Compressed Gas Insulated Transmission Bus Systems
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INTRODUCTION

Company Background

CGIT (Compressed Gas Insulated Transmission) Bus Systems have been in use worldwide since 1970. First developed by High Voltage Power Corporation in cooperation with the Massachusetts Institute of Technology, purchased by the Westinghouse Electric Co. in 1974 and purchased by ABB Power T&D in 1989. In 1999 AZZ incorporated purchased the product line. CGIT Westboro, Inc. remains the world leader in the supply of transmission bus for long distance gas insulated bus applications.

Product Background

CGIT provides a compact, reliable and economical alternative to conventional cable systems and overhead lines for power transmission. The effective electric and magnetic shielding afforded through the CGIT design allow for minimized right-of-way requirements as well as safer environmental conditions. Standard CGIT systems are suitable for voltages between 115 kV through 1200 kV with current ratings as high as 6000 Amperes.

The first commercial CGIT system was installed in 1972. Since then, more than 46 miles (75km) of CGIT have been delivered and installed worldwide. Simple and inexpensive interfaces exist to almost all types of high-voltage equipment including GIS, transformers, oil paper cables, and SF₆-air bushings. The CGIT system has been utilized in many unconventional applications in addition to standard transmission paths. The CGIT system can be installed in the following ways:

- At ground level
- Elevated above ground on pillars or support structures
- Below grade in an open or covered trench
- Directly buried underground
- Vertically in tunnels, shafts or towers
- Suspended from existing substation structures

The CGIT system provides economic advantages for installation, operation, and maintenance. A pre-designated number of sections, each terminating in plug/socket joints, are pre-established prior to arrival to site. Type HM contact assemblies provide the high current conductor connections that continue the low loss electrical paths of the system. The lower losses within the CGIT circuits equate to lower operating costs. Once installed, maintenance of the system can be reduced to annual SF₆ gas moisture and pressure checks, and mechanical assembly checks (i.e. bus exterior, supports, etc.). Since the CGIT system includes no active or switching components that may wear during use, it is never intended that the system be opened for inspection or maintenance.

Further advantages of CGIT are:
- No auxiliary pumping or cooling equipment
- No fire hazard
- The safety of dead-front, grounded, construction
- Long life with high reliability
- No radio noise interference
- No appreciable external magnetic fields
- Very low dielectric losses

**CGIT DESIGN FOR SF₆ TRANSMISSION BUS SYSTEMS**

**General Design**

The CGIT bus system is intended for 3-phase, 50 Hz or 60 Hz operation, and is made in fully assembled and factory tested straight modules of up to 18 meters (59 feet) in length. Changes in direction are accomplished with elbows, which are pre-assembled in the factory and high voltage tested prior to shipping.

Each single-phase unit of the CGIT consists of a grounded aluminum enclosure tube containing a concentric tubular aluminum alloy conductor arranged in a coaxial configuration. The conductor is supported using the well-proven and reliable CGIT epoxy insulators. For added reliability particle traps are mounted at each support insulator location. Particle traps were pioneered by CGIT Westboro, Inc., and has been an integral part of the CGIT product since the first installation in 1972.

**Design Considerations**

The design of the CGIT system is based on the following criteria:

- Maximum System Voltage
- Rated Lightning impulse Withstand Voltage (BIL)
- Rated Switching Impulse Withstand Voltage (SIL)
- Power Frequency Withstand Voltage

Table 1 shows the CGIT characteristics for the various voltage classes offered. The critical dielectric design parameter for compressed gas insulated transmission lines is usually the lightning impulse requirements (BIL). Another factor influencing the dimensions of the coaxial system is the ampacity rating. For a high ampacity system the current requirements determine the size of the conductor. Thus, the design of a gas insulated transmission line is an optimization of the dielectric, ampacity and material costs.
### CGIT Systems Characteristics by Voltage Class

<table>
<thead>
<tr>
<th>CGIT Voltage Class</th>
<th>145 kV</th>
<th>242 kV</th>
<th>362 kV</th>
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<td>kg/m³</td>
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Table 1
**CGIT System Dimensions**

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<th>Voltage KV</th>
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**System dimensions and minimum clearance - millimeters**

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</table>

**CGIT Westboro, Inc.**

"Compressed Gas Insulated Transmission Bus Systems"
**Description of Components**

The **CGIT Westboro Inc.** bus system consists of four major elements:

- Conductor
- Enclosure
- Support insulators
- Conductor contacts

A detailed description of the system and key components follows.

**Bus Assemblies**

The basic **CGIT** bus system consists of three parallel isolated phases of coaxial transmission line. Each phase of the transmission line consists of a grounded 6063-T6 aluminum alloy tube, which encloses a concentric tubular 6101-T64 aluminum alloy conductor. The inner conductor is supported within the outer enclosure by solid dielectric insulators. The interior of the bus is filled with \( \text{SF}_6 \) to provide electrical insulation between the inner conductor and the outer enclosure.

The various components of the bus assembly including straight sections, elbows, tees and crosses are factory assembled in shipping units up to 60 feet (18 meters) long. Depending upon the physical requirements of a particular installation, the bus sections may also be factory assembled to switches, breakers or other active station components. The sections are shipped filled with dry nitrogen at 5 psig (35 kPag) to keep the interior of the bus clean and dry.

In the field, center conductors are joined together using plug-in contacts. The outer enclosure is either butt welded with an internal backup ring or bolted together using flanges with double O-ring seals. The joints are then leak checked after assembly. In the case of underground joints, a coating of corrosion protection material is applied. When an electrical proof test and hookup of accessory systems is complete, the bus is ready for operation.

Each section of bus may take many forms: straight, elbow as shown in [Figure 1](#), or tee bus. Multiple assemblies may also be factory-joined to create double elbows, elbow-tee or other combinations. Bus sections are usually constructed with one fixed insulator, which anchors the conductor to the enclosure. On long sections, one or more moving insulators may be included to support the conductor. These moving insulators are rigidly attached to the conductor and are allowed to move at the enclosure to compensate for thermal expansion.

The fixed insulator may be either a Tripost or a conical insulator. The conical insulator may be either a particle barrier with integral filter or a full gas stop insulator used to separate the system into separate gas compartments. On a straight bus section, the fixed insulator is located near one end of the section. On elbow or tee bus the fixed insulator is always located near the elbow or tee element to insure that the conductor in the elbow or tee will remain centered in the enclosure.
The moving insulator is always a Tripost insulator. Between sets of fixed insulators there is always a set of conductor contacts, which compensate for differential thermal expansion movement between enclosure and conductor.

Each section of bus is stamped with a part number and a serial number for positive identification. This stamp is located on the top of the bus at the fixed insulator position.

**Tripost Support Insulator**

The conductor is centered and supported in the enclosure by a Tripost epoxy insulator. The insulator is cast directly to an aluminum sleeve, which is then fixed onto longer lengths of conductor as required. The Tripost insulator is shown in Figure 2.

For fixed insulators, each leg of the Tripost is terminated at the enclosure with an aluminum bar capped with a plastic bearing. The bar is in turn welded to the enclosure. This strap type mounting arrangement provides mechanical flexibility between the conductor and enclosure elements.

The moving Tripost insulator is welded to the conductor in the same way as a fixed insulator. The bottom two legs of the insulator terminate in plastic rollers, which provide for low friction motion between the insulator and enclosure. The top leg terminates in a spring loaded copper graphite contact assembly. This contact assembly provides a reliable, high contact force, electrical connection between the insulator and the enclosure. A Tri-Trap® particle trap (Figure 2) surrounds each insulator.
Conical Insulators

Where it is necessary to have a gas or contamination barrier in the bus, a conical insulator is used. The epoxy insulator is cast onto a short section of conductor, which is then factory welded into a longer conductor section. This insulator is shown in Figure 3. A two-piece grading shield is assembled over the outside diameter of the insulator. This shield is in turn welded to the inside of the enclosure tube. The shield is either welded all the way around with a gas tight weld or only tacked in several places depending on whether a gas barrier or contamination barrier is required. In the case of a contamination barrier, a plastic filter material is mounted between the shield and the enclosure tube. This filter allows free flow of gas from one side of the insulator to the other, but blocks the flow of particulate contaminants. Like the Tripot insulator, the cone is completely surrounded by a particle trap.
Where the conical insulator is used to separate compartments that operate at different gas densities, a flange-mounted insulator may be used. This insulator is the same as internally mounted conical insulators, except that the outside of the cone is sealed between flanges using a double O-ring seal. This configuration insures that there is no possibility of hidden leakage from the higher density section to the lower one.

**Elbows, Tees and Crosses**

Changes in direction or multiple junction points in the bus system are accomplished using elbows, tees or crosses. All are formed by a mitered aluminum joint on the enclosure, and a rounded cast conductor elbow. An insulator nears the junction supports and centers the conductor. Since the support insulator is inside the straight section, the elbow, tee or cross is always factory assembled to at least one straight section of bus. The adjacent field joint is identical to that between two straight sections.

Where additional strength is needed at a turn in the bus, a double miter elbow can be used.

**Particle Traps**

Both the Tripost and conical insulator system include a Tri-Trap® particle trap. Basically, the particle trap provides a region with a very low field between itself and the enclosure. The simple but effective design consists of an aluminum shield with slots that is electrically connected to the enclosure. Any conducting particle is moved by the electric field through the slots into the very low field region. Here the particle is effectively trapped as the field is so low that the particle will not be elevated or moved. During the high-voltage field acceptance test, the voltage is raised in steps specifically designed to move any contamination into the particle traps, thus insuring a completely reliable system. The trap is also installed at low points in the system to trap particles moving under the influence of gravity.

**Finger Contacts**

HM type finger contacts are used throughout the system for joining the center conductors of adjacent sections. This contact is located in the socket end of a conductor. The silver plated plug end of the adjacent conductor slides into the socket. This contact arrangement provides a low-resistance and compact current transfer path.

The HM contact assembly consists of a ring of segmented individually spring biased, silver plated, copper alloy contacts. The surface of the contact is coated at the factory with a lubricant. Care is to be taken when working with the contacts to avoid removing the lubricant or causing dirt to be introduced onto the surface of the contacts.
To reduce the voltage field at the plug and socket, and to insure that any particles generated by the contact do not escape into the dielectric region, a thin aluminum shield is provided. This shield bridges the transition connecting one conductor to another and is secured in place by spring loaded contacts in the conductor. The contacts seat in a groove cut in the I.D. of the shield. An adhesive particle trap is used inside the shield to captivate any particles before they can escape into the dielectric space of the bus.

Inside the conductor a particle filter is installed in both the plug and socket halves of the contact, to prevent particles inside the conductor from migrating into the contact area. The contact assemblies will normally allow a total of over plus or minus 1.5 inches (38 mm) of longitudinal motion and plus or minus 2.5 degrees of angular motion to compensate for assembly tolerance and thermal expansion. Where required in the system a style of bus socket contact is used that can also be offset radially up to 0.1 inch (2.5 mm) to minimize alignment forces when making up a field joint.

**SF₆ to Air Bushings**

Where the SF₆ bus must terminate to an air-insulated component such as a transformer or overhead line, an SF₆ to air bushing is used. The bushing consists of a porcelain shell or composite material filled with the same SF₆ gas pressure as the rest of the CGIT bus.

**Bus Supports**

Periodically the bus sections must be supported from the foundation or other structures. Each installation has a unique selection of support locations and design details to insure that the bus is properly supported. Since aluminum has a rather high thermal expansion rate it is necessary to provide both a fixed type of support to anchor the bus in place and sliding supports to allow the bus sections to move during thermal expansion and contraction.

Both types of supports use a specially shaped support saddle that is welded to the bus enclosure, usually at the factory. The fixed support saddle is in turn bolted or welded to the support structure or foundation. The sliding support uses the same saddle as the fixed support with the addition of plastic glides and a polished stainless steel wear plate on the bottom side. This provides a low friction surface to permit the bus run to move easily during thermal expansion or contraction. Plastic stops are provided to limit the sideways motion of the bus and act as a guide to insure that the motion is in the correct direction. The guides also act as motion limiters during a seismic event.
APPLICATIONS OF SF\textsubscript{6} CGIT BUS

Introduction

CGIT bus has many applications beyond its use in new GIS installations. Following are the major installation types that demonstrate the range of applications:

- Power Plant Optimization
- Transmission Line Crossing
- Underground Transmission
- Long Vertical Shafts
- Elevated Installations
- Retrofit of Existing Installations
- Long-term Extensions

Power Plant Optimization

One of the greatest problems in the design of a power substation is how to maximize its potential while maintaining safe conditions for workers as well as the surrounding environment. The greatly reduced electric and magnetic fields as well as the superior dielectric strength of SF\textsubscript{6} gas allow for exceptionally compact transmission systems with high power capabilities.

For example, the outside diameter of the enclosure sheath for 362 kV service is only 15 inches (381mm). And since the phases are installed only 22 inches (599mm) apart (center-center), a typical 3 phase system would require a trench of only 6 feet (1.85m) wide. In addition, the right of way width can be reduced to less than 10% of the right of way required by conventional overhead lines.

CGIT systems are more adaptable to tight space limitations than oil-filled cable systems because CGIT lines can turn corners at extremely sharp angles, unlike the large radius bends required by oil-filled cable. Also, the large current carrying capacity of CGIT allows the combination of outputs from multiple generator step-up transformers into feeder circuits, resulting in more compact transmission line and GIS arrangements than would be required with cable.

Both of these advantageous aspects of CGIT bus are exemplified in the project described below, the PP8 Generating Power Station, in Saudi Arabia.
**PP8 Power Station**

The PP8 Generating Power Station, in Saudi Arabia, originally consisted of three power generating units, each with a separate step-up transformer. A GIS substation was to be located at the opposite end of the plant, requiring the transmission of the generator output power through a considerable distance to reach the GIS.

The space available for transmission lines between the transformers and the GIS was limited at grade level by roadways and other equipment and structures, and below ground by multiple buried installations. This meant that the transmission line would have to be elevated, would have to negotiate several tight changes in direction, and had to be as compact as possible.

In addition, the long range design for the plant called for the future addition of two new generating units, and thus provisions had to be made to allow for the planned increase in transmission capacity.

**CGIT** bus proved to be the optimum answer to these requirements. The original layout consisted of three independent circuits of 380 kV bus, on elevated steel supports and overlapping each other, each connecting a step-up transformer to the GIS, with an average circuit length of over 750m. The overlapping circuits had a narrow footprint, and shared common supports for most of their length.

Additionally, the bus was designed with reserve capacity to allow for the increase in current that would result from the planned generating capacity expansion. When two new transformers were added later on, they required only two short new runs of bus to connect them to two of the existing circuits. This approach avoided the need for two full additional circuits of approximately 600m each, and also the need to add switching modules to the GIS, since the original GIS was also designed with reserve capacity to absorb the increased current supply.

*Figures 3a & 3b: PP8 Power Station – Saudi Arabia*
Line Crossings

Occasionally, a situation arises in which existing substations looking for an extension finds itself limited by the amount of line congestion. Such conditions are hard solved without the use of CGIT bus. Proper clearances will not be achieved with air-insulated bus. Oil cable and solid dielectric cable are both limited in their abilities for directional changes (i.e. angles). Typical examples of usage of CGIT bus in these situations are the Rowville, Australia, and Peñuelas, Puerto Rico, projects.

Rowville Project

Rowville is a 550 kV above ground installation located in Melbourne, Australia. The sole purpose of the gas insulated bus was to safely transmit two, three-phase circuits of 550 kV power across an existing 230 kV overhead transmission corridor. The customer’s main concern in this project was the possible mechanical failure of either the 230 kV or 550 kV (if overhead lines were used) transmission towers or lines. Failure of one or the other could result in damage to the lower feeder such that outages would be much more inclusive and costly.

The grounded enclosure sheath of the CGIT, however, would protect the ground level 550 kV line from breakdown and prevent further outages to result from 230 kV line failure. A spare phase was installed at the request of the customer as a further precaution should a single phase of CGIT experience a breakdown. In the event of single-phase failure, this would reduce the outage time to a matter of hours by simply adjusting the line feeder leads accordingly.

Figure 4: Rowville Project, Australia.
Peñuelas Project

The Penuelas project in Puerto Rico required a compact installation for a 230 kV line crossing under existing overhead lines, and also had to meet particular environmental and access requirements imposed by wetlands and roadways at the site. The CGIT bus supplied by CGIT Westboro Inc., besides allowing the addition of a new 230kV circuit under the space constraints of the existing lines, made it possible to cross over underlying wetlands with minimum impact. Part of the bus, running inside a steel truss bridge, spans without interference a natural floodwater stream. Another section runs under a roadway, in a covered trench. Figures 5-a and 5-b show both aspects of the installation.

*Figure 5-a. Peñuelas Project. Bus over floodwater stream.*

*Figure 5-b – Peñuelas Project. Bus under roadway*
**Underground Transmission**

There are two kinds of underground CGIT installations; direct-buried and trenched. Direct buried has the advantage of lower cost installations in open fields. Trenches are necessary when crossing roads or installing in areas where water tables are close to ground level. Either way, below-ground installations are more aesthetically pleasing, provide less above ground congestion, and result in lesser right-of-way distances. Hudson Switching Station in New Jersey, USA and the Midway Sunset Cogeneration in California, USA are two examples, respectively, of these types of installations.

**Direct-Buried**

The aluminum sheath of a CGIT transmission line, while made of a corrosion resistant aluminum alloy, is still subject to corrosion when buried in the earth. One way to prevent corrosion is to bias the aluminum relative to the earth such that it becomes cathodic, that is, its potential relative to the earth is made negative.

A zinc anode is utilized to this cause and is in effect sacrificed and corrodes in place of the aluminum. A Cu-CuSO4 half-cell is used to meter the potential of the buried metal compared to the earth. Polarization cells are also utilized to provide a special means of grounding the system for AC fault currents. In order to prevent underground currents from transmitting into the sheath of the bus, an extruded polyethylene coating is applied to the underground portion of the CGIT enclosure. A complete coating, cell and metering set up is provided for each end of the underground line for every CGIT direct-buried installation.

**Trenched**

Road crossings are the main consideration when choosing trenched installations. The Midway Sunset Cogeneration Project is a perfect example of the advantages of trenched transmission. The layout consisted of three 242 kV circuits. Each circuit crossed the path of the plant’s main access road. Placing the CGIT in trenches allowed for an undisturbed road routing as well as access to the trench’s access panels for easy installation and maintenance of the bus between the GIS and connecting transformers. Figure 6 shows a typical combined trenched and above ground installation.

*Figure 6: Combined Trenched and Above Ground Installation*
Long Vertical Shafts

Hydroelectric generating stations often require transmission of the energy over large vertical distances. Since it is usually more economical to transmit the power at transmission voltages rather than the generation voltage, the step-up transformers are often located at the lowest elevation while the transmission system is most accessible at higher elevations.

At transmission voltages, there are four possible methods to transmit this power:

- Air insulated bus
- Oil cable
- Solid dielectric cable
- SF₆ Gas Insulated Bus

The air-insulated bus would require large clearances. Shaft sizes would need to be very large to accommodate this solution. In addition, there is a significant safety hazard due to the exposed high voltage conductors.

While the oil cable would solve the size problem, it has two distinct disadvantages: (1) Large vertical drops result in very large pressure heads, and (2) Since oil burns easily, a real fire hazard exists should a fault occur in the cable system. If a fault were to occur in one cable circuit, the potential fire would spread to the adjoining circuits eliminating all power transmission capabilities. Solid dielectric cable, while not as flammable as oil cable, still offers a fire hazard. Close attention to support over the vertical distances would be required to prevent the cable from stretching and failing, especially at field splices.

The utilization of SF₆ CGIT bus for vertical shaft applications offers the following advantages relative to the other technologies:

- Since the SF₆ bus is enclosed and grounded, clearances can be small thus reducing the required shaft size. Also, the dead-front construction eliminates any high voltage safety hazards.
- SF₆ is an inert gas and will not burn, so there is no fire hazard. Since SF₆ is a gas, the pressure head is very low; typically about 10 psi per 1000 feet of vertical head.
- The design of SF₆ bus enclosures offers little risk of stretching or mechanical damage. Since the joints offer the same mechanical strength as the balance of the bus system, no elaborate support methods are required.

The CGIT Westboro System concept has been successfully applied in vertical installations. An existing installation at the Southern California Edison Balsam Meadows Station, operates at 242 kV and transmits 200 MW of power up a 1000-foot vertical shaft.
Balsam Meadows Hydro Electric Station

The 242 kV, 1200 amp system was installed over a six week period, in 1987. The shaft is 1000 feet high, and 20 feet in diameter. In addition to the SF$_6$ bus, the shaft contains an elevator, power and control cables, and functions as a ventilation shaft.

Short horizontal sections at the top and bottom ends of the bus run connect to the overhead lines and transformer, respectively. Conventional air connections were chosen for the transformer connection to keep the electrical system simple. Gas insulated disconnect switches, ground switches, and surge arresters are not required. The conventional air bus link and surge arresters in the transformer room provide all of these functions (Figure 7-a).

The entire 1000 foot vertical run of SF$_6$ bus is hung from a single support near the top of the shaft. Each 20,000-pound phase is guided and supported horizontally at forty-foot intervals. This is done both to provide seismic restraint during normal service, and to prevent column collapse of the bus during installation and service, at which time the bus is supported from the bottom of the shaft. A hydraulic ram system beneath the elbow at the bottom of the shaft acts as a seismic damper during normal service and provides support for the bus during installation and maintenance. Thermal expansion of the bus is accomplished by flexing at the bottom elbow. No enclosure expansion joints are required.
Because the station is in the Sierra Mountains, where winter access to the summit is limited, the station is designed with a permanently mounted crane at the top of the shaft. To minimize outage times should a fault ever occur, a complete spare 252 foot gas zone is hung at the top of the shaft, ready to be installed at a moments notice. The station was commissioned in July 1987, and has functioned without incident.
Revelstoke Hydro Project

Another example, this not quite in a vertical shaft but in a long inclined tunnel, is in British Columbia Hydro’s Revelstoke Project, in Canada. This hydroelectric plant included a multiple stage GIS arrangement, for which CGIT provided the best solution given the particular connection requirements and the installation constraints.

Within the Power house, there are gas insulated breaker/grounding switch sets at each step up transformer output, and a dual set of 500kV GIS connecting the generator transformers output into two main feeder circuits. At the substation building end, another set of 500kV GIS modules connects the feeders to the outgoing overhead lines; a separate 230kV GIS receives incoming power for internal plant service.

The connections from the transformer breakers to the powerhouse GIS, and between the later and the substation GIS were all made with dual circuits of 500kV CGIT bus. The GIS-to-GIS portion runs almost entirely inside an 1830m long, inclined tunnel (Figure 8).

Another CGIT bus circuit, outside the substation building, connects the incoming 230kV power line bushings into the secondary GIS, from which cable lines bring the power into the rest of the plant.

The CGIT bus allowed a compact installation along the walls of the tunnel, and, because of its fully grounded enclosure, it permitted the use of the tunnel as the main access route to the powerhouse with minimum space interference and no electrical hazard to personnel.

![Figure 8: Revelstoke Hydro: Bus inside tunnel](image)
Elevated Installations

Every station layout design has certain physical boundaries to which the transmission components must adhere. When determining a transmission line route through a given area, the choice of available power transmission methods may become limited. If the space available precludes the use of air-insulated bus, and the lack of available land prevents continuous a transmission line at ground level or below grade, one solution is to elevate the bus system. An example of this type of installation is the Teesside Power Plant.

Teesside Power Plant

Teesside is a 1725 MW combined-cycle gas-fired power plant located in the United Kingdom. The arrangement of the generators and transformers, and the location of the gas insulated switchgear created a need for an extensive array of 275 kV, 1200 amp transmission links.

The amount of space available for this power transmission was very limited. An installation below grade was not possible due to the existing system of underground lines, steam pipes, etc. In addition, the water table in this region was located approximately three feet below grade, which would require any underground transmission lines to be placed in a concrete trench. A ground-level arrangement was not possible due to roadway requirements.

What was required was an elevated compact power line. For this application, CGIT was selected. The overall installed cost of the CGIT was less than oil cable, and the level of experience at these system ratings favored CGIT as well.

What made this project unique for CGIT Westboro was the height requirement. Due to the proposed structures and access requirements, the CGIT bus ran at elevations as high as 29 feet above grade. Support structures for this project were designed to hold as many as five circuits (fifteen phases) of bus, with at least six phases running at the maximum height.

One important consideration in the bus layout and piping analysis of the system was thermal expansion of the enclosure. The system must accommodate the enclosure growth experienced due to temperature rise. This can be done using expansion bellows, but at an elevation of 29 feet, the supporting requirements to withstand the pressure thrust of an expansion bellows would be prohibitively expensive, and would create excessive foundation loads. Another option is to fix the bus near the mid-point of each long run, to direct the growth toward an elbow. In this case, and the flexibility of the mitered elbows allowed sufficient growth, eliminating the need for expansion bellows. The Teesside Project, consisting of over 18,000 phase feet of SF₆ gas insulated bus, was installed and commissioned in 1992. Figures 9-a and 9-b show the installation application and overall view of the CGIT bus at Teesside.
Figures 9-a & 9-b: Teesside Combined Cycle Power Plant - United Kingdom
**Retrofit of Existing Installations**

Substations often require new equipment to upgrade existing facilities, or to replace damaged equipment. This can require interfacing to equipment from different manufacturers and technologies of existing equipment. If damage occurs to an in-service substation, replacement parts are required immediately to minimize outage time.

In the case of a retrofit to an existing GIS substation, the ability to design and install a variety of interfaces, and to allow sufficient installation tolerance is paramount. The existing equipment could include GIS supplied by different manufacturers who may follow different design philosophies and operating parameters.

In other retrofit cases, outdated equipment must be replaced. Here again, the challenge is to minimize the outage time required to affect the change, and to use as much existing peripheral equipment as possible to reduce costs.

**CGIT** offers solutions to the problems faced when retrofitting existing installations. One completed **CGIT** retrofit project involves the GIS at the Consolidated Edison Dunwoodie station in Yonkers, New York.

**Consolidated Edison Dunwoodie Station**

The original Dunwoodie substation was commissioned in 1974. The layout is a 345 kV ring bus arrangement consisting of six dual-pressure ITE circuit breakers and interconnecting ITE bus duct. The station contains G & W oil cable pothead interfaces and GE capacitive voltage transformers (CVT’s). The substation also has three feeders with SF₆-air bushings to overhead lines. The Dunwoodie substation functioned well until 1988 when Consolidated Edison experienced an oil cable fire which destroyed a circuit breaker, the adjacent oil cable pot heads, interconnecting breaker bus, and disconnects.

In response to Consolidated Edison's emergency requirements, **CGIT** Westboro provided interconnecting breaker bus to bypass the damaged breaker position and re-energize the ring. The **CGIT** bus left future expansion capabilities to interface to a new circuit breaker position that would be supplied at a later date. The interconnecting bus required adaptations to existing ITE bus. **CGIT** Westboro was the only manufacturer that could respond to this emergency.

In 1990, Mitsubishi Electric provided a replacement GIS circuit breaker, and again **CGIT** Westboro provided the necessary interconnecting bus, which this time included interfaces to both ITE and Mitsubishi GIS. At the same time, **CGIT** Westboro developed a CVT design to replace those formerly provided by GE, and an additional feeder position of SF₆ air bushings was provided.

Con Ed recognized the need to upgrade the entire ring to improve reliability of this key substation, and is continuing the retrofit process. At this time, three breaker positions have been replaced. Eventually all six breakers will have been replaced, with the possibility of a two breaker extension.

**Seabrook Nuclear Power Plant Substation.**

Another retrofit example is the Seabrook gas insulated substation project, consisting of 345kV ITE GIS and Bus, had developed a history of unreliability
due leaks and insulator failures within the bus. This was a particularly cause of concern within areas of the substation that were not protected by redundant sections of the installation, thereby having no backup in case of section bus failures.

**CGIT** bus, backed by its established record of reliability in long-term service, was selected to replace the ITE bus for these critical connections. They involved connections from the GIS to both main transformers and to auxiliary transformers.

In addition to offering a reliable bus design, **CGIT** Westboro was able to complete the installation within a one-week outage to comply with the NRC approved outage schedule, and under tight space and access conditions.

The first of the Seabrook **CGIT** bus installations has been in service without fault since its completion in 1990.

![Figure 10 – Seabrook Nuclear Plant Substation – Bus to Transformer Connections](image)
**Long-Term Extensions**

Retrofit projects like Dunwoodie were unplanned; however, many existing GIS substations have been designed with provisions for future expansion. When a utility is able to anticipate growing needs, and foresees necessary technological advances, substations can be designed to accommodate both short- and long-term requirements.

Many of the same challenges presented by a retrofit project are also encountered when expanding existing stations. There are various interfaces to be designed, and restrictive outage schedules that must be adhered to. In addition, the supplier of the expansion equipment must compile enough station data to ensure that the new equipment does not interfere with any existing equipment. Also, system ratings may have changed based upon customer experience, or load growth.

The Ontario Hydro Claireville TS in Toronto, Ontario, is an example of such an extension.

**Claireville**

Often gas-insulated substations only allow unidirectional reductions in yard dimensions due to the space needed for incoming lines. At the Claireville TS, Ontario Hydro reduced yard dimensions in all directions with the "spaghetti junction" arrangement of bus circuits. The decision to use GIS switchgear was based on the size of the station and its location near urban centers. A conventional station at Claireville would require approximately two hundred acres of land. The use of GIS switchgear reduces the space requirement to about forty acres.

The Ontario Hydro Claireville TS was initially commissioned in 1975 and has undergone several phases of expansion over several years. The station consists of gas insulated switchgear and multiple layers of **CGIT** bus, arranged to untangle line exits and feed twenty-six 550 kV and fifty-two 250 kV circuit breakers. The GIS is housed in an elevated switchgear building, and the **CGIT** bus exits through the floor. Incoming lines enter the Claireville substation along power corridors from the North, South, East and West.

The latest extensions of the Claireville TS are currently installed. These include the following:

- One bay of 250 kV GIS and three circuits of **CGIT** line exits. The system requirements were increased from 3000 to 4000 amps per circuit.
- One bay of 550 kV GIS and three circuits of **CGIT** line exits. The BIL requirement for the bus increased from 1550 to 1800 kV.
- Three circuits of 550 kV **CGIT** interfacing to existing **CGIT** Westboro and GEC Alsthom (now Alstom) GIS.
- Four circuits of 250 kV 4000 amp bus interfacing to existing 230 kV 3000 amp bus.
For these most recent extensions, over approximately 12,500 feet of CGIT was supplied. In order to ensure that this bus did not interfere with existing equipment, a layered CAD file was created, and included the following:

- Three levels of existing bus
- Foundation footings
- Drainage pipes
- Cable trays
- Stairways
- Access roads
- Building columns

The proposed routings for the new bus extension were added to this file, and revised as was needed to prevent interference. The routing of the bus, piping analysis, and foundation location became an iterative process due to the magnitude of potential interference points.

Other design parameters involved installation considerations. Requirements include clearances for welding, personnel access, and coordinating a practical installation sequence with the allowable outage schedules. At that time, installation was proceeding in accordance with the scheduled outages and manpower availability. Figure 11 shows the condensed installation of existing GIS equipment and new CGIT bus.

![Figure 11: Claireville Extension - Ontario, Canada](image-url)
CONCLUSION

For more than twenty-five years CGIT has been selected for a wide range of unique applications, and the uses of CGIT are not limited to GIS installations. The examples outlined above -- power plant optimization, line crossings, underground transmission, long vertical shafts, elevated installations, retrofits, and extensions -- each solve a unique problem.

CGIT has many distinct advantages over other methods of power transmission. Low required clearances, safe operating conditions, and the ability to route right-angled transmission make CGIT an ideal candidate for both conventional and unconventional applications.

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