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Gas Insulated Substation Installation

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This course provides practical information that has been collected from a number of different GIS projects. The GIS equipment installation is demanding and asks for a detailed plan and sequence of works. With great amount of involved parts in the assembly, a proper sequence plan is a basic requirement to allow an efficient work flow and a high quality installation. Course also discusses safety standards and useful assembly tips. Substantial planning is needed including complex engineering and design, preparation of construction documents, material gathering, identification of material storage locations, potential GIS extensions, other power utility interconnections at the remote ends, identification of necessary permits, energization schedules, testing and commissioning demands, documentation check etc.

The project planning process needs to consider initial site surveys, core borings, security evaluations, identification of environmentally sensitive locations, checking heavy equipment requirements for site grading, civil works, and managing material, formulating gas processing routines, and organising special test equipment deliveries, personnel requirements and their training and qualifications etc. Visual inspections, testing for control of cables, bus leakage and gas quality verifications, main circuit resistance checks, mechanical switching inspections, interlocking verifications, grounding measurements, and instrument transformer verifications are some of the necessary tests and they are presented in this course. The student will be presented with an overview of the requirements to plan and perform a successful and effective GIS installation.

Provided information can be used as reference to support the manufacturers' directions or to use in the case that GIS modifications are needed on older devices that may not be supported by the manufacturer. As presented in the next paragraphs, staff involved in the GIS installation needs to be properly trained, well aware of the high voltage electrical and mechanical risks, and the chemical handling aspects. Generally, it is a common practice to have a manufacturer's representative present during the installation to direct utility staff or contractors. As soon as GIS equipment is energized, the owner's or utility's operations and safety routines are applied. These routines include minimum approach distances to equipment exposed live parts (e.g.,

bushing connections) and switching and tagging routines. In line with local or regulatory directives, the owner or utility may define gas handling procedures and SF6 use records (e.g., the gas amount in each compartment).

Safety Aspects and Assembly Suggestions

1. Just like for any other power equipment, there is a risk of electrical shock and lethal injury. GIS devices also bring the complexities of working with pressurized elements and gas manipulation. When installing new GIS equipment, especially additions or expansions to energized equipment, it is important to follow adequate lock-out tag-out routines and ensure that devices or hardware are adequately sectionalized, grounded, and depressurized before inspecting a GIS compartment.
2. If the installation includes a cable trench or vaults, basements, or confined spaces below floor level, the space needs to be tested for oxygen levels. SF6 is heavier than air and may cumulate in low or confined facility areas.
3. GIS devices have numerous mechanisms in small enclosures and can be controlled remotely. To prevent injury ensure that motor mechanisms and spring/pneumatic and hydraulic operators are discharged and de-energized before any work starts.
4. Use approved mechanical and electrical tools, including the correct size wrenches, handles, and other hardware. Some projects demand metric and English toolsets to work with locally provided materials and the GIS.
5. Current transformers may already be included in the GIS assembly. To prevent damage, the secondaries, if not used, should be shorted before energization.
6. Avoid unreasonable force during the assembly routines. Epoxy insulators can break with a substantial jolt or unusual lateral or axial tensions during alignment.
7. If GIS devices are equipped with view ports to check disconnect or ground switch status, do not directly observe while the device is switching. Electrical arcs may start and they can harm eyesight.

Overall Project Planning Procedure

An overall installation process, including considerations for future extension of GIS bays and equipment, is essential for an efficient and successful project. Typically, the preassembled devices and bus sections coupled with the manufacturer's directions will impact the assembly process and they need to follow a series of the following steps:

1. Preconstruction discussion between the end user and the manufacturer including the installation and assembly contractor.
2. Site initial works that include grading, drainage installation, foundations and equipment grounding, access roads, and auxiliary removal facilities.
3. Arrangement of construction equipment that will be needed for the installation.
4. Final alignment and foundations levelling for associated devices.
5. Collecting, unloading, and stacking away GIS devices
6. On-site GIS primary assembly
7. Leak tests
8. Protection relay, revenue metering, SCADA, communications, station service and the related control wiring installation.
9. Vacuum processing and gas filling with moisture and gas quality verifications.
10. Mechanical and operational tests on the switches, instrument transformers, and circuit breakers.
11. Primary bus high voltage dielectric and partial discharge checks. It is also crucial to discover the test connection point especially in the case of indoor devices where a temporary air to inspect bushing may be required.

12. Commissioning and start procedure

13. Construction snag list and site cleaning

Future GIS Expansion Aspects

The basic GIS design should include provisions for expansion and future requirements. For example, if system planning studies envisage two transmission lines in a breaker-and-a-half arrangement, and within the next ten to fifteen years load growth will demand additional bus connections, space should be provided for the future devices, especially if a new building is part of the project. In addition to space considerations, it may be a wise step to install isolation disconnects where the future sections are to be placed. When the future connection is done, SF6 gas is taken out from the disconnect zone and the existing bus on the opposite side is only decreased in pressure, not completely discharged. This step will prevent potential pollution and moisture infiltration in the bus.

Additional Planning and Initial Site Assessment

As part of the preliminary design, the different parties (contractor, manufacturer and end user) should collectively make a composite project plan for the overall project. The plan should be very detailed with crucial milestones well defined and analysed. Precise planning and project coordination is a crucial element for success. Important elements of a project schedule should include:

1. Design, engineering and regulatory approvals
 - a. Management and project organization data (milestone execution dates, major payments)
 - b. Document, study and drawing approval procedures
 - c. Single line and electrical schematic release sequences
 - d. Specification and coordinated release of construction drawings (structural, civil, electrical primary and GIS installation, wiring and controls etc.)

e. Assembly and building approvals

f. Regional or national electrical transmission authority approvals (security, safety, communications, protection systems)

2. Material procurement

a. Big long lead-time elements: GIS device/circuit breakers, bus, underground transmission cable and transformer bushing terminations, and other big interconnected devices – underground cables and power transformers

b. Typical electrical construction materials: fittings, conduit, cable tray, control and instrumentation cables

c. Structural and civil materials: anchor bolts, steel supports, rebar, concrete

3. Construction procedure

a. Site planning and organisation: yard grading, fence

b. Structural and civil works, foundations, basement and building construction

c. Electrical primary devices

d. Secondary control wiring and panels

e. Other: station service power, security etc.

4. Testing and commissioning procedures

a. Initial tests and measurements (cables and point to point measurements)

b. Vacuum and gas handling

c. High voltage conditioning

d. Energization and in-service tests

5. Project completion

a. Construction and as-built drawings, maintenance test record turnover

b. Spare parts and tools list

c. Operations and maintenance direction and routines

All of the above listed steps should be additionally divided into particular tasks and should have start dates, durations, estimated completion dates, person/company responsible, percent completed, etc. Once the precise steps are defined by the team, software can be used to schedule development.

Project progress and status should be presented on a frequent basis with the report frequency variable dependent on the project status or importance. While regulatory and design progress may only demand monthly updates, construction actions are typically presented on a weekly basis. Both progress and delays need to be distinguished to introduce effective changes and avoid impacts on the critical path stages. Subcontractor actions need to be also tracked on the composite schedule to prevent potential conflicts. Dependent on the owner's bid process, on some projects numerous companies may be involved in the project. For example, Company A may provide the GIS equipment, Company B the GIS bus, Company C the local control panels, with Company D responsible for the complete design and engineering. Project planning needs to consider proper coordination between these companies. Frequent meetings throughout the project will ease scheduling, material deliveries, construction in critical locations, safety, security, and the complete work effectiveness.

Document and Record Control

Document and record control is critical element for overall project success. A master summary document presents all the needed studies, design calculations, preliminary/conceptual drawings, design drawings, material and equipment lists, and maybe other correspondence such as approvals. The document or drawing number,

its title and description are included along with the party preparing and reviewing the data, critical dates and its latest revision number. The drawing statuses are also described, for example, preliminary, design review, and ready for construction. Drawing or document transmittal sheets are also useful to keep record of the changes as engineering releases, owner reviews, and released-for-construction drawing issues are done. Transmittal sheets need to include in the title: the project name, customer name, bid number, action needed etc. The transmittal body needs to define each document or drawing included, the recipient's name and address and the document return date.

Preliminary Site Assessment and Survey

Typically, this is done before any installation or construction work is started. The survey should be a written document that is occasionally checked and updated. A basic drawing or installation layout is a useful tool to understand risks, lay down locations, environmentally important areas or wetland boundaries, trailer positioning, excavated soil storage etc. Risks that should be defined include existing transmission lines, buried facilities including gas connections, electric underground cables, subsurface structures, and water or sewer connection lines. Many utilities give free underground services' specification or contract third party companies, who will identify and label underground utility equipment. In some densely populated areas, it is a legal necessity to contact the responsible identification authority before starting any excavation. Once the physical risks are understood, they should be clearly labelled with tape, paint, reflective drums or cones, and showed on the site drawing. This data should be put as part of the site brief for installation and construction staff, and placed in staff trailers or similar meeting areas. As the work advances and storage locations are eliminated, traffic patterns change, construction staff needs to be briefed and the site survey drawing updated.

Site Transportation Access

A site survey to define the preferred shipping route into the site is suggested. Particular concerns may include limited delivery hours due to staff operations or a residential/urban area, bridge heights or weight restrictions, oversized load or vehicle width restrictions, noise etc. Directions to the site, material reception times, and a

project construction contact should be presented on purchase orders and available with each shipment.

Security

Police should be notified of the construction actions and as necessary after work hours patrols requested. Local authorities may also provide historical details on incidents in the immediate locations, which would be beneficial to determine the required security level. Material storage locations are most susceptible to theft. The use of lockable storage containers, security lighting, fences and, if the situation justifies it, surveillance cameras or security guards should be considered. Cable reels, ground grid conductors and other high value materials should be covered or kept out of the public view.

Material Storage

Equipment storage locations need to provide heavy equipment access, allow large component off-loads, and need to be secure. Indoor or covered locations are favoured, but if outdoors, a well-drained area needs to be chosen. Crane clearances from energized transmission lines should be assessed. Material handling equipment certifications should be verified for current status and the up to date lift/rating tests confirmed. Operators and rigging licenses should be verified for current status and the certification data recorded. Some utilities will allow storage in an existing switchyard. In that case GIS bus and equipment crates should be laid at least 10 feet from the perimeter fence. At new “green field” areas, erection of a security fence is advised. For indoor locations a secure lockable storage area, basement area, or loading dock bay may be sufficient.

Health and Safety Plan

A health and safety plan (HASP) needs to be made for the site. This document needs to include:

1. Scope of work.
2. Project staff list: roles and duties, necessary qualifications.

3. Risk identification and risk assessment.
4. Communications: emergencies, incident reports and documents, safety meeting, and job responsibilities.
5. Technical safety demands: personal protective equipment (PPE), clearances, tool check, rigging devices, equipment isolation, tagging, fall protection and traffic control.
6. Compliance standards and demands: inspections, problem identification, mitigation actions
7. Environmental aspects: suggestions and permits, erosion controls, preventative actions, response steps, wetland/species protection
8. Site-specific issues

Before staff begins installation work, they need to be given a HASP briefing. Also, staff needs to sign a site log to declare that they understood the HASP, emergency actions, and specific environmental issues. Site evacuation details including an emergency marshaling location and local hospital details need to be posted in conspicuous areas throughout the work site. Individuals with first aid or other emergency medical training need to be found. Emergency supplies should be checked for current status and quantities. These include fire extinguishers, first aid boxes, emergency eye washes, and environmental spill clean-up tools. Occasional site safety updates and staff briefings are advised as the installation advances. As an addition to the HASP, material safety data sheets (MSDSs) should be gathered for every chemical, solvent, cleaner and fuel that are used at the installation site. They need to be put in easily accessible binder.

Environmentally Sensitive Locations

These locations, including endangered vegetation, animal nesting, and wetland boundaries, need to be highlighted and documented on the site assessment survey drawing. Any street, roadway, roof, or similar area with drains leaving the installation/construction area need to also be defined and the outfall highlighted. Spill

cleanup tools should be put where there is a possibility of spills, including locations adjacent to construction equipment, in order to keep hydraulic fluid or fuel leaks. As demanded by the authority having jurisdiction, a site environmental plan and/or a spill prevention, control, and countermeasure (SPCC) plan may be needed. These should also be put in easily accessible locations.

Specialized Equipment Demands

Gas insulated substation or bus arrangements demand specific equipment for gas handling and testing. These devices should be procured and verified well before the actual use.

1. Gas-processing devices with sufficient storage capacity. SF6 gas is treated using available gas-processing trailers that have oil-free vacuum pumps, and process devices, gas storage tanks, compressors, filters, dryers and all other necessary equipment. The size of the individual gas areas and the evacuating and storage capacity of the gas-handling devices are particularly important in big stations. Adequate evacuation devices and an auxiliary vacuum pump may assist to expedite the gas processing. To directly fill compartments from gas cylinders or gas treatment devices, heat sources may be required to counteract the chilling effect of the expanding gas and maximize gas expansion from the tank.

2. Gas tank regulators and an electronic SF6 gas leakage sensor.

3. Electronic assessment devices to verify SF6 gas purity and moisture levels.

4. Dry air in adequate quantity to back-fill all compartments and back up construction efforts, specifically for temporary storage during assembly of big bus/device sections or temporary work stoppages.

5. Cleaning or bus protection supplies that include:

- a. Commercially available vacuum cleaner with HEPA filters and non-metallic accessories.

b. Clean plastic gloves and work clothes. Some power utilities, particularly if energized devices are in the project vicinity, may demand fire-retardant (FRE) clothing. One important consideration is that the installation staff wear clean clothing that will not bring in contaminants into the bus during assembly process.

c. Lint-free clothing and manufacturer-advised solvents.

d. Temporary bags or covers for sealing openings after elements have been disassembled.

6. Special tools supplied and suggested by the manufacturer. When tools not commercially available on the market are needed for installation and maintenance of the devices, one new set should be provided by the supplier before commissioning.

7. Miscellaneous

a. Ventilating devices

b. Handling and lifting devices

c. Welding and metal working devices

d. Ladders and platforms as needed

8. Specialized electrical test devices

a. Micro-ohm tester

b. Circuit breaker stroke measurement and travel and timing test device

c. Insulation resistance tester

d. High voltage insulation test devices. High voltage test devices (series resonant is needed to verify the quality of the insulation system before energization. Additional entrance bushings or adapters may be needed, especially where direct cable or transformer links are made. Termination caps and corona plugs may also

be required for closing the end of an assembly when the complete bus has not been done.

Staff Training

GIS staff training includes three basic elements: the construction/assembly staff, end user operations and maintenance (O&M) staff, and the dispatchers/operators. O&M group staff should participate with the construction/assembly staff and supervise the installation, gas handling, and commissioning of the GIS equipment. O&M teams should be advocated to take progress photographs, verify assemblies before gas compartments are sealed, especially where direct transformer or cable connections are in application, operate disconnects and earth switches, witness commissioning tests, record SF6 gas filling and gas purity/quality tests, and understand the equipment operations before the primary circuit is energized. Dispatchers need to visit the site after construction completion, and if possible before energizations, to acquaint themselves with the equipment operation, gas zones, tagging routines, and other operational processes.

Construction and Assembly Team

The construction/assembly team should be given instructions on the GIS switchgear and bus before commencement of the work. Color-coded cross section views of the devices will provide the assembly team with a better understanding of “what is in the container or bus assemblies.” The training needs to be organized in two parts. The first part consists of a classroom environment where a manufacturer’s representative can present proper component handling and rigging, the “delicate” nature of the device and bus, the criticality of device alignment, site and installation cleanliness and dust control, the moisture impacts on bus and gas treatment, overnight or longer term “open” times, the importance of dry air back-fills, regulated gas handling/weighing and environmental reports, leak and vacuum rise inspections, high voltage commissioning checks, and turnover records. The second part of the training considers field work, site verification or installation location, the equipment or bus that is to be installed, confirming hardware weights and rigging plans, and retrospection of assembly routines. During morning briefings, where the day’s work plan is talked about, the initial training should be reinforced and teams occasionally reminded of the importance of

cleanliness in the work location and bus sections, tool accountability, and other technical aspects.

Safety matters should also be discussed during the morning meeting and include rigging, gas treatment, needed personal protective equipment (PPE), etc. Other items that need to be considered during the initial training are to provide the project organization chart, complete schedule, site drawing(s), any needed assembly checklists, emergency and security/access routines, and any site-specific risks or environmental limitations.

Personnel with necessary skills should present copies of their credentials, including, welding certifications, riggers and equipment operator's diplomas, first aid/medical/safety courses, etc. If numerous companies are involved in the project, the interface points need to be determined for the construction teams. Company representatives should supply work drawings that show the assembly points, including alignment criteria, tolerances, wiring termination areas, gas fill responsibilities etc. It is also crucial to use a mutual measurement reference for all parties e.g. survey site marker, top of foundation point, floor level or final completed grade.

Operational and Maintenance Team

Similar to the construction teams, the owner's O&M staff training should include both classroom training and practical "hands-on" tasks. Classroom work needs to consider a detailed description of the GIS equipment work, including internal cross section drawings, gas treatment, safety considerations, earth and disconnect switch functions (manual and motorized) and numerous switch position indications (stops, viewports, flags, cameras, etc.), circuit breaker maintenance (lubrication, operations counters, interrupter operations), satisfactory moisture and gas quality verifications etc.

The practical exercises need to include breaker functioning, correct earth switch and disconnect for open/close, gas density meter placement, local control cabinet interfaces, and remote control areas.

Dispatch Team

Dispatch education needs to focus on the electrical functions of the GIS device and couple with the importance of the mechanical aspects, including the gas zone integrity, gas zone limits, alarm and trip circumstances, interlock logic schemes, tagging processes etc.

On-Site Staff Not Directly Involved with Installation

For other on-site staff except, for example, visitors, civil or mechanical contractors installing foundations, HVAC systems, buildings, and so on, electrical hazard awareness training is advised, so their staff is aware of the site risks and/or restrained locations.

Material Receipt and Control

With the defined material storage location, a storage plan needs to be made with materials to be used toward the project end, put toward the rear or less accessible locations to avoid double picks. The plan needs to describe the material, its position on site, and any needed routine verifications. Elevated signs defining the different elements may be beneficial if the storage is outdoors, where snow accumulation is an issue. Devices placed outdoors need to be on wood pallets at adequate distance off the earth to avoid water, snow accumulation, etc. with enough room to walk between boxes or hardware, check nameplates or shipping labels/component IDs, etc.

Bus, Disconnect Earth Switch, Circuit Breaker Transport

GIS bus, disconnects, and earth switches may be transported with dry air at a slight positive pressure. When this device is likely to be stored for prolonged time, the pressures need to be verified on a regular, weekly basis and noted down. Similarly, circuit breakers may be delivered with a positive SF6 pressure, which is “topped off” after assembly. The circuit breaker needs to be equipped with a density gage that can be used to verify the breaker compartment(s) pressure. Control cabinet heaters may also need station service power to reduce moisture accumulation in the cabinet.

Incoming Material Verification

All materials received on the job site need to be inspected. The manufacturer may also have special inspection routine to record for important items. Generally, the verification should verify for shipping damage including damaged containers, broken support frames, or other signs the equipment was dropped or damaged by impact. Some equipment (e.g., circuit breakers) is transported with pressure/density gages and a zero gage reading, due to transport or handling issues. This may show a loss of positive pressure, with moisture infiltration into the equipment. All hardware needs to be verified against the shipping manifest. The manufacturer and transportation company should be notified of any damage or strange observations. Any impact recorders or similar handling quality or provided shock detection instruments should be interrogated for evidence of mishandling.

Over sea transport may be handled and picked several times before reaching the final destination. GPS devices, attached to the GIS assemblies may assist in tracking shipment deliveries.

Equipment shipping weights should be given on the manifest documents and inspected against the container/crate labels and adequately rated material handling equipment provided on site. For assembly needs, installation teams also require the real equipment or hardware weights less the crate or packaging materials. If there are any questions, the manufacturer needs to be consulted to confirm the weights before any equipment is lifted. Center of gravity and load pick points need to be also clearly defined.

The GIS bus needs to be checked for dents, gouges, cracks, and other indications on the surface that could indicate interior damage. Major dents in the bus may change the electrical insulation and bus mechanical strength properties.

Once materials have been verified and received, an inventory check may be needed to make sure that materials are installed or that consumables are ordered in a timely fashion to avoid delays. Generally, a material inventory table consists of: the item description, part number, supplier, quantity, order, ship and delivery date, drawing reference, storage area and responsible party, and any specific instructions.

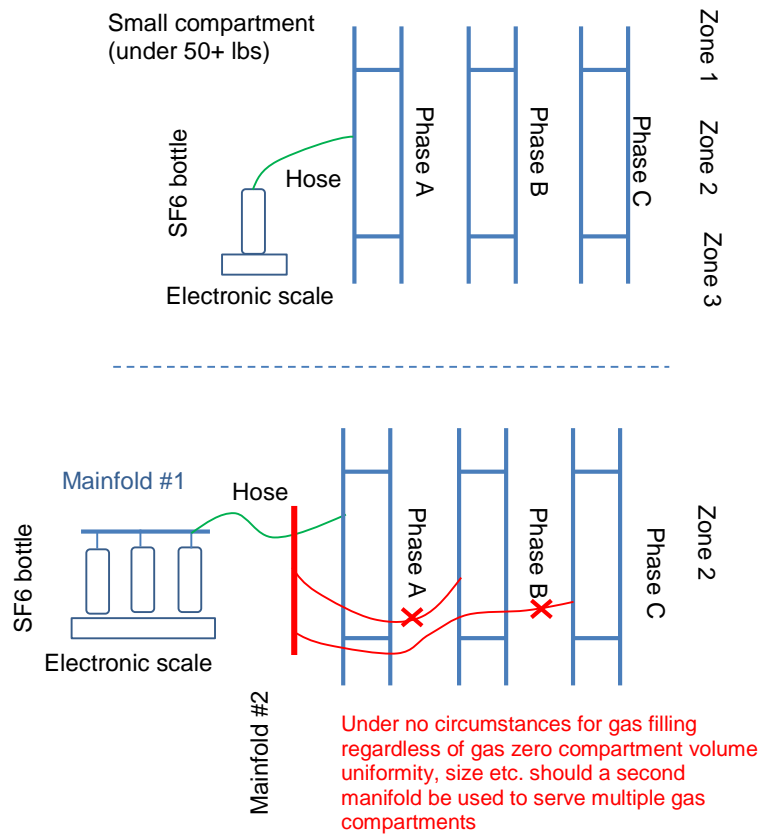


Figure 1. Typical gas weight record and sketch

SF6 Gas Treatment

SF6 gas treatment is another important issue. As a substantial greenhouse gas, SF6 demands careful inspections. In some situations there are government standards that by law require SF6 to be measured upon receipt at a job site, the individual cylinders weighed as gas is extracted and put into a bus and then the gas cylinders separately weighed before leaving the installation area. All these weight checks are recorded and officially sent to the responsible regulatory authorities. Depending on the site circumstances, a common gas handling and storage location may be useful. SF6 tanks are color coded with a green top and silver on the bottom with high internal pressures. The typical safety rules for pressurized cylinders should be followed including: not picking up by the valve protection cap, securing cylinders not in use, making sure material handling device is available to move cylinders etc. A gas quality measurement should also be done once each gas zone is filled. This information will be used to make a maintenance benchmark.

Installation/Assembly Guidance

GIS installation relies on a rigid base as a mechanically bolted or welded assembly. The foundation or baseplate level tolerances are critical for the project success. Typically, the manufacturers have defined special criteria for the foundation and baseplates. Modern GIS assemblies may use built in channel where the equipment is tack welded and, as soon as the final position is made, a bead weld is done along the support foot. Some assemblies may use leveling bolt/nut combinations. During the project initial design phase, the manufacturer and end user need to review the installation demands and agree on the foundation design criteria. During construction and GIS equipment installation, precise surveyed control points will be needed to confirm correct equipment locations. The manufacturer's drawings and assembly instructions need to be given to the installation staff well before commencement of the work to allow enough time for review and site survey work.

Shipping Covers

Transportation covers should not be taken away until the equipment is ready for connection. It is important to mention that GIS elements are transported with a positive pressure of dry air or nitrogen to prevent moisture infiltration. Before taking away the transportation covers, the shipping pressure should be relieved. Interior cleanliness of the bus should be kept using plastic covers sealed to the outer enclosure with tape. The interior compartment should only be open during flange cleaning or the final assembly. If the GIS equipment "open time" is extended, it can impact the time required to reach necessary vacuum level. If an extended open time is required, the vacuum time could be decreased by increasing the dry air or nitrogen back-fill set time.

Big Pieces

When transporting or moving big pieces of equipment, tag lines are suggested to control the load. If the assembly is outdoors and high winds are present, the installation staff may postpone the work due to the big "sail" area and inability to control the lift. If there is precipitation or high humidity, the staff should avoid opening and exposing the container interiors to moisture.

Clean Bus and Flange

Materials used to clean the bus or flanges need to be nonconductive and lint-free. Cleaning materials and tools need to be properly and regularly disposed of. They need to be put in dedicated containers to minimize the possibility of a fire. Alcohol or similar flammable chemicals need to be kept in approved lockers or areas with adequate ventilation. Fire extinguishers need to be kept in the vicinity of cleaning solvents.

Lubricants and Sealants

Only manufacturer's approved lubricants, greases, sealants can be applied in the assembly. Use of other chemicals may have adverse and corrosive effect on the insulators, mechanism links, or other GIS elements.

Tools

All tools used in the vicinity of open equipment need to be subject to an inventory and the count checked before the bus is sealed. An internal bus and equipment verification need to be done with staff looking for tools, extraneous cleaning materials, loose hardware, shipping elements, foam rings, or any other part that might affect the insulation system integrity.

Bus Assembly

The bus assembly needs to be carefully guided by a team leader. Forced fit of the bus or other elements needs to be avoided to prevent insulator or contact damage. While expansion joints may give certain assistance with component alignment, these joints are not used to fix major bus displacements or misalignments. Once the flanges or GIS parts are secure, bolted connections should be verified for the adequate torque. It is an established practice to mark the bolt heads after the final torque verification.

Checklists need to be done as the equipment, different sections, or compartments are assembled. It needs to contain items such as connection tightness, visual verification for debris or tools etc. Questions such as:

- Are pressure relief vents pointed away from locations where operating actions

happen or staff is present (walkways)?

- Is sufficient maintenance space provided around the equipment? As most breaker interrupter assemblies slide out of their container to replace arc contacts or nozzles, will structural foundations, cable tray, conduit runs or gas monitors block or restrict the access?

need to be asked and answered. Where duties change either between manufacturers or between contractors or subcontractors, a joint interface assembly checklist needs to be made and used to verify the correct dimensional measurements.

Disconnect and earth switches need to be verified after installation to check correct operation. Manual operation needs to be checked and contact penetrations examined. External linkages need to be verified for correct alignment as well as adequate operation of position indicators, stops and flags. If temporary power is available motorized switches need to be operated. However, circuit breakers should not be operated at below design pressures since the SF6 gas may be used to assist in dampening the interrupter assembly operation.

SF6 Gas Treatment

After a cylinder assembly is done, nitrogen or dry air with low moisture content is used to back-fill the compartment. Manufacturers differ on the length of time the back-fill is required. Field experience shows 24 to 48 hours typically results in optimum moisture absorption. At the end of the back-fill, the vacuum process using a gas cart with vacuum capabilities starts to test the compartment integrity. A vacuum manifold may assist in facilitating the evacuation process. After a pre-set time of 1 to 2 hours of vacuum, a rise test is performed, with readings taken at 10 minute intervals. The cylinder vacuum levels will initially increase but should finally level out or flatten for an acceptable test as shown in Figure 2.

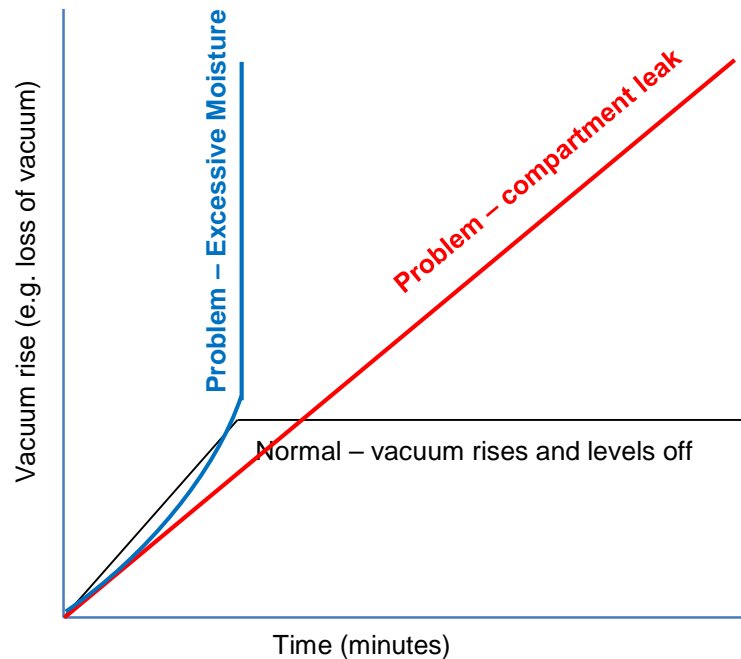


Figure 2. Vacuum rise test

Winter outdoor GIS assembly introduces some particular challenges. Moisture removal via a vacuum process is very challenging at low ambient temperatures, so provisions need to be made to give supplementary heat and temporary containers. These containers can be made from wood and plastic, and should include blankets or similar insulation. Outdoor gas treatment and processing may also ask for supplemental heaters. If possible, gas tanks need to be kept in a heated container before use.

The installation team needs to keep records of how long the bus or equipment was open, the time spent with the nitrogen or dry air back-fill, the vacuum rise test, and the overall vacuum time to reach accepted manufacturer levels. In the absence of manufacturer's directions, the bus is typically taken to 300 μm and equipment is taken to 1000 μm , and then vacuum is continued for one extra hour. These records need to be on a per-compartment, per-phase basis. As the back-fill, vacuum, and gas process continues, the installation team needs to tag the status of each compartment. These tags can contain "Partial Pressured", "Under Vacuum" and "Fully Pressurized" labels and may be color coded. The installation team training needs to highlight the importance of the tagging system and the color code. Tags need to be placed in conspicuous areas near gas valves. Few individuals need to be responsible for the complete gas treatment process including tagging. A record needs to be maintained

on the job site, especially on big projects with continual updates made for each step. Posting complete gas zone diagrams with the status of each zone helps project management, increases safety, and gives the installation team ready reference of the job status.

Retro-fit

During retro-fit it may be mandatory for safety reasons to decrease the gas pressure in adjacent gas zones. Staff needs to define the GIS gas zone limits by locating the barrier insulators using drawings or if available the manufacturer's physical bus markings. In some situations end users will define a color coded band using tape or paint on the bus or insulator showing a barrier/gas zone barrier or boundary. A universally adopted practice is to decrease the immediately adjacent zone to 2 or 3 PSIG and the zone immediately beyond to 50% nominal operating pressure. This process is shown in Figure 3.

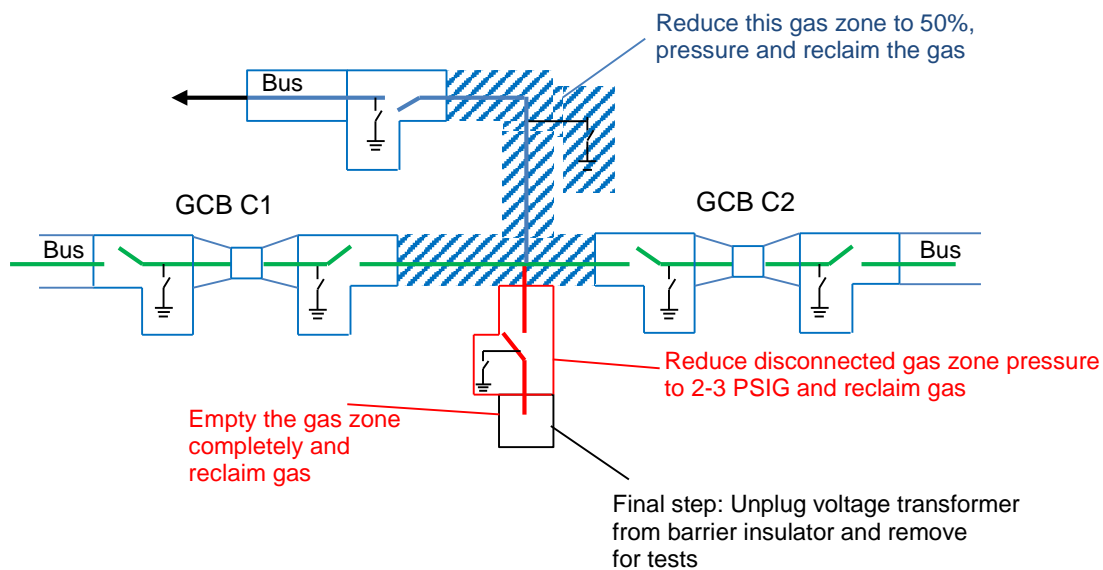


Figure 3. Gas zone pressure reduction procedure (This drawing shows suggested pressure control in the bus.)

Presenting a gas zone diagram for the work team is also a prudent safety action. The gas zone diagram needs to display the zones involved with the work and the status of the remaining zones within the facility. In addition to tagging the gas zone statuses lock-out tag out procedures are a prudent and mandatory in some locations.

Gasket and O-rings should be adequately placed until ready for use in a dry, room temperature space. After a GIS flange is cleaned and verified, the adequate sealant needs to be used followed by the gasket or O-ring. Before assembly, the gasket or O-ring need to be inspected for cuts, nicks, rigidity, or similar damage that could potentially compromise the gas seal. In the case of retrofits, when flanges are opened, especially after a long time period, the gasket or O-ring will likely have a “set”, and means it should be changed. Desiccant needs to be changed in the affected zone.

GIS Equipment Tests

Construction Visual Verification

These tasks typically involve:

1. Verify all bonding and earthing conductors are installed, connected, and tight.
2. Verify the status of the gas valves for normal operations.
3. Verify the appearance and condition of the primary GIS, e.g., damaged paint, construction scraps, tight structure support connections, viewport covers, etc.
4. Cleanliness of the circuit breaker container, disconnect and earth switches, and marshalling and local control cubicles.
5. Equipment labeling including nameplates and equipment identification plates.
6. Complete job site appearance and cleanliness.
7. Condition of safety devices, including fire extinguishers and first aid kits.

Control Cable

Commonly performed control cable tests fall into two categories. First, the insulation integrity is verified using a 1000 volt source that can be manual or motorized. The end user and manufacturer have to be asked for a site-specific process. Nevertheless, the goal is to confirm that individual conductors are insulated from each other and the

cable shield in the case it is available. The cable jacket integrity is also verified. The goal is to find missing or damaged insulation. Successful tests need to present show high resistive readings.

The second category is a point-to-point continuity test to check that the conductors are placed on the correct terminals. Installation staff needs to isolate the connections using slide links and then check, using sound powered phones, buzzers, or similar devices, that the connection is adequate. The installation team needs to keep records of the insulation checks and the point-to-point wiring tests. It is also a typically accepted process to trace the different protection, control, interlocking wiring, etc. during the point to point verifications. Related electrical wiring or schematic drawings also need to be made.

Bus Gas Leak Tests

Once the different GIS cylinders have been processed and gas-filled, a second leak verification is suggested by the manufacturers, especially for long bus runs. Each flange is wrapped by plastic and sealed with duct tape. A small stone is put in the bottom of the plastic “bag.” This plastic “enclosure” stays for 12 to 24 hours. An SF6 detection element is then placed into the bag. If there are gas leaks, since SF6 is heavier than air, it will settle to the bottom of the plastic bag and trigger the detector. This process is shown in Figure 4.

Gas Density Monitor and Local Alarm Checks

This verification includes keeping the gas density monitor wired but electrically isolated with open terminal block slide links or a similar switch mechanism, before mechanically isolating the density switch using adequate valves. Bleed a small quantity of gas off and applying an ohmmeter at the terminal block, observe and record the alarm point. Two-way radio may be needed for big installations. In a similar fashion, slowly introduce some gas and as the pressure increases, observe the density switch reset point. The test objective is to check the final wiring and actual alarm settings.

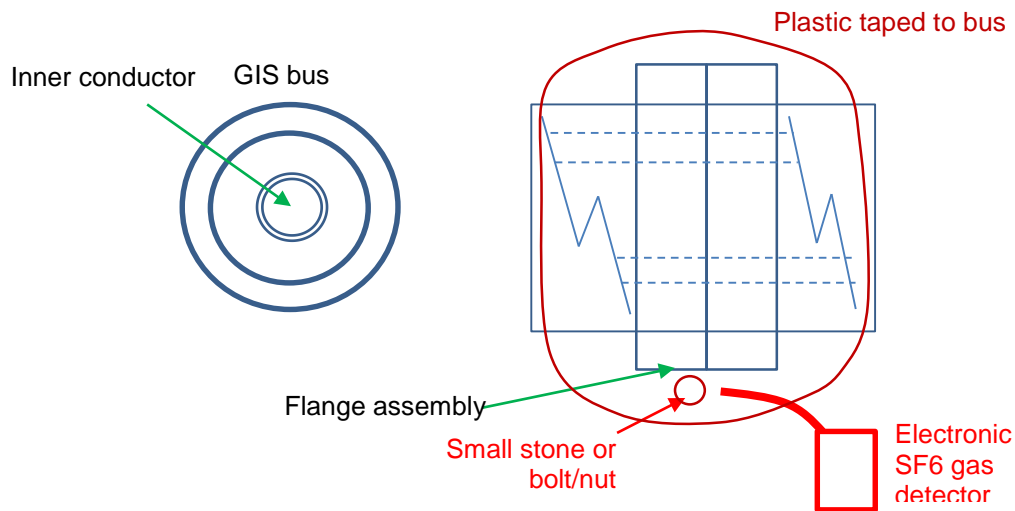


Figure 4. Flange gas leakage test (This drawing presents method to verify the integrity of a gas bus flange for SF6 leakage)

Primary Circuit Resistance Test

Typically, this test demands a 100 A DC $\mu\Omega$ meter with separate voltage and current sources. Tests are performed on an assembled GIS part or element as defined by the manufacturer, isolating the circuit using an earth switch and removing its earthing strap. The different GIS switches in the test circuit are configured to meet the measurement demands, and with the current lead connected to the “floating” earth strap and the $\mu\Omega$ meter voltage lead linked to the earth switch enclosure, 100 A are injected into the circuit. The obtained readings are compared to mathematical calculations, which may also include a certain tolerance. An acceptable field measurement should closely match with the engineered calculation.

SF6 Gas Quality Verification

Once the gas cylinders are processed and filled to the adequate pressure/density, gas purity verifications are done. These verifications demand a small quantity of gas and identify the moisture level and the SF6 gas purity. For new GIS assemblies acceptable values are moisture levels in the 150 ppm to 300 ppm range and gas purity in the 99.5% range. Certain manufacturers reduce the acceptable figures in older or reprocessed gas to 500 ppm moisture with a gas purity of 98%. These figures need to be recorded for maintenance baseline use when gas quality measurements are done in the future.

Circuit Breaker Checks

Before continuing with any breaker operations checks, any closing or tripping prevention pins or lock elements need to be distinguished. Depending on the check, the pins or lock elements may or may not be needed. The breaker operating pressures should also be checked to ensure that the circuit breaker is at full operating levels.

Mechanism Stroke, Wipe Measurement

These verifications are typically done at the factory and checked at the site to make sure that transport or the installation procedure has not damaged the breaker mechanism or caused it to diverge from acceptable tolerance levels. Manufacturers will suggest the measurement technique and satisfactory limits for both the stroke and main contact wipe. This set of measurements is typically done when manually operating the circuit breaker.

Open/Close Function Including Anti-pumping

This verification will clarify if the circuit breaker properly opens and closes. One manual test is performed and then the defined number of open and close operations at the operating control voltage is done in a specified time. The goal is to understand if the lights and indicators work adequately and the end user's specification demands are met.

The anti-pumping test includes closing and opening the breaker with an uninterrupted signal on the close coil. If the anti-pumping circuit is operating, the breaker should not re-close until the close coil is de-energized.

Travel and Timing Verification

These verifications are done to understand the breaker dynamic operating performance by assessing the operating times on a per pole basis and discovering any discrepancies or deviations with the phases. Generally, manufacturers will give the timing range and the maximum phase discrepancy limit. Any recordings outside the manufacturer's defined values need to be checked and necessary adjustments

need to be made.

Low Gas Tripping and Block Close Operations

This verification is done on the circuit breaker gas system to understand if gas leakage detection (multiple alarm levels) is functional and the control limits, e.g., serious loss of gas, will block close and prevent the breaker service. Typically, the manufacturer suggests that these verifications are acceptable before a circuit breaker is put in service.

Earth and Disconnect Switch and Circuit Breaker Interlock Checks

Typically, GIS installation is equipped with interlocks to prevent incorrect service; e.g., most disconnects are not made for load break operation and similarly earth switches cannot be closed without interconnected circuit breakers and disconnects open. The manufacturer's interlock logic scheme needs to be consulted to understand different open and close arrangements and ensure that incorrect operations are blocked. These interlock diagrams should also be consulted for proper integration into the owner's protection and switching logic.

High Voltage Bus and Equipment Conditioning Checks

Before the GIS equipment is put in service, a high voltage conditioning check is done with momentary voltages in excess of the equipment rated line-to-ground voltages. The goals of the test are: to discover any abnormalities in the bus (loose hardware, cleaning material inadvertently left in the bus, etc.) that could compromise the internal electrical clearances, discover increased moisture levels and move conductive and semi-conductive materials to low stress areas or particle traps to prevent insulation flashovers. The test voltage levels and time durations differ between manufacturers and are determined upon the equipment voltage class. For example, on a 362 kV class, 1050 BIL equipment, the test levels may be as presented in Table 1.

Table 1. Equipment Voltage Test Levels

Step	Step (kV)	Time (s)
1	100	20
2	125	15
3	175	10
4	225	2
5	275	1
6	300	1
7	325	1
8	350	1
9	400	1

The test transformer and the capacitance of the GIS equipment are selected in such a way that they make a resonance circuit in the range of 50–100 Hz. This allows application of much smaller test equipment.

The benefit of using a series resonant test is the inherently limited available fault current, in comparison to fault energy once the GIS equipment is connected to the transmission system. A routine verification on 362 kV device will take roughly an hour. A three person team is advised including a safety observer, a timer, and the test set operator. The substation or switchyard low voltage station service connections and capacity need to be defined early in the project. If inadequate capacity is available for the test set, a small portable generator may be needed.

The GIS equipment can be examined in numerous ways. To speed up the process, one method is to check large bus sections at once, taking into consideration the test set capacity. The weakness of this method is that if a discrepancy is discovered, the test section will need to be sectionalized into smaller elements to isolate the problem area. A second method is to begin with smaller test sections, but this will need more test time. During normal tests at the higher voltages, corona may be noticed around the test set wire linked to the GIS bushing.

The test fails, if the needed voltages cannot be accomplished or the test set trips off before the peak voltage level is achieved. In situations in which new GIS equipment is retrofitted to older designs, both sections must be concurrently examined. It may be wise to decrease the test levels to avoid problems with the older devices. After a test failure, given the low energy involved using the test set, repeat tests can be completed

to help isolate the problem. If achievable, the test part should be decreased with parts of bus systematically removed from the test, until the problem section is found. It may also be useful to assign individuals at points along a bus to assist in locating the “ping” or audio noise that may happen when a flashover happens inside the bus. Staff has to be positioned in safe areas, well clear of the test set and its connections.

Instrument Transformer Checks

Current and voltage transformer verifications include polarity, ratio, and current transformer saturation curves. These verifications demand voltage and current injection and are equivalent to testing completed on similar air insulated devices. The records are cross compared to the manufacturer’s published records.

Other Checks/Records

AC Station Service Verifications, Heater and Control Cabinet Light Operations

This stage includes checking the heater circuits for current with a clamp-on ammeter, understanding correct light operations using a door or manual switch, understanding if all power receptacles are functional, and testing for tight connections.

Earth fault protection needs to be provided for receptacles especially if the local control or marshalling cubicle is installed outdoors. Three phase 60 or 100 A disconnects with independent power sources placed on the exterior of the local control or marshalling cubicles may also be convenient to connect welders or gas cart/processing tools. The equipment and control cubicle heater test results need to be recorded. The circuit breaker and other heaters in the GIS primary circuit are important, especially in cold climates to stop SF6 liquefying and loss of gas density. Heaters may also be needed at transition points between heated indoor areas and outdoors. In installed, thermostatic control settings need to be checked and the levels recorded.

Final Circuit Breaker Counter Records

Before equipment is made available for end user operations staff, all circuit breaker counters are recorded and the values entered in the commissioning sheets.

Turnover Gas Zone Density Records

In a similar fashion, all gas zone pressures are recorded including circuit breakers on a compartment, per phase if an iso-phase bus is used. The bus temperature is also noted down and the pressure reading temperature-compensated. The obtained value is cross compared to the engineered nominal value.

It is interesting to point out that some end users prefer gas density gages with numerical readings. In alternative designs a colour coded gage may be satisfactory with the gage needle in the green area on the gage face indicating satisfactory, the yellow area indicating caution or investigation of a potential leakage situation and the red area asking for a prompt action and possibly a major issue. The gas density gage design needs to be discussed during the initial engineering process.

Commissioning, Energization, and Outage Processes

Most transmission systems in densely populated locations are heavily loaded and commissioning schedules may have to be submitted months in advance of the actual ready-for service date. A common approach is to split the commissioning into two stages. The first stage is the complete energization plan. The second stage is the outage plan. The energization plan needs to consider:

1. Use the owner's area or dispatch key single line diagrams to discover where the new GIS equipment will interface with existing facilities.
2. Determine outage responsibilities between the end user, contractor, test contractor, control authority, etc., including staff and time requirements.
3. Discover the general outage steps, e.g., energize transmission line 1, bus sections W-1, W-2, and cable ABC.
4. Define measurement points for in-service readings and phase checks using voltage and current transformers recording voltages and currents as different elements are energized.

5. Define all pre-energization documentation demands including: construction punch list resolution, a detailed program, final regulatory or permit approvals, regional operations compliance, etc.

6. Determine when the operations ownership transfer will happen.

It is useful to develop a checklist with input from all the responsible sides and list the different energization activities and the personnel with responsibility for specific tasks. Also included in the pre-energization approval process may be protection and controls organizations that will demand acknowledgment that regional security and protection standards are met including: internet security, redundant protection diagrams, back-up AC and DC power sources, dual and independent circuit breaker trip coils etc.

As the pre-energization work advances, meeting(s) with the end user dispatch staff happen where the switching and tagging protocols, commissioning staff qualifications, communication methods, and personal protective equipment demands are discussed. If the project is sufficiently big, a commissioning group organization chart may be useful, which also defines the different individual's responsibilities.

The second stage in the commissioning process is to make a detailed outage strategy. As part of the commissioning process a separate team may be needed to make detailed switching orders. Typically, an outage or cutover plan is drafted by the installation contractor and then revised and approved by the dispatch group. In big, complex transmission systems there may be few approval levels, including the local authorities, then regional system operators, and, in the case the interconnection is across borders or regional control areas, perhaps a national authority has jurisdiction. The outage plan defines:

1. The schedule, timing and real equipment and their identification numbers (disconnect switches, circuit breakers) to be used as the new GIS installation is energized.
2. How parts or portions of the new GIS assembly will be energized.
3. Hold points in the process as measurements are done and equipment operating

conditions are verified.

4. If applicable, “soak times” where the equipment is energized, but no load is applied.
5. Control or Hold points for all involved staff to “sign off” as the steps are done. If the commissioning process happens over few months or even years, depending on the interconnection of transmission lines, cables, or generators, a commissioning log may be mandatory so that, as the test teams and engineers change, a coherent history of the work and measurements is done.

Maintenance and Turnover Records

As part of the commissioning routine, the end user, manufacturer, and contractor should occasionally meet and make a turnover strategy. Some of the items to consider are:

1. What maintenance and test documents are needed and in what format?
2. Is special software required, e.g., to access cable schedules and termination information in the future?
3. Project records and as-built drawing transfers?
4. How will warranty items be addressed?
5. What are the routine maintenance demands?
6. Emergency manufacturer’s contact and suggested spare parts details?
7. Are any spare parts included in the purchase? If so an inventory should be made and a storage location defined.
8. An inventory of special tools needs to be made including manual disconnect handles and circuit breaker manual jack assemblies and a storage location selected. It may be useful to the O&M teams to provide frequently used tool storage points in the vicinity of the GIS assembly including one line and gas zone schemes.

9. Are all gas areas/limits and devices including viewports labelled with the end user's defined nomenclature, especially disconnect and earth switches and circuit breakers? A turnover checklist made by the responsible parties may help to make sure that all the documentation, tools, spare parts, permits, gas handling documents etc. are adequately addressed.

Connecting to the Transmission Network - Network Connection Considerations (Long-Term System Planning)

Attention has to be given to the geometry and clearances of the transmission lines and their interconnection to the GIS installation. The property lines and rights-of-way will also determine the GIS connections. Therefore, gas insulated equipment and direct cable connections have the desirable characteristics and geometry to reduce phase spacing. This spacing is much lower in comparison to conventional air insulated systems.

The sequencing of the transmission, generation, or transformer lines will likely be determined by the bulk power authority or the sponsoring utility. The project staff needs to consider the clearances (both electrical and staff) needed to construct and commission the facility including any temporary structures or required line supports.

For the cutover of the lines to be completed in a timely manner, the protective relaying at the remote line terminal(s) needs to be compatible and coordinated with the new GIS installation. Factors that need to be considered include: the relaying philosophy (current differential, directional, comparison, blocking, permissive overreach transfer trip, etc.) and the communication system to the remote ends.

GIS Earthing System

The GIS equipment earthing system markedly differs from air insulated substations. Because of the relatively high capacitance value between the center conductor and the concentric enclosure of GIS equipment, especially at higher voltages, it is possible to make major charges on to the GIS enclosure during the switching process. For this reason, the GIS equipment earthing system will be multi-point earthed. Calculations are needed to find out the touch, step and transfer potential and design the earthing

system to limit the potential levels to safe values. The project staff needs to consult with the selected manufacturer during the design of the earthing grid and ancillary equipment. Special care needs to be put on the earth connections within the GIS equipment and their connections to the complete substation earthing system.

Gas Zones

The number of gas zones needed for GIS equipment will significantly differ depending whether the equipment is made in isolated phase connections or a 3-in-1 design with a common enclosure for three phases. The design will differ from manufacturer to manufacturer, but, typically, the higher the voltage class, the bigger the likelihood that isolated phase connections will be needed. Prior to manufacture, it is crucial to make sufficient gas zones in the equipment to allow for maintenance or repair without jeopardizing or preventing the operation of nearby GIS equipment. GIS manufacturers may enforce limits on nearby gas zone density differentials, that is, operations may not be allowed to keep full density on one zone while the nearby zone is under total vacuum. For this reason, an intermediate zone may be needed and has to be taken into account.

Consideration needs to be provided for the use of independent valves for the gas zone density gauges or contacts. The benefit of this valve during the maintenance operations typically offsets the small extra cost.

Operational Considerations

Operating staff of the sponsoring utility or independent power producer has to be early involved in the establishment of naming conventions. Some naming conventions examples and standards include: gas zone identification, switch or breaker identification, colour coding, mimic bus patterns, position indication method, viewport and camera use, etc. Operating staff, together with SCADA staff and the transmission authority, needs to be consulted in the formation of SCADA tabulation standards and point priorities. An orderly strategy for commissioning the new SCADA points as they become “live” needs to be assessed with all involved parties.