

IEEE Standard for Gas-Insulated Substations

Sponsor

**Substations Committee of the
IEEE Power Engineering Society**

Secretariat

**Institute of Electrical and Electronics Engineers
National Electrical Manufacturers Association**

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Foreword

(This Foreword is not a part of IEEE C37.122-1983, IEEE Standard for Gas-Insulated Substations.)

The development of this standard began almost simultaneously with the application of SF₆ gas-insulated substations in the early 1970s. Its purpose is to assist both users and manufacturers in the orderly design, development, and application of gas-insulated substations and gas-insulated substation equipment.

The standard was prepared by Working Group 70.1 on Gas-Insulated Substations of the Transmission Substations Subcommittee of the Substations Committee of the IEEE Power Engineering Society.

In 1988 certain editorial comments were provided by the Gas-Insulated Substations Subcommittee, R. Matulic, Chairman, of the Substations Committee of the IEEE Power Engineering Society.

At the time this standard was published it was under consideration for approval as an American National Standard.

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IEEE Standard for Gas-Insulated Substations

1. Introduction

1.1 Scope. This standard establishes ratings and requirements for planning, design, testing, installation, and operation of gas-insulated substations for alternating-current applications. Typical installations are assemblies of specialized devices such as circuit breakers, switches, bushings, bus, and instrumentation. It does not include certain items that may be directly connected to the gas-insulated substations such as power transformers and protective relaying.

To facilitate the use of this standard, it is divided into four sections:

Section 1, Introduction

Section 2, Standards

Section 3, Recommended Practices

Section 4, Guides

Each of the sections may be used in combination with other sections or other standards and guides.

Additional information on gas-insulated substations may be found in bibliographies published in [23].¹

1.2 References. The following publications shall be used in conjunction with this standard.

[1] AISC S326-78, Specification for Design, Fabrication, and Erection of Structural Steel for Buildings.²

[2] ANSI C37.06-1979, American National Standard Preferred Ratings and Related Required Capabilities for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.³

[3] ANSI C63.2-1987, American National Standard for Instrumentation of Electromagnetic Noise and Field Strength, 10 kHz to 40 GHz.

[4] ANSI MC96.1-1982, American National Standard Thermocouples Temperature Measurement.

[5] ANSI/ASME B31.1-1983(SI), Power Piping.⁴

[6] ANSI/AWS D1.1-88, Structural Welding Code—Steel.⁵

[7] ANSI/IEEE C37.04-1979, IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.⁶

[8] ANSI/IEEE C37.09-1979, IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

[9] ANSI/IEEE C37.010-1979, IEEE Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

[10] ANSI/IEEE C37.30-1971 (R1987), IEEE Standard Definitions and Requirements for High-Voltage Air Switches, Insulators, and Bus Supports.

[11] ANSI/IEEE Std 24-1984, IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings.

[12] ANSI/IEEE Std 80-1986, IEEE Guide for Safety in AC Substation Grounding.

[13] ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.

¹The numbers in brackets correspond to those of the references in 1.2.

²AISC publications can be obtained from American Institute of Steel Construction, 400 North Michigan Avenue, Chicago, IL 60611.

³ANSI publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

⁴ANSI/ASME publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from ASME Order Department, 22 Law Drive/Box 2300, Fairfield, NJ 07007-2300.

⁵ANSI/AWS publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from American Welding Society, Inc, 550 NW LeJeune Road, PO Box 351040, Miami, FL 33135.

⁶ANSI/IEEE publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from the Service Center, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331.

- [14] ANSI/IEEE Std 367-1987, IEEE Recommended Practice for Determining the Electric Power-Station Ground Potential Rise and Induced Voltage from a Power Fault.
- [15] ANSI/NFPA 70-1987, National Electrical Code.⁷
- [16] ASME Boiler and Pressure Vessel Code: Section VIII, Pressure Vessels, Division 1, Basic Coverage.⁸
- [17] ASTM D2472-71 (R1980), Standard Specification for Sulfur Hexafluoride.⁹
- [18] Draft IEEE C37.24-1986, IEEE Guide for Evaluating the Effect of Solar Radiation on Outdoor Metal-Enclosed Switchgear.¹⁰
- [19] IEEE Std 48-1985, IEEE Standard Test Procedures and Requirements for High-Voltage Alternating-Current Cable Terminations.
- [20] IEEE Std 119-1974, IEEE Recommended Practice for General Principles of Temperature Measurement as Applied to Electrical Apparatus.
- [21] IEEE Std 344-987, IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations.
- [22] IEEE COMMITTEE REPORT. Use of Aluminum for Substation Buses. Paper 62-280, Working Group 57.1.
- [23] IEEE COMMITTEE REPORT. IEEE Transactions on Power Apparatus and Systems, Paper 82 WM 169-1, vol PAS 101, no 11, p 4289.
- [24] BELLASCHI, P. L., ARMINGTON, R. E., and SNOWDEN, A. E. Impulse and 60-Cycle Characteristics of Driven Grounds-II. AIEE Transactions, vol 61, 1942, pp 345-363.9.
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- [35] HEPPE, R. Step Potentials and Body Currents Near Grounds in Two-Layer Earth. IEEE Power Engineering Society Winter Meeting, 1978, Paper no F78-210-7.
- [36] LINCK, H. Shielding of Modern Substations Against Direct Lightning Strokes. IEEE Transactions on Power Apparatus and Systems, vol PAS-94, no 5, Sept/Oct 1975, pp 1675-1679.

⁷ ANSI/NFPA publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

⁸ ASME publications can be obtained from ASME Order Department, 22 Law Drive/Box 2300, Fairfield, NJ 07007-2300.

⁹ ASTM publications can be obtained from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

¹⁰ IEEE publications can be obtained from the IEEE Service Center, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331.

[37] SVERAK, J. G. Optimized Grounding Grid Design Using Variable Spacing Technique. IEEE Transactions on Power Apparatus and Systems, vol PAS-95, no 1, Jan/Feb 1976, pp 362-374.

[38] SVERAK, J. G. Sizing of Ground Conductors Against Fusing. IEEE Power Engineering Society Winter Power Meeting, 1980, Paper no F80-256-8.

[39] SVERAK, J. G. Safe Substation Grounding Part I. Working Group 78.1, Report Paper 80 SM652-08. IEEE Transactions, vol PAS-100, Sept 1981, pp 4281-4290.

[40] WALSH, G. W. A Review of Lightning Protection and Grounding Practices. IEEE Transactions on Industry Applications, vol IA-9, no 2, Mar/Apr 1973.

1.3 Definitions. The definitions in this section establish the meanings of words in the context of their use in this standard. Other terms shall be defined in accordance with ANSI/IEEE Std 100-1984 [12].

acting stress (working stress). The maximum applied or expected stress in a material during operation of the apparatus of which it is a part and including the stresses caused by gas pressure, wind, ice, or seismic loading.

assembly (GIS). A gas-insulated substation that is fully constructed.

auxiliary circuits. In this standard all control, indicating, and measuring circuits are auxiliary circuits.

circuit-breaker grouping. The three poles of a circuit breaker grouped in adjacent configuration along the line of the same row.

Class A seismic component. That 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.

Class B seismic component. That 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 either meet 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.

compartment (GIS). Any gas section of the gas-insulated substation assembly that can be isolated from the system by internal or external means.

conformance tests. Those tests that are specifically made to demonstrate the continuing conformance of the equipment with the applicable standard.

continuous enclosure. A bus enclosure in which the consecutive sections of the enclosure for the same phase conductor are electrically bonded together to provide a continuous current path throughout the entire enclosure length.

NOTE: Cross-connections to the other phase enclosures are made only at the extremities of the installation and at selected intermediate points.

continuous monitoring. The process of sampling the state of some phenomenon either continuously or at a sample interval of one second or less.

damping. A dynamic property of a vibrating structure that indicates its ability to dissipate mechanical energy. The phenomenon of damping is represented by a quantity called the damping factor, which is expressed as a percentage of critical damping. After being forced to deflect and allowed to freely vibrate, structures with zero damping will vibrate with a harmonic motion indefinitely. Structures with critical damping will creep back to their static or neutral position with no velocity reversal.

design earthquake. The greatest earthquake postulated during the life of the gas-insulated substation, which the user wishes the gas insulated substation to survive.

design tests. Those tests made to determine the adequacy of the equipment comprising the gas-insulated substation, which enables it to operate satisfactorily under specified service conditions.

NOTE: Design tests are made on representative samples of the same type and rating and are not intended to be used as a part of normal production.

The applicable portions of these design tests may also be used to evaluate modifications of a previous design and to ensure that performance has not been adversely affected. Test data from previous similar designs may be used for current designs, where appropriate.

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

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

failure mode. A process of failure of equipment that causes a loss of its proper function.

gas barrier insulator. A spacer insulator specifically designed to prevent passage of gas from one side to the other.

gas density, minimum. The minimum operating gas density at which the gas-insulated substation and its components will meet their assigned electrical ratings.

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

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 which normally consists of buses, switchgear, and associated equipment (subassemblies).

gas-insulated-substation (GIS) surge arrester. A surge arrester specifically designed for use in a gas-insulated substation.

gas leakage. Loss of insulating gas from the pressurized system.

low-level testing. Mechanical testing performed to determine natural frequencies and damping of complete assemblies, subassemblies, or components.

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

main ground bus. A conductor or system of conductors that provides for connecting all designated metallic components of the gas-insulated substation to station ground (ground grid).

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 another. In such cases, an evaluation of the equipment or device application must include a determination that the degree of relay contact bounce, changes in device calibration, or degradation of pressure-retaining boundaries are within acceptable limits.

metallic enclosure. A grounded leaktight enclosure that contains the compressed insulating gas and associated electrical equipment.

mode shape. A plot of the displacements of various points in which the vibrating structure at a particular instant in time.

NOTE: With each natural frequency of a vibrating structure there is associated a characteristic mode shape.

noncontinuous enclosure. A bus enclosure in which the consecutive sections of the enclosure for the same phase conductor are electrically insulated from each other.

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

parts per million by volume (ppmv). The volume of water vapor in the total SF₆ system at the pressure the system is operated.

parts per million by weight (ppmw). The weight of water vapor in the total SF₆ system at the pressure the system is operated.

periodic monitoring. The process of sampling the state of some phenomenon at a sample interval greater than one second.

phase grouping. The same phase of a number of circuit breaker's poles is grouped in an adjacent configuration along the line of the same row.

production tests. Those tests made to check the quality and uniformity of the workmanship and materials used in the manufacture of gas-insulated equipment.

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

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, displacement) versus forcing frequency for a constant forcing input, it would be seen that as the forcing frequency approaches one of the natural frequencies the response increases until it is at a maximum at the natural frequency. The response of the structure at resonance may be much greater than the input, depending on the damping.

response spectrum. 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 (that is, on the ground for a ground response spectrum or on the floor for the floor response spectrum) when that surface is subjected to a given earthquake's motion as modified by intervening structures.

row arrangement. Circuit-breaker pole units installed in a consecutive mode thus physically forming a continuous line. The natural expansion of the substation would normally continue in the direction of the row. Arrangements can be two, three, four, or more rows in parallel configuration.

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.

spacer insulator. A spacer insulator as used in a gas-insulated system is an insulator used to support the inner conductor in the enclosure.

subassembly. One or more compartments that comprise the gas-insulated substation assembly.

sulfur hexafluoride (SF₆). A gaseous dielectric for high-voltage power applications having characteristics as specified in ASTM D2472-71 (Reapproved 1980) [17].

time history. The trace of acceleration, velocity, or displacement as a function of time that the ground, the floor of a building, or a point of support experiences due to an earthquake.

transition compartment. The compartment specifically designed for joining gas-insulated-sub-

station equipment of different design or manufacture. This compartment provides the necessary transition for the current-carrying conductor and the gas enclosure.

water vapor (moisture) content. The amount of water in parts per million by volume that is in the gaseous state and mixed with the insulating gas. Water vapor content may vary with temperature.

zero-period acceleration. The peak acceleration experienced by a rigid, single-degree-of-freedom oscillator when it is subjected to the design earthquake either directly to its base or through an intervening structure.

NOTE: Generally, a body can be considered rigid, for seismic excitation purposes, if its natural frequency is greater than 30 Hz. The peak acceleration for a body with a natural frequency greater than 30 Hz is the same as that of a body with an infinitely high natural frequency, or conversely, a body with an infinitely small period (zero period). On a response spectrum, the zero-period acceleration is also equal to the asymptotic value of acceleration.

1.4 Service Conditions

1.4.1 Usual Service Conditions. Devices conforming to this standard shall meet the electrical, mechanical, thermal, etc, requirements of the gas-insulated substation on which it is used and be capable of operation under the following conditions.

1.4.1.1 Temperature Range. The normal ambient temperature range shall be -30°C – $+40^{\circ}\text{C}$.

1.4.1.2 Heat Absorption Due to Solar Radiation. Solar radiation shall be considered in the design of GIS. Draft IEEE C37.24-1986 [18] provides guidance in evaluation of the effects of solar radiation on outdoor apparatus.

1.4.1.3 Internal Pressure. The internal pressure range shall be from 0.1 mm of mercury to the maximum operating pressure specified by the manufacturer.

1.4.1.4 Wind and Ice. Wind and ice conditions shall correspond to ANSI/NFPA 70-1987 [15] for heavy loading on structures.

1.4.1.5 Electromagnetic Interference. The equipment shall not operate falsely or fail to operate because of induced transient or steady-state fields.

1.4.1.6 Power Frequency. The standard power frequency shall be 50 Hz or 60 Hz.

1.4.1.7 Vibration and Shock. The equipment shall withstand for its service life the vibration of any directly connected equipment such as transformers and the shock caused by the operation or maintenance of the equipment.

1.4.1.8 Altitude. The normal installation altitude shall not exceed 3300 ft (1000 m).

1.4.2 Unusual Service Conditions. The application of this equipment at other than the usual service conditions shall be considered as special. Standard assemblies may be applied at unusual service conditions but performance may be affected, and special consideration should be given to these applications.

1.4.3 Other Conditions that May Affect Design and Application. Where other conditions exist, they should be brought to the attention of those responsible for the design and application of these assemblies. Among such conditions are:

(1) Exposure to damaging fumes or vapors, steam, salt air, oil vapors, hot humid climate, excessive dust, abrasive dust, dripping water, falling dirt, explosive mixtures of dust or gases, extreme high or low temperatures.

(2) Unusual insulation requirements, space or ventilation limitations, special duty, frequency or other operating requirements, difficulty of maintenance, nonstandard or unstable control voltage, abnormal vibration.

2. Standards

2.1 Equipment Ratings

2.1.1 Temperature Limitations

	Maximum Allowable Total Temperature
(1) Silvered joint	105 °C
(2) External surfaces — accessible	70 °C
(3) External surfaces — inaccessible	110 °C
(4) External surfaces — normally handled by an operator	50 °C

All other conditions regarding temperature limitations are as noted in ANSI/IEEE C37.010-1979 [9], Table 1 and ANSI/IEEE C37.30-1971 [10], Table 3.

2.1.2 General Ratings. The general ratings that all components of the station shall meet or exceed are as follows:

2.1.2.1 Voltage Ratings of Gas-Insulated Substations. See Table 1.

2.1.2.2 Rated Continuous Current (Amperes rms) at Ambient Temperature. The value of rated continuous current shall be selected from the following table:

Rated Continuous Current Amperes rms	
1200	3000
1600	4000
2000	5000

2.1.2.3 Load Current-Carrying Capability Under Various Conditions of Ambient Temperature. The variation of rated continuous current with ambient temperature shall be as per ANSI/IEEE C37.010-1979 [9] and ANSI/IEEE C37.30-1971 [10].

2.1.2.4 Short-Time Load Current Capability. The short-time load current capability shall be per ANSI/IEEE C37.010-1979 [9].

2.1.2.5 Rated Momentary Current. The rms and peak value of the rated momentary current shall be 1.6 and 2.7 (respectively) times the rated short-time current-carrying capability.

2.1.2.6 Short-Time Current-Carrying Capability. The value for the short-time current-carrying capability shall be selected from the following table:

Short-Time Current-Carrying Capability kA rms	
16	
20	50
25	63
31.5	80
40	100

The standard duration for the short-time current shall be three seconds. For durations greater than three seconds, the relation between current and time, unless otherwise specified by the manufacturer, shall be in accordance with the formula $I^2t = \text{constant}$.

NOTE: The duration is for single-phase GIS. For three-phase GIS, the duration is under study.

2.1.2.7 Voltage Rise of Metallic Enclosure. Excessive voltage on the metallic enclosure shall be prevented as specified in 4.3.

2.1.2.8 Gas. Insulating-gas requirements, gas-leakage limitations, gas-water vapor content, and gas-density levels are as specified in 2.4.

2.2 Barriers, Bus, Bus Supports, Enclosures, and Expansion Joints

2.2.1 General. This section establishes the requirements for barriers, bus, bus supports,

Table 1
Voltage Ratings of Gas-Insulated Substations
At Normal Operating Gas Pressure

Column 0	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10
Substation Test Values				Disconnect Switch Open Gap			Interrupter Open Gap			
Rated Max Voltage kV rms	Rated BIL kV Crest	Low Freq Withstand kV rms	Sw Impulse Withstand kV Crest	Rated Field Tests Low Freq Withstand kV rms	Impulse Withstand kV Crest	Low Freq Withstand kV rms	Sw Impulse Withstand kV Crest	Impulse Withstand kV Crest	Low Freq Withstand kV rms	Sw Impulse Withstand kV Crest
72.5	300	140	*	105	330	154	—	300	140	—
72.5	350	160	*	120	385	176	—	350	160	—
121	450	215	*	160	495	236	—	450	215	—
121	550	260	*	195	605	286	—	550	260	—
145	550	260	*	195	605	286	—	550	260	—
145	650	310	*	230	715	341	—	650	310	—
169	650	310	*	230	715	341	—	650	310	—
169	750	365	*	270	825	401	—	750	365	—
242	750	365	*	270	825	401	—	750	365	—
242	900	425	*	320	990	467	—	900	425	—
362	900	425	720	320	990	467	800	900	425	800
362	1050	500	825	375	1155	550	900	1050	500	900
550	1300	615	1050	460	1430	676	1175	1300	615	1175
550	1550	740	1175	550	1705	814	1300	1550	740	1300
800	1800	860	1425	645	1980	946	1550	1800	860	1550

*For rated maximum voltage 72.5 kV to 242 kV, impulse shall be at least the crest value of those given in column 2.

NOTES: (1) Reference Columns 5, 6, and 7. For certain switches energized at normal voltage on one terminal and subject to impulse or switching surges on the other side, such as line switches in a ring bus, higher open gap withstand voltages may be desirable. However, it must be remembered that an open gap flashover in a gas-insulated switch must promptly initiate a flashover to ground at all gas pressures from atmosphere to maximum rated, which then would clear the circuit in approximately 4 cycles, depending on relaying, breaker speeds, etc.

(2) Routine low-frequency 1 min withstand tests are conducted prior to shipment from the factory at the rated withstand voltage shown in Column 2.

(3) The values given in Columns 5 through 10 are provided for design criteria.

enclosures, and expansion joints used in gas-insulated substations.

2.2.2 Enclosures

NOTE: Working Group K-3 of the GIS Subcommittee is preparing a standard for GIS pressurized electrical enclosures, which when approved and published will supersede 2.2.2.

The ASME Boiler and Pressure Vessel Code [16], Section VIII, Division 1, and the American National Standards Institute Standard Code for Pressure Piping, ANSI B31.1-1973 [5], and local and state ordinances shall be used as a guide for design and construction of the enclosures. The material specification shall be consistent with requirements for conductivity, corrosion resistance, and mechanical strength.

The enclosure shall be designed to withstand an external pressure of one atmosphere (with a 1.5 safety factor) with zero internal pressure absolute and be designed and tested to withstand an internal test pressure of 1.5 times the design pressure.

The enclosure shall be divided into several compartments or sections separated by gastight

barriers permitting removal of a section or sections from service for maintenance without affecting adjacent sections. The gas system shall be designed to permit sections to be isolated. The volume of each gas compartment should be limited so that gas processing and storage can be accomplished with available equipment within a reasonable time.

The enclosure shall be designed so that overpressures caused by internal faults are limited by using pressure relief devices, gas barrier insulators designed to rupture and increase the volume of the affected section, enclosure burn through, or other suitable means. Pressure relief devices, if supplied, shall be located so that they do not pose a hazard to operating personnel.

2.2.3 Adjacent and Supporting Structures.

Most bus systems are of the continuous enclosure design, which provides adequate shielding to eliminate induced magnetic heating and to permit grounding as necessary (See 4.4.3 regarding grounding enclosures). For high-current noncontinuous bus designs, consideration shall be given

to induced magnetic heating and induced circulating current in nearby metallic members such as support beams, reinforcing rods, and transformer tanks. Suitable insulated gaps in the metallic framework to eliminate closed loops and amortisseur bands around steel members, etc, may be used to limit the circulating current. The structure shall be designed so that the temperature rise in any of its members or in any adjacent members does not exceed the limits specified in 2.1.1.

2.2.4 Expansion Joints. Expansion and installation alignment shall be considered in the design of the bus and enclosure, and expansion joints shall be provided, if required. When bellows are provided in the enclosure for installation alignment, means shall be provided to prevent movement after alignment is complete. Bellows provided to permit movement caused by expansion and contraction or foundation settlement shall have specially designed means to preserve the mechanical strength of the bus and enclosure as well as contact alignment and penetration. Joints provided for direct connection to transformers shall be designed to inhibit transfer of audible vibration from the transformer to the bus and bus enclosure.

2.2.5 Electrical Requirements. When three single-phase enclosures terminate in a single metallic enclosure (or three single enclosures, metallic-connected) the three single-phase enclosures must be electrically isolated from the single metallic enclosure unless the single metallic enclosure is designed to carry the circulating currents associated with the three single-phase enclosures.

2.3 Bushings and Transition Compartments

2.3.1 General. This section covers bushings and transition compartments for use with gas-insulated substations (GIS). Typical uses are as follows:

2.3.1.1 Bushings

(1) Air Entrance—Conventional overhead circuits to GIS

(2) Equipment Entrance—(a) Separation of different insulation media, such as at transformers or circuit breakers.

(b) Separation based on use of different pressures of the same insulation media, such as at gas-insulated circuit breakers.

2.3.1.2 Transition Compartments. Transition compartments may be required when joining GIS equipment of different design or manufacture.

2.3.2 Bushing Requirements. Characteristics for GIS bushings are under review for inclusion in ANSI/IEEE Std 24-1984 [11].

2.4 Insulating Gas—Requirements. Sulfur hexafluoride (SF_6) for use as an electrical insulation material shall conform to the requirements prescribed in ASTM D2472-71 (Reapproved 1980) [17].

2.5 Gas Monitoring and Instrumentation

2.5.1 Monitoring

2.5.1.1 Gas Density. The gas density in each compartment shall be continuously monitored. The monitoring device shall be capable of operating a relay contact upon descending gas density at each of two different density levels. Gas density level settings and functional operating requirements (alarm, trip, etc) at each level below normal shall be agreed upon between the manufacturer and user. If the device has a visual indicator, it shall be readable from the ground.

2.5.1.2 Gas Temperature. Gas temperature provides for periodically monitoring a representative temperature.

2.5.1.3 Gas Pressure. Gas pressure provides for periodically monitoring the gas pressure.

2.5.1.4 Water Vapor Level. The water vapor level and temperature of each gas compartment should be determined at filling, upon addition of any gas, after two weeks and then once a month until it has stabilized. After the water vapor level has stabilized, it should be periodically monitored every six months to a year. The water vapor level should not exceed levels agreed upon between the manufacturer and user. Depending upon the method used during filling, the water vapor content may increase from two to six times the initial gas filling level.

2.5.1.5 Other Gases. Since each gas compartment is evacuated before being filled with SF_6 the probability of filling with something other than SF_6 is very low. No testing for other gases is suggested.

2.5.2 Monitoring Device Contacts and Calibration

2.5.2.1 Contacts. Gas density monitors shall have at least two electrically separate contacts, convertible from *a* to *b*, at each specified density level. Contact voltage and current rating shall be specified by the user. The manufacturer shall supply contact resetting data, that is, differential levels at which contacts will return to normal position on increasing gas density.

2.5.2.2 Calibration. Gas density monitors shall be capable of being calibrated with the station in service.

2.5.3 Leakage. The leakage rate from any single gas section of the substation shall not exceed 2% per year, with the total leakage from the substation not exceeding one percent per year.

2.5.4 Piping. If gas monitoring piping and connections are subject to being stepped on during normal operation or maintenance, they shall be provided with protective covers. The gas monitoring piping shall be isolated so that it does not carry electric currents.

2.6 Factory Testing

2.6.1 General. This section establishes requirements for factory testing of components of gas-insulated substations; however, it does not cover all accessory devices used in the substation. It does not preclude the use of other equivalent or more effective methods of demonstrating ratings. These tests are divided into two categories: (1) Design Tests and (2) Production Tests.

Test requirements in this section are not applicable to power transformers, surge arresters, or voltage transformers, that may be connected to gas-insulated equipment but are applicable to gas-insulated compartments and connections furnished as an integral part of such equipment.

The purposes of the test procedures are:

(1) To verify that all components of the GIS can perform satisfactorily both electrically and mechanically at the ratings assigned.

(2) To establish that production sections have been adequately tested during manufacture and after assembly and that they have characteristics essentially the same as those subjected to design tests.

2.6.2 Design Tests. The design tests provide a method of demonstrating that the apparatus meets the specifications.

2.6.2.1 Rated Continuous Current Tests. Rated continuous current tests demonstrate that the gas-insulated substation components can carry rated continuous current at rated frequency without exceeding any of the temperature limitations in 2.1.1. The effect of solar radiation should be considered in assigning the temperature rise to the equipment. Draft IEEE C37.24-1986 [18] governs how this factor is to be applied.

2.6.2.2 Conditions of Test. (1) The ambient temperature shall be between 10 °C and 40 °C inclusive, so that no correction factors need be applied.

(2) The equipment shall be in a new condition.

2.6.2.3 Duration of Rated Continuous Current Tests. The rated continuous current test shall be continued until the temperatures of all components that carry continuous current in normal operation are substantially constant as indicated by three successive readings at thirty-minute intervals. Temperature-rise tests shall be conducted on a three-phase bus sample having a minimum length of 19.7 ft (6 m). The sample shall have at least one joint per conductor and enclosure (sliding, bolted, clamped, or welded). Return current in the single-phase test should be equal to the conductor current. All joints not similar to this one design should be similarly tested.

2.6.2.4 Temperature Measurements. Temperatures shall be measured by the following methods (see IEEE Std 119-1974 [20] and ANSI MC96.1-1982 [4]):

- (1) Thermocouple
- (2) Thermometer (preferred method for ambient temperatures)
- (3) Resistance

The measuring device shall be located at the hottest spot even though it may involve drilling holes that destroy some parts on a design test. This will require the use of thermocouples in locations that are inaccessible to thermometers so as to obtain the hottest-spot measurement. It is recognized that thermocouples cannot be located in the actual contact point of line or point contacts.

Measurements shall be made at junction points of insulation and conducting parts to ensure against exceeding temperature limits of the insulation.

The bulbs of thermometers used for taking apparatus temperatures shall be covered by felt pads cemented to the apparatus or by oil putty. Dimensions of felt pads for use with large apparatus shall be 1½ in × 8 in × ¼ in (38 mm × 203 mm × 3 mm). The use of smaller pads is permissible on small apparatus.

2.6.2.5 Ambient Temperature. The ambient temperature shall be taken as that of the surrounding air. The ambient shall be between 10 °C and 40 °C, inclusive, so that no correction factors need be applied. The ambient temperature shall be determined by taking the average of the readings of three thermometers placed in locations unaffected by drafts, horizontally 12 in (305 mm) from the projected periphery of the enclosure, and approximately on a vertical line as follows:

- (1) One approximately 12 in (305 mm) above the enclosure.
- (2) One approximately 12 in (305 mm) below the enclosure.

For floor-mounted equipment, it shall be 12 in (305 mm) above floor or mounting base.

(3) One approximately midway between the above two positions.

2.6.2.6 Short-Circuit Current Rating. The short-circuit current tests demonstrate the rated short-circuit current and the related required capabilities when used on grounded and ungrounded systems, and the values shall be as described in 2.1.

Tests to demonstrate the required capabilities shall be made in accordance with the conditions specified in ANSI/IEEE C37.09-1979 [8], 4.5.4, under specified testing conditions in ANSI/IEEE C37.09-1979 [8], 4.5.5 and 4.5.6.

These tests shall be made on single shipping sections and various other configurations of bolted, welded, plug-in, or otherwise jointed sections to verify the integrity of the GIS components as joined together.

2.6.2.7 Dielectric Withstand Tests

(1) Power frequency voltage at the rated withstand value shall be applied for one minute between the main bus and ground and across all isolating gaps. Tests shall be made at minimum gas density specified by the manufacturer.

(2) Lightning impulse voltage at the rated withstand value shall be applied between the main bus and ground and across all isolating gaps. Both positive and negative 1.2/50 μ s impulses are to be used. See ANSI/IEEE C37.09-1979 [8], 2.3.2.

(3) Switching surge impulse voltage at the rated withstand value shall be applied between the main bus and ground and across all isolating gaps. Both positive and negative 250/2500 μ s impulses are to be used. See ANSI/IEEE C37.04-1979 [7], ANSI C37.06-1979 [2], and ANSI/IEEE C37.09-1979 [8].

(4) Dielectric strength versus gas density over minimum/maximum allowable density range.

(5) All internal portions of the gas-insulated system shall be free of partial discharge voltage at 150% of rated maximum voltage. This condition must be satisfied on the downward excursion of voltage from a test voltage that is twice the line-to-ground voltage or equal to the low-frequency withstand voltage of Table 1, except that systems for rated maximum voltage of 800 kV and above use low-frequency withstand, Table 1, Column 2.

Extinction of the partial discharge voltage must occur above the 150% point. Partial discharge tests shall be made in accordance with ANSI C63.2-1987 [3].

2.6.2.8 Switching Tests. These may be defined as

- (1) Load current
- (2) Capacitive current
- (3) Reactive current
- (4) Line charging current
- (5) Excitation current
- (6) Switching parallel transformers
- (7) Out-of-phase switching
- (8) Close and latch, momentary, and short time where applicable
- (9) Loop switching

2.6.2.9 Insulator Tests. The thermal performance of each insulator design shall be verified by subjecting five insulators to ten thermal cycles each. A thermal cycle is defined as:

- (1) Four hours at an ambient temperature of -40°C
- (2) Two hours at room temperature
- (3) Four hours at an ambient temperature of $+125^{\circ}\text{C}$
- (4) Two hours at room temperature

If the test insulator fails, a batch of five from the same lot shall be tested without additional failures. If more than one insulator fails in the initial batch, the design is unacceptable. Different test facilities may give different rate of change of temperature between the specified test temperatures, therefore the time between the test temperatures is not specified.

2.6.2.10 Mechanical Life Test on All Assorted Mechanisms. Considerations should be given to dielectric degrading of insulation after all life tests.

2.6.2.11 Mechanical Bushing Test for Cantilever Loading. See 2.3.2.

2.6.2.12 Pressure Tests. Pressure tests shall be performed on one of each assembly or component making up the substation at 1.5 times maximum working pressure. This test does not include pressurized porcelains, which may require tests for higher values (See ANSI/IEEE C37.04-1979 [7] and ANSI/IEEE C37.09-1979 [8]).

2.6.3 Production Tests

2.6.3.1 Types of Tests (Checks). Production tests are normally made by the manufacturer at the factory.

Production tests or checks shall include, but not be limited to, the following tests or checks as appropriate or as deemed necessary between manufacturer and user. See ANSI/IEEE C37.09-1979 [8], Section 5.

- (1) Current transformer and linear coupler transformer tests per ANSI C57
- (2) Gas receiver tests
- (3) Pressure tests of enclosures
- (4) Nameplate checks

- (5) Leakage tests
- (6) Resistors, heaters, and coils check tests (control mechanism)
- (7) Control and secondary wiring check tests and continuity tests
- (8) Clearance and mechanical adjustment check
- (9) Mechanical tests on operational assemblies
- (10) Timing tests on operational assemblies
- (11) Stored energy system tests
- (12) Conductivity of current path test
- (13) Rated-frequency withstand voltage tests on major insulation
 - (a) Bushings
 - (b) Shipping assemblies components

NOTE: See 2.1, Table 1, Column 2—Low-frequency withstand, kV rms.

- (14) Rated-frequency withstand voltage tests on control and secondary wiring
 - (15) Gas monitoring systems alarms contacts
 - (16) Color
 - (17) Inspection windows for clarity if they exist
- Component tests are acceptable if GIS cannot conveniently be tested as a complete unit at factory.

NOTE: See 2.1, Table 1, Column 2—Low-frequency withstand, kV rms.

2.6.3.2 Dielectric Tests. The dielectric tests for shipping sections shall be made at the minimum operating pressure unless otherwise stated.

2.7 Installation of Gas-Insulated Substations—Requirements

2.7.1 Shipment and Preinstallation Storage. Equipment shall be factory assembled and shipped in preassembled sections as large as practicable to facilitate onsite installation. The equipment shall be prepared for shipment and preinstallation storage in a manner that will prevent the ingress of moisture and other contaminants.

2.7.2 Access During Construction. Structural supports, access platforms, ladders, stairs, cable raceway, conduit, and other auxiliary equipment required for operation and maintenance shall be incorporated, if practical, into the design. Such equipment shall be coordinated with the substation components to ensure availability for access during installation of the substation.

2.7.3 Temporary Protective Covers. Covers and other suitable provisions for protecting the equipment from damage or contamination during shipping and installation shall be furnished.

2.7.4 Special Tools. When special tools and alignment templates not readily available on the

open market are required for installation and maintenance of the equipment, one set shall be furnished.

2.7.5 Installation Drawings and Instructions. Installation drawings, instructions, and data shall be furnished but not limited to the information noted below. Dimensions and weights shall be in English or metric, or both, as specified by the user.

- (1) Instruction and procedures sequenced for storage, assembly, maintenance, and disassembly
- (2) Assembled shipping component identification
- (3) Assembly and maintenance clearance requirements
- (4) Component outline dimensions and weights
- (5) Method of lifting components
- (6) Item or subassembly identification, or both
- (7) Torque specifications
- (8) Equipment adjustment and preparation
- (9) Calculated point to point resistance for each assembled shipping component, or shipping section, or both
- (10) Gas system installation procedures, gas handling procedures, and schematic diagrams
- (11) Specifications and procedures for cleanliness
- (12) Foundation and anchor bolt requirements
- (13) Grounding requirements
- (14) Logic, control, flow, and wiring diagrams
- (15) Operating instructions and procedures
- (16) Nameplate(s) indicating equipment ratings
- (17) Identification of component and assembly thermal expansion limits
- (18) List of recommended spare parts
- (19) List of components that may require replacement during a major overhaul
- (20) Resistance values referred to in 3.4.3.2.2.

3. Recommended Practices

3.1 Equipment Handling and Cleanliness

3.1.1 General. This is a recommended procedure for equipment handling and cleanliness, during maintenance or repair work on gas-insulated substations.

3.1.2 Design Considerations for Ease of Maintenance or Repair

- (1) It is desirable to be able to repair and maintain major elements (such as breakers and switches) without removing them from the system. However, this may not always be possible, and it is recommended that station components be installed and arranged so that devices that might have to be removed for repair or maintenance

nance can be removed with a minimum amount of disturbance to other equipment in the system. This will require sectionalizing components or sections with gas barrier insulators. In some cases, specially designed temporary protective covers that can withstand the same electrical and mechanical stresses as the other GIS components may be required.

(2) At points where disconnection or removal is likely, the following suggestions should be considered:

(a) Suitable terminals should be provided for the connection of the control wiring.

(b) Provisions for disconnecting gas pipelines should be incorporated.

(c) Cutting of metal should be avoided if possible. Where it is required, design should be such that contaminants to the system are minimized. Particular attention must be given to vertical runs, where contamination could fall into the equipment.

(3) A 100 μm or smaller particle filter suitable for pressures involved may be installed at the gas service connection. This filter does not replace the filters associated with the gas handling equipment system but serves as an additional safety feature.

3.1.3 Safety During Maintenance or Repair.

Before maintenance work is performed on the gas-insulated substation, see 3.3 and follow normal utility safety precautions.

3.1.4 Environmental Considerations. All work should be done during favorable weather conditions and in a clean environment. When it is necessary to work during inclement weather, a temporary protective shelter should be provided, with adequate room and heat when necessary.

3.1.5 Equipment Necessary at the Site. The following materials should be on hand before the bus is opened:

(1) A gas-processing trailer with adequate storage capacity

(2) Electrolytic or electronic hygrometer or comparable equipment for measuring moisture levels down to 20 ppmw (162 ppmv) or less.

(3) Insulating gas leak detector suitable for the detection of the insulating gas. 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 either at a sensing hole, at welds, or at bolted flanges.

(4) Dry Nitrogen (See 2.4 on gas standards and 3.2 on gas handling)

- (5) Clean plastic gloves and work uniforms
- (6) Lint-free cloths and recommended solvents
- (7) Temporary plastic bags or covers for sealing openings after components have been removed
- (8) Commercial-type vacuum cleaner with filters and nonmetallic accessories
- (9) Tools supplied and recommended by the manufacturer
- (10) Ventilating equipment
- (11) Handling and lifting equipment
- (12) Maintenance manual and erection drawings
- (13) Ladders and platforms as required

3.1.6 Work Procedure

3.1.6.1 Opening the Equipment

(1) All items in 3.3 should be followed.

(2) 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 cleaned with a vacuum cleaner and wiped with cloths.

(3) Evacuate the gas from the section on which work is to be performed to at least 5 mm of mercury (666.6 Pa), then fill with dry air or nitrogen to a gage pressure of 0 psi (1 atmosphere).

(4) 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 3.3.4.

(5) All work should be completed as quickly as possible, but 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 must be left overnight or longer, it should be pressurized with dry nitrogen to a gage pressure of approximately 5 psi (1.34 atmosphere) to avoid condensation or entrance of moist air.

3.1.6.2 Closing the Equipment

(1) Inspect the conductor and sheath for nicks, burrs, or scratches and repair according to the manufacturer's instructions. Reclean as required.

(2) Thoroughly clean the enclosure. Wipe and vacuum clean the inside of the sheath and conductor using lint-free tissues and gloves. The

insulators should be cleaned according to the manufacturer's instructions.

(3) Reassemble and be careful not to introduce any foreign particles. Dry air flow should be continued until this step is completed. However, it will be necessary to discontinue air flow when welding is being done so as to prevent the inert shielding gas from being blown away.

(4) Refill with dry nitrogen with at least 5% of a suitable tracer gas such as Freon 12 or SF₆. Check for leaks. When the system meets tightness requirements agreed to by the manufacturer and user, evacuate and hold for the time period stated in the manufacturer's instructions; then fill with insulating gas to specified pressure at ambient temperature. Check water vapor (moisture) content immediately, and several days later recheck pressure and moisture content. See 2.5 on gas monitoring for further monitoring requirements. When major repairs or modifications have been made, it may be necessary to make a dielectric test on the equipment to verify the insulation integrity. This decision should be made between the customer and manufacturer. See 3.4 on field testing for recommended procedures.

3.2 Gas Handling

3.2.1 General. This recommended practice is intended to outline those points that should be considered in the handling of SF₆ gas used in GIS apparatus. The handling of the gas relates to the storage, transfer, purifying, and reclaiming of the gas and also the evacuation and filling of the gas compartments of the GIS apparatus.

Gas-insulated substations require substantial amounts of SF₆ gas for proper insulation and interrupting functions. Because the performance of the GIS apparatus is directly related to the quality of the SF₆ gas dielectric, appropriate attention is required in the handling and processing of the gas. The specific requirements for gas purity, handling, processing, filling and refilling, which are provided by the equipment manufacturer, should be strictly adhered to for proper equipment operation.

This recommended practice is not intended as a substitute for instructions or procedures provided by the manufacturer of the electrical apparatus or the gas handling equipment.

3.2.2 Service Conditions. Service conditions to be encountered during the handling of SF₆ gas are as stated in 1.3. It should be noted, however, that manufacturers' recommendations and handling equipment limitations may restrict gas handling to temperatures above the minimum

operating temperatures specified for GIS apparatus.

3.2.3 New Gas

3.2.3.1 Shipment. SF₆ is shipped as a liquefied gas in steel cylinders from the manufacturer. Bulk quantities are available for large installations in tube trailers.

3.2.3.2 Storage. SF₆ containers should be stored away from direct sunlight and sources of heat. The storage area should be free of explosives or flammable material.

Cylinders should be secured to support so that they will not fall and should be protected against physical damage.

Cylinders should not be stored on damp ground or in contact with moisture.

Valve caps should always be in place when cylinders are not in use or when they are being moved.

Precautions to be observed in cylinder handling are as follows:

- (1) Do not drop cylinders
- (2) Do not allow cylinders to slam together
- (3) Do not apply heat to cylinders¹¹
- (4) Do not allow cylinders to be chilled below -29 °C (-20 °F)
- (5) Do not add gas to the cylinder¹¹
- (6) Do not tamper with the valve or safety devices

3.2.3.3 Withdrawing the Gas. SF₆ gas may be withdrawn from the cylinder in either the gaseous or liquid phase. When the cylinder is upright, the SF₆ gas will discharge as a gas. When the cylinder is inverted, the SF₆ gas will discharge as a liquid.

Withdrawing SF₆ as a liquid when filling equipment requires less time; however, the SF₆ should be vaporized before it enters the equipment or otherwise the equipment may be overpressurized. Damage to gas compressors will occur if liquid SF₆ is drawn into the compressor.

For the initial filling of new equipment, it is recommended that new SF₆ should be used and drawn directly from cylinders provided by the gas supplier.

In other cases, the SF₆ may be withdrawn from the cylinders into a gas transfer device, also referred to as gas transfer cart, before it is used for filling GIS apparatus.

The use of a transfer system facilitates the removal of SF₆ from cylinders after the pressure has become equal to that within the GIS equipment.

In such a procedure, caution should be used to avoid overfilling the GIS apparatus, and the man-

¹¹ Except as recommended by the gas supplier.