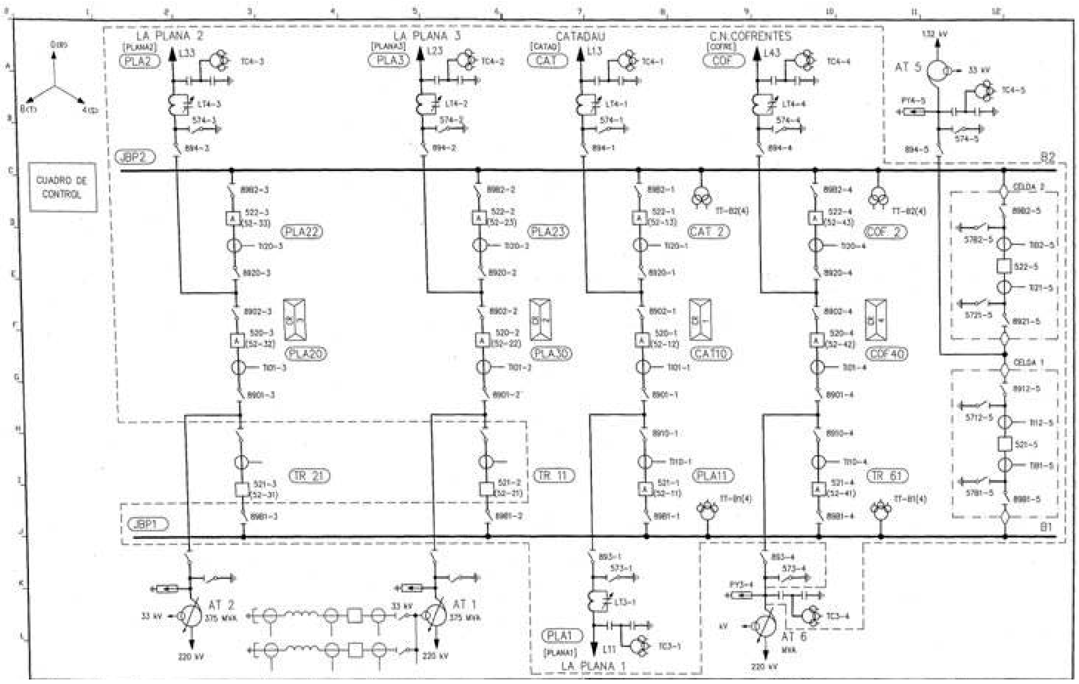
Single line diagram



B 2.3 Extension of AIS Substation with MTS (GIS Technology): Red Electrica (REE), Spain, Valencia, Substation La Eliana

Ratings	**old**	U_r	420 kV	**new**	U_r	420 kV
		I_r	2000 A		I_r	4000 A
		U_{BIL}	1425 kV		U_{BIL}	1425 kV
		I_S	30 kA		I_S	50 kA

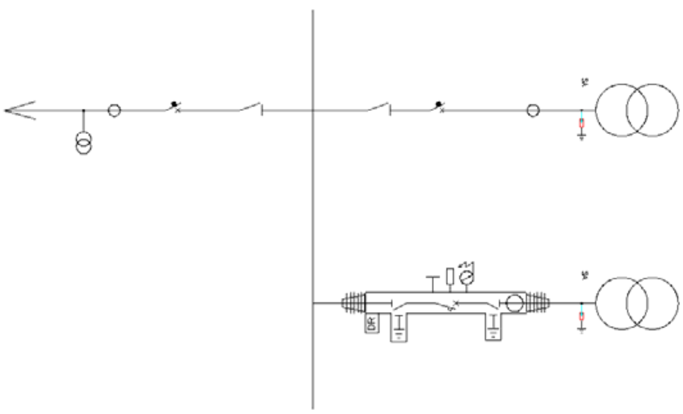
Single line diagram



B 2.4 Extension of AIS Substation with MTS (GIS Technology): GEG, France, Grenoble, Substation Geg

Ratings:	**Old**			**New**		
		Ur	72,5 kV		Ur	72,5 kV
		Ir	2000 A		Ir	2000 A
		Is	31,5 kA		Is	31,5 kA
		Ubil	325 kV		Ubil	325 kV

Single Line diagram:

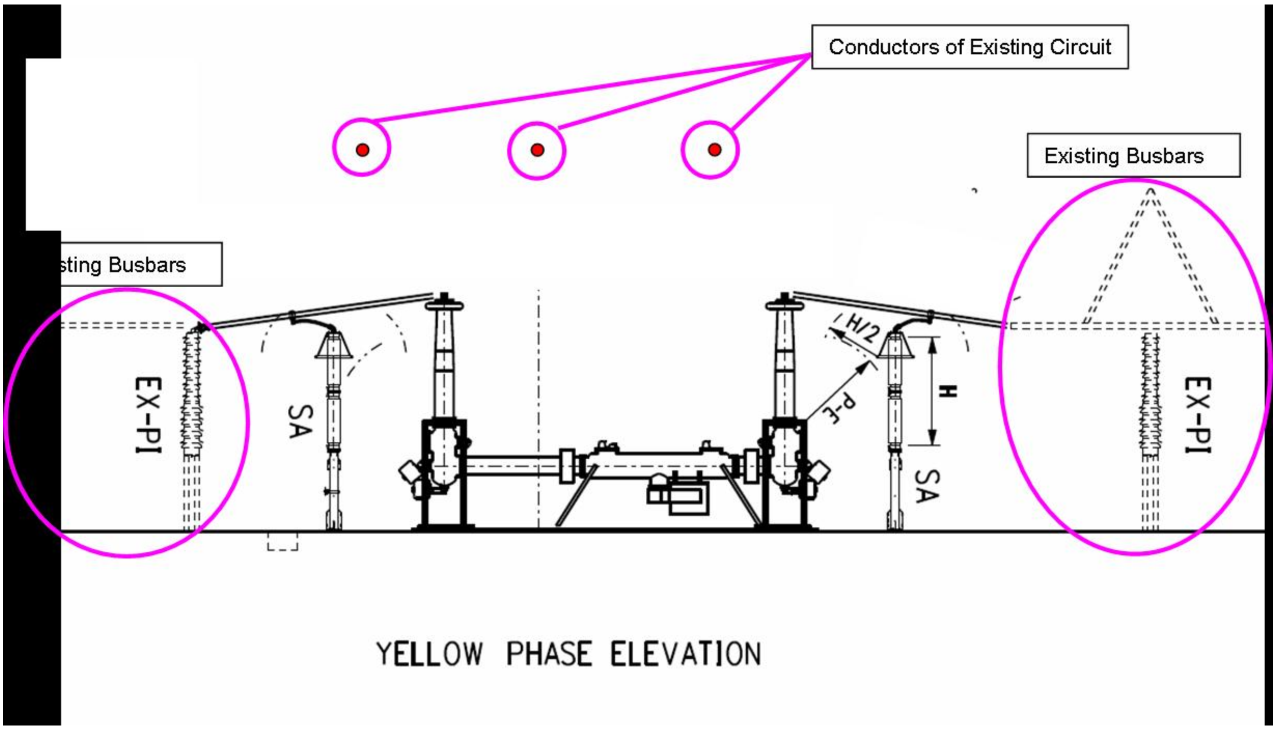


B 2.5 Extension of AIS Substation with MTS (GIS Technology): SE England (National Grid) UK, Chatham, Substation Grain

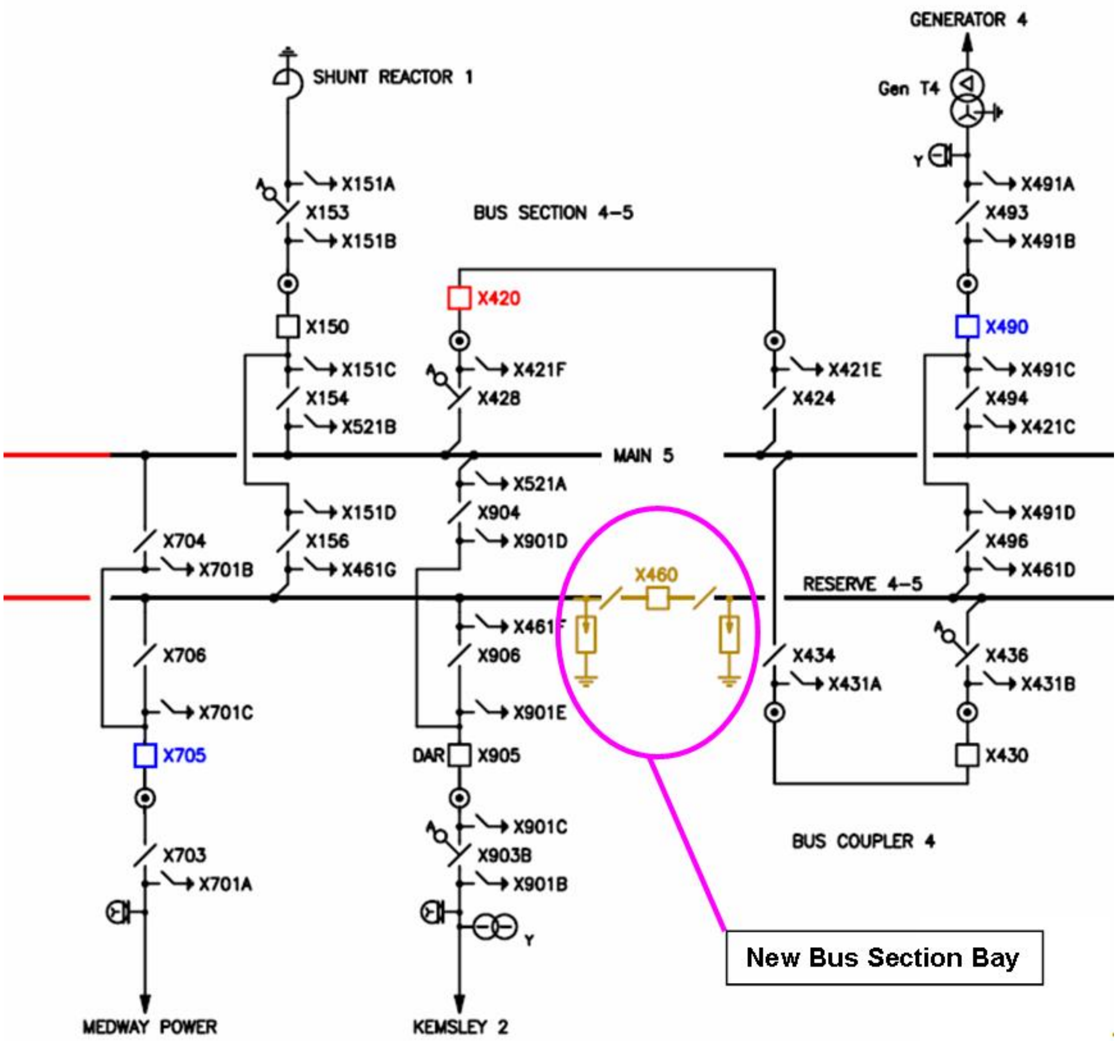
Ratings	**old**	U_r	420 kV	**new**	U_r	420 kV
		I_r	4000 A		I_r	4000 A
		U_{BIL}	1425 kV		U_{BIL}	1425 kV
		I_S	63 kA		I_S	63 kA

The project required the installation of an additional bus section circuit-breaker in the reserve busbar of an AIS double busbar substation. No space had been allowed for this extension in the original substation layout.

Using MTS, the space beneath existing busbar crossover connections is to be utilised to accommodate the new CB (X460) with associated CTs & disconnectors. Conventional AIS surge arresters are also to be provided.



Single line diagram

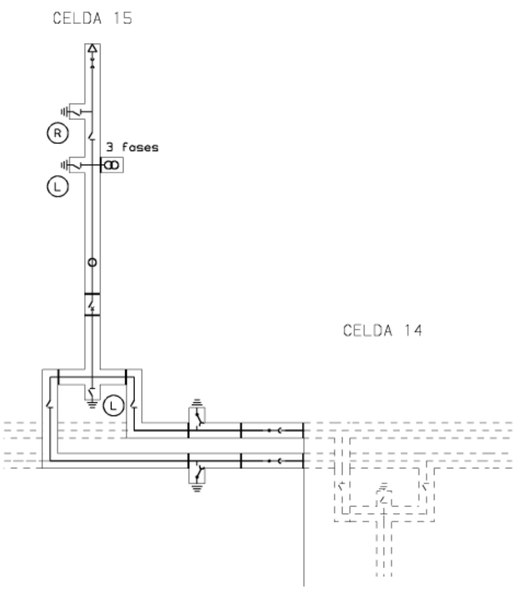


B.3 Extension of Existing GIS Substations

B 3.1 Extension of GIS Substation with GIS: Endesa, Spain, Canary Island, Grandilla Substation

Ratings	**Old**	*Ur*	245 kV	**New**	*Ur*	245 kV
		Ir	3150 A		*Ir*	3150 A
		U_{BIL}	1050 kV		U_{BIL}	1050 kV
		Is	40 kA		*Is*	50 kA

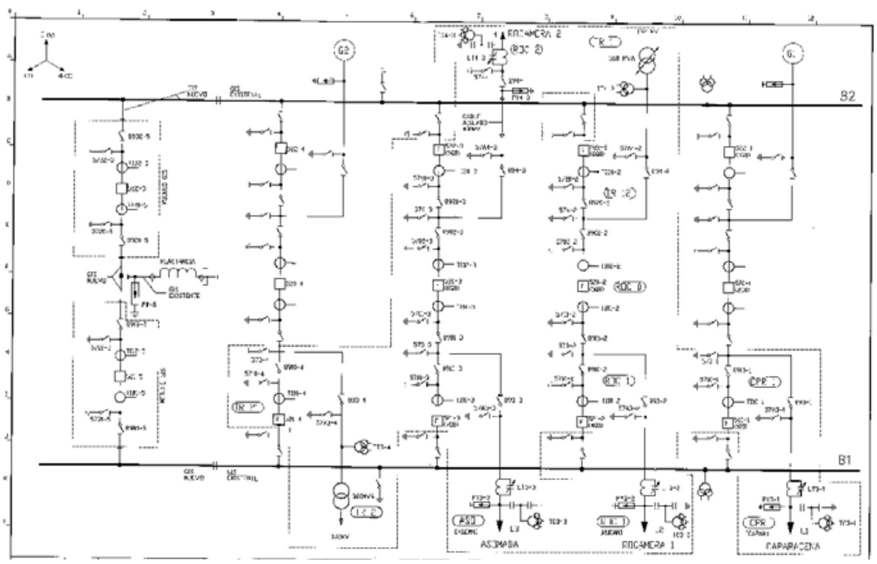
Single line diagram



B 3.2 Extension of Existing GIS with GIS (GIS Technology): Red Electrica (REE), Spain, Litoral, Substation Litoral

Ratings	old			ext.		
		U_r	420 kV		U_r	420 kV
		I_r	2500 A		I_r	4000 A
		U_{BIL}	1425 kV		U_{BIL}	1425 kV
		I_S	50 kA		I_S	63 kA

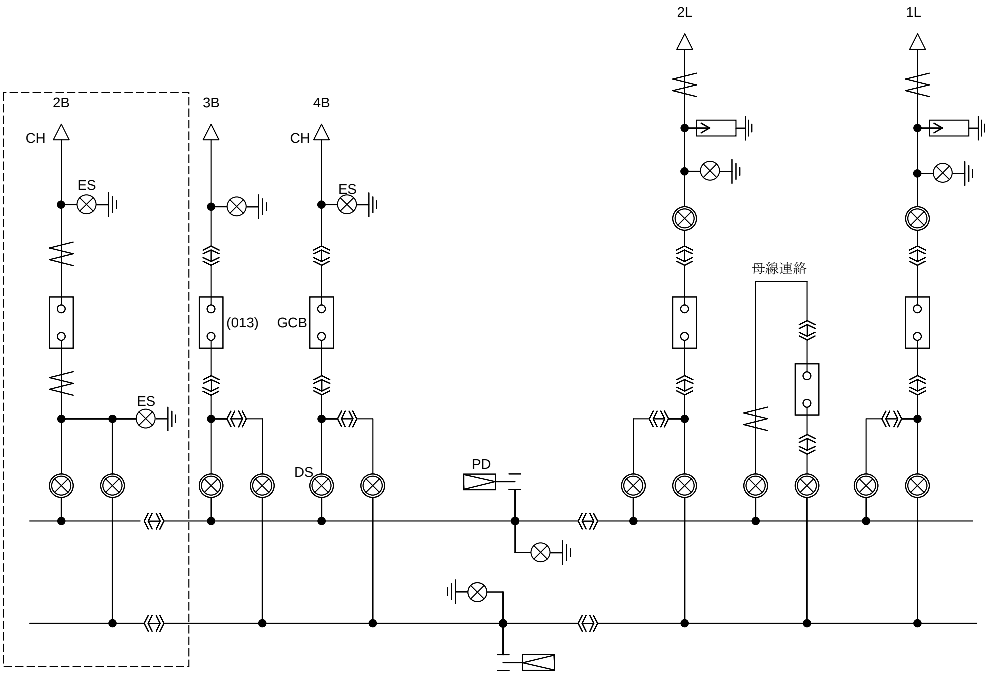
Single Line Diagram



B 3.3 Extension of existing GIS (Extension of existing GIS by new-type GIS) Hanamigawa Substation (TEPCO) Japan

Ratings :	U_r	300 kV
	I_r	4000 A (Main Bus), 2000A (Bank feeder)
	U_P	1050 kV
	I_S	50 kA

Single line diagram



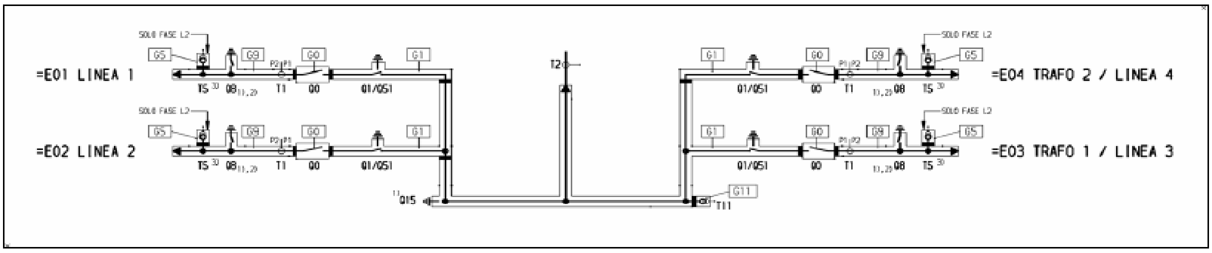
Extension parts

B.4 Mobile and/or Temporary Installations

B 4.1 Mobile Substation with GIS: Union Fenosa, Spain,

Ratings	U_r	145 kV (switchable 72.5 kV)
	I_r	3150 A
	U_{BIL}	650 kV
	I_S	40 kA

Single line diagram

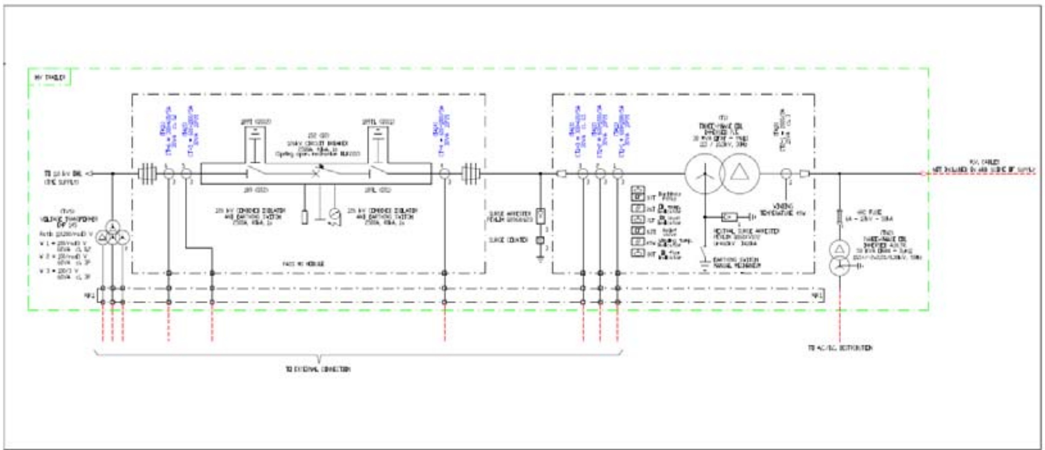


B 4.2 Mobile Substation with MTS: JSC Technopromexport, Russia

Ratings

U_{m}	115 kV (max. 145 kV)
I	2500 A
I_{sc}	40 kA
U_{BIL}	650 kV

Single line diagram

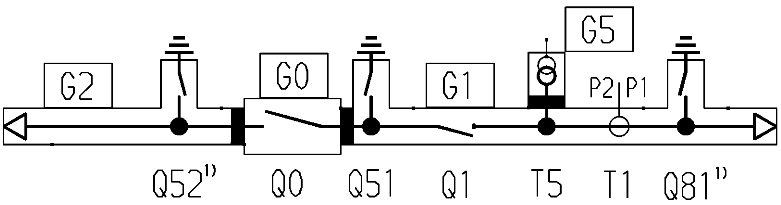


B 4.3 Mobile GIS Trailer Unit - Substation with GIS (GIS Technology): ADWEA, United Arab Emirates, Abu Dhabi, Substation Samha

Ratings:

U_r	245 kV
I_r	4000 A
U_p	1050 kV
I_S	50 kA

Single line diagram

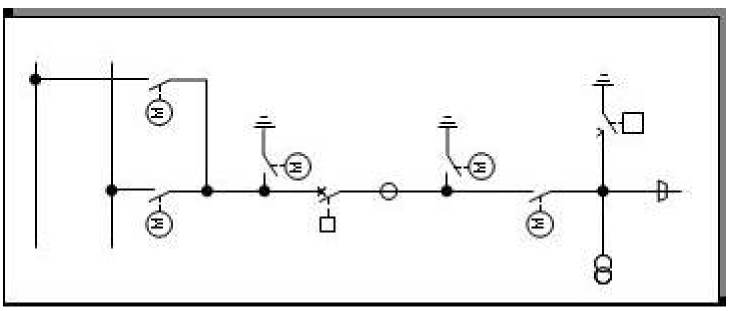


B4.4 Container Substation, GIS Technology, Temporary Installation :Tractebel, Belgium, Substation Bruegel

Ratings

U_r	170 kV
I_r	2500 A
U_{BIL}	650 kV
I_S	40 kA

Single line diagram

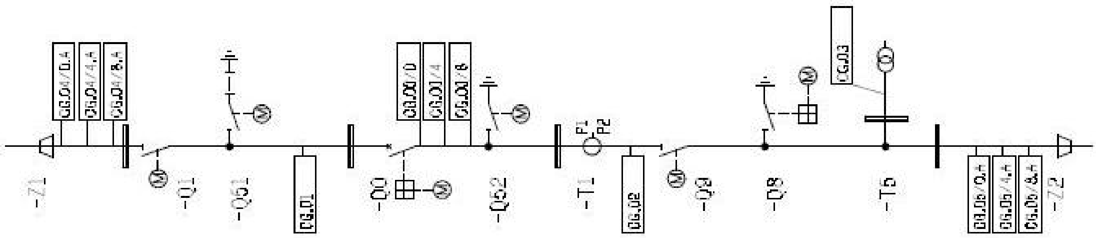


B 4.5 Mobile Container Substation, GIS Technology, Temporary Installation : Red Electrica, Spain, Aceca Substation

Ratings

U_{r}	245 kV
I_{r}	3150 A
U_{BIL}	1050 kV
I_{S}	50 kA

Single line diagram:

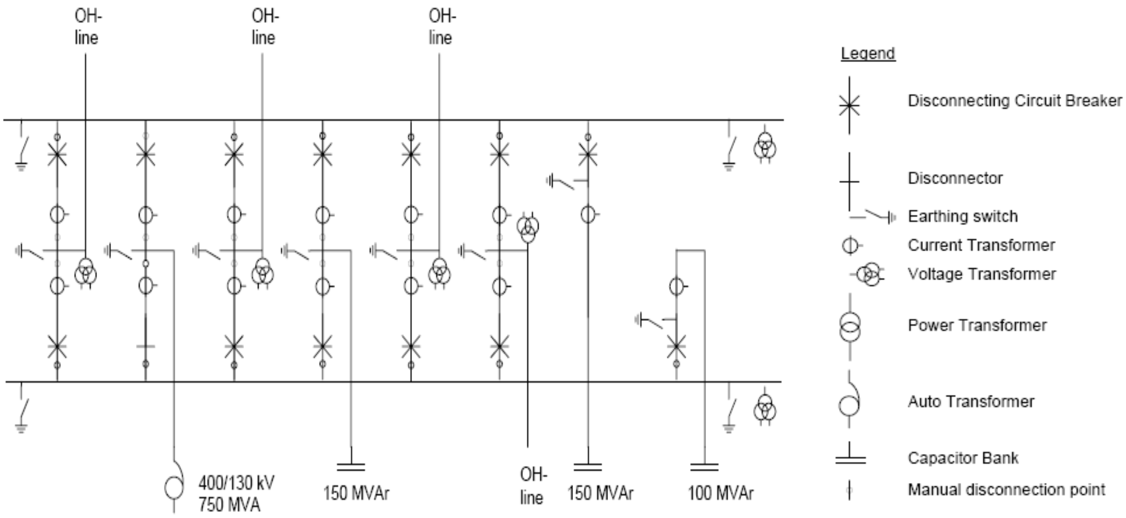


B.5 Upgrading/Refurbishment/Replacement

B 5.1 Refurbishment of AIS with AIS Combined Functions (Disconnecting Circuit Breaker): Svenska Kraftnät, Sweden, Substation Hemsjö

Ratings:	U_r	420 kV
	I_r	4000 A
	U_{BIL}	1425 kV
	I_S	50 kA

Single line diagram:



B 5.2 Refurbishment of AIS (Dead Tank Circuit-Breaker) with GIS (GIS Technology): Puget Sound, USA, Bellevue, Substation Bowlake Bellevue

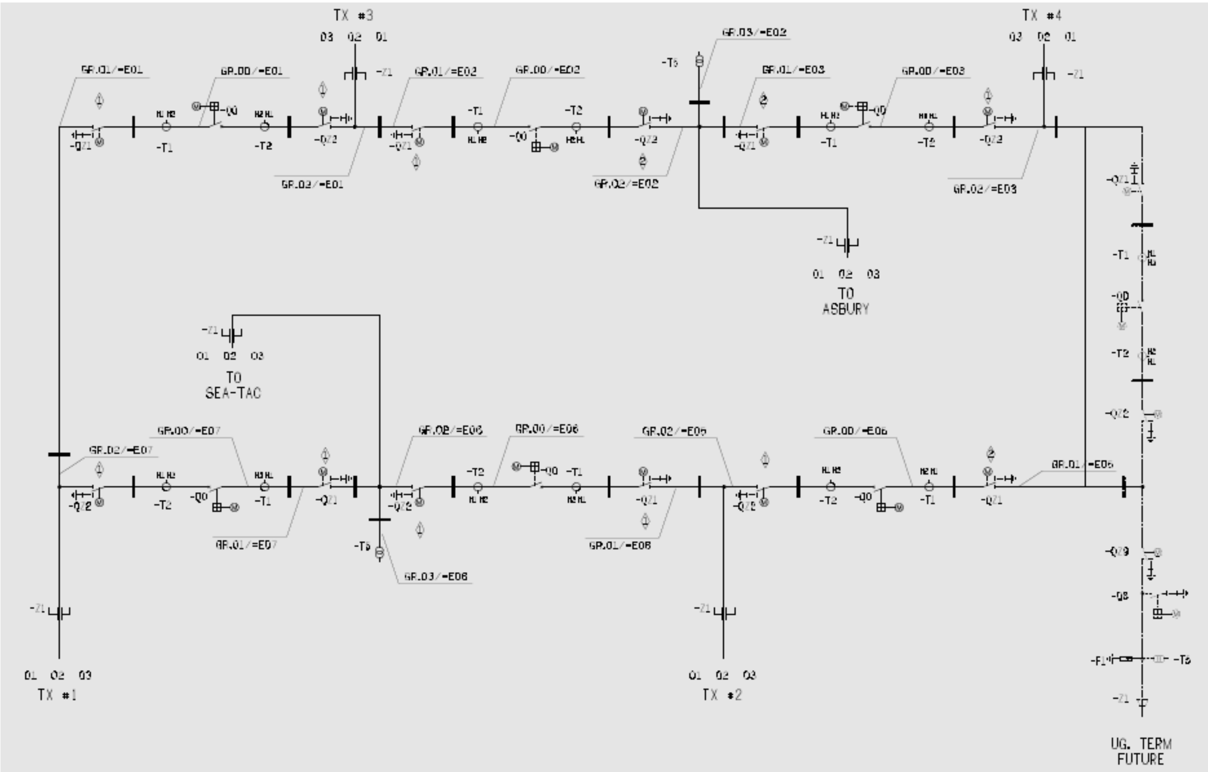
Ratings:

U_r	145 kV
I_r	4000 A
U_{BIL}	550 kV
I_S	40 kA

Before

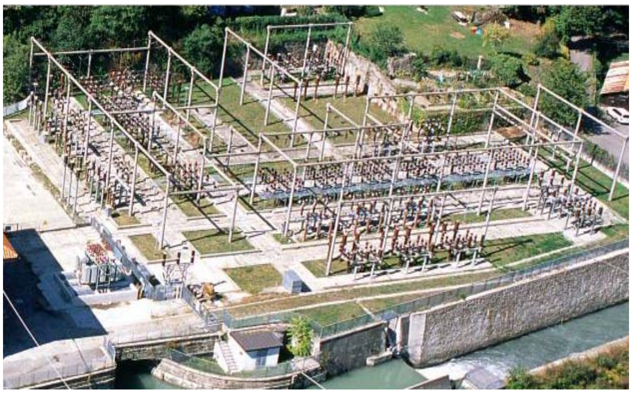
Afterwards

Single line diagram

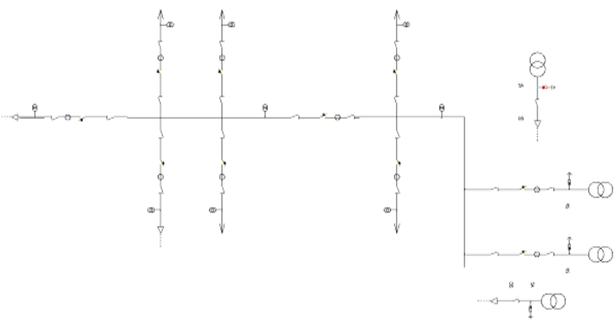


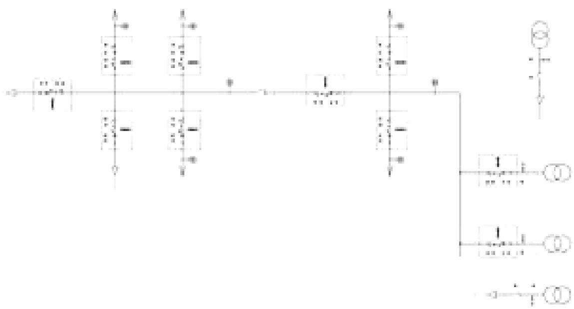
B 5.3 Refurbishment with Upgrading of AIS Substation with MTS (Compact AIS Technology): Tel Hydroelectric Central - Azienda Energetica S.p.A. - Etschwerke AG, Italy, Bolzano, Substation Tel

Before Refurbishment (AIS bays)		After Refurbishment (compact MTS bays)	
U_m	66 kV (max. 72.5 kV)	U_m	132 kV (max. 145 kV)
I	1600 A	I	2000 A
I_{sc}	31.5 kA	I_{sc}	40 kA
U_{BIL}	325 kV	U_{BIL}	650 kV



Single line diagram



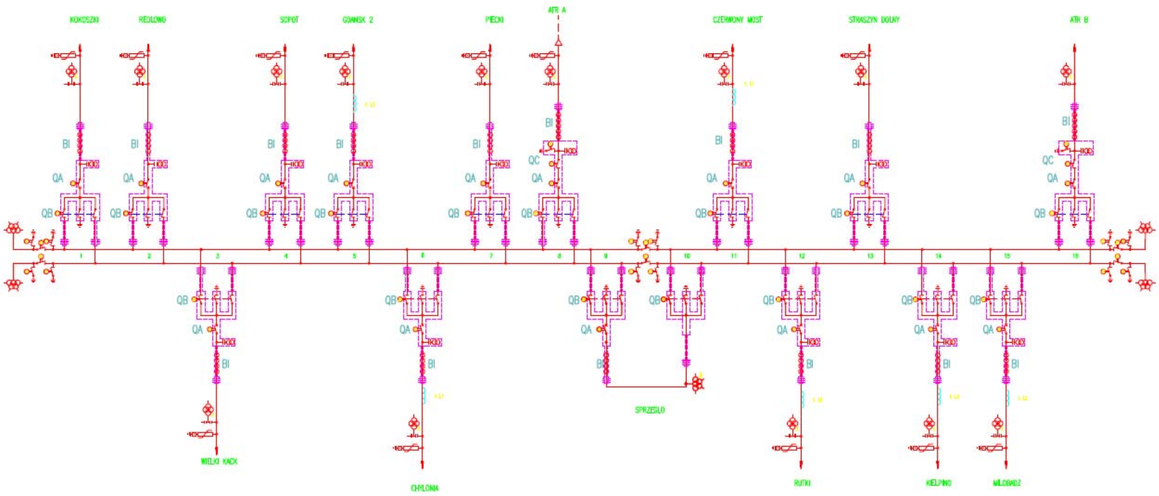


B 5.4 Refurbishment of AIS with MTS (GIS Technology): Polish Power Grid Co (PSE), Poland, Gdansk, Substation Gdansk

Ratings:	Old			New		
		U_r	123 kV		U_r	123 kV
		I_r	2500 A		I_r	2500 A
		U_{BIL}	550 kV		U_{BIL}	550 kV
		I_S	40 kA		I_S	40 kA

New MTS and old AIS substation **MTS substation**

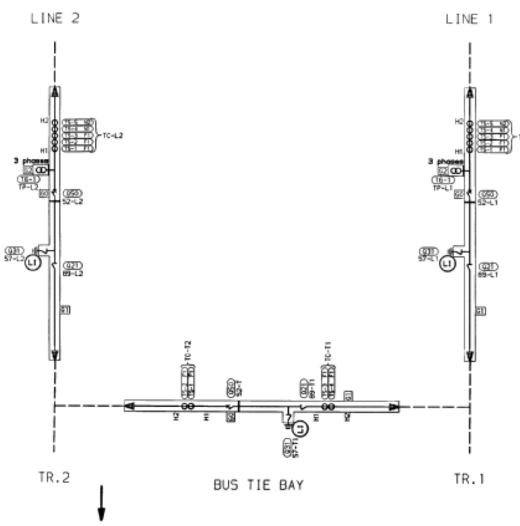
Single line diagram



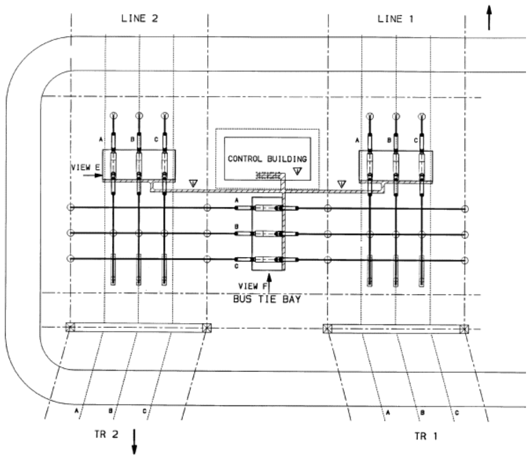
B 5.5 Refurbishment of AIS by MTS (GIS Technology): Furnas, Brazil, Rio de Janeiro, Substation Termobahia

Ratings	**Old**	U_r	245 kV	**New**	U_r	245 kV
		I_r	2000 A		I_r	2000 A
		U_{BIL}	1050 kV		U_{BIL}	1050 kV
		I_S	40 kA		I_S	40 kA

Single line diagram



Layout

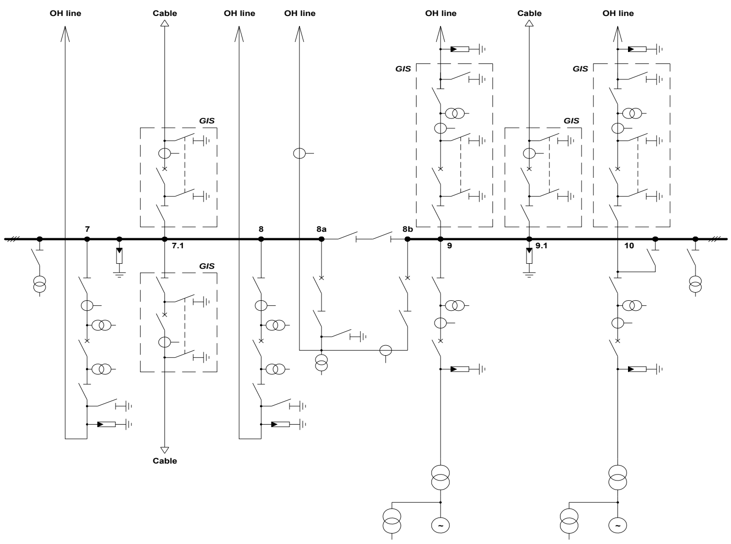


B 5.6 MTS – Hybrid IS with GIS Part Installed in Container , New Construction (Complete Refurbishment of an Old AIS: CEZ, Czech Republic, Melnik, Power Plant Melnik

Ratings :

U_r	123 kV
I_r	1600 A
U_{BIL}	550 kV
I_s	31.5 kA

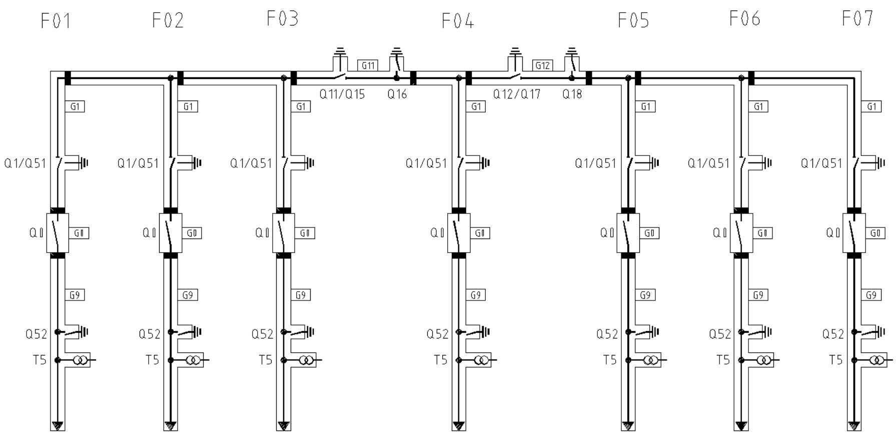
Single line diagram



B 5.7 Replacement of an Old AIS Indoor by GIS and Addition of Two Bays: EBS Switzerland, Substation Hinterthal

Ratings	**old**	*U*	72.5 kV	**new**	*U*	72.5 kV
		Ir	2000 A		*Ir*	2000 A
		U_P	325 kV		U_P	325 kV
		Is	31.5 kA		*Is*	31.5 kA

Single line diagram

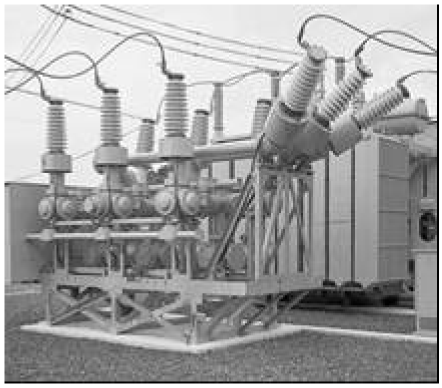


B 5.8 Example of Old and New MTS Application (Kurayashiki 77kV S/S_Japan)

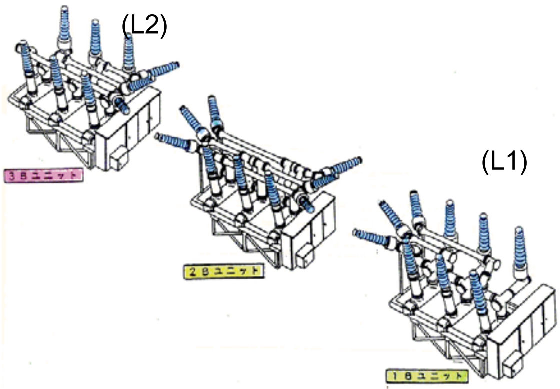
Ratings : (old and new)

U_r	77 kV
I_r	800 A
U_P	400 kV
I_S	20 kA

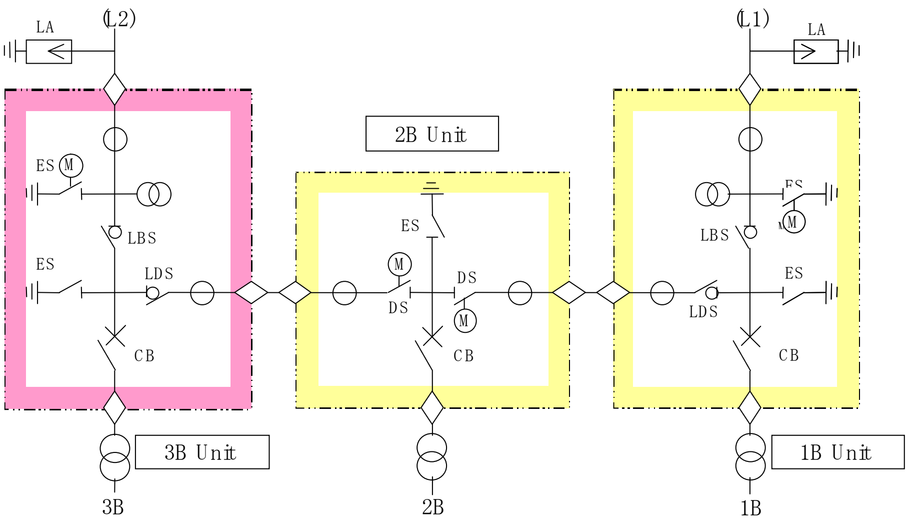
Old GIS Since 1980 (All in one cubicle type outdoor GIS / 100% Installation Space)



New design (MTS – named D-GCS)



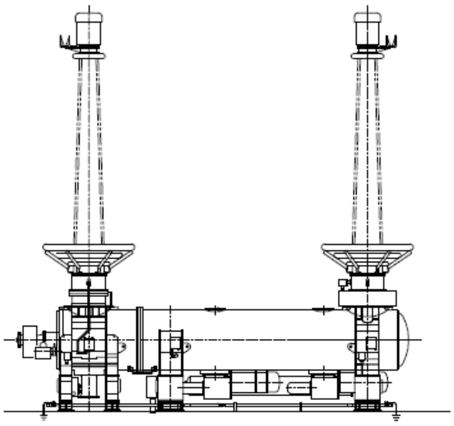
Substation Layout Standardized by New MTS



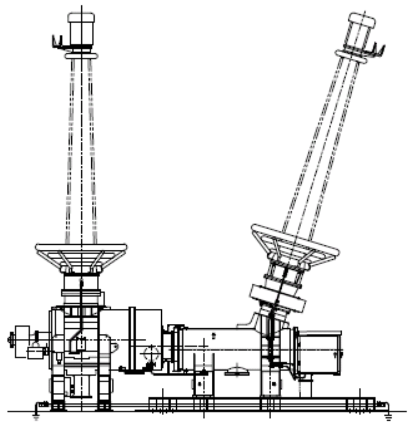
B 5.9 Partial replacement of existing MTS Shin-Okabe Substation (TEPCO) Japan

Ratings :

U_r	550	kV
I_r	8000	A
U_P	1550	kV
I_S	63	kA



4-break GCB MTS



Partial replacement
1 break GCB from
4-break GCB

Appendix C Project Examples

C.1 Practical Example of Life Cycle Cost Study

Background

Due to a sustained growth in electricity demand an unprecedented level of network investment was required. This investment had to be delivered in an environment of increasing downward pressure on price. In order to response to these demands, a comprehensive study was undertaken of substation designs, equipment technology and construction techniques. The study focused mainly on 110kV/MV substations as these represented the largest capital investment.

Existing Standard Designs

The existing standards utilized AIS equipment, with installations using GIS equipment limited to urban areas or areas of high pollution.

The experience with the two technologies is summarised below:

	AIS	**GIS (25 year history)**
Advantages	Lowest material prices as best value option is bought for each item	Excellent service history
	Freedom from long-term dependence on any particular supplier as layouts allow for use of equipment from any supplier in new construction or in individual item upgrading or replacement	Short construction time
		Small site size
Disadvantages	Normal AIS maintenance issues, particularly with disconnectors	High initial cost
	Large site size	Corrosion issues on exposed flanges
	Construction time	Awkward to extend or modify once the particular equipment has gone out of production.

Cost Reduction Study

The initial stage of the study identified the following areas as being the most promising in terms of delivering cost reductions whilst still maintaining the traditional levels of reliability.

1) Use of prefabricated equipment and buildings
2) Reduction in site dimensions
3) Reduction in construction time
4) Reduction in engineering costs
5) Optimisation of individual design issues
6) Reduction in life cycle costs

The next phase of the study involved an examination of designs that were available on the market and this was carried out in consultation with suppliers. A review of practices adopted by other utilities, including a number of site visits, was undertaken. Substations in 7 countries – France, Germany, Hong Kong, Italy, Japan, Portugal and UK - were visited.

The Utility itself had some limited experience with these new solutions in the form of:

- Compact AIS on a single frame used in the refurbishment of a generation-associated 110kV station in a restricted site (Fig. 1)
- GIS modules used in the extension of a small generation-associated 110kV station on a very restricted site (Fig. 2)

Fig. 1 Compact AIS

Fig. 2 GIS modules

- GIS modules used to provide 110kV mobile bays (Fig. 3)
- GIS modules used as part of relocatable capacitor banks (Fig. 4)

Fig. 3 110kV mobile bay

Fig. 4 Relocatable 110kV capacitor bank

Preliminary Layouts

The arrangement of the AIS 110kV/MV station is a very basis H configuration and hence it was not considered worthwhile looking at alternative configurations. Using this configuration as a baseline, a number of layouts were prepared using different types of equipment to determine the station footprint. The equipment considered included:

- Rotating circuit breakers
- Withdrawable circuit breakers
- Outdoor GIS
- GIS modules
- Compact AIS on single base frame

Possible layouts proposed by suppliers in their technical brochures were reviewed and modified in cases where it was felt that they were based in over-optimistic assumptions. A particular example of this was a proposed layout for adjacent bays using open terminal connections using a bay spacing based on electrical clearances rather than maintenance clearances. Detailed civil designs and associated costs were prepared for each layout.

The next step in the process was to prepare a comprehensive project programme including resource requirements as well as timeframes for each layout. Estimates for erection and commissioning for the different types of equipment were prepared in conjunction with the suppliers.

The final activity was to prepare a cost estimate, based on the total cost of ownership (material costs, installation, commissioning, maintenance and disposal) for each layout. The material costs were based on indicative pricing provided by the suppliers.

The study showed that savings of the following order were feasible:

Total Project cost:	0% to 19%
Required site area:	25% to 46%
Construction time:	25% to 42%

The cost of land had a material impact on the potential level of savings. So a sensitivity analysis was undertaken using land prices as a variable.

In general the equipment cost was higher than the traditional AIS equipment but this additional cost was counterbalanced by the reduced land cost, reduced civil works cost and the impact of the shorter construction time.

The best results seemed were obtainable from the use of Mixed Technology Switchgear (MTS) either in the form of GIS modules with an AIS busbar or GIS modules using a GIS busbar i.e. outdoor GIS.

These designs also appeared to offer the lowest operating costs as all switching device/contacts are enclosed in SF6 rather than exposed to atmosphere. This reduction is only valid if the corrosion previously experienced on the flanges of GIS located outdoors has effectively been solved as claimed by suppliers.

An unanticipated benefit was the lower profile of this equipment compared to AIS which resulted in reduced visual impact, with the potential to use this type of equipment in suburban locations where previously the only suitable alternative was indoor GIS.

PILOT PROJECT

In order to verify the results of the study a pilot project was undertaken. An enquiry, using a basic functional specification, was issued for 3 green-field sites located in suburban areas.

Financial Analysis

Tenders were received for all of the equipment types covered in the feasibility study. The tender evaluation process confirmed the conclusions of the study.

A graphical representation of the evaluation outcome is given below in Fig 5, based of local civil works and labour costs. To factor in variable land prices, the evaluation was completed for a range of land price from €100 - €500 m^2.

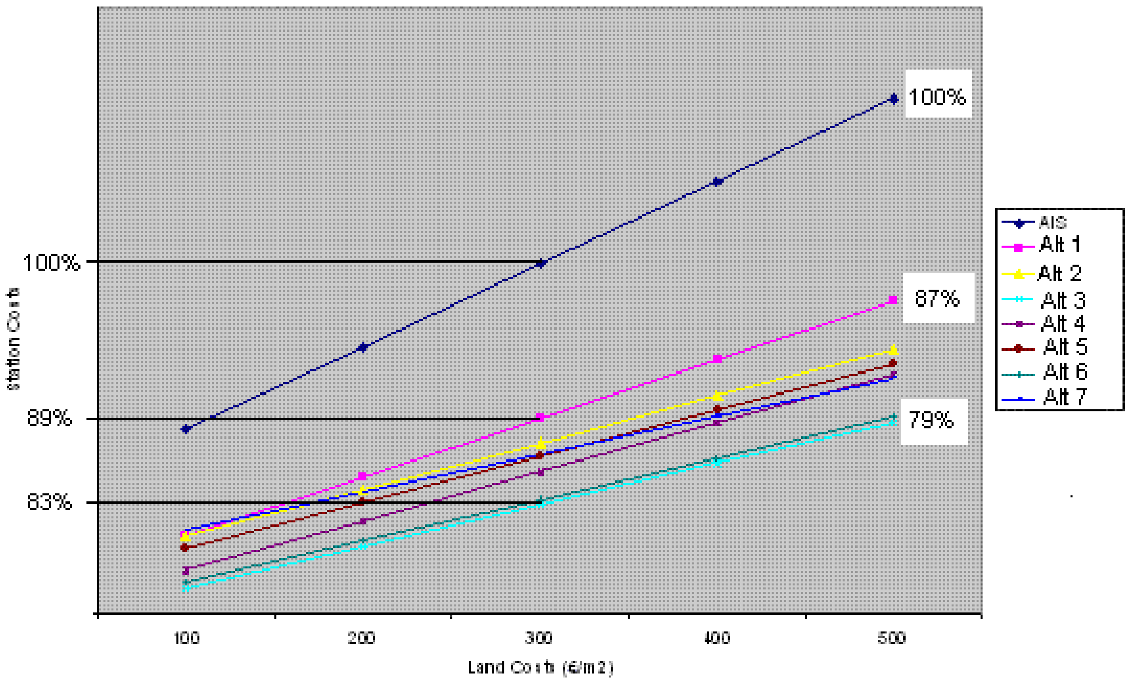


Fig. 5 Variation in Station cost with land price

The consistent level of saving achieved compared to the traditional AIS can be clearly seen as can the increased percentage saving achieved as land costs increase.

Station Footprint

The reduction in site dimensions achieved compared to a traditional cable-connected AIS 110kV/MV station is shown below in Fig 6.

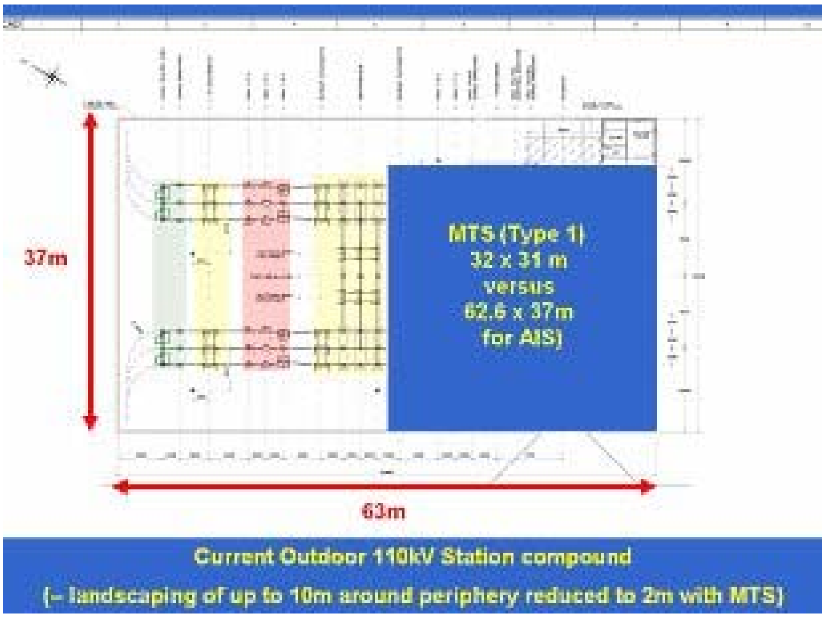


Fig. 6 Reduction in site dimensions

Contracts Placed

On completion of the tender evaluation process contracts were placed for:

- MTS of the GIS busbar type (for two stations of the basic H type, see Fig 7)
- MTS of the AIS busbar type (for one larger station requiring four transformer bays, see Fig 8).

Fig. 7 MTS (GIS Busbar type)

Fig. 8 MTS (AIS Busbar type)

Planning Permits

Feedback from the planning permitting process has been favourable due to the reduced visual impact of the smaller switchgear and also from the decision to change to a 3m high boundary wall rather than the previously-used combination of a 2.8m high palisade fence and extensive landscaping. See Fig. 9

Fig. 9 Elevation of MTS Station Frontage

CONCLUSIONS

This case study concluded that substantial saving in total ownership costs, even when basic equipment costs are higher, could be achieved by adopting MTS equipment. The savings produced are directly linked to land costs. Overall construction times are also reduced. These conclusions were verified by a pilot project for the construction of three substations in suburban areas.

Unanticipated benefits included easier permitting due to the reduced visual impact of the substation and less complicated negotiations with land owners due to the lower land take required.

Based on this work MTS equipment has been adopted for all future 110kV substations.

Prefabricated enclosures

A parallel process was carried out to investigate the benefits of replacing conventional concrete buildings by prefabricated enclosures for MV switchgear and, control and protection equipment. Cost benefits were identified however the details are outside the scope of this paper.

C.2 Replacement Project Study

C2.1 Replacement of 500kV Airblast Circuit Breaker Bays with MTS units

Ingledow (ING) is a critical substation in the British Columbia (Canada) Transmission system. It serves the Lower Mainland (most populated area of British Columbia around Vancouver) and connects the system, via 2-500kV lines, to Bonneville Power Authority (BPA). These 2 tie lines are heavily used for import/export, allowing BC Hydro to make the best use its potential to store energy in its massive water reservoirs. Their reliability is of maximum importance, as the financial consequences of an un-planned outage can be severe.

The 500kV switchyard presently includes 10 airblast circuit breakers with associated CT's and disconnect switches, arranged in a breaker and 1/3 – see below.

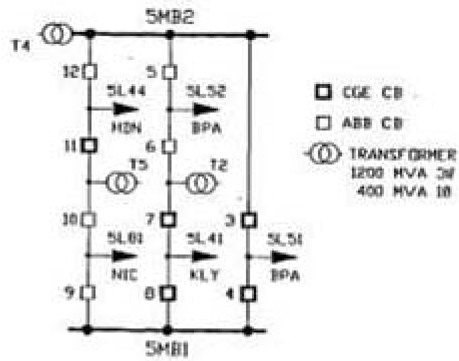


Fig 1 (a)
Ingledow 500 kV existing 1 1/3 circuit breaker arrangement

These circuit breakers were installed between 1968 and 1973 and are approaching their end-of-life. Drastically lower MTBF values, difficulties to obtain spare parts and the high cost of rebuilding led to a decision to replace. The associated disconnect switches and oil-filled CT's are of similar vintages and performance, hence a decision to include them in the replacement program. BC Transmission Corporation (BCTC) has adopted a policy whereby oil-filled CT's are no longer acceptable, and when replaced, SF6 CT's or dead tank breakers with bushing CT's must be used.
The options at hand were:

- Replacement with Live Tank cb's, new SF6 CT's and disconnect switches
- Replacement with Dead Tank cb's (with bushing CT's) and new disconnects
- Replacement with MTS that include CT's and disconnects

Besides the installed cost, other issues were also considered. The maintenance aspects (projected costs and accessibility) and ability to facilitate switchyard expansion were factored in.
A study performed by BC Hydro in 1988 recommended a switchyard reconfiguration of the system to a 4x6 arrangement for better system reliability (see below)

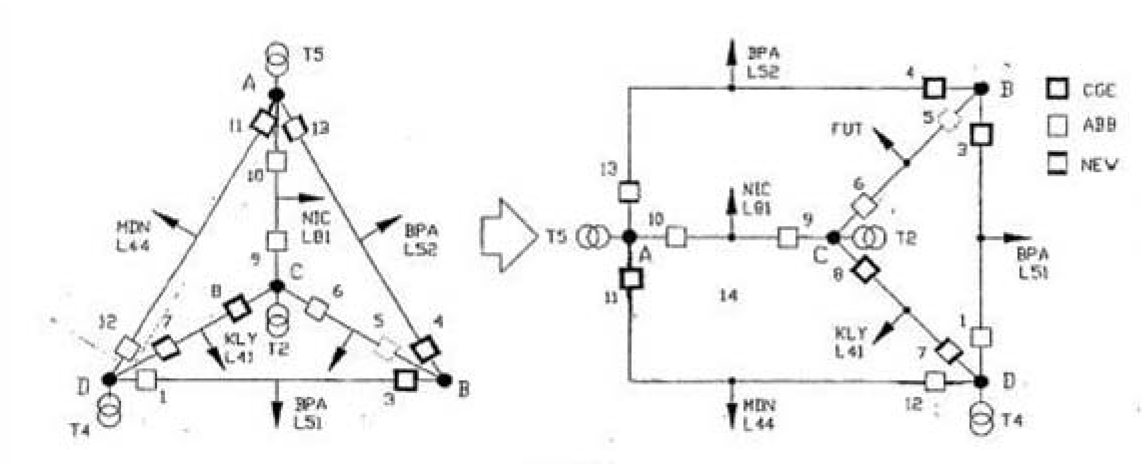
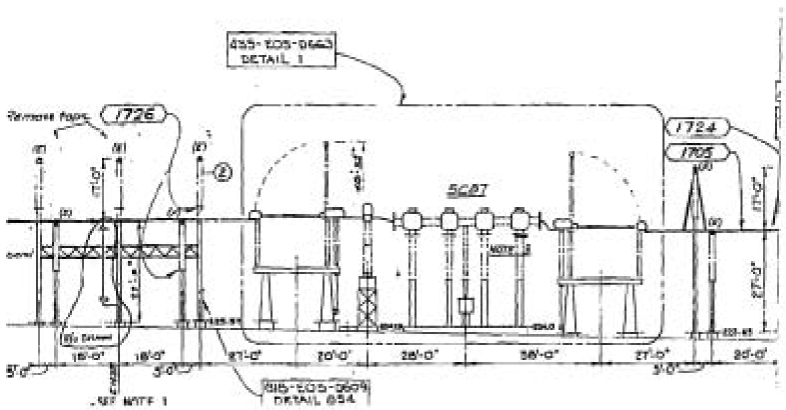


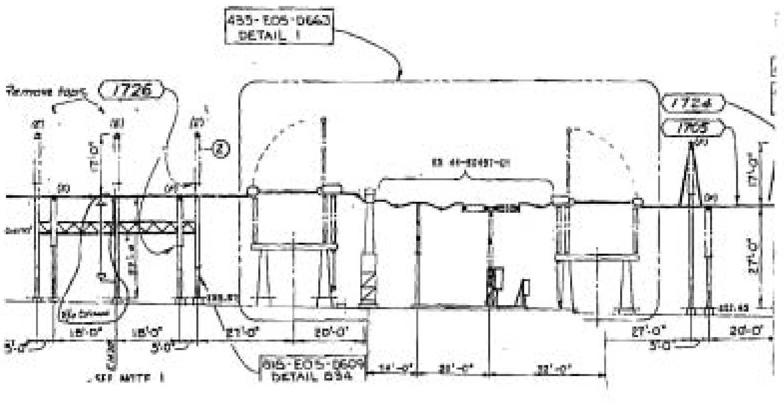
Fig 1 (b)
A proposed 4X6 circuit breaker arrangement

Such an arrangement requires an additional main bus, with associated spacing. Only the MTS solution, because of the compactness built-in, would allow this option see sketches below)

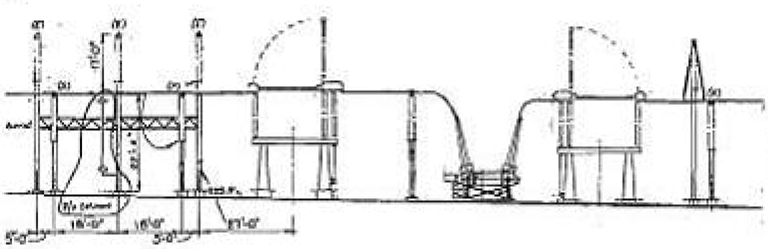
Ingledow Substation
500 kV Circuit Breaker Replacement Alternatives



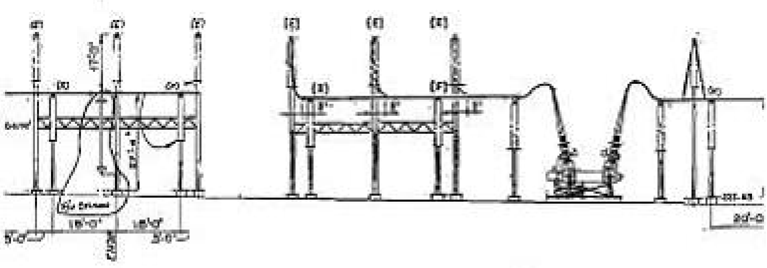
Existing CGE model AT circuit breaker installation



Alternative 1
with Live tank CB



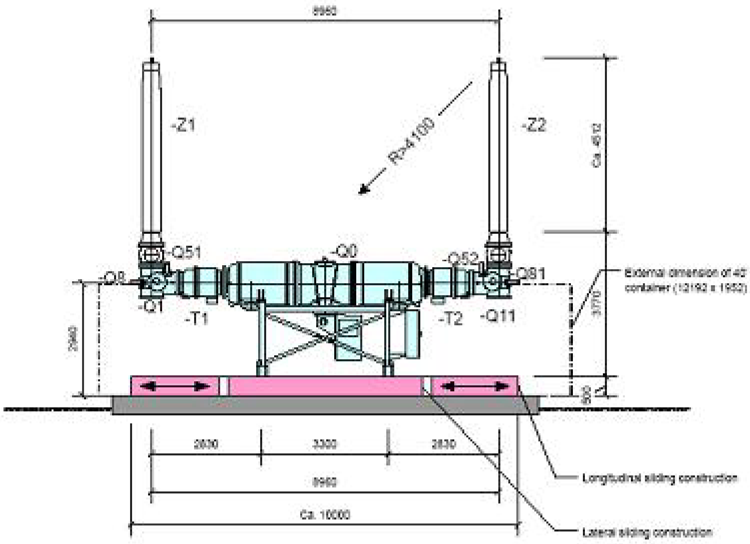
Alternative 2(b)
Replace circuit breaker and CTs with dead tank CB



Alternative 3(b)
Replace circuit breaker, CTs and disconnects with hybrid CB
(Addition of main bus for 4X6 arrangement also shown)

While the switchyard reconfiguration is not imminent, System Planning was interested in it as a long term project.
Other important considerations were the ability of the replacement equipment to withstand very high TRV's that can occur in the BCTC system (peak of up to ????kV at t2=?ms), availability of point-on-wave relays that can mitigate the effects of trapped charge during re-closing on long (300km) series compensated lines, ability of equipment to withstand the seismic conditions prevalent in the area, the type of operating mechanisms offered (with preference to spring-spring mechs able to perform 2 cycle interruption).
After obtaining tenders for 500kV MTS equipment and technical and commercial evaluation of all options, the option to proceed with replacement of the 10 bays with MTS equipment was decided upon. An order for 10 units was placed with the selected manufacturer. To allow for the necessary outages and construction effort, the project will be implemented over a period of 2 years (summers of 2008 and 2009). An additional advantage offered by the MTS solution is shorter outages, as existing disconne4cts can be left in place as visible isolation until installation of the MTS. The outage for each breaker can thus be reduced to approx. 4 days/position, versus up to 2 months for other options.

Pictures of the existing switchyard and dimensional sketch of the MTS units are attached.



MTS Module 500 kV, single phase encapsulated

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