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# Gas Insulated Substation Testing and Application

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## **Gas Insulated Substation Testing and Applications**

To provide the function and safety the GIS installation for which it was designed, the GIS has to be tested. The testing procedure is done to confirm the technical information as well as safe operation of the GIS installation over its life duration. Related to the GIS installation use, the main tests are dielectric tests, short-circuit tests, mechanical tests, and temperature rise tests.

Two different test processes are used: type tests that are also known as design tests, and routine tests, that are known as factory or production tests. While type tests confirm the functions of one GIS type after product development, routine tests check that each manufactured item functions according to the technical demands to which the GIS installation is supposed to adhere.

### **Type Tests**

Once of the crucial steps in development of GIS equipment are type tests. They are done to check the performance of the GIS equipment. The ratings defined in the type tests will also be declared as default data when the GIS equipment is in the production cycle. Type tests at least include:

- Measurement of the resistance of the main circuits
- Tightness tests
- Temperature rise checks
- Short-time withstand current and peak withstand current tests
- Dielectric checks
- Electromagnetic compatibility (EMC) test
- Check of the degree of protection of the enclosure
- Switch operating mechanical life tests

- Check of making and breaking capacities
- Verifications to check performance under thermal cycling and gas tightness tests on insulators
- Proof tests for enclosures
- Low and high temperature verifications
- Pressure test on partitions
- Fault-making capability of high speed earthing switch
- Circuit breaker design tests

The following paragraphs present some of the tests.

### **Dielectric Tests**

Dielectric tests are done to check the dielectric capability of the GIS installation under all foreseeable operating circumstances, including temporary and transient over-voltages, and hence involve power frequency verifications, lightning impulse checks, switching impulse checks, partial discharge verifications, and tests on auxiliary and control circuits. In Table 1, an overview of the various dielectric tests presented. The high voltage tests need a big size of test equipment to create the test voltages of some thousands or millions of volts.

### **Resistance Measurement of the Main Circuits**

This test assesses the resistance of a set of conduction paths in a GIS installation. The test will show the conductivity of conductor material, conductor connections, and associated contacts. At a current of generally 100 A DC, the resistance or voltage drop of specified arrangements will be measured. The test results provide information about the conductor quality connections and contacts and also give a basis for a cross comparison between the three phases. The lower the resistance values, the lower the temperature rise would be when in operation. The temperature rise is crucial factor for

checking the continuous current capability of the product. The test results make a benchmark for the GIS test later during manufacturing process.

Table 1. Dielectric tests

Dielectric tests				
Power frequency tests	Lighting impulse tests	Switching impulse tests	Partial discharge tests	Tests on aux. & control circuits
Simulating conditions under operating frequency	Assessing atmospheric overvoltage	Assessing over-voltages caused by switching operations	Testing to ensure that design and solid insulation is free of partial discharges	Checking that the insulation of aux. & control circuits withstands the dielectrical conditions
Primary equipment				Secondary equipment

### Temperature Rise Tests

To determine at what maximum continuous current the GIS equipment can be operated, a temperature rise test is done. Thermocouples will be installed at different locations such as conductors, connections, contacts, and insulators to assess the temperature rise at a defined continuous current the GIS equipment is made for. Other than this discrete measure technique, by using thermocouples extra thermographic measures can be implemented to support the evaluation of the arrangement related to the temperature rise, particularly during development tests.

### Short-Time Withstand Current and Peak Withstand Current Tests

This test is for verification that main circuits of the GIS installation will be able to conduct the peak withstand current and the rated short-time withstand current. Elements of the main circuit as well as support insulators need to withstand the dynamical stress during the short-time withstand current and the peak withstand current that the GIS installation has to conduct in the closed position of the circuit breaker and disconnect switches. Common values of the short-circuit duration are 1 s or 3 s. With a time duration of 45 ms and for a frequency of 60 Hz the value of the peak withstand current is 2.6 times the rated short-time withstand current. The short-

circuit verifications demand high currents, which are created in big, special generators. In some situations, the short-circuit current is taken from the electrical network, but as this might cause disturbances in the network it is usually prohibited.

### **Tightness Verifications**

Tightness tests verify that the SF6 leakage rate of the tested GIS equipment does not surpass a predetermined value of a permissible leakage rate. According to GIS IEEE and IEC standards the leakage rate must not surpass 0.5% per year per gas compartment. Certain GIS manufactures claim even leakage rates of 0.1% per year per gas compartment.

### **Low and High Temperature Verifications**

This verification is part of the mechanical and environmental tests. All GIS components must work under predetermined low and high temperature conditions. The GIS or elements of the GIS will be installed in a climate chamber. At minimum and maximum temperatures, operation verifications will be done. After the test cycles, the SF6 gas pressure and the SF6 leakage rate over a period of 24 hours will be checked.

### **Proof Verifications for GIS Enclosures**

Proof verifications of the enclosures can be destructive or nondestructive. The graph in Figure 1 presents the type test pressure as the highest pressure before the burst and rupture pressure of the enclosure. Coordination of the design and test pressure levels for the GIS enclosures is presented in Figure 1.

### **Circuit Breaker Design Verifications**

Apart from the tests already presented, such as the dielectrical verifications and temperature rise tests, circuit breakers have to be type-tested according to their adequate operation duties.

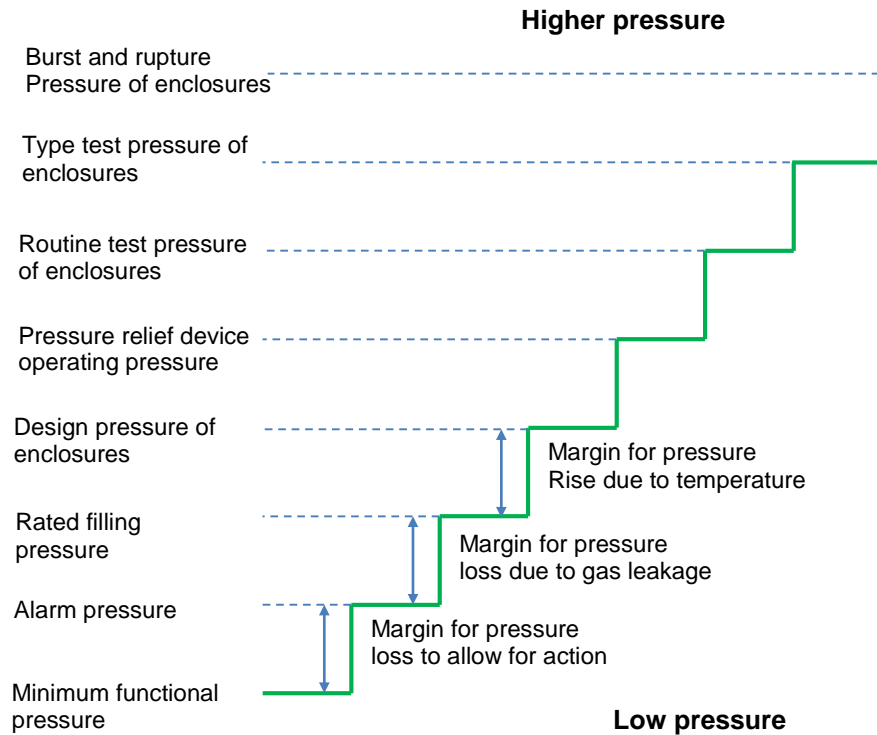


Figure 1. Pressure coordination of enclosures and pressure-relief elements

These tests involve, but are not limited to, interrupting time verifications, transient recovery voltage (TRV) verifications, short-circuit current interrupting verifications, load current checks, capacitor switching current checks, out-of-phase switching verifications, and mechanical endurance tests. These verifications are presented in the IEEE standard for test procedures for high voltage circuit breakers (IEEE Std. C37.09).

### Switch Operating Mechanical Life Verifications

To check the mechanical durability of the GIS disconnect and earthing switches, these switches are operated with at least 1000 close/open operations according to IEEE C37.122 standard. The test has to show that the switch and the operating mechanism do not show significant wear and that they are in a good mechanical condition. This will be accomplished by an examination of the switch contacts and associated elements of the kinematic chain and of the mechanism as well. A contact resistance measurement, will restate the contact capability to conduct the continuous current after being exposed to stress by the mechanical operations. To check that the mechanical

operation test does not affect the SF6 tightness, SF6 gas tightness verification is done before and after the mechanical operation test.

## **Routine Tests**

Routine tests, typically referred to as production verifications, are done to make sure that each GIS installation works as it has been designed and type-tested for. The routine verifications are done for each GIS installation after assembly and present a major quality gate before the GIS installation leaves the factory. The test options are based on the type test results, which means that, within defined tolerances, the routine tests need to reflect the type test parameters. Routine tests are defined in IEEE C37.122 and involve:

- Pressure checks on partitions
- Measurement of the resistance of the main circuits
- Pressure tests of enclosures
- Mechanical operation checks
- Checks on auxiliary and control circuits
- Dielectric verifications
- Tightness verification
- Verifications on auxiliary circuits, equipment, and interlocks in the control mechanism

The following paragraphs present tests taken from the above list.

## **Dielectric Verifications**

The dielectric verifications are completed after the mechanical routine testing and show the dielectric performance of the GIS installation, ensuring the correct

installation, precisely produced parts from a dielectric point of view, and the absence of particles and other pollutants. For routine verifications, the dielectric test is power frequency withstand voltage verification. Impulse verification, such as lightning and switching impulse, is not commonly part of the routine testing. At minimum functional SF6 pressure, the following circumstances are verified: phase-to-earth, phase-to-phase (in the case of three phases in one enclosure arrangement), and across open switching elements. Successfully withstanding the one minute withstand level without a disruptive discharge is the main criteria to mark that the test completed successfully. To discover potential material and manufacturing issues, partial discharge testing is also done as part of the dielectric routine verifications.

### **Resistance Measurement of the Main Circuits**

Commonly, the voltage drop or resistance of main circuits are assessed using a DC current of 100 A. Correct contact arrangement, adequate treatment of clean contact surfaces, and the adequate contact materials used will be evaluated with this test. The test values should be within a 20% tolerance band in comparison with the type test values.

### **Tightness Verification**

Using equipment such as SF6 leakage detectors, all parts of enclosures assemblies, SF6 piping, adaptation of SF6 gauges, and SF6 density monitoring will be verified for leaks. Precise assembly, including proper application of sealing rings, will also be checked with this test.

### **Pressure Verification of Enclosures**

After complete machining of enclosures, pressure checks are done at 1.3 times the rated pressure for welded aluminum and welded steel enclosures and at 2 times the rated pressure for cast enclosures. With the state-of-the-art equipment used today, containers are made of cast aluminum. Using 3D CAD systems and FEM numerical techniques, cast aluminium containers can be shaped to meet the dielectric and mechanical demands while giving excellent gas tightness.



Automated test stations ease the inclusion of a tightness test using helium after the container pressure verification.

### **Mechanical Operation Verifications**

Mechanical operation verifications involve all equipment of the GIS installation that will be mechanically operated, such as a circuit breaker, disconnect switches, earthing switches, and high-speed earthing switches. The tests involve a predefined number of operation cycles at various control voltage levels and the precise function of the associated auxiliary equipment; for instance, auxiliary switches to show the status of the circuit breaker and switches. During these verifications, few parameters will be recorded to ensure that the equipment works in their tolerance bands: closing and opening times and pole difference times, travel curves of interrupter elements, charging times and currents of motors of a spring-operated mechanism or hydraulic-operated mechanism, as well as running times and currents of motors of disconnect and earthing switch mechanisms. These verifications check that the assembly of a circuit breaker and switches has been completed correctly and that the adequate function of these GIS installations is ensured when the GIS equipment is in operation.

### **Checks on Auxiliary and Control Circuits**

These checks verify that, during production, all wiring has been completed correctly according to the related circuit schemes. Functional tests of all low voltage circuits and of auxiliary, control, and protection elements check their correct function and proof of their interconnection with the GIS installation. Next to functional testing at low and upper voltage levels, dielectric tests are done to make sure the dielectric withstand capability of the wiring insulation and elements.

### **Pressure Check on Partitions**

Partitions are gastight insulators that divide one gas chamber from the other. They allow full pressure on one side and vacuum on the other side. Each chamber has to be checked to twice that of the nominal pressure. It has to be checked that the weakest mechanical direction of the element is being considered for the verification. This test checks that the partition has been correctly produced to withstand the pressure the

partition is made for. Partitions will also be checked to the dielectric withstand capability and a sensitive partial discharge measurement.

### **On-Site Field Verification**

Commonly, a gas insulated substation is only partially assembled in the factory. Major elements of a GIS installation are occasionally produced in various factories in different countries, sometimes by various manufacturers, and sent directly to the job site. The final assembly of the gas insulated substation is then done at the site, where all the different elements that comprise a GIS installation meet for the first time. Even if the gas insulated substation could be totally assembled in one factory, it would still need to be disassembled for shipment, shipped, and then reassembled at the site. The purpose of the field checks is to confirm that all the GIS elements work satisfactorily, both electrically and mechanically, after assembly at the job site. The verifications give a method of demonstrating that the GIS equipment has been assembled and wired correctly and will work satisfactorily.

### **Gas Leakage and Gas Quality (Moisture, Purity, and Density)**

After processing and filling each gas chamber to the manufacturer's demanded nominal rated filling density and checking the density value, the assembled gas insulated substation has to be tested. An initial verification is done to discover any and all gas leaks and ensure compliance with the defined maximum gas leak rate. These gas leak tests have to include all enclosure flanges, welds of containers, and all gas monitoring elements, gas valves, and interconnecting gas piping that have been assembled at the job site.

The gas moisture content gas in each chamber has to be measured directly after installation and again at least five days after final filling. These verifications are to make sure that the moisture content does not surpass the defined maximum limits. The second test after five days is needed to take into account the possibility of moisture from elements internal to the GIS. The gas purity in each gas chamber needs to be measured directly after installation. These verifications are to make sure that any gas impurities (mostly air) does not surpass the defined maximum limits.

## **Electrical Verifications: Contact Resistance**

Contact resistance measurements of the main current carrying circuits has to be done on each bus connecting joint, circuit breaker, disconnect switch, earthing switch, bushing, and power cable connection to show and check that the resistance values are within defined requirements. Because the metallic container inhibits accessibility to current carrying elements, it is not typically possible to assess the resistance of individual elements. Hence, the resistance readings are obtained for few elements connected in series. These field measurements can then be cross compared to the expected resistance values provided by the manufacturer as a basis for checking acceptable test results at the site.

Contact resistance measurements also need to be done on the GIS enclosure bonding connections, in situations where an isolated (single) phase bus is being used.

## **Electrical Verifications: AC Voltage Withstand**

The gaseous and solid insulation of the gas insulated substation has to be exposed to an AC voltage withstand test. Due to the big capacitance variations of various GIS installations, it is often that a variable frequency hi-pot test unit is applied. The variable frequency high potential unit can create low frequency (30 Hz to 300 Hz) voltage applications at magnitudes and durations defined in standards. This one-minute low frequency voltage withstand verification is done at 80% of the rated low frequency withstand voltage done in the manufacturer's factory. A conditioning voltage application sequence, with magnitude and durations determined by the manufacturer, should precede the defined one-minute withstand test. The intention of the conditioning verification is to drive any small particles, if they exist, to low electric field intensity locations such as particle traps.

The objective of these high voltage verifications is to check that the elements of the gas insulated substation have survived transport, have been assembled correctly, that no extraneous material has been left inside the chambers, and that the GIS installation can withstand the test voltage. The conditioning voltage application sequence and the one-minute low frequency voltage withstand verification has to be completed after the GIS installation has been totally installed, the gas chambers have been filled to the

manufacturer's suggested nominal rated fill density, and the moisture content and purity of the gas have been checked to be within defined limits.

### **Electrical Verifications: AC Voltage Withstand Requirements and Conditions**

Voltage withstand verifications have to be done between each energized phase and the earthed enclosure. For enclosures containing all three phases, each phase has to be verified, one at a time, with the enclosure and the other two phases earthed. Before voltage withstand verifications are started, all power transformers, surge arresters, protective gaps, power cables, overhead transmission lines, and voltage transformers have to be disconnected. Voltage transformers may be tested up to the saturation voltage of the transformer at the frequency of the test.

### **Electrical Verifications: AC Voltage Withstand Arrangements and Applications**

When the GIS installation being checked is connected to the GIS equipment that is already in operation, the in-service part has to be electrically isolated from the tested part. Nevertheless, it is highly possible that the test voltage could be 180 degrees out of phase with the in-service voltage, potentially exposing the open gap of a disconnect switch, being used for isolation, to voltages in excess of what can be withstood. Hence, an isolated section with suitable grounds has to be applied between the in-service GIS and the GIS to be checked. This ensures that the test voltage cannot create service disruptions to the electrical system nor can the service voltage create severe defects to the testing equipment or danger to the test staff.

Due to the electrical loading restrictions of the testing equipment, it may be mandatory to isolate GIS sections using open disconnects and test each section separately. To achieve this, it may need that parts of the GIS equipment be subjected to more than one test voltage application. The parts that are not being examined have to be earthed.

Isolating parts of the GIS equipment may give an extra benefit of field testing the open gap of some disconnecting switches, even though such a field test is not a requirement. In addition, it may be mandatory to isolate GIS sections to facilitate location of a disruptive discharge or to limit the energy potentially discharged during a disruptive discharge. The test voltage source may be connected to any convenient

point of the phase being examined.

### **Electrical Verifications: DC Voltage Withstand Tests**

DC voltage withstand verification is not advised on a completed GIS installation. Nevertheless, it may be mandatory to complete a DC voltage withstand test on power cables connected to a GIS installation. These test voltages would, by necessity, be applied from the end of the cable opposite to that of the GIS installation, hence subjecting a small portion of the GIS to the DC voltage. It is suggested that the portion of the GIS subjected to this DC voltage be kept as small as possible. The manufacturer should be consulted before completing these verifications.

### **Mechanical and Electrical Functional and Operational Verifications**

The following has to be checked after assembly of the GIS installation at the job site:

1. The torque value of all bolts and connections assembled at the site has to be checked to be in line with the defined requirements.
2. The conformity of the control wiring has to be checked to be in line with the schematic and wiring drawings.
3. The adequate function of each electrical, pneumatic, hydraulic, mechanical, key, or combination of interlock routines has to be checked for adequate operation in both the permissive and blocking condition.
4. The adequate function of the controls, gas, pneumatic, and hydraulic monitoring and alarming installations, protective and regulating devices, operation counters, including heaters and lights, has to be checked.
5. Each mechanical and electrical position indicator for each circuit breaker, disconnect switch, and earthing switch has to be checked that it correctly indicates the device's status, both open and closed.
6. The conformity of the gas zones, gas zone identification, gas valves, gas valve statuses, and interconnecting piping has to be checked to be in line with the physical

drawings.

7. The operating options, such as contact alignment, contact travel, velocity, opening time, and closing time of each circuit breaker, disconnect switch, and earthing switch has to be checked in line with the determined requirements.

8. The adequate operation of compressors, pumps, auxiliary contacts, and anti-pump schemes has to be checked to be in line with the defined requirements.

9. The circuit breakers have to be trip-tested at minimum and maximum control voltages to check proper operation.

10. The secondary wiring has to be checked to have adequate wire lugs, correct crimping, tightened terminal block screws, adequate wire and cable markers, and correct wiring in line with the manufacturer's schemes.

11. The polarity, saturation, turns ratio, and secondary resistance of each current transformer, including all installed secondary wiring, has to be checked to be in line with the predefined requirements.

12. The turns ratio and polarity of each tap of each voltage transformer, including all connected secondary wiring, has to be checked to be in line with the predefined requirements.

13. Dielectric and adequate resistance tests have to be completed on all interconnecting control wiring.

### **Connecting the GIS Installation to the Electrical Network**

Once the gas insulated substation has been installed, wired, and all field testing has been done satisfactorily, the new equipment is ready to be connected to the existing electrical network. This effort involves another series of verifications to check protective relay service, ability of the circuit breakers to trip on command from remote areas, and adequate phase relationships with different transmission lines. This second series of verifications is expected to be similar, if not exactly the same, as the

verifications completed on an AIS substation.

## **Common GIS Layouts**

Operational demands and power system reliability are major aspects used to decide on the GIS substation scheme. In addition, additional extensions, service and maintenance aspects as well as investment costs will contribute to enable a decision to be made for a proper substation layout. The following GIS installation arrangements present typical layouts used for GIS installations.

### **Single Bus Configuration**

When substation reliability is not a crucial issue the single bus scheme has the lowest investment needed to make a GIS substation. This may be the situation for small substations in relatively unimportant areas where limitations to operational demands and maintenance activities can be accepted. The substation would be impacted by an outage in the case of busbar failures and service or maintenance procedures.

### **Double Bus Configuration**

Operation flexibility and reliability increases by extending the GIS scheme by a second bus bar when selecting the double bus arrangement. For important network areas the bigger investment allows the substation to be operated with two bus bars that are coupled via a tie breaker. Each feeder is linked to the two bus bars. Maintenance can be completed on one bus bar while the other bus bar remains in service.

### **Ring Bus Configuration**

In a ring bus arrangement the GIS bays are installed in a ring, which gives good reliability at moderate costs since there is no additional bus bar. In case of a failure in one bus section only the circuit in that bus section will be impacted, and the other circuits can stay in service. Doing maintenance on one GIS breaker can be completed by isolating this bus section and keeping the other bus sections in service. The ring arrangement normally includes around six GIS feeders and is limited for extensions.

## **H-Scheme Configuration**

The H-scheme can be described as two single bus sections that are linked by a center circuit breaker. In cross comparison with the single bus configuration the H-arrangement gives bigger reliability but also bigger costs due to extra circuit breakers. In case of a breaker failure the complete substation would not be out of operation. Maintenance of one feeder can be completed while the other feeders remain in service.

## **Breaker and a Half Configuration**

With a relatively big investment the breaker and a half configuration provides very big reliability. Even in the case that one bus bar would fail the power supply of feeders will be kept in service. This configuration allows flexible service. Any breaker can be isolated, for instance, for maintenance or service work, while the other feeders can still be operated. The two bus bars are energized under regular operation conditions. As named for this configuration, there is one and a half breakers per circuit. Three circuit breakers are made for two circuits where each circuit shares the circuit breaker in the center.

## **Mobile GIS Installation**

The compact design of a GIS installation allows technical solutions that are very unconventional as a mobile GIS installation. This does not mean that the GIS could be shifted around while connected to the high voltage transmission network; the meaning is that for temporary use a GIS installation including all control devices could be installed inside a container or on a trailer and can be transferred from one temporary use to the next one. This might be the situation when substation extensions or upgrades need to dismantle parts of the substation or in situations of a disaster to replace a defected substation until it is replaced or repaired. Common voltage levels of such mobile GIS installation are usually up to 170 kV.

## **Containerized GIS Installations**

For rated high voltages up to 150 kV complete switchgear bays and the needed control gear can be placed inside a 40 foot container. Only the SF6 gas-to-air bushings have



to be installed on top to get the bay connected to the substation. The container with the GIS bay is placed on concrete basements. The three phase containerized bushing connection is connected to the GIS bay on top of the container. The GIS bay is assembled and routine verified in the factory so that only few weeks are needed to connect the containerized GIS in the substation. Short installation time is a big benefit of containerized GIS installations and also the easy accessibility during operation under controlled indoor conditions.

To extend the containerized GIS installation only, additional containers have to be added and to be connected to the substations air insulated bus bar. This is a common solution for extending existing air insulated substations.

### **Truck-Mounted GIS Installation**

GIS installation can be placed on trucks for temporary use in a substation. Lower voltage ranges are three-phase insulated and few GIS bays find space at one truck trailer. For bigger voltage levels bigger single-phase insulated GIS installations can be placed on a truck trailer and assembled on site to a complete bay. The benefits of truck-mounted GIS installation are short installation times and the possibility to move the GIS installation from one location to another as required.

### **Mobile High and Medium Voltage Substation**

The principle of a mobile substation concept is to have a complete substation available in case of emergency or natural disaster to replace high and medium installations. Hence, the substation is separated into high and medium voltage parts, which are placed each on a trailer. The trailers are then transported to the location of need and are connected. The AIS module contains a voltage instrument transformer, a surge arrester, and a compensation coil and capacitor, if required. The GIS module contains the complete GIS bay including the circuit breaker, disconnectors and earthing switches, voltage and current instrument transformers, and at both ends SF6 gas-to-air bushings. The transformer module contains the transformer and at both ends the transformer-to-air bushings. The medium voltage module with medium voltage GIS is placed in a container including the protection and control devices.

The trailer with the high voltage GIS container needs electrical clearances on both sides for the SF6 gas-to-air bushings, which meet the air insulation demands. The compact design of the GIS installation does not allow direct connection of the air insulated lines because of big distances between phases needed in air. Hence, the three phases are extended to the side to meet these requirements.

The high voltage GIS installation on the trailer may be connected by cables or by overhead lines. The medium voltage GIS is placed inside a container on the truck trailer and also contains all control, protection, and auxiliaries. With this modular concept it is also feasible to install more complex substations by using several trailers. At 72,5 kV voltage levels a 15-bay double bus bar arrangement including control, protection and auxiliaries can be installed in one container. Factory assembled and tested, the container is ready to be installed at site.

### **Mixed Technology Switchgear (MTS) Installation**

Gas insulated substations have long been known for their compact design and reliability. Therefore, manufacturers and users have been searching for options where parts of the GIS installation could be used to give compact, flexible, and reliable solutions in existing air insulated substations (AIS). Mixed technology switchgear (MTS) was developed of the idea of fitting this type of compact solution for optimizing existing air insulated sections that were not able to manage expansion using fully air insulated equipment. MTS is typically known as a hybrid arrangement.

Mixed technology switchgear is a compact switchgear development consisting of at least one switching element directly connected to or sharing elements with one or more other elements such that there is an interaction between the functions of the individual devices. Such installations are made up of individual elements that are designed, tested, and supplied for use as a single unit.

The interaction between elements may be due to proximity, sharing of components, or a combination of both. The MTS installation typically involves components of air and gas insulated substations and may be delivered completely prefabricated or partially assembled. The MTS space demands can be as little as 30% if the air insulated devices are used. The big difference in space demands is apparent and relates to the

part of how much of the substation is SF6 insulated. In an AIS substation only the circuit breakers are SF6 insulated, while in an MTS the circuit breakers, disconnectors, and earthing switches are SF6 insulated, but not the bus bar. The most compact design is offered by the GIS where all switching devices and the bus bar are SF6 insulated.

### **MTS Design Features and Applications**

The mixed technology design features mirror those of GIS technology, while organised in modular units. Those characteristics include compact design, increased reliability, integrated functions, modular elements, preassembled and tested transportation units, decreased construction time, and easy exchange of complete modules. It also provides optimum life cycle costs (investment, operation, and maintenance) to users. The most typical MTS application is an assembly placed in an existing AIS substation. Lack of space in this type of station could end in the need for different types of MTS assembly. MTS is also appropriate for installations with high operating frequency (capacitor and reactor). The most usual MTS installation uses a circuit breaker, circuit breaker disconnect and earthing switches, current transformers, and control unit in a single assembly. There has been a more recent application of MTS technology. It is a mix of two circuit breakers and their disconnect switches and current transformers, called the double breaker. The double breaker device can be used in double bus, double breaker, or ring bus configurations. The switchgear is installed on steel structures with a common base frame. The link to the overhead line is done by an SF6 gas-to-air bushing on top of the switchgear.

### **Functional Specification**

Functional specifications provide a cost reduction potential on the total substation cost. The special GIS solutions (e.g., double bus bar, ring bus) to meet the demands of the functional specification will have a standardization effect on GIS solutions. Standardized GIS can be made on a bigger market share with higher numbers of standard design to be delivered. The key is that standards for functions have to be made on a substation level not limited to today's existing company-specific solutions. System-related standardization will introduce a large step cost reduction when the end users can precise standard functional values for complete substations. Manufacturers

then can provide standardized products with fixed ratings. The standardization will lead to less change and the most cost reductions will be achieved with simplified project engineering, operation, and maintenance.

### **Simpler Design**

Technical developments in production processes and new materials for metal elements as well as for insulating parts will additionally drive GIS design to simpler technical solutions. This will decrease material and manufacturing costs and because of simplicity it will further increase the reliability. When a design is simpler it typically extends the equipment lifetime and will decrease maintenance. Typically, simpler design is using new materials or manufacturing processes to decrease manufacturing costs without decreasing functionality and reliability. The number of different elements to be assembled in a 145 kV GIS bay have been decreased from around 20 000 parts in the first generation GIS in the 1970s to the present range of 4000 parts. At the same time the performance of switching capabilities and the reliability increased from about 1000A rated current to about 3000 A. The number of type-tested mechanical switching operations increased from 2000 to 20 000. All of this refers to simpler design.