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IEEE Guide for Gas-Insulated Substations

Sponsor

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of the
IEEE Power Engineering Society

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Abstract: The technical requirements for the design, fabrication, testing, and installation of a gas-insulated substation (GIS) are covered. Parameters to be supplied by the purchaser are suggested, and technical requirements for the design, fabrication, testing, and installation to be furnished by the manufacturer are established.

Keywords: gas-insulated substation, GIS, GIS design, GIS equipment, GIS installation, GIS testing, SF₆, sulfur hexafluoride

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Introduction

(This introduction is not a part of IEEE Std C37.122.1-1993, IEEE Guide for Gas-Insulated Substations.)

IEEE Std C37.122-1983 was initiated in the early 1970s when the first gas-insulated substations (GIS) were introduced. Approved in 1983, it contains standards, recommended practices, and guides. Circumstances beyond the control of the responsible Technical Committees delayed its availability to users until late 1988. Simultaneous to its publication, the Gas-Insulated Substations Subcommittee of the IEEE Power Engineering Society (PES) Substations Committee began work on the necessary update, revision, and expansion of the document.

The reliability of GIS has improved greatly since the first installation in the late 1960s. Utilities have taken advantage of the greater flexibility offered by GIS to locate substations closer to load centers with considerable savings in subtransmission systems. In addition, GIS typically offers 20 years or more of operation before major overhaul is required.

During the Working Group and Subcommittee deliberations on the update, it was recognized that users would be better served if the original document were divided in two, becoming IEEE Std C37.122-1993 (a standard) and IEEE Std C37.122.1-1993 (a guide). The two documents can be referred to individually or jointly depending on the purpose of the referral.

Although all Working Groups of the Gas-Insulated Substations Subcommittee contributed to this revision, the prime responsibility belonged to Working Group K2, Revision of IEEE Std C37.122-1983, which approved this guide. At the time this guide was completed, Working Group K2 had the following membership:

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IEEE Guide for Gas-Insulated Substations

1. Overview

This guide provides information of special relevance to the planning, design, testing, installation, operation, and maintenance of gas-insulated substations (GIS) and equipment. This guide is intended to supplement IEEE Std C37.122-1993.¹

In general, this guide is applicable to all ac GIS from 72.5–800 kV. However, the importance of the topics covered varies with circumstances. For example, issues related to advanced field test techniques and very fast transients (VFT) are of particular interest for extra-high-voltage (EHV) GIS (345 kV and above), and are of lesser importance at lower voltage levels.

2. References

This guide shall be used in conjunction with the following references.

AISC S335-89, Specifications for Design, Fabrication, and Erection of Structural Steel for Buildings.²

ANSI/ASME 1992 Boiler and Pressure Vessel Code—Section VIII: Pressure Vessels, Division 1.³

IEC Draft 17A-339 (SECRETARIAT) [IEC Draft 17C-102 (SECRETARIAT)], Electromagnetic Compatibility (EMC) for Secondary Systems in Gas-Insulated Metal-Enclosed Switchgear for Rated Voltages of 72.5 kV and Above.⁴

IEC 68-1 (1988), Environmental Testing—Part 1: General and guidance.

IEC 68-2-6 (1982), Test Fc and guidance: Vibration (sinusoidal).

¹Information on references can be found in clause 2..

²AISC publications are available from the American Institute of Steel Construction, 400 N. Michigan Avenue, 8th Floor, Chicago, IL 60611, USA.

³ASME publications are available from the American Society of Mechanical Engineers, 22 Law Drive, Fairfield, NJ 07007, USA.

⁴IEC publications are available from IEC Sales Department, Case Postale 131, 3 rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse. IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

IEC 68-2-47 (1982), Mounting of components, equipment and other articles for dynamic tests including shock (Ea), bump (Eb), vibration (Fc and Fd) and steady-state acceleration (Ga) and guidance.

IEC 68-2-57 (1989), Test Ff: Vibration. Time-history method.

IEC 68-2-64 (1993), Part 2: Test methods—Test Fh: Vibration, broad-band random (digital control) and guidance.

IEC 68-3-3 (1991), Part 3: Guidance. Seismic test methods for equipments.

IEC 1166 (1993), High-voltage alternating current circuit-breakers—Guide for seismic qualification of high-voltage alternating current circuit-breakers.

IEEE Std 80-1986 (Reaff 1991), IEEE Guide for Safety in AC Substation Grounding (ANSI).⁵

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).

IEEE Std 344-1987, IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations (ANSI).

IEEE Std 693-1984 (Reaff 1991), IEEE Recommended Practices for Seismic Design of Substations (ANSI).

IEEE Std C37.98-1987 (Reaff 1991), IEEE Standard for Seismic Testing of Relays (ANSI).

IEEE Std C37.122-1993, IEEE Standard for Gas-Insulated Substations.

IEEE Std 1125-1993, IEEE Guide for Moisture Measurements and Control in SF₆ Gas-Insulated Equipment.

NEMA CC 1-1993, Electric Power Connectors Substations⁷

*Uniform Building Code*TM, 1991 ed., and 1993 Accumulative Supplement, International Conference of Building Officials (ICBO).⁸

Additional references on gas-insulated substations may be found in the bibliography in clause 5.

3. Definitions

The following definitions are applicable only to the subject treated in this guide. At the time this guide was approved there were no corresponding definitions in IEEE Std 100-1992 .

3.1 acting stress (working stress): The maximum applied or expected mechanical stress in a material during operation of the apparatus of which it is a part and including the stresses caused by seismic and other loading, acting independently or simultaneously as determined by the user.

3.2 allowable stress: The maximum stress permitted by applicable standards or codes, or both.

3.3 amplification (mechanical): The relationship between response acceleration and ground acceleration.

⁵IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

⁶As this standard goes to press, IEEE Std 1125-1993 is not yet published. It is, however, available in manuscript form from the IEEE Standards Department, (908) 562-3800. Anticipated publication date is Fall 1994, at which point IEEE Std 1125-1993 will be available from the IEEE Service Center, 1-800-678-4333.

⁷NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street NW, Washington, DC 20037, USA.

⁸Available from the International Conference of Building Officials (ICBO), 5360 S. Workman Mill Road, Whittier, CA 90601, USA.

3.4 assembly (GIS): A collection of GIS components that are interconnected and ready for insertion as a subassembly in a GIS, such as a breaker bay shipping assembly. The term is also used to describe a complete GIS.

3.5 auxiliary circuits: All control, indicating, and measuring circuits.

3.6 Class A seismic component: A component or system whose failure, malfunction, or need for repair prevents the proper operation of the gas-insulated substation during or after the design earthquake.

3.7 Class B seismic component: A component or system whose failure, malfunction, or need for repair does not prevent the proper operation of the gas-insulated substation during or after the design earthquake. Class B components are designed to meet either normal building codes and national standards in force at the site or another lower-level design earthquake. Application of further design requirements is left to the discretion of the user.

3.8 compartment (GIS): Any gas section of the gas-insulated substation assembly that provides gas isolation.

3.9 continuous enclosure: A bus enclosure in which the consecutive sections of the enclosure are electrically bonded together to provide a continuous current path through the entire enclosure length.

3.10 continuous monitoring: The process of sampling the state of some phenomenon at a time interval shorter than the time constant of the phenomenon.

3.11 damping (mechanical): A dynamic property that indicates the ability of a structure to dissipate energy.

NOTE — The phenomenon of damping is represented by the damping ratio, a percentage of critical damping. After being forced to deflect and allowed to vibrate freely, structures with zero damping vibrate indefinitely. Structures with critical damping return to their static or neutral position in the shortest time without oscillation.

3.12 design earthquake: The greatest earthquake postulated during the life of the gas-insulated substation that the user wishes the gas-insulated substation to survive in operating condition.

3.13 design pressure (working pressure): The maximum steady-state gas pressure to which a gas-insulated substation enclosure is subjected under normal operating conditions.

3.14 enclosure currents: Currents that result from the voltages induced in the metallic enclosure by effects of currents flowing in the enclosed conductors.

3.15 gas barrier insulator: A spacer insulator specifically designed to prevent passage of gas from one gas compartment to another.

3.16 gas density, minimum: The minimum operating gas density at which the gas-insulated substation and its components are certified to meet their assigned electrical ratings.

3.17 gas density, nominal: The manufacturer's recommended operating gas density (usually expressed as a pressure at 20 °C).

3.18 gas-insulated substation (GIS): A compact, multicomponent assembly, enclosed in a grounded metallic housing in which the primary insulating medium is a compressed gas, and that normally consists of buses, switchgear, and associated equipment.

3.19 gas-insulated surge arrester: A metal-enclosed surge arrester specifically designed for use in a gas-insulated substation.

3.20 gas leakage: Loss of insulating gas from the pressurized compartment.

3.21 high-level testing (mechanical): Testing performed to determine a damping of complete assemblies, subassemblies, or components.

3.22 low-level testing (mechanical): Testing performed to determine natural frequencies of complete assemblies, subassemblies, or components.

3.23 main circuit: All the conducting parts of the gas-insulated substation assembly included in or connected to the circuits that its switching devices are designed to close or open.

3.24 malfunction: The loss of capability to initiate or sustain a required function, often a protective action, or the initiation of undesired spurious action.

NOTE — A certain degree of equipment degradation may be acceptable in one system and not in another. In such cases, an evaluation of the equipment or device application should include a determination that the degree of relay contact bounce, changes in device calibration, or degradation of pressure-retaining boundaries are within acceptable limits.

3.25 maximum ground acceleration: The maximum value of acceleration input to the equipment during a given earthquake for a particular site.

3.26 metallic enclosure: A grounded, leak-tight enclosure that contains the compressed insulating gas and associated electrical equipment.

3.27 mode shape (mechanical): A plot that shows displacements of various points in the vibrating structure at a particular instant in time. There is a characteristic mode shape associated with each natural frequency of a vibrating structure.

3.28 moisture content: The amount of water in parts per million by volume (ppmv) that is in the gaseous state and mixed with the insulating gas.

3.29 natural frequency (mechanical): The frequency (ies) at which a body vibrates due to its own physical characteristics (mass, shape, boundary conditions, and elastic forces brought into play) when the body is distorted and then released, while restrained or supported at specific points.

3.30 noncontinuous enclosure: A bus enclosure in which the consecutive sections of the enclosure are electrically insulated from each other, though each section is connected to ground.

NOTE — This construction prevents longitudinal currents from flowing beyond each enclosure section. This design is no longer in common usage.

3.31 periodic monitoring: The process of sampling the state of some phenomenon at a sample interval greater than 1 s.

3.32 qualification testing (mechanical): Testing of the complete assembly or subassemblies to determine acceptability by applying an actual input that has a test response spectrum (either ground- or floor-response spectrum) equal to or larger than the design earthquake response spectrum.

3.33 resonance (mechanical): A dynamic condition that occurs when any forcing frequency of mechanical vibration coincides with one of the natural frequencies of the structure.

NOTE — In a plot of the response of the structure (acceleration, velocity, and displacement) vs. forcing frequency for a constant forcing input, as the forcing frequency approaches one of the natural frequencies of the structure, the response increases to a maximum at the natural frequency if damping is less than critical. The response of the structure at resonance may be much greater than the input, depending on the damping.

3.34 response spectrum (mechanical): A plot of the maximum response of single-degree-of-freedom bodies at a damping value expressed as a percentage of critical damping of different natural frequencies when these bodies are rigidly mounted on the surface of interest (i.e., on the ground for a ground-response spectrum or on the floor for a floor-response spectrum) when that surface is subjected to a given earthquake's motion as modified by intervening structures.

3.35 single-phase enclosure: A metallic enclosure containing the buses and/or devices associated with one phase of a multiple-phase system. *Syn:* Iso-Phase GIS.

NOTE — A single gas-insulated substation need not be composed of all single-phase or all three-phase enclosures. A common compromise is to use buses in three-phase enclosures mated with equipment in single-phase enclosures.

3.36 soil structure interaction (SSI): A general concept for effects caused by the influence of the soil dynamic behavior on the response of a structure.

3.37 spacer (insulator): An insulator used to support the inner conductor in the enclosure.

3.38 station ground: A ground grid or any equivalent system of grounding electrodes buried beneath or adjacent to the gas-insulated substation that determines the rise of ground voltage level relative to remote earth and controls the distribution of voltage gradients within the gas-insulated substation area during a fault.

3.39 sulfur hexafluoride (SF₆): A gaseous dielectric for high-voltage power applications having characteristics as specified in ASTM D2472-92 [B9]⁹.

3.40 three-phase enclosure: A metallic enclosure containing the buses and/or devices of all phases of a three-phase system. *Syn:* 3-in-1 GIS.

3.41 threshold limit value—short term exposure limit (TLV-STEL), as defined by the American Conference of Governmental Industrial Hygienists: The maximum concentration to which workers can be exposed for a period of up to 15 min continuously without suffering adverse effects, or materially reduced work efficiency, provided that no more than four 15 min excursions per day are permitted with at least 60 min between exposure periods, and provided that the TLV-TWA is not exceeded. (In most jurisdictions in North America, the TLVs are legislated limits to exposure.)

3.42 threshold limit value—time weighted average (TLV-TWA), as defined by the American Conference of Governmental Industrial Hygienists: The time-weighted average concentration for a normal 8 h work day and 40 h work week to which nearly all workers may be exposed repeatedly, day after day, without adverse effect.

3.43 time history (mechanical): The record of acceleration, velocity, or displacement as a function of time which the floor of a building or the ground experiences due to an earthquake.

3.44 transition compartment: The compartment specifically designed for joining gas-insulated substation equipment of different design or manufacture. This compartment provides the necessary transition for the current-carrying conductor and the enclosure.

3.45 type tests: Tests made on representative samples that are intended to be used as part of routine production. The applicable portions of these type tests may also be used to evaluate modifications of a previous design and to ensure that performance has not been adversely affected.

3.46 very fast transients (VFT): Switching- or breakdown-induced transients with rise times of 3–10 ns that propagate as traveling waves throughout the GIS and cause overvoltage waveforms that vary as a function of position throughout a substation, and that couple to the external enclosure of SF₆-to-air terminations and can thereby cause external sparking between the enclosure and the support structure.

3.47 zero period acceleration: The peak time history acceleration that can be determined by the merging of response spectra, for all damping values, in the high-frequency range (usually above 30 Hz), in which no change in acceleration occurs with frequency.

4. Guidelines for GIS

4.1 GIS arrangement

4.1.1 Bus schemes

The bus schemes illustrated in figure 1 are those most commonly applied by the industry.

4.1.2 Arrangement constraints

The GIS arrangement is influenced by a number of important constraints. Certain of these are of more interest to the manufacturer while the others are of more interest to the user. The constraints are as follows:

- a) *Area.* The required area for the GIS will be influenced by the selected clearance between breaker poles, by the mode of the circuit-breaker mounting (i.e., vertical or horizontal), and by the need for adequate maintenance clearances.
- b) *Height.* For an outdoor installation, the GIS height may have important aesthetic considerations. For an indoor installation, the required headroom may be a factor determining the mode of the circuit-breaker mounting.

⁹The numbers in brackets correspond to the bibliographical entries in clause 5.

- c) *Bus and junctions.* The arrangement may influence the length of the bus and the number of junctions required.
- d) *Line exits.* The overall GIS dimensions will be influenced by the type of line exit selected. For EHV substations in particular, overhead exits require spreading the GIS arrangement to meet minimum phase-to-phase clearances in air.
- e) *Position indicators.* The arrangement should afford a clear view of as many mechanical position indicators for disconnecting and grounding switches, from as few locations as practical. All position indicators should be visible from the floor or a readily accessible platform.
- f) *Expansion.* If expansion is foreseen, the arrangement should be such that expansion of the original installation can be accomplished with minimum GIS downtime.
- g) *Auxiliary connections.* The length and the number of terminal points of control wiring, hydraulic, and SF₆ gas connections should be minimized.
- h) *Control cabinets.* The number and the location of control cabinets may be influenced by the arrangement.
- i) *Shipping units.* It is essential to minimize the number of shipping splits in order to keep the installation time of GIS to a minimum.
- j) *Maintenance.* The arrangement should afford maximum flexibility for routine maintenance. Equipment removal and SF₆ gas handling should be accomplished with ease.

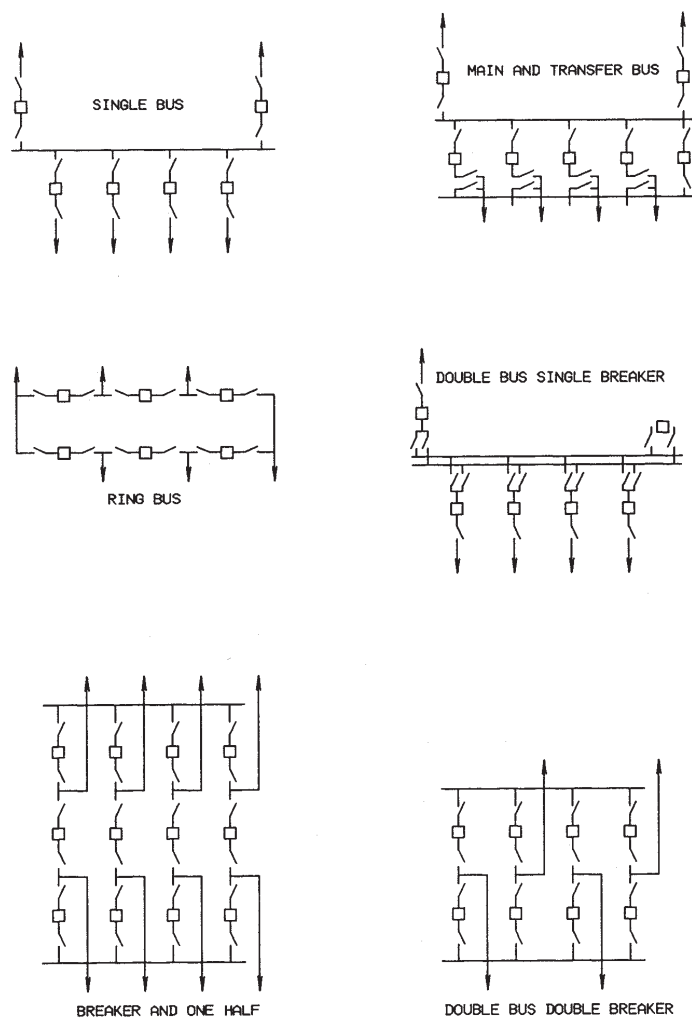


Figure 1— Common one-line schemes

- k) *Operation.* The ease of operation should be ensured. Operating handles should be accessible and grouped. All indicating devices and gauges should be clearly visible and easily accessible. Access to viewports should be convenient.
- l) *Power transformer.* Location and type of electrical connection for the power transformers will affect arrangement (SF₆-oil, SF₆-air, or through an SF₆-cable bushing).
- m) *Cable connections.* Location and type of electrical connection for cables will affect arrangement (SF₆-oil, SF₆ to solid dielectric cable, or through an SF₆-air bushing).
- n) *Surge arresters.* The arrangement, and particularly the length, of bus connections may dictate whether surge arresters are required inside the GIS.
- o) *Layout.* The modular design of GIS components offers a high degree of flexibility for any single-line diagram specified. Considering the high reliability of today's GIS components, with over 2000 operations before maintenance, simplified arrangements with less redundancy could be a way to reduce costs, particularly in stations with limited outage cost. A ring bus arrangement instead of a one-and-a-half breaker scheme, or a single instead of a double bus bar, can considerably reduce the total cost of a GIS. Using cable connections to overhead lines and/or transformers, especially at voltage levels up to 242 kV, may considerably reduce the total space required for an installation without limiting the access for ease of maintenance. As illustrated in figure 2, many different physical arrangements are possible for the same single-line diagram, balancing the shortest connection to adjacent equipment with the best fit to a particular site.

4.1.3 Three-phase or single-phase enclosure

A user should consider a number of factors in selecting between a three-phase enclosure design and a single-phase enclosure design, including the following:

- a) The initial cost of a three-phase design is generally less for the lower voltage ratings.
- b) Installation costs may differ depending on the amount of factory preassembly or on the overall size or weight of shipping sections.
- c) Three-phase enclosure designs may be smaller and consequently occupy less land or require a smaller building.
- d) When a fault occurs in a three-phase enclosure design, it rapidly evolves into a three-phase fault. This may be less tolerable than a single-phase fault from the point of view of system stability. However, in a three-phase enclosure design, the possibility of a burn-through is less. Venting of the pressure relief ports is less likely because the enclosure volumes tend to be larger.
- e) Some users require circuit breakers with independent pole operation. This may be more readily available with a single-phase design than a three-phase design.
- f) Hybrid designs employing single-phase and three-phase enclosure elements are both available and practical.

4.2 Installation and equipment handling

The following subclauses contain recommended procedures for installation and maintenance of gas-insulated substations.

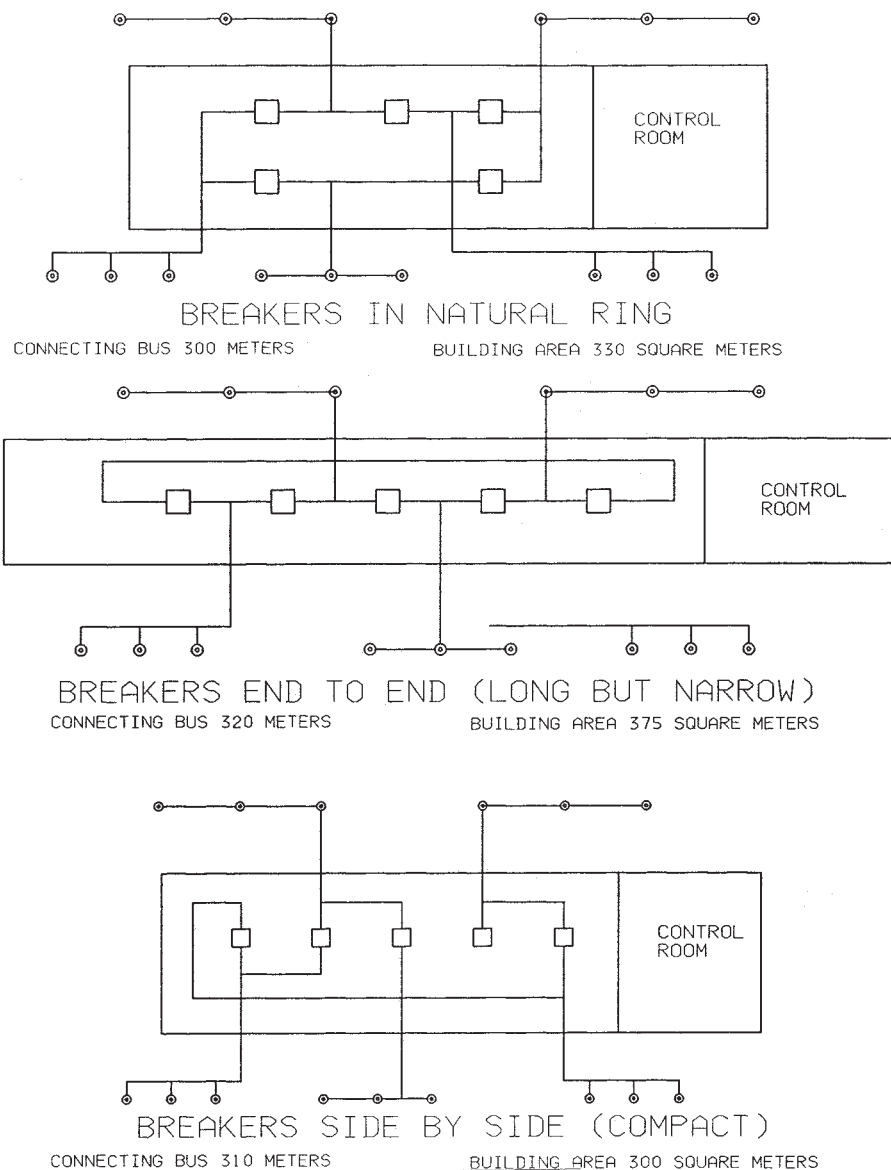


Figure 2— Comparison of physical arrangements for five-circuit ring bus requiring a building and SF₆ air bushings to overhead lines

4.2.1 Planning the installation

A deliberate and complete installation plan, including the future addition of similar equipment, is essential so that all aspects of construction can be reviewed. The preassembled sections of the equipment and the manufacturer's instructions dictate the assembly sequence and, in most instances, follow a series of steps categorized as follows:

- Preconstruction meeting between the user and the manufacturer
- Site preparation including grading; installation of drainage, foundations, and grounding mats; access roads; and auxiliary power
- Staging of construction equipment required during the installation
- Final alignment and leveling of foundation supports
- Receiving, unloading, and storing GIS equipment

- f) On-site assembly
- g) Leak testing
- h) Connection of control wires
- i) Purging and filling with insulating gas
- j) Mechanical or operational testing
- k) Dielectric testing
- l) Cleanup in accordance with applicable regulations
- m) Energization

Other planning considerations are as follows:

- A schedule for work crews should be prepared to provide for more economical use of manpower and to minimize conflicts caused by limited space. Scheduling may also result in the release of specialized skills in the shortest possible time.
- On-site or nearby preassembly areas should be planned when practical so that specialized equipment can be set up and repetitive assembly tasks can be performed under controlled conditions.
- A site layout designating erection equipment locations should be prepared to allow maximum use of the equipment with minimum movement. The layout should include details for each phase of installation so that orderly movement of the equipment can be maintained.
- The capacity of cranes, hoists, gas-handling equipment, welding equipment, etc., should be considered to ensure that the proper size equipment is available for the job.
- Electric power, heat, water, etc., should be available at the appropriate time in the installation sequence.
- The suitability of the site for each phase of construction and installation should be planned in advance (e.g., to move about the work area requires proper ground preparation).
- Cleanliness, in accordance with manufacturer's instructions, should be observed at all times.
- Material safety data sheets and other health and safety information should be readily available to the work crews.

4.2.2 Installation crew

The training of crews or the selection of individuals having the proper skills should be planned well in advance. The timing of the training should be integrated into the overall project plan.

A factory service technician is recommended for the installation of this equipment. Most manufacturers will train the user's personnel to ensure proper installation and equipment operation.

4.2.3 Equipment access

Structural supports, access platforms, ladders, stairs, cable raceway, conduit, and other auxiliary equipment required for operation and maintenance, as furnished by the manufacturer, should be incorporated, if practical, into the design.

4.2.4 Temporary protective covers

Covers and other suitable provisions for protecting the equipment from damage or contamination during shipping and installation should be furnished. Necessary quantities should be retained for future use.

4.2.5 Equipment and tool requirements

Cranes or hoists having adequate lifting capacities should be available for handling material during installation. Nylon web slings provide an ideal means for lifting equipment without damaging it.

Gas is handled through commercially available gas-processing trailers that contain vacuum pumping equipment, gas storage tanks, compressors, filters, and dryers. The size of the individual gas compartments and the evacuating and storage capacity of the gas-handling equipment is especially important in large stations. Suitable evacuating

equipment and a heat source to counteract the chilling effect of the expanding gas may permit filling directly from gas cylinders or gas-handling equipment. Filling procedures for GIS apparatus are covered in 4.4.4.

High-voltage test equipment is required for checking the quality of the insulation after installation. Adapters for high-voltage testing may be required. These include a suitable entrance bushing for connecting the high voltage to the gas-insulated conductor and a termination for closing off the end of the equipment when the entire assembly has not been completed. In many cases, it may be possible to use an entrance bushing that is a part of the installation. Field testing is covered in 4.10.

When tools and alignment templates not readily available on the open market are required for installation and maintenance of the equipment, one set should be furnished, by the supplier, with the equipment when it is delivered.

The following materials should be on hand before the bus is opened:

- a) Gas-processing equipment with adequate storage capacity
- b) Electrolytic or electronic hygrometer or comparable equipment for measuring moisture levels
- c) Insulating gas leak detector (Where double “O” rings are used, a manometer can sometimes be connected at the sensing hole to measure any increase in pressure between the “O” rings. Commercial high-viscosity, noncorrosive solutions may be used to locate larger leaks at a sensing hole, at welds, or at bolted flanges.)
- d) Dry air
- e) Clean plastic gloves and work uniforms
- f) Lint-free cloths and manufacturer-recommended solvents
- g) Temporary plastic bags or covers for sealing openings after components have been removed
- h) Commercial-type vacuum cleaner with high efficiency particulate air (HEPA) filters and nonmetallic accessories
- i) Tools supplied and recommended by the manufacturer
- j) Ventilating equipment
- k) Handling and lifting equipment
- l) Maintenance manual and erection drawings
- m) Ladders and platforms as required

4.2.6 Drawings and instructions

Installation drawings, instructions, and data should be furnished by the supplier. This should include but not be limited to the information listed below. Dimensions and weights should be in English or in metric, or both, as specified by the user.

- a) Instruction and procedures sequenced for storage, assembly, maintenance, and disassembly
- b) General arrangement and shipping assembly
- c) Assembly and maintenance clearance requirements
- d) Component outline dimensions and weights
- e) Method of lifting components
- f) Item or subassembly identification, or both
- g) Torque specifications
- h) Equipment adjustment and preparation
- i) Calculated point-to-point resistance for each assembled shipping component or shipping section, or both
- j) Gas system installation procedures, gas handling procedures, and schematic diagrams
- k) Specifications and procedures for cleanliness
- l) Foundation and anchor bolt requirements
- m) Grounding requirements
- n) Logic, control, flow, and wiring diagrams
- o) Operating instructions and procedures
- p) Nameplate(s) indicating equipment ratings
- q) Identification of component and assembly thermal expansion limits

- r) List of recommended spare parts
- s) List of components that may require replacement during a major overhaul
- t) Resistance values referred to in item i) above

4.2.7 Environmental considerations

All work should be done in a clean, dry environment. For outdoor work during inclement weather, a temporary protective shelter should be provided with adequate room (and heat when necessary). Moisture infiltration should be minimized.

4.2.8 Work procedures

4.2.8.1 Opening the equipment

Great care should be taken when opening GIS in order to avoid introduction of impurities in the apparatus. To this end, the following procedures are recommended.

- a) All safety precautions in 4.5 should be followed.
- b) The area around the junction to be opened, including supporting steel and other parts from which dirt or contaminants could fall or be blown into the enclosures, should be vacuumed and wiped with lint-free cloths.
- c) Evacuate the gas from the section on which work is to be performed to at least 670 Pa; then fill with dry air to a pressure of 100 kPa.
- d) Open the junction between components or sections in accordance with the manufacturer's recommendations, using temporary caps or covers as required. In some circumstances, it may be advantageous while working on the equipment to maintain a slight flow of dry, clean air across the area being maintained so that the probability of dirt or moisture entering the equipment will be minimized. When a compartment containing sulfur hexafluoride (SF_6) gas arc byproducts is opened, the byproducts, which are usually in the form of a white-to-tan powder, should be removed at once in accordance with 4.4.1.5.2.
- e) All work should be completed as quickly as possible. When delays are encountered, any open sections should be covered with temporary shipping covers or other suitable seals. It may also be necessary to add heat to prevent condensation. When any section is left overnight or longer, it should be pressurized with dry air to a pressure of approximately 136 kPa to avoid condensation or entrance of moist air.

4.2.8.2 Closing the equipment

The following procedures are to be followed:

- a) Inspect the conductor and sheath for nicks, burrs, or scratches and repair according to the manufacturer's instructions. Re-clean as required.
- b) Clean the enclosure thoroughly. Vacuum the inside of the enclosure and wipe the conductor and then the inside of the enclosure with a lint-free cloth. Insulators within easy reach should be cleaned according to the manufacturer's instructions.
- c) Reassemble the equipment and ensure that no foreign particles are introduced. Dry air flow should be continued until this step is completed. However, it will be necessary to discontinue air flow during welding to prevent the inert shielding gas from being blown away.
- d) Refill with dry air to a pressure suitable for preliminary leak checking and/or to a slightly positive pressure to maintain the interior clean and dry. Evacuate to the level agreed to between the manufacturer and the user and hold for the specified period of time. Perform a vacuum pressure rise test. Fill the enclosure with insulating gas to the specified pressure at ambient temperature and check for leaks. Check the water vapor (moisture) content immediately, and several days later recheck the pressure and moisture content. See 4.4.4 for further filling requirements. When major repairs or modifications have been made, it may be necessary to perform a dielectric test on the equipment to verify the insulation integrity. This decision should be made by the user, in consultation with the manufacturer. See 4.10 for recommended procedures on field testing.

4.3 Control wiring—Practices in GIS

IEEE standards cover qualification of substation control apparatus for immunity to damage from control wiring transients and electromagnetic interference (EMI). The standards developed for conventional substations are inadequate for GIS; however, the required standards for GIS are a straightforward extension of the existing standards and are already in draft form within the IEC. IEC Draft 17A-339 [IEC Draft 17C-102] introduces the principles that apply to control wiring practice in GIS.

Both conventional substations and GIS generate transients during switching. The transients generated in GIS have rise times roughly an order of magnitude shorter than those generated by conventional substations, which results in a frequency bandwidth roughly an order of magnitude greater. This causes increased coupling of interference into the control wiring, with the result that control wiring practice which has proved adequate for conventional substations may not be adequate for GIS. However, control wiring practice for GIS has been brought to the state which permits reliable operation of programmable controllers and computers within GIS. For a more detailed discussion of very fast transients (VFT) in GIS, see 4.9.

4.3.1 Background

Control wiring in early GIS was often implemented using well-shielded control cables (solid copper shields) that were installed with one end of the shield floating to eliminate unpredictable circulating currents in the cable shield. The grounded end of the shield was often connected to ground using a pigtail, which could vary in length from a few centimeters to 1 m. Where a cable entered a control cabinet, the cable and shield were often brought into the cabinet, and a pigtail was pulled from the cable shield to the cabinet ground within the cabinet. Control wiring systems installed in this manner often caused damage to electromechanical relays, especially as a result of flashovers during testing, as such flashovers cause the largest transients to which the control system is likely to be subjected. Even after the ungrounded end of the control cable shield was grounded (usually through another pigtail), routine switching operations sometimes caused incorrect operation of computers within GIS. For the very short rise time transients that occur in GIS, a pigtail represents a transmission line of significant impedance rather than a ground.

As a result of grounding the cable shield through a pigtail, significant lengths of control wiring conductors are likely to be left unshielded near the cable termination. Exposure of 15 cm of control wiring conductor can result in the coupling of transient voltages of up to 15 kV during a breakdown at a line-to-ground voltage of about 350 kV when the unshielded control wiring is located near a gas-to-air termination [B42]. The voltage generated during disconnecter operation would be less than half this value, in both cases with frequencies in the range of 1–30 MHz. A 30 cm (1 ft) pigtail can generate in the range of 1000 V on the shield as a result of the inductive voltage drop across the pigtail at 20 MHz [B42]. These problems were addressed and solved when utilities started to install computer-controlled GIS.

4.3.2 Appropriate control wiring practices

Transient generation and propagation within and along the GIS enclosure are covered in 4.9. Such transients generate substantial radiated energy, electric and magnetic fields, and transient currents within the substation grounds. Any of these phenomena can couple into poorly executed control wiring systems, but none of them can couple to an appreciable degree into well-executed control wiring systems. The obvious and correct approach to GIS control wiring is to enclose the entire control system in a Faraday cage, i.e., within a metal enclosure. This is much simpler than it sounds, as will be described below.

A Faraday cage is a metal enclosure that fully surrounds the system, offering protection from EMI. In the case of control wiring, the system is typically a sensor (e.g., a gas density relay), the attached control wiring, the local control wiring cabinet in which the control wiring is terminated, the control wiring from the local cabinet to the substation control room, and the relay or computer racks in the control room. Each of these elements is usually well shielded. The sensor is usually housed in a metal case that sits on the GIS. The control wiring is usually shielded by a solid copper shield or several layers of braid. The local control cabinet is metal and well shielded, as are the computers or relay racks in the substation control room. The problem, therefore, is not to shield the individual elements, which are all

usually well shielded, but to ensure the continuity of the shield from one element to the next. To this end, it is necessary to understand something about the flow of high-frequency currents in metals.

From 1 MHz to 100 MHz, the skin depth of current in copper varies from about 70 μm to 7 μm , respectively, so that almost no current flows in the conductor more than 0.25 mm below its surface. Since the copper cable shield, sensor enclosure, and local cabinet are all thick compared to the skin depth in this frequency range, independent currents can flow on the inner and outer surfaces of the cable shield. A large switching-induced transient current could be flowing on the outside surface of the shield with negligible current flowing on the inside surface. No coupling will occur to the sensor or control wiring within the shield so long as the current is not allowed to cross over from the outside of the shield to the inside. The key to proper control wiring practice for GIS is effecting connections between shielding elements that provide shield continuity and avoid such crossover.

When a cable enters a control cabinet, the cable shield should be terminated immediately on the control cabinet enclosure as the cable conductors enter the cabinet. A long pigtail termination of the cable shield after the cable has entered the cabinet is poor practice, as this brings the transient on the control cable shield within the control cabinet where it can couple to all of the conductors therein. Coaxial termination of the cable shield on the cabinet forces the shield currents to flow on the outside of the metal cabinet, which shields the conductors within from the shield currents. A range of connectors and cables is suitable for coaxial termination of cable shields. Cable with a solid copper shield offers best performance, and such cables do not necessarily cost more than cable with a less effective braided shield.

Some components in GIS require careful design to avoid the coupling of transients into the control wiring system. Voltage transformers (VT) are of special concern, as they effect a connection between the high-voltage conductor and the control wiring system. The interwinding capacitance in a magnetic VT can result in unacceptable coupling of transients from the GIS conductor to the low side of the VT unless an electrostatic shield is employed between the windings.

4.4 Gas handling—SF₆ and GIS

The purpose of the following subclauses is to familiarize the substation engineer, operator, maintenance worker, and industrial safety personnel with the nature of SF₆, SF₆ decomposition byproducts, and safety issues associated therewith as they relate to the maintenance and repair of GIS. The following subclauses reflect the consensus of GIS user practice and expert opinion. They do not prescribe work practices or required safety apparatus. Rather, they identify the issues that should be addressed in a document that specifies safe work practices, and provide some suggested guidelines for incorporation in such a document.

4.4.1 Pure SF₆

4.4.1.1 Physical and chemical properties

SF₆ is a heavy, nontoxic gas consisting of one sulfur atom surrounded by six fluorine atoms. As fluorine is the strongest of oxidizers, the fluorine atoms of SF₆ are tightly bound to the sulfur atom, resulting in a highly stable molecule. As a result of its symmetry, the intermolecular forces between SF₆ molecules are very low, resulting in a very low liquefaction temperature for its relatively high molecular weight of 146. Most materials of similar molecular weight are liquids or solids at room temperature.

As SF₆ is much heavier than air, it can “fall” into low places and displace the air, which can result in suffocation. However, once mixed with air, SF₆ will not separate and collect in low places. Although SF₆ is not toxic, a TLV-TWA of 1000 ppmv has been assigned for exposure to SF₆ in a working environment.

SF₆ is thermally very stable. However, in the presence of certain metals, it starts to decompose (0.2% per year) at temperatures as low as 200 °C, reaching a decomposition rate in the range of 2% per year at 250 °C. Above 600 °C, SF₆ degrades rapidly. Self-sustaining chemical reactions (burning) are possible between certain materials and SF₆.

Finely divided aluminum will burn in SF₆ if heated to a sufficiently high temperature. However, bulk aluminum will not burn, as the material carries heat away too rapidly for a self-sustaining reaction. Some molecular sieves and desiccants will go into a self-sustaining reaction with SF₆ at temperatures slightly above 100 °C.

4.4.1.2 Electrical properties

SF₆ is a highly electronegative gas, which means that it readily absorbs electrons to form negative ions. This gives it a very high dielectric strength of about 89 kV/cm-bar (225 kV/in-bar) in a uniform field. The dielectric properties of SF₆ vary greatly with electric field inhomogeneity, so that while SF₆ is an excellent dielectric for relatively uniform fields, its dielectric strength is reduced in the presence of stress-enhancement-causing defects. While the dielectric performance of SF₆ increases with pressure for uniform fields, it can decrease with pressure for nonuniform fields. Thus if the performance of an SF₆-insulated system is limited by defects that cause substantial electric field inhomogeneity, increasing the pressure of a system will not necessarily improve its dielectric performance.

SF₆ is useful as an insulating and arc interrupting medium as a result of the following properties:

- a) SF₆ liquefies at a sufficiently low temperature for a wide range of power engineering applications.
- b) SF₆ is electronegative, making it an excellent arc-quenching medium.
- c) SF₆ has a high dielectric strength.
- d) When SF₆ is decomposed as in an electrical arc, no solid conducting compounds are formed and the dielectric strength of the resulting mixture of gaseous decomposition byproducts and SF₆ is not degraded relative to that of pure SF₆.

4.4.1.3 Sources of SF₆ decomposition

SF₆ can be decomposed as a result of the following:

- a) *Excessive heating.* Excessive heating is most likely to occur as a result of improperly formed, high-current electrical contacts in switchgear.
- b) *Electric sparks.* Electrical sparking occurs routinely in some devices such as GIS disconnectors. The amount of SF₆ decomposition will vary widely with disconnector design and operating conditions. However, disconnector operation can generate as much as 1 ppmv of SF₆ decomposition byproducts within the switch compartment per operation.
- c) *Power arcs.* The temperature at the core of a power arc is about 20,000 °C, which results in a fully ionized plasma. After a power arc in pure SF₆, the recombination of the plasma into SF₆ is highly efficient, which results in small amounts of decomposition byproducts. As impurities in the plasma increase (e.g., H₂O, metal vapor, etc.), the amount of byproducts formed increases. Power arcs occur routinely in circuit breakers. However, circuit breakers are designed to minimize the amount of SF₆ decomposition through the following means:
 - 1) The arcing contacts are designed to react with the decomposed SF₆ in the arc at a very low rate. Also, the materials in the arcing contacts generally form gases (WF₆ or CF₄) rather than solids when reacting with SF₆.
 - 2) The moisture level in SF₆ circuit breakers is very low as a result of desiccant installed within the breaker; this reduces the formation of gaseous byproducts.
 - 3) Circuit breakers typically interrupt within three cycles to minimize the arc duration. Circuit breakers always include an adsorbent to remove arcing byproducts (as well as moisture) from the SF₆ within the breaker.
 - 4) An in-service fault in GIS also results in a power arc, usually between aluminum electrodes. Because aluminum is easily melted and vaporized, because the reaction between aluminum and an SF₆ plasma is highly exothermic (gives off a great deal of heat as the aluminum “burns” in the SF₆), and because a fault arc generally lasts much longer than the arc during breaker operation, a great deal more solid and gaseous arcing byproducts are formed during a fault than during breaker operation. A fault can result in up to 20% decomposition of SF₆ within a relatively small GIS gas compartment and the generation of several hundred grams (0.5 lb) of solid arcing byproducts. For an arc between aluminum electrodes, the