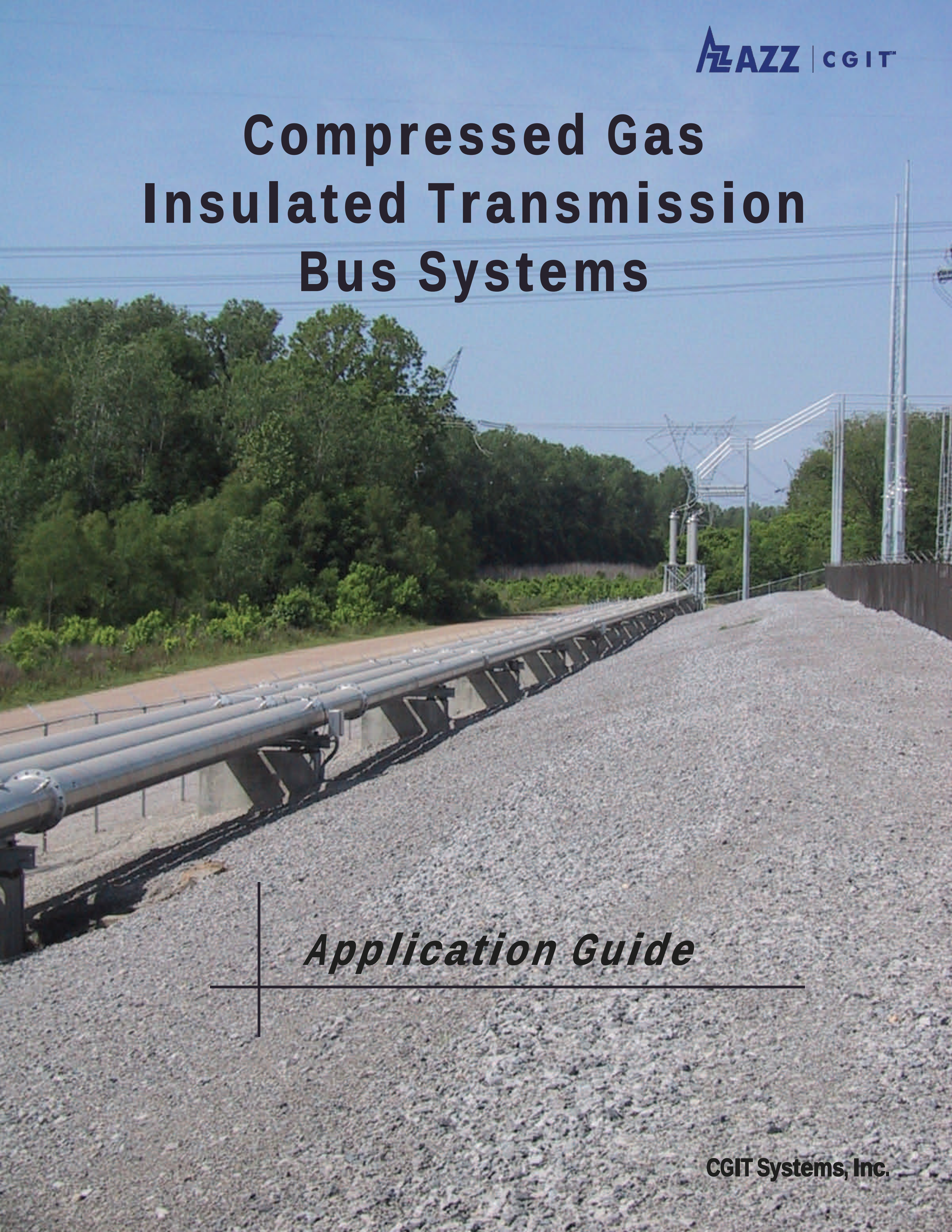
Compressed Gas Insulated Transmission Bus Systems



Application Guide

CGIT Systems, Inc.

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Company Background

CGIT: Compressed Gas Insulated Transmission

CGIT bus systems have been in use worldwide since 1972. First developed by High Voltage Power Corporation, in cooperation with the Massachusetts Institute of Technology, CGIT bus systems provide a compact, reliable method for transmitting large amounts of power over long distances. High Voltage Power Corporation was purchased by Westinghouse Electric in 1974, then ABB in 1989, and AZZ incorporated in 1999. Since it's inception, CGIT Systems, Inc. has been the world leader in supplying proven solutions for long distance power transmission applications.

Baxter Wilson Power Plant, Mississippi, USA
550kV, 3000A Grid Connection Across Transmission Lines

CGIT Applications

CGIT provides a compact, reliable and economical alternative to conventional cable systems and overhead lines for power transmission. The effective electric and magnetic shielded design minimizes right-of-way requirements and provides safer operating conditions than air insulated equipment, or conventional cable systems. Standard CGIT systems are suitable for transmission voltages from 115 kV to 1200 kV, with continuous current ratings as high as 5500 amperes. The first commercial CGIT system was installed in 1972, and is still in operation today. Since then, more than 79 miles (127 km) of CGIT bus systems have been delivered and installed worldwide. Simple and inexpensive interfaces exist for almost all types of high-voltage equipment, including GIS, transformers, oil cables and XLPE cables. Connections to air insulated substations and transmission lines are easily accomplished through the use of SF_6 to air bushings. CGIT systems have been used to solve numerous problems in substation design, transmission line applications, and power plant de-

GIS Substation Connections

- Overhead line and power transformer connections
- Expansion of existing GIS substations

Substation Extensions

- Cross existing air insulated bus and transmission line connections

Rowville Substation, Australia
550kV, 3000A Transmission Line Crossing

Power Plant Designs

- Combine the output of multiple transformers into a single circuit of CGIT bus to reduce substation size and switchgear requirements
- Install connection circuits above ground to promote access when space is limited underground
- Quickly connect to the transmission grid with reduced permitting time compared to overhead lines

Hydroelectric Power Plants

- Install CGIT bus systems in vertical shafts to transmit power from the underground powerhouse
- Connect multiple transformers into a single CGIT bus circuit to reduce tunnel sizes

Transmission Line Applications

- Cross under existing transmission lines where new transmission connections are required
- Move transmission lines underground for aesthetic reasons or to reduce land usage

CGIT Design for SF_6 Transmission Bus Systems

The CGIT bus system is intended for three phase, 50 Hz or 60 Hz operation, and is made in fully assembled and factory tested sections up to 18 meters (60 feet) in length. Changes in direction are accomplished with elbows, which are pre-assembled to individual shipping sections in the factory. The CGIT elbow design enables changes in direction of any angle from 89 degrees through 179 degrees. This provides designers with flexible layout options and a more economical solution by decreasing the total system length. The CGIT system also includes pre-assembled tee sections for branch circuits and connections to other system components including SF_6 surge arresters and potential transformers.

Each single-phase unit of CGIT bus consists of a grounded aluminum enclosure with a concentric 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 and at each low point in the system. The CGIT particle trap design enables installation in adverse conditions and supports long term system reliability. Particle traps were pioneered by CGIT Systems, Inc., and have been an integral part of the CGIT product since the first commercial installation in 1972.

The CGIT system provides economic advantages for installation, operation, and maintenance. The longer section lengths are unique to CGIT's design and decrease the number of connections required during installation and lowers the risk of gas leakage during operation. HM Contact assemblies provide the high current conductor connections that provide the low loss electrical path of the installed system. The low losses within the system lowers overall operating costs. Once installed, maintenance of the system can be reduced to annual SF_6 gas moisture and pressure checks, and mechanical assembly inspections (bus exterior, supports, bellows assemblies, etc.). Since the CGIT system includes no active or switching components that may wear during use, the system does not require internal inspection or maintenance. The robust CGIT system is designed to provide fifty years of operation for a long term, reliable, and low operating cost solution for power transmission applications.

Revelstoke Hydroelectric Plant, British Columbia, Canada
550kV, 4000A CGIT System Installed in Inclined Tunnel

Benefits of the CGIT Design

- Continuous current capacity through 5500 amperes
  - Decreases the number of circuits required in power plant and substation design
- Small right of way requirements
  - Resolves limited space issues that prevent use of air insulated bus or overhead transmission lines
- Designed for fifty years of reliable operation
  - Exceeds the life expectancy of cable systems and lowers total ownership costs
- Flexible installation options
  - CGIT bus systems can be buried underground or installed in trenches, on supports above ground, or in vertical shafts
- Longer section lengths with fewer field joints
  - Reduces installation time and risk of gas leakage during operation

Flexible Installation Options

CGIT provides a compact solution with multiple installation options. When above ground space is limited, CGIT systems can be buried underground. This can free up space for development, and provide an aesthetically pleasing solution in populated or environmentally sensitive areas. With continuous current ratings in excess of 3000A, a single circuit of CGIT bus can be used to place an existing overhead transmission line underground. Other installation options for CGIT bus systems include the following:

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

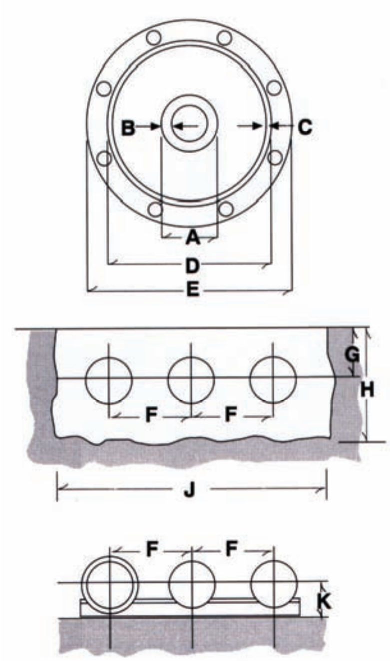
Decatur Substation, Nevada, USA
242kV, 1200A CGIT System Installed in Open Trench

Valley Substation, California, USA
550kV, 4000A CGIT System Installed on Elevated Supports

CGIT System Technical Data

Voltage Class	Typical CGIT Bus System Dimensions - millimeters									
	A	B	C	D	E	F	G	H	J	K
145 / 172 kV	89	15.2	7.6	241	343	368	914	1219	1270	241
242 / 300 kV	102	12.7	7.6	307	406	457	914	1219	1524	318
362 kV	127	12.7	6.4	375	483	559	914	1219	1829	356
420 / 550 kV	178	12.7	6.4	508	648	711	914	1321	2286	457
800 kV	178	12.7	7.9	676	775	1000	1067	1524	2921	533
1200 kV	203	12.7	9.5	762	889	1016	1219	1676	3099	610

Voltage	Typical CGIT Bus System Dimensions - inches									
	A	B	C	D	E	F	G	H	J	K
145 / 172 kV	3.5	0.6	0.30	9.50	13.5	15	36	48	50	9.5
242 / 300 kV	4.0	0.5	0.30	12.10	16.0	18	36	48	60	12.5
362 kV	5.0	0.5	0.25	14.75	19.0	22	36	48	72	14.0
420 / 550 kV	7.0	0.5	0.25	20.00	25.5	28	36	52	90	18.0
800 kV	7.0	0.5	0.31	26.63	30.50	39.37	42	60	115	21.0
1200 kV	8.0	0.5	0.38	30.00	35.0	40	48	66	122	24.0



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CGIT Design Specifications

CGIT system design 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
- Continuous Current Rating
- Peak Short Time Current Rating

The critical dielectric design parameter for CGIT bus systems is the lightning impulse requirement (BIL). The other critical parameter influencing the overall design is the continuous current rating. For a high ampacity system, the current requirements determine the size of the conductor and enclosure. The design for any CGIT system installation is an optimization of the dielectric and ampacity design requirements, and material costs. The following table shows CGIT system ratings for the standard voltage classes available.

CGIT System Ratings								
Rated voltage		kV rms	145 / 172	242 / 300	362	420 / 550	800	1200
One minute power frequency withstand voltage		kV rms	310/365	425/460	500	740	960	1200
Lightening impulse withstand voltage		kV peak	650/750	900/1050	1050/1300	1550	2100	2175
Switching surge insulation level		kV peak	540/600	720/750	850/950	1175	1550	1800
Frequency		Hz	50/60	50/60	50/60	50/60	50/60	50/60
Open air current rating [1]		A	2500	3000	3500	4500	5000	5500
Power loss—open air	Per phase foot	W	36	46	52	71	79	74
	Per phase meter	W	117	150	170	232	260	242
Direct buried current rating [2]		A	1200	1500	2000	2300	2400	3750
Power loss—direct buried	Per phase foot	W	11	12	13	16	14	35
	Per phase meter	W	35	39	44	51	47	115
Short circuit current	3 seconds	kA	63	80	100	100	100	100
Effective AC resistance	Per phase foot	μΩ	5.72	5.09	4.24	3.5	2.49	2.44
	Per phase meter	μΩ	18.78	16.71	13.90	11.47	8.17	8.01
Capacitance	Per phase foot	pf	18.1	16.0	16.2	16.5	12.91	13.0
	Per phase meter	pf	59.5	52.6	53.1	54.2	42.34	42.7
Inductance	Per phase foot	μH	0.057	0.064	0.064	0.062	0.078	0.079
	Per phase meter	μH	0.187	0.211	0.210	0.205	0.255	0.260
Surge impedance		Ω	56.0	63.4	62.8	61.5	78.7	78.0
Enclosure diameter		mm	241.3	307.3	374.7	508.0	676.3	762.0
		inches	9.5	12.1	14.8	20.0	26.6	30.0
Conductor diameter		mm	88.9	101.6	127.0	177.8	177.8	203.2
		inches	3.5	4.0	5.0	7.0	7.0	8.0
Weight of bus without SF_6 gas	Per phase foot	lbs.	17.47	20.54	22.81	31.79	41.95	50.59
	Per phase meter	kg	26.00	30.57	33.95	47.31	62.35	75.28
Weight of SF_6 gas [3]	Per phase foot	lbs.	0.76	1.31/1.43	2.03/2.22	3.85	6.90	8.88
	Per phase meter	kg	1.13	1.95/2.13	3.02/3.30	5.72	10.26	13.21

1. Open air current ratings are based on an ambient temperature of 40 degrees C, with solar radiation, and temperature rise limits in accordance with IEC requirements. Higher current rating designs are available.
2. Direct buried current ratings are based on a soil ambient temperature of 20 degrees C and the phase spacing and burial depths specified. The direct buried current ratings can be increased by increasing the installed phase spacing.
3. Nominal fill pressure 55 psig (480kPa) or 60 psig (515 kPa) depending on system requirements.

Description of CGIT Components

Bus Sections

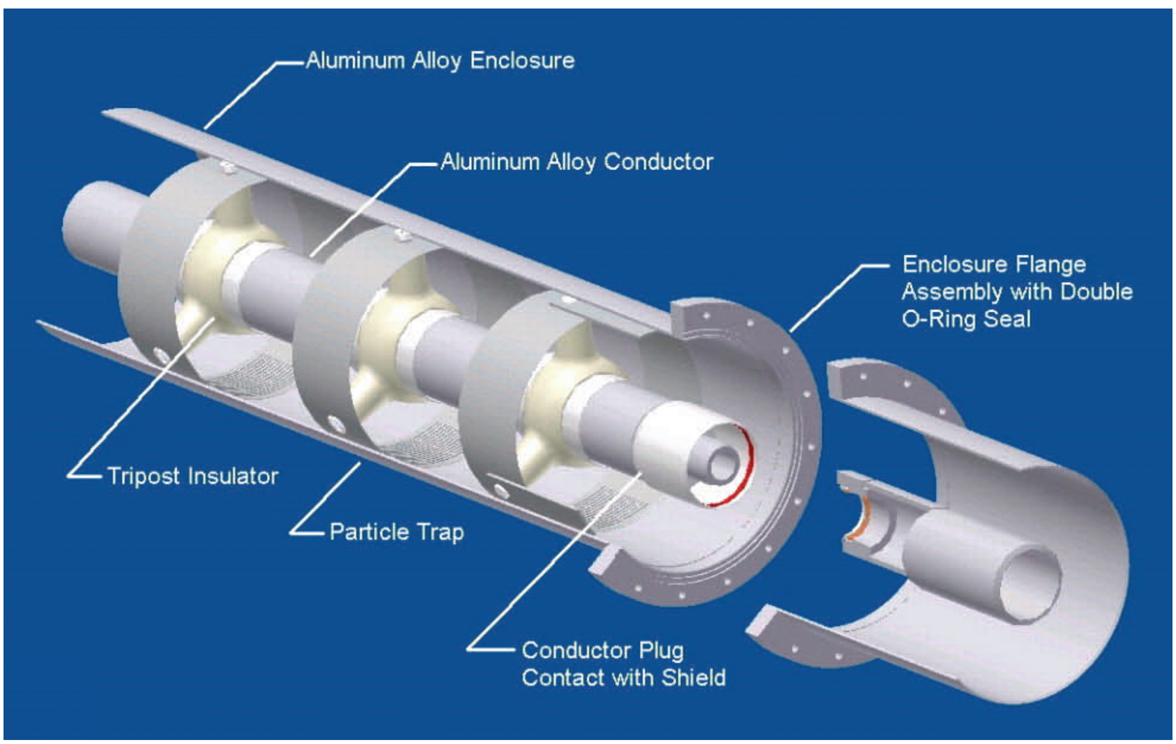
The basic CGIT bus system consists of three parallel phases of isolated coaxial transmission line. Each phase of the transmission line consists of a grounded aluminum alloy tube, which encloses a concentric tubular aluminum alloy conductor. The inner conductor is supported by solid dielectric insulators. The interior of the bus is filled with SF_6 gas 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 18 meters (60 feet) long. The assembled sections are factory tested and filled with dry nitrogen (N_2) at 5 psig (35 kPag) to keep the interior of the bus assembly clean and free from moisture during transportation.

Each section of CGIT bus may take many forms: straight, elbow, tee or cross assemblies. Multiple sections may be factory-joined to create double elbow sections, elbow and tee sections, or other combinations. Bus sections are usually constructed with one fixed insulator, which fixes the conductor within 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 within the enclosure to compensate for thermal expansion.

The fixed insulator is either a Tripost or a Conical epoxy insulator. The Conical insulator may be a contamination barrier with an integral filter, or a gas barrier insulator 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, tee, or cross bus sections the fixed insulator is always located near the elbow, tee, or cross element to insure that the conductor in the elbow or tee will remain centered in the enclosure.

During installation, center conductors are joined together using plug-in contacts. The outer enclosure can be welded 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 field test and installation of accessory systems is complete, the CGIT bus system is ready for operation.

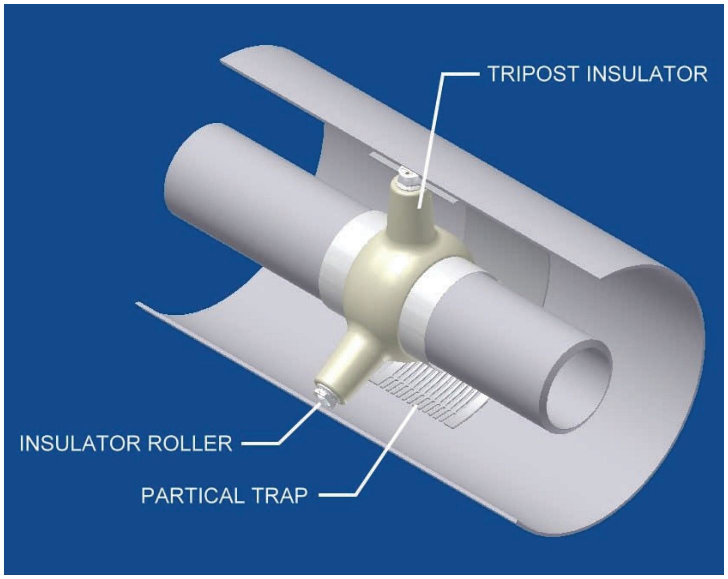


CGIT Bus System Design

Tripost Support Insulators

The CGIT system uses Tripost insulators to support the conductor in most locations. The insulator is cast directly to an aluminum sleeve, which is then fixed onto the conductor. Each Tripost insulator is surrounded with a Tri-Trap® particle trap to increase system reliability. For fixed insulators, each leg of the Tripost insulator is fixed to the enclosure with aluminum straps. This strap type mounting arrangement provides mechanical flexibility between the conductor and enclosure elements.

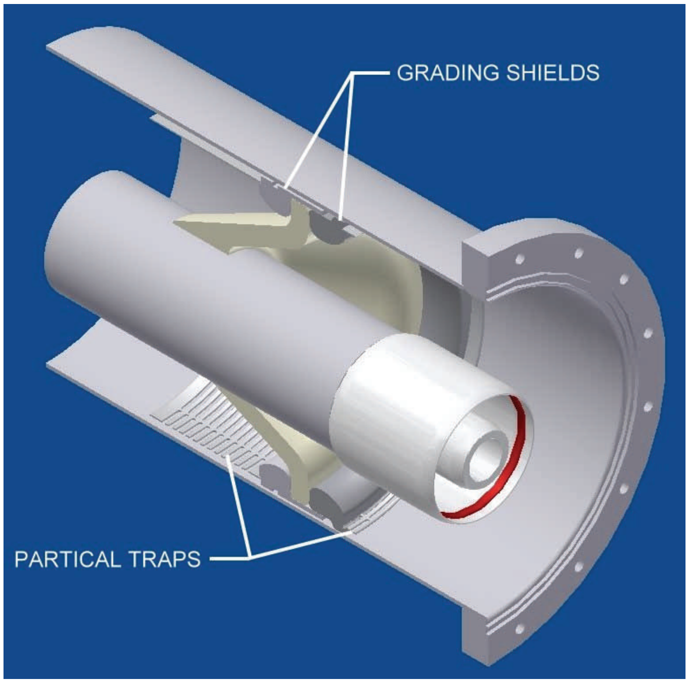
The moving Tripost insulator is rigidly attached to the conductor in the same way as a fixed insulator. The bottom two legs of the insulator include rollers which allow low resistance motion between the insulator and the enclosure. The top leg terminates in a spring loaded copper graphite contact assembly. This contact assembly provides a reliable electrical connection between the Tri-Trap particle trap and the enclosure.



CGIT Tripost Insulator

Particle Trap System

Tripost and Conical insulator systems include a Tri-Trap® particle trap. The particle trap is electrically bonded to the enclosure and provides a region of low voltage potential between the particle trap and the enclosure. The simple but effective design consists of a slotted aluminum shield that allows particles to pass through to the zero or low potential 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 reliable system operation. The trap is also installed at low points in the system to trap particles moving under the influence of gravity.



CGIT Gas Barrier Insulator

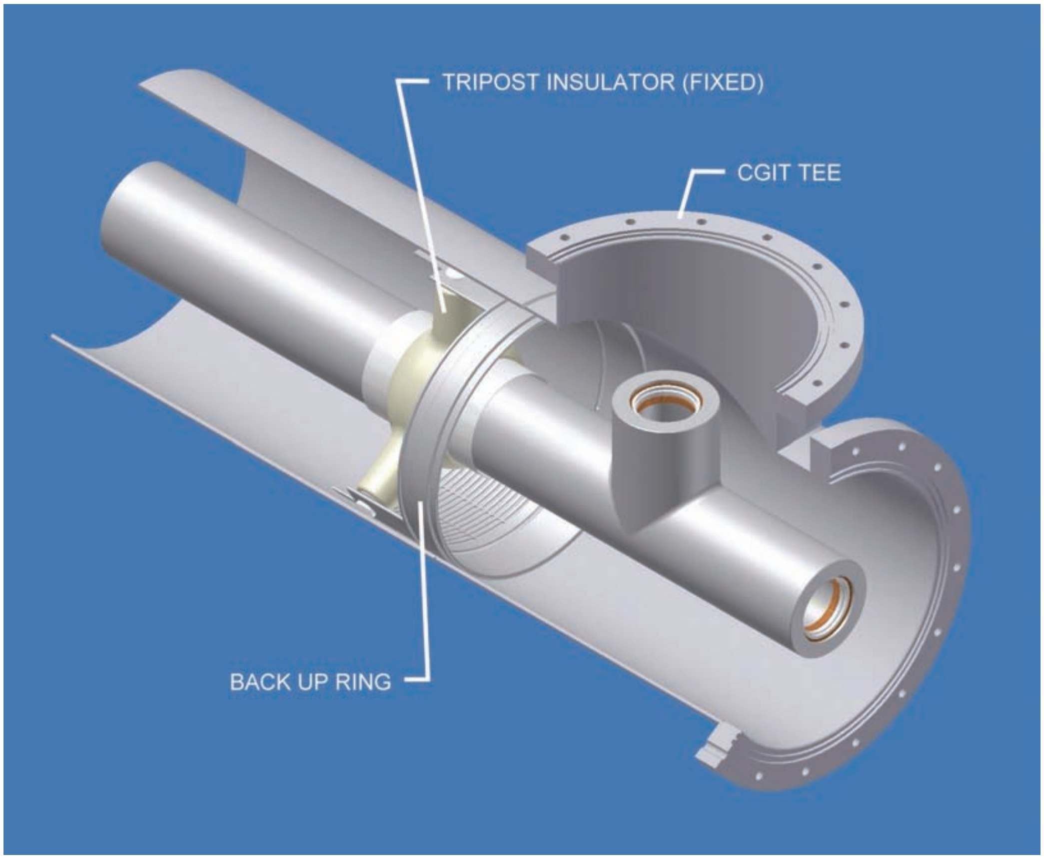
Gas Barrier Insulators

Where it is necessary to separate gas compartments or provide a contamination barrier, a Conical gas barrier insulator insulator is used. The Conical insulator is cast onto a short section of conductor, which is then factory welded into a longer conductor section. A two-piece aluminum grading shield is assembled over the outside diameter of the insulator. This shield is in turn welded to the inside of the enclosure. For gas barriers, the shield is completely welded to the enclosure with a gas tight weld. In the case of a contamination barrier, a filter is mounted between the shield and the enclosure tube. This filter allows flow of gas from one side of the insulator to the other, but blocks the flow of particulate contaminants. Similar to the Tripost insulator, the cone is completely surrounded by a particle trap on both sides.

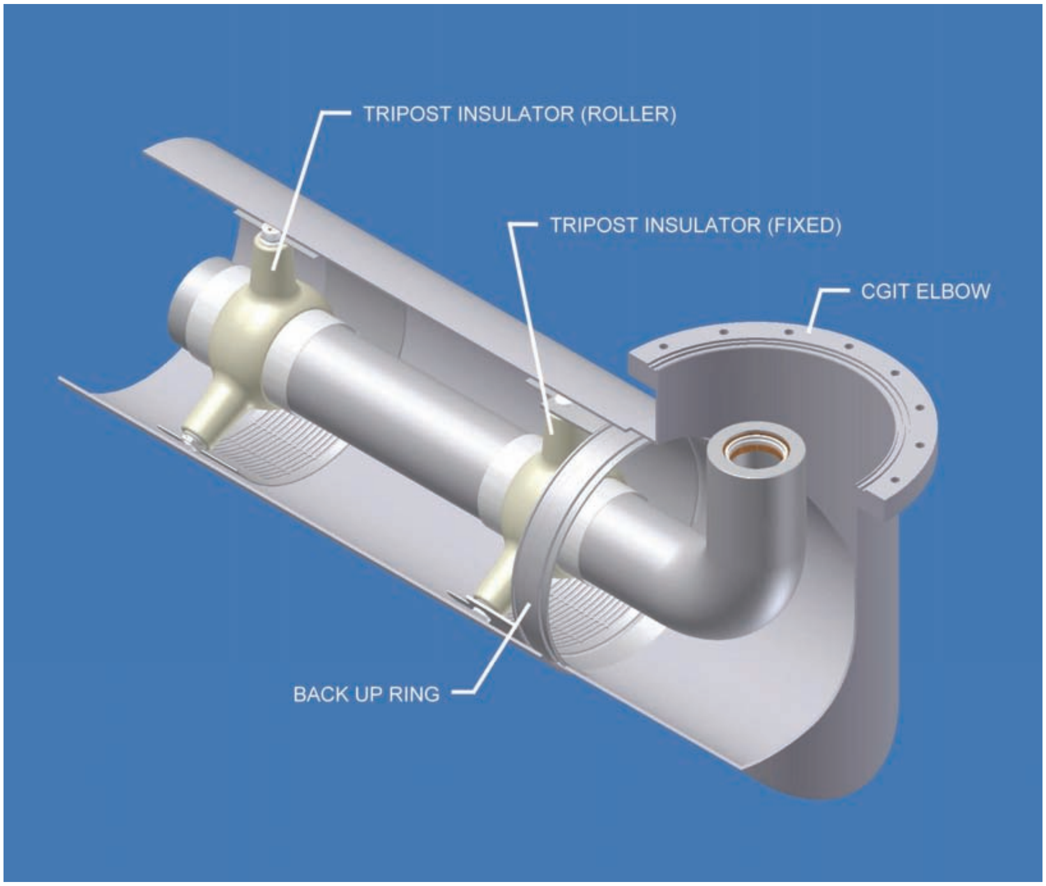
Elbows, Tees, and Crosses

Changes in direction or multiple junction points in the CGIT bus system are accomplished using elbows, tees or crosses. These elements enable the CGIT system to create tee branch circuits, tee connections to SF_6 surge arresters, voltage transformers, and custom configurations. The CGIT elbow can be designed to provide changes in direction at any angle, from 89 degrees to 179 degrees. This provides extreme flexibility when designing circuit layouts.

All elbows, tees, and crosses are formed by a mitered enclosure joint, and specially cast conductor elements. An insulator near 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 joint is identical to that between two straight sections in a field welded system. Where additional strength is needed at a turn in the bus, a double miter elbow may be used.



CGIT Tee Design

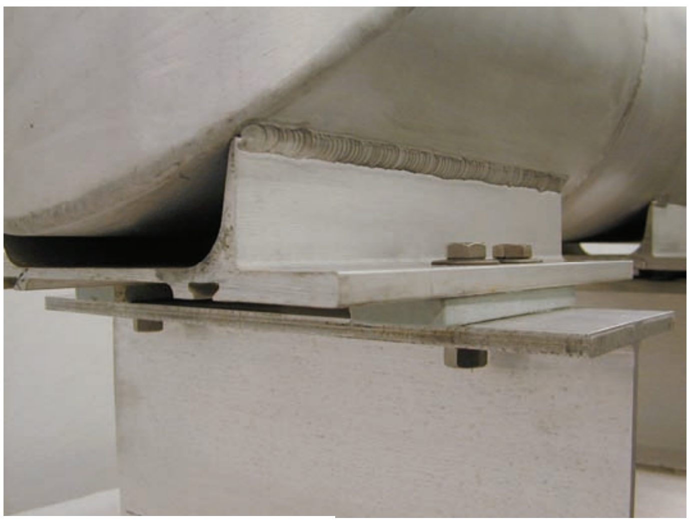


CGIT Elbow Design

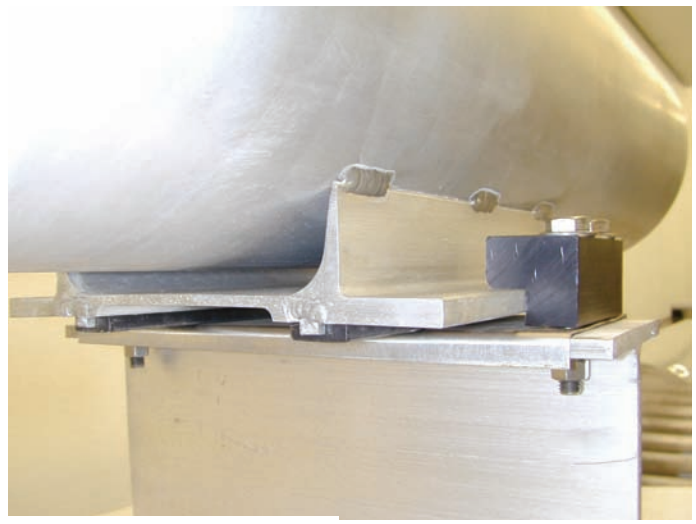
CGIT Support System

When the CGIT bus system is installed above ground, or in a trench, support structures are installed periodically to support the system during operation. Each installation has unique support locations and design details to insure that the CGIT bus system is properly supported and will continue to operate during normal operation, and during unusual events, including earthquakes. The high thermal expansion rate of the aluminum bus enclosure requires fixed type supports to anchor the bus in place, and sliding supports to allow the CGIT bus system to move during thermal expansion and contraction.

Both types of supports use a specially designed support saddle that is welded to the bus enclosure. At fixed support locations, the CGIT bus saddle is bolted or welded to the support structure. Sliding support locations utilize the same saddle design welded to the bus enclosure, combined with low resistance sliding elements to allow unimpeded thermal motion. Guides are provided on the support structure to limit the lateral motion of the CGIT bus, even under seismic events, and to insure that the motion is in the correct direction.



CGIT Fixed Support Style



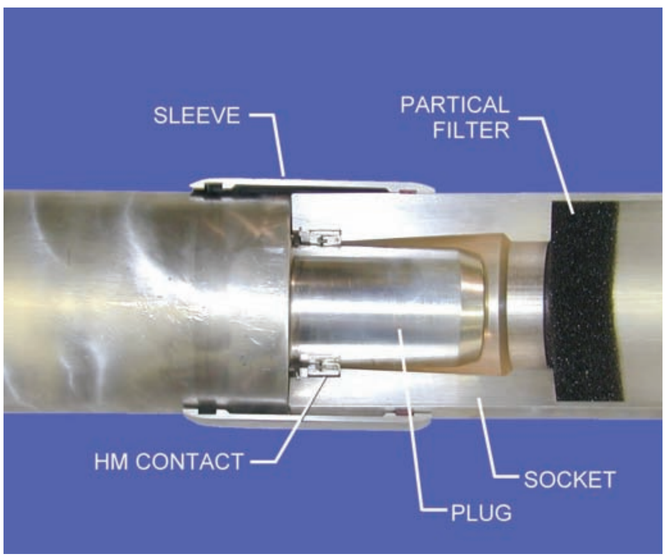
CGIT Sliding Support Style

Elevated Bus and Bushing Supports

Conductor Contact System

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 current path during operation. The HM contact assembly consists of a ring of spring loaded individual silver plated copper contacts. The spring loaded design provides continuous low pressure contact with the contact elements to ensure reliable long term operation. 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 reduce the voltage field at the plug and socket conductor joint, and to insure that any particles generated by the contact do not enter the dielectric field of the bus system, an aluminum gradient shield is provided. This shield bridges the transition connecting one conductor to another and is secured in place by spring loaded contacts. An adhesive particle trap is used inside the gradient shield to capture any loose particles within the conductor joint area. A particle filter is installed in both the plug and socket halves of the conductor contact to prevent particles inside the conductor from migrating into the contact area.



CGIT Conductor Contact System

Enclosure Connection Design

CGIT bus sections are installed typically using bolted flange connections. The CGIT flange incorporates a double o-ring seal design to prevent SF_6 gas leakage. The inner o-ring is designed to maintain the system pressure, while the external o-ring is used as an environmental barrier. To ensure reliable operation after installation, a leak check port is provided at each flange connection to verify that the inner o-ring has been installed properly.

Alternatively, an all welded design is available where the enclosures of adjacent sections are welded together in the field. The exclusive CGIT welded joint design is used on buried installations, and can be used on above ground installations as well.

CGIT Gas Monitoring System Design

The CGIT gas monitoring system uses a temperature compensated gas density monitor mounted directly on the CGIT bus enclosure. The gas density monitor is normally supplied with two alarm contacts, at 10% and 20% below normal operating density. The CGIT system has been designed and tested to withstand specified dielectric ratings at the second alarm level. Additional alarm contacts can be provided including an overpressure alarm contact in case the system has been overfilled. The CGIT gas density monitor is supplied on each single-phase gas compartment. Occasionally, adjacent gas compartments may be monitored using gas bypass assemblies.


CGIT Gas Density Monitor

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CGIT Interfaces

Flexible System Design

CGIT bus systems have been designed and installed with connections and interfaces to a variety of equipment. Primarily used on typical GIS substation projects, CGIT systems have interfaced with every major supplier of GIS equipment including ABB, Alstom, Hitachi, Mitsubishi, Toshiba, VA TECH, and others. For substation design flexibility, CGIT can provide a variety of interfaces including the following:

- SF_6 insulated connections to generator step-up and station transformers
- SF_6-to-air bushing connections to conventional substation equipment or transmission lines
- Interfaces to SF_6 surge arresters and voltage transformers
- SF_6 interfaces to a variety of GIS equipment including circuit breakers, disconnect switches, and grounding switches

CGIT takes responsibility for designing and supplying the interface to any substation equipment, regardless of whether the substation interface equipment is supplied by CGIT or by others.

SF_6 to Air Bushings

Where CGIT bus systems terminate to an air-insulated component such as a transformer, circuit breaker, or overhead transmission line, an SF_6 to air bushing is used to make the transition. The bushing consists of a composite insulator filled at the same SF_6 gas pressure as the rest of the CGIT bus system. The SF_6 to air bushings can be supplied with a variety of terminal pads and gradient shields depending on the termination design, voltage rating, and current rating. CGIT Systems can design and supply the bushing assemblies from the factory, or supply them from a third party supplier.

SF_6 to Air Bushings

Transformer Interfaces

When CGIT systems connect to a generator step-up transformer, or a station transformer, a complete SF_6 insulated connection can be provided to minimize space usage. CGIT transformer interfaces include an SF_6 insulated tank that surrounds the high voltage bushing on the transformer. The transformer interface tank is usually supplied with a gas barrier insulator to isolate the gas system, and a disconnect link that can be removed to facilitate high voltage testing of the CGIT system or testing of the transformer. An enclosure bellows is used for installation adjustment.

Transformer Connections

CGIT BUS SYSTEM APPLICATIONS

Introduction

CGIT bus systems have many applications beyond new GIS installations. Applications range from power plant substation designs to transmission line connections:

Power Plant Applications

- Design Optimization
- Grid Connections
- Flexible Installation Options

Hydroelectric Power Plants

- Vertical Installations
- Inclined or horizontal tunnels

Transmission Line Applications

- Transmission Line Crossing
- Underground Transmission

Extensions to Existing Substations

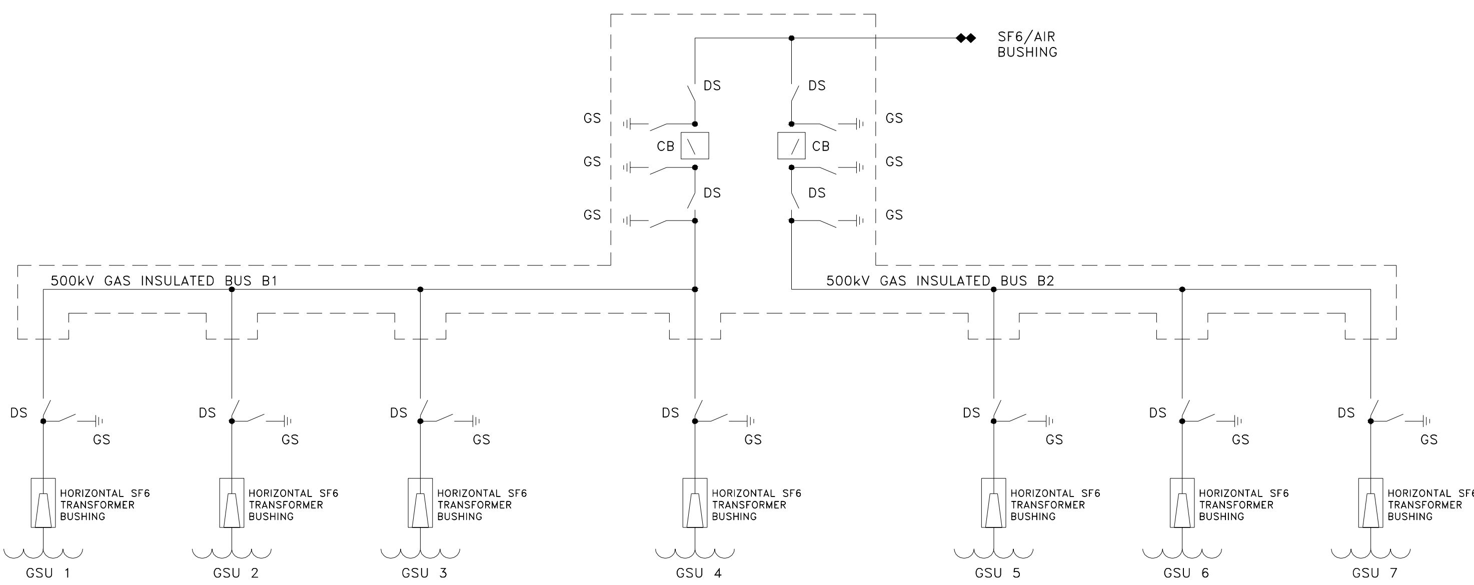
- Extensions and Retrofits to GIS Substations
- AIS Substation Applications

Power Plant Applications

Design Optimization

One of the challenges in the design of a power plant substation is how to maximize its potential while maintaining safe conditions for workers and the surrounding environment. The greatly reduced electric and magnetic fields, combined with the superior dielectric strength of SF_6 gas, enable CGIT bus systems to provide a compact power transmission solution. For example, the outside diameter of the 362kV rated CGIT design is only 15 inches (381mm) per phase. With a phase spacing of 22 inches (599mm) center to center, a typical 362kV CGIT bus circuit requires a trench of only 6 feet (1.85m) in width. This compact right of way requirement is less than 10% of what would be required by conventional transmission lines, yet the CGIT system can transmit in excess of 3000MVA.

CGIT's compact design is also more adaptable to tight space limitations than typical high voltage cable systems because CGIT lines can turn corners at extremely sharp angles, unlike the large radius bends required by cable systems. 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.



CGIT Bus System Design Schematic

Power Plant Design Optimization

Power Plant 8 Extension I & II, Saudi Arabia

Power Plant 8 in Riyadh, Saudi Arabia was being planned for a 500MW expansion. The original power plant consisted of 380kV GIS and oil filled cables to connect the generator step-up transformers to a 380kV GIS Substation. The initial planned expansion of 500MW consisted of six GE gas turbines and three generator step-up transformers. The issue facing Saudi Electric Company (formerly SCECO) was how to connect the new generator step-up transformers to the GIS substation, 800 meters away. Several obstacles existed that made the expansion difficult:

- Existing 380kV and 138kV oil filled cables installed underground
- Control cable and auxiliary systems underground
- Existing roadways and civil foundations

The space available for installing multiple circuits of 380kV oil cables was limited due to existing buried cable systems and plant equipment. This required that the system be installed above grade. To minimize impact at roadways and other access areas, the system would need to be elevated to allow passage of plant personnel and equipment. In addition, the long range plan for the power plant called for the future addition of two more generating units, requiring additional power transmission capability and ease of installation. CGIT bus proved to be the optimum solution.

The original layout consisted of three independent circuits of 380kV CGIT bus on elevated steel supports, each connecting one generator step-up transformer to the GIS substation 800 meters away. The CGIT bus circuits were installed in a stacked configuration to minimize the right of way requirement. Support structures were installed at spans of up to 18 meters to minimize civil construction requirements. The bus was designed with reserve capacity to allow transmission of the additional power from the future two generating units using the existing system.

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, they required only two new short circuits to connect them to two of the existing CGIT bus 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.

Power Plant 8, Saudi Arabia
380kV, 1200A CGIT System Connecting to Transformers

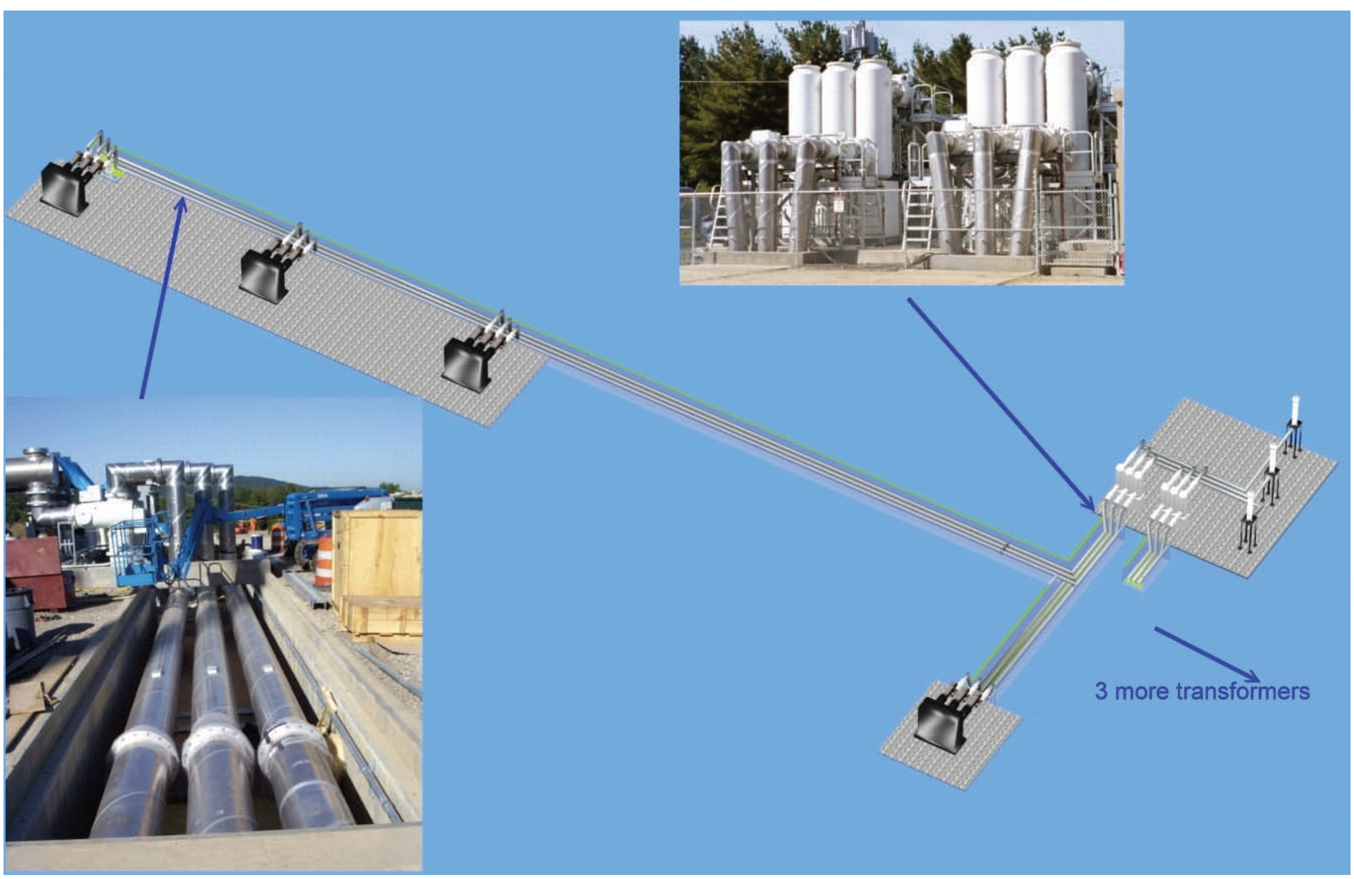
Power Plant 8, Saudi Arabia
380kV, 1200A CGIT System Installed Above Ground

Power Plant Design Optimization

Bethlehem Power Plant, Pennsylvania, USA

Conectiv Mid-Merit's planned 1100MW Combined Cycle Power Plant consisted of two power "modules" , each rated at 550MW, for connection to a 500kV transmission line. Each power module initially consisted of four generator step-up transformers, three from gas turbines, and one from a steam turbine. The power plant was located on a relatively small space, with an existing 500kV transmission line in close proximity. The design of the power plant had the high side of the generator step-up transformers located near the edge of the property, facing the transmission line. This arrangement did not provide enough space for a conventional substation, or multiple connection circuits to the transformers. An additional challenge was the need to provide an access road between the transformers and the edge of the property. CGIT provided a compact and reliable solution for Conectiv.

With no space available for air insulated equipment to connect to the high side of the transformers, and limited space available underground for multiple cable circuits, CGIT proposed a single circuit of 500kV bus for each power module. The high current rating of CGIT bus enabled all four generator step-up transformers of each power module to be combined into a single circuit, with GIS disconnect switches located at each transformer for isolation. To provide space for an access road, CGIT designed the 500kV bus circuits for installation below grade in a covered trench within the available space . The space above the covered trench was utilized for the access road. To isolate each power module from the transmission grid, CGIT supplied 500kV GIS substation breakers from VA TECH located at the edge of the power plant property. CGIT provided the entire solution including turnkey installation and commissioning of the 500kV CGIT bus, VA TECH GIS circuit breakers and disconnect switches, SF_6 surge arresters from Toshiba, and complete control equipment.



Bethlehem Power Plant, Pennsylvania, USA
550kV, 2000A Complete Substation From Transformers to Transmission Lines

Power Plant Applications: Grid Connections

New power plant projects, and many extensions to existing power plants, require new connections to the transmission grid. In many cases obstacles exist that make conventional transmission line connections unfeasible. Possible obstacles include crossing existing transmission lines, traversing wetlands or hazardous areas, or limited space availability. CGIT's compact design combined with flexible installation options can help make these vital connections with reduced permitting and installation time.

Baxter Wilson Power Plant, Mississippi, USA

Entergy was adding additional generating capacity to their existing Baxter Wilson Power Plant outside of Vicksburg, Mississippi, requiring a new connection to the transmission grid. The new generator step-up transformers were located on the opposite side of the power plant from the 500kV transmission grid connection point, with several obstacles in between. Existing transmission lines crossing the power plant property would have presented a permitting issue for conventional transmission equipment, and an existing flood plain prevented the use of buried cable systems. CGIT proposed a solution to Entergy that addressed these issues, and would enable them to get power to the grid in the shortest possible time.

The solution provided to Entergy included a single 550kV rated circuit installed above ground under existing 230kV and 500kV transmission lines. The circuit was installed on concrete foundations elevated above ground where flooding occurred each spring. The height of the circuit was established to prevent the water level from rising to the level of the CGIT bus system. Each end of the circuit terminated in SF_6-to-air bushings for connection to the generator step-up transformers and to the overhead transmission line. The CGIT gas monitoring system alarms were connected into the power plant control system for protection. The total solution was provided to Entergy on a turn-key basis by CGIT, including installation and commissioning, nine months after the order was placed. Significantly less time than permitting for a new transmission line.

Baxter Wilson Power Plant, Mississippi, USA
550kV, 3000A Grid Connection Across Transmission Lines

Power Plant Applications: Flexible Installation Options

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 conventional air insulated equipment, or obstructions below grade prevent the use of cable systems, one possible solution is to provide an elevated system.

Teesside Power Plant, Teesside, England

Teesside is a 1725 MW combined-cycle gas-fired power plant located in England. The arrangement of the generators and transformers, and the location of the gas insulated switchgear created a need for an extensive array of 275kV, 1200 ampere connection circuits from the generator step-up transformers to the gas insulated substation. The amount of space available for the connection circuits was very limited. An installation below grade was not possible due to a relatively high water table, and the existence of underground steam lines to an adjacent chemical plant. Access roads at ground level made a ground level installation unfeasible. The only solution was to elevate the connection circuits above ground in a compact right of way that allowed access of equipment and personnel underneath.

CGIT provided the optimum solution with a smaller right of way, increased access, and a lower installed cost than 275kV oil cable.

Teesside Combined Cycle Power Plant, England
275kV CGIT Bus Connections Between Generator Step-up Transformers and GIS Building

Power Plant Applications: Flexible Installation Options

Teesside Power Plant, Teesside, England (Continued)

What made this project unique for CGIT Systems was the height requirement. Due to the access requirements, the CGIT bus system was elevated as high as 9 meters (29 feet) above grade. Support structures for this project were designed to hold as many as five circuits (fifteen phases) of CGIT bus, with at least six phases running at the maximum height. The support structures were spaced approximately 14 meters (45 feet) to provide as much accessibility to other equipment as possible.

One important consideration for the system design was thermal expansion of the long runs, in excess of 100 meters at the longest point. The system must accommodate thermal expansion due to increased ambient temperature, solar loading, and self heating due to operation. Normally, long systems utilize enclosure bellows to accommodate thermal expansion and contraction, For the Teesside project, with an elevation of up to 9 meters, the supporting requirements to withstand the pressure thrust of a standard enclosure bellows would be prohibitively expensive, and would create excessive foundation loads. The solution was to design the system utilizing CGIT's flexible elbow design to accommodate the anticipated thermal expansion. This provided an economical solution that only CGIT's system design can provide.

As part of the overall system, CGIT provided SF_6 insulated surge arresters at each generator step-up transformer to protect the transformers from switching surges and high speed transients. CGIT also provided SF6 enclosed transformer bushing tanks with isolation links, and metering CT's for each circuit. The Teesside Project, consisting of over 5,400 single phase meters of CGIT bus, was installed and commissioned in 1992.

Teesside Combined Cycle Power Plant, England
275kV CGIT Bus Elevated Connection Circuits

AZZ | CGIT

Hydroelectric Power Plant Applications

Hydroelectric generating stations often require transmission of the energy over large vertical distances or long underground tunnels. 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
- High pressure fluid filled cable
- Solid dielectric cable
- SF_6 gas insulated bus

The air-insulated bus would require large clearances. Shaft and tunnel 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, which could lead to premature failure; (2) the risk of catastrophic damage resulting from a fire occurring in the cable system. If a fault were to occur in one cable circuit, the potential fire could spread to the adjoining circuits eliminating all power transmission capabilities. Solid dielectric cable, while not as flammable as oil cable, still offers a potential fire hazard, and has significant long term reliability issues when cable joints are used. In vertical applications, solid dielectric cable is subject to stretching and conductor core slippage. Special measures are required to support the cable over long vertical distances to minimize the potential risk of stretching and failure, particularly at cable joints.

The utilization of CGIT bus for vertical shaft applications offers the following advantages:

- CGIT bus is enclosed and grounded, reducing clearance requirements and shaft sizes. The safety of dead-front construction eliminates any high voltage safety hazards.
- SF_6 is an inert gas, eliminating any potential fire hazard. The pressure head with SF_6 gas is very low, even in long vertical installations.
- The high current carrying capacity of CGIT bus can reduce the total number of circuits required to transmit power from the underground cavern, while also reducing power losses.
- The design of CGIT bus enclosures eliminates the risk of stretching or mechanical damage, with simple supporting methods.
- The CGIT bus system is designed and tested for a reliable operating life of 50 years.

The CGIT bus system concept has been successfully applied in vertical installations including a 200MW pumped storage project with a 328m (1000ft) vertical shaft.

Balsam Meadows Pumped Storage Plant, California, USA

230kV CGIT Bus Exit From Top of Shaft Enclosure Building to Overhead Line Bushings

Hydroelectric Power Plant Applications

Balsam Meadows Hydro Electric Station

The 242kV, 1200 amp CGIT bus system was installed in a 328m (1072 feet) high shaft with a diameter of 6m (20 feet) . In addition to the CGIT bus, the shaft contains an elevator, power and control cables, and functions as a ventilation shaft. For the underground powerhouse. The bus system design includes short horizontal sections at the top and bottom ends of the vertical shaft for connection to the overhead transmission line and generator step-up transformer. Conventional air insulated connections are used in the transformer room to simplify the electrical system design, including air insulated disconnect switches and surge arresters. Gas insulated disconnect switches, ground switches, and surge arresters were not required due to sufficient clearance being available above the transformer.

Balsam Meadows Pumped Storage Plant, California, USA
230kV CGIT Bushings Installed in Transformer Room

The entire 1000 foot vertical run of SF_6 bus is hung from a single support near the top of the shaft. Each 9090 kg (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 in the unlikely event of a fault, a complete spare 77m (252 feet) 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 operated without incident.

Hydroelectric Power Plant Applications

Revelstoke Hydroelectric Project

Another example of CGIT's applications in hydroelectric projects is British Columbia Hydro's Revelstoke Project in Canada. This hydroelectric plant included gas insulated switchgear in the underground powerhouse, and connection circuits installed in an inclined tunnel to a gas insulated substation where the output of the power plant connects to the transmission grid. CGIT provided the best solution for the connections between the GIS substations.

Within the Revelstoke powerhouse, there are gas insulated circuit breakers and disconnect switches at each generator step-up transformer, and a dual set of 500kV GIS configurations connecting the generator transformer 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, and a separate 230kV GIS substation receives incoming power for internal plant service. The feeder circuits, including the connections to the 500kV GIS in the powerhouse, utilize dual circuits of 550kV, 4000 A rated CGIT bus.

The high current rating of the CGIT bus, combined with the switching configuration, enables the full output of the Revelstoke power plant to be transmitted through either one of the two feeder circuits. This provides 100% redundancy for plant operation. This system redundancy could not be accomplished using conventional cable systems. 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.

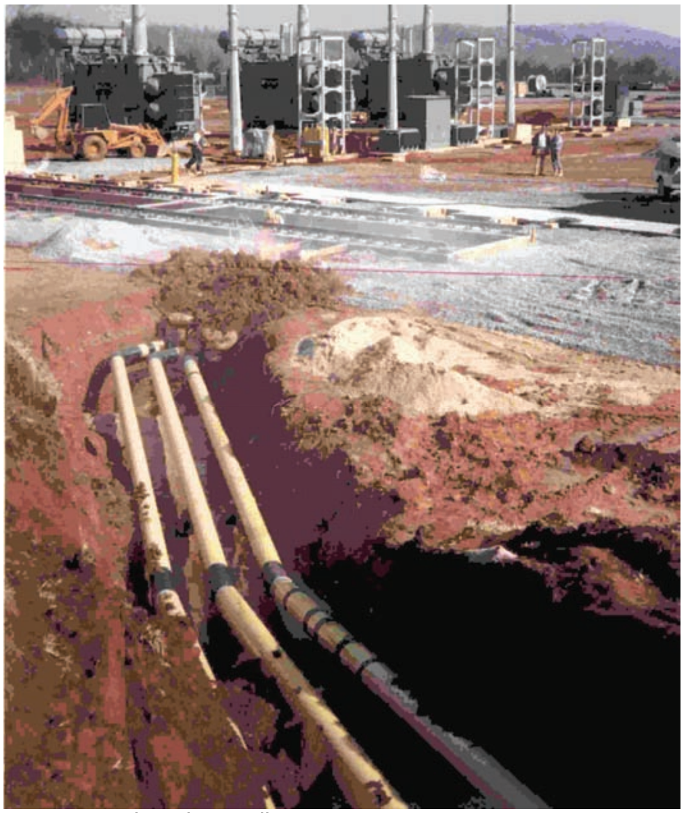
Another CGIT bus circuit, outside the substation building, connects the incoming 230kV transmission lines to the 230kV GIS substation, from which conventional 230kV oil cable is used to transmit power into the rest of the power plant.

Revelstoke Hydroelectric Project, British Columbia, Canada
550kV, 4000A CGIT Installed in Inclined Tunnel

Underground Transmission Applications

Underground Transmission

There are two kinds of underground CGIT installations: buried and open or covered trenches. Buried installations have the advantage of lower installation costs 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, eliminate above ground congestion, and reduce right-of-way requirements. CGIT Systems installed it's first buried underground installation at the Hudson Generation Station in New Jersey, USA in 1972, which is still in operation today.



Spy Run Substation, Indiana, USA
138kV, 1250A Direct Buried CGIT System

Buried Installation

Buried CGIT bus installations offer the advantage of reduced installation costs by eliminating civil foundations and trench fabrications. Buried installations are particularly applicable in areas where space is limited, or it is preferred to limit access to the system. Applications include buried transmission lines in urban or congested areas, and connection circuits within power plants where space is at a premium. Buried CGIT systems cannot transmit as much current as open air systems. The continuous current rating depends greatly on the phase spacing, resistivity of the thermal sand used to backfill the system, and the ambient temperatures of the surrounding soil. As a general guideline, buried CGIT systems transmit 40% less power than an equivalent open air CGIT systems.

CGIT's buried system utilizes an extruded polyethylene coating on the enclosure to prevent corrosion, and does not require a cathodic protection system. Adjacent sections are welded together in the field, and the completed joints are wrapped in polyethylene tape to prevent corrosion.

Open or Covered Trench Installation

Road crossings or power plant and substation access are the main considerations when choosing a trenched installation for CGIT systems. 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.

Midway Sunset Cogeneration Plant, California, USA
242kV, 2000A Combined Trench and Above Ground Installation

Retrofit of Older GIS Installations

Substations often require new equipment to upgrade existing facilities, or to replace damaged equipment. This can require interfacing to equipment from different manufacturers. 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. 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 or extending existing installations including turn-key installation and commissioning.

Consolidated Edison Dunwoodie Station

The original Dunwoodie substation was commissioned in 1974 with ITE GIS equipment The layout is a 345 kV ring bus arrangement consisting of six dual-pressure ITE circuit breakers and interconnecting ITE bus. The station contains G&W oil cable pothead interfaces and GE capacitive voltage transformers (CVT's). The substation also has three feeder circuits with SF_6-to-air bushings to connect 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.

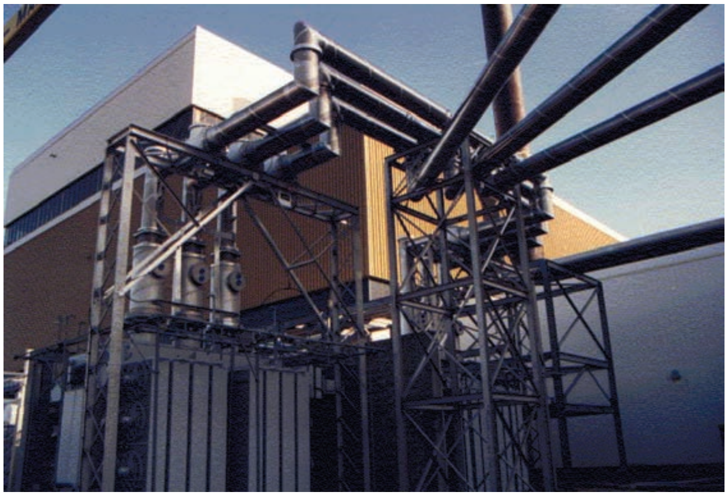
In response to Consolidated Edison's emergency requirements, CGIT Systems provided interconnecting breaker bus to bypass the damaged breaker position and re-energize the ring. The CGIT bus left future expansion capabilities to interface to a new circuit breaker position that would be supplied at a later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

In 1990, Mitsubishi Electric provided a replacement GIS circuit breaker, and again CGIT Systems provided the necessary interconnecting bus, which this time included interfaces to both ITE and Mitsubishi GIS. At the same time, an additional feeder circuit with SF_6-to-air bushings was provided.

Seabrook Nuclear Power Plant Substation.

Another retrofit example is the Seabrook gas insulated substation project. The Seabrook Station 345kV ITE GIS and Bus, had developed a history of unreliability due to leaks and insulator failures within the bus. This was a particular 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 and long-term service, was selected to replace the ITE bus for these critical connections. Replacement sections involved connections from the GIS to both main transformers and to auxiliary transformers.



Seabrook Nuclear Power Plant, New Hampshire, USA
345kV, 3000A Combined trench and above ground Installation

In addition to offering a reliable bus design, CGIT Systems 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.

Long-Term Extensions

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. When proposing long term extensions to existing substations, there are several considerations including increased system ratings, control and operating procedures, and physical space limitations. CGIT Systems can assist in developing a plan that addresses all of these issues.

Claireville Transmission Station, Ontario, Canada

Often gas-insulated substations only allow unidirectional reductions in yard dimensions due to the space needed for incoming lines. At the Claireville Transmission Station, Hydro One (formerly 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 and gas insulated bus reduced the space requirement by 80 percent, to approximately forty acres. The Claireville Station was initially commissioned in 1975 and has undergone several phases of expansion. The station consists of multiple circuits of CGIT bus arranged to untangle dozens of line exit circuits and feed twenty-six 550kV and fifty-two 250kV GIS circuit breakers. The GIS is housed in an elevated switchgear building, and the CGIT bus exits through the floor. Incoming lines enter the station along power corridors from the North, South, East and West. In 1991, CGIT Systems, in conjunction with ABB, added the following equipment to increase switching capacity at Claireville:

- One bay of 250kV GIS and three 250kV, 4000A CGIT line exit circuits
- One bay of 550kV GIS and three 550kV, 4000A, 1800kV BIL CGIT line exit circuits
- Three 550kV, 1800kV BIL CGIT bus circuits connecting to existing Alstom GIS (formerly GEC Alstom)
- Four circuits of 250kV 4000 A CGIT bus interfacing to existing 230kV 3000 A CGIT bus

Over 4000 meters of CGIT bus were supplied to the Claireville station. Extensive use of CAD was required to insure that the new system would not interfere with access platforms, civil foundations and existing equipment above and below grade. Additional design parameters considered installation requirements, including; clearance for welded installation of the CGIT bus sections, personnel access, and installation sequencing to accommodate outage schedules.

Claireville Transmission Station, Ontario, Canada
250kV CGIT Bus Line Exits

SUMMARY

For more than thirty-five years CGIT has been selected as the choice for a wide range of unique applications. The use of CGIT is not limited to GIS installations. As outlined in this guide, CGIT has a number of unique applications, including:

- Power plant optimization
- Line crossings
- Underground transmission
- Long vertical shafts
- Elevated installations
- GIS retrofits
- GIS extensions

CGIT has many distinct advantages over other methods of power transmission. CGIT's compact design requires minimal right of way clearances and can transmit significantly more power than conventional cable solutions.

CGIT is an ideal candidate for both conventional and unconventional applications. Let us show you how CGIT bus can be applied to solve your problems with a reliable, economical, proven solution to your high voltage power transmission needs.

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