



IEEE Guide for Sulphur Hexafluoride (SF6) Gas Handling for High-Voltage (over 1000 Vac) Equipment

IEEE Power and Energy Society

Developed by the
Substations Committee

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STANDARDS

IEEE Guide for Sulphur Hexafluoride (SF₆) Gas Handling for High-Voltage (over 1000 Vac) Equipment

Developed by the

Substations Committee
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Abstract: Significant aspects of handling SF₆ gas used in electric power equipment such as gas recovery, reclamation, recycling in order to keep the gas permanently in a closed cycle and aid to prevent any deliberate release in environment are described. The purpose of this guide is to provide state-of-the-art technologies and procedures to reduce SF₆ gas emission to a minimum level for the electric power equipment to preserve the environment. All the aspects for consideration during commissioning and recommissioning, topping up, refilling, checking the gas quality at site, sampling and shipment for off-site gas analysis, and recovering and reclaiming during normal operation and at the end of the life of power equipment while dismantling will be included in this guide. The state-of-the-art tools and measuring devices including the necessary personnel protective equipment is also presented. The basis for the preparation of this guide is CIGRE Brochure No. 276, Guide for preparation of customized “Practical SF₆ handling instructions,” August 2005 edition, developed by the Study Committee B3, Task Force B3.02.01.

Keywords: IEEE C37.122.3™, SF₆analysis, SF₆handling, SF₆reclaiming, SF₆recovery, SF₆safety, SF₆transportation

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Introduction

This introduction is not part of IEEE Std C37.122.3-2024, IEEE Guide for Sulfur Hexafluoride (SF₆) Gas Handling for High-Voltage (over 1000 Vac) Equipment.

The purpose of this document is to provide practical recommendations for a customized “Practical SF₆ Handling Instruction Guide” that applies to all equipment and can become a standardized document containing standard information and procedures covering the following:

- Commissioning or recommissioning
- Topping-up
- Refilling
- Checking gas quality on-site
- Sampling and shipment for off-site gas analysis
- Recovery and reclaiming
- Recovery and reclaiming at the end of life when the electric power equipment is dismantled

The guide is organized into individual sections that can be bound together to form a customized “Practical SF₆ Handling Instructions” manual. The standard manual describes the SF₆ handling procedure according to the state-of-the-art technique. Following the procedures in this guide promotes operational efficiency, work safety, and environmental benefits such as the following:

- Safer operation of the equipment
- Optimization of resources and tools required
- Minimization of out-of-service time for equipment
- Standard training of personnel handling SF₆
- Reduction of the amount of gas released during handling operations down to minimum practical levels
- Help to avoid any deliberate release (e.g., flushing to the atmosphere)
- Reduction of SF₆ losses during commissioning, operation, and service to minimize emissions

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IEEE Guide for Sulphur Hexafluoride (SF₆) Gas Handling for High-Voltage (over 1000 Vac) Equipment

1. Overview

1.1 Scope

This guide describes aspects of the handling of SF₆ gas used in electric power equipment, such as gas filling, recovery, reclamation, testing, quality analysis, and recycling, in order to keep the gas permanently in a closed-loop system and to avoid any release into the environment.

1.2 Purpose

To provide technologies and procedures to minimize SF₆ gas emissions for electric power equipment to preserve the environment. This guide will include all the aspects for consideration during filling, topping up, checking the gas quality, sampling and shipment for off-site gas analysis, reprocessing, and recovery during normal operation and at the end of the life of power equipment while dismantling. This guide also presents the tools and measuring devices including the necessary personal protective equipment.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{6,7}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

⁶ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷ The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ASTM D2472, Standard Specification for Sulfur Hexafluoride.⁸

IEC 60376, Specification of technical grade sulfur hexafluoride (SF₆) for use in electrical equipment.⁹

IEC 60480, Guidelines for the checking and treatment of sulfur hexafluoride (SF₆) taken from electrical equipment and specification for its reuse.

IEC 62271-1, High-voltage switchgear and control gear—Part 1: Common specifications.

ISO 14040, Environmental Management—Life cycle assessment—Principles and framework.¹⁰

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.¹¹

cylinder scale: A device to measure the weight or mass of a gas cylinder and is calibrated and within the regulation requirements for accuracy.

energized: Qualifies a conductive part of the electrical equipment that has an electric potential difference with respect to a relevant reference. The reference potential is usually earth or an equipotential frame.

evacuation: The transfer of air and moisture from the electric power equipment to the atmosphere.

guides: Documents in which alternative approaches to good practice are suggested, but no clear-cut recommendations are made.

pure gas: A gas made up of identical atoms or molecules used for insulation and/or switching within electric power equipment.

recondition: Sulfur hexafluoride (SF₆) gas processing to remove other vapors (i.e., air, N₂, CF₄, etc.) to improve the purity of the SF₆ gas being processed to meet the purity specified in the applicable standards and specifications for SF₆.

reconditioned gas: Gas that has been processed to improve purity for reuse in gas insulated equipment (GIE) in its pure form or as part of a mixture.

recover/SF₆ recovery: To remove sulfur hexafluoride (SF₆) in any condition from a gas insulated equipment (GIE) and store it in an external container.

⁸ ASTM publications are available from the American Society for Testing and Materials (<https://www.astm.org/>).

⁹ IEC publications are available from the International Electrotechnical Commission (<https://www.iec.ch>) and the American National Standards Institute (<https://www.ansi.org/>).

¹⁰ ISO publications are available from the International Organization for Standardization (<https://www.iso.org/>) and the American National Standards Institute (<https://www.ansi.org/>).

¹¹ *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

recovery system: Device for recovery and processing of sulfur hexafluoride (SF₆) gas to remove moisture and by-product contaminants.

recycle: To recover sulfur hexafluoride (SF₆) from any gas insulated equipment (GIE) or other container and scrub said SF₆ for immediate reuse. In general, recycled SF₆ is SF₆ that is cleaned using single or multiple passes through devices, such as replaceable filter-core (through desiccant and aluminum oxide filter cores) which remove contaminants such as SF₆ by-product (acidity), moisture, particulate matter, and oil mist (through charcoal filter cores).

separation process: To recondition sulfur hexafluoride (SF₆) gas by the process of separation of other vapors (i.e., air, N₂, CF₄, etc.) from SF₆ by means of increasing pressure and lowering the temperature of gas being processed.

tight drilling system: When connection to a gas-filled compartment via available openings (e.g., filling points, pressure gauge) is not provided, then a tight drilling system should be used. This generally consists of a drill fitted with a hollow bit connected to hoses with appropriate gasket systems to help avoid leakage during and after drilling.

top-off/topping-off: Filling a pre-filled or partially filled gas compartment with a gas or gas mixture to the filling pressure (density) for insulation and/or switching at the specified mixing ratio, if applicable

3.2 Acronyms and abbreviations

ASTM	American Society for Testing and Materials
CF ₄	carbon tetrafluoride
CIGRE	International Council on Large Electric Systems
EPA	Environmental Protection Agency
GIE	Gas Insulated Equipment
GWP	global warming potential
HV	high voltage
IEC	International Electrotechnical Commission
IPCC	Intergovernmental Panel on Climate Change
MFM	mass flow meter
MV	medium voltage
N ₂	nitrogen
OEM	original equipment manufacturer
ppmv	parts per million by volume
ppmw	parts per million by weight
SF ₆	sulfur hexafluoride

4. General background

4.1 General

Since the early 1960s, SF₆ has been successfully used by the electric industry in power equipment for the high-voltage (HV) transmission and medium-voltage (MV) distribution of electricity (e.g., gas-insulated substations, gas insulated bus, circuit breakers, transformers, and cables) because of its properties.

Fluorinated gases introduced into the atmosphere can be Hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and nitrogen trifluoride. These gases are synthetic and have been found to be powerful greenhouse gases, as reported by the Environmental Protection Agency (EPA), the Intergovernmental Panel on Climate Change (IPCC), and other international committees.

Other agencies, working groups, committees, and associations such as the EU, United Nations Framework Convention on Climate Change (UNFCCC), and the UN Environment Program have either reported similar findings or have adopted programs and policies as a result of the impact which fluorinated gases have on the environment.

It is important to note that fluorinated gases are not emitted from natural occurrences. They are mainly emitted due to activities that are related to human activities. These activities are a variety of industrial processes that include but may not be limited to the following:

- Aluminum and semiconductor manufacturing
- Refrigeration
- Aerosol propellants
- Foam blowing agents
- Solvents
- Fire retardants
- Transmission and distribution using gas-insulated equipment (i.e., SF₆ gas).

Sulfur hexafluoride (SF₆) is used as an insulator and arc-quenching gas in electrical gas insulated transmission and distribution equipment, including circuit breakers, switches, transformers, and insulated electrical bus ducts. The global warming potential (GWP) of SF₆ is 24 300, which as a result, the Intergovernmental Panel on Climate Change (AR6 report) has classified SF₆ gas as the most potent greenhouse gas.

As consequence of the environmental impact of greenhouse gases, the Environmental Protection Agency (EPA) has instituted the Greenhouse Gas Reporting Program (GHGRP). The program requires specific facilities that “emit significant quantities of these compounds” to report annual emissions to the EPA as part of the GHGRP.

Greenhouse gas emitters that are subject to the GHGRP may include producers of fluorinated gases (F-gases) as well as other emitters of fluorinated greenhouse gases (F-GHGs). The program does require companies “that supply these compounds (i.e., producers, importers, and exporters)” to report the quantity of the gas supplied annually for analysis of emissions and overall impact on the environment. The reports are public and are available on the EPA GHGRP website.

In summary, the policies differ from country to country. However, the goal is the same. Reporting programs such as the GHGRP, the EU policies and other international agreements are striving for reduction of F-gases to lessen the impact of greenhouse gases on the environment. The policies include eliminating and replacing high (GWP) F-gases with substances that have lower or no GWP and improved handling and processing techniques to eliminate emissions. Furthermore, the processes of destruction and recycling are also included as part of the

local, regional, and global policies. Recycling aids in reducing CO₂ emission during the production processes and also reduces the need to continue to introduce new F-gases into the supply. This may be especially true for F-gases that have the ability to be 100% recyclable with little to no emissions and negative impact on performance.

This guide is intended to serve as recommended practice in the handling of SF₆ in the absence of established procedures or manufacturer recommendations.¹²

4.2 Gas characteristics

SF₆ offers both excellent electric insulation and arc extinguishing capability in a stable form which is advantageous for use in switchgear.

4.2.1 Molecular structure

SF₆ is a synthetic gas formed by six atoms of fluorine gathered around a centrally situated atom of sulfur. The chemical formula is SF₆, and the molecular weight is 146.05 g/mol.

The chemical bond between fluorine and sulfur is known as one of the most stable existing atomic bonds. Six of these bonds grant the molecule very high chemical and thermal stability. In addition, the compatibility of SF₆ with material used in electric constructions is similar to that of nitrogen (N₂) up to temperatures of about 180 °C (356 °F).

4.2.2 Properties

Pure SF₆ is odorless, tasteless, non-toxic, non-corrosive, non-flammable, and chemically inert at ambient temperature. It does not support combustion. At its nominal temperature and pressure of 20 °C and 101.3 kPa (14.7 psi) 20 °C (68 °F and)], SF₆ is about five times heavier than air. [2] Its density is 6.1 g/L (0.38 lb./ft³).

The solubility of SF₆ in water (7000 ppmv) is four times lower than that of air.

4.2.3 Thermodynamic and electric properties

As the critical temperature and pressure of SF₆ are 45.54 °C and 3.759 MPa (113.97 °F and 545.197 psi), respectively, it can be liquefied by compression and is usually transported as a liquid in cylinders or containers.

The heat capacity of one mole of SF₆ is around three times greater than air.

SF₆ is strongly electronegative (i.e., it tends to attract free electrons). It has a unique combination of physical properties, including high dielectric strength (about three times that of air), high thermal interruption capabilities (about 10 times that of air), and high heat transfer performance (about twice that of air).

4.2.4 Environmental

SF₆ does not harm the ecosystem; biological accumulation in the food chain does not occur. It is an inert gas with very low solubility in water and therefore presents no danger to surface water, groundwater, or the soil.

SF₆ has no impact on the stratospheric ozone layer—its ozone depletion potential is 0. However, SF₆ is a potent greenhouse gas with a global warming potential (GWP100) of 25 200. It is also a persistent greenhouse gas with an atmospheric lifetime of 650 to 3200 years. The difference in the figures is a consequence of the adoption of different calculation models.

¹² Additional details are available from the EPA in the IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (see the information at the following website <https://www.epa.gov/ghgemissions/overview-greenhouse-gases#f-gas>)

The GWP of SF₆ alone is not adequate to measure the environmental impact of electric power equipment based on SF₆ technology. The environmental impact of any specific application should be evaluated and/or compared using the life-cycle assessment approach, as regulated by ISO 14040.

SF₆ has to be used in a closed cycle. When gas removal from containment is needed, a proper handling procedure should be implemented to help avoid any deliberate release into the atmosphere.

The yearly SF₆ emission rate from the overall electric industry accounts for approximately 0.1% of all man-made CO₂ equivalent emissions.

4.3 Characteristics of electric power equipment

The tightness of certain older installed gas-insulated power equipment, especially for HV systems, could be a significant issue for environmental impact. Nevertheless, it has to be kept in mind that handling SF₆ during installation, on-site testing, and maintenance activities may contribute significantly to the overall emissions.

State-of-the-art electric power equipment is designed and manufactured for tightness so that it is compatible with environmental protection guidelines. This implies the following:

- Very low leakage rates due to the quality of the encapsulation, including its material, the machining process, the design of gaskets, the sealing material itself, and the factory testing procedures
- Very low handling losses due to smaller gas compartments, reduced maintenance frequency, more sophisticated tools and instruments to handle and check the gas quality, and specific training of designated personnel

In addition to these items noted, procedures for installation, service, maintenance, repair, and proper disposal should be described by the manufacturer in as detailed a manner as possible. Specially trained personnel should carry out the practical work.

4.3.1 Controlled pressure systems (obsolete)

In controlled pressure systems, a volume is automatically replenished from an external or internal gas source. The volume may consist of several permanently connected gas-filled compartments.

Controlled pressure systems are no longer used in new equipment because of their high leakage rate. It is recommended that controlled pressure systems in old equipment be replaced by closed-pressure systems because of the unacceptable leakage rate.

4.3.2 Closed-pressure systems

In closed-pressure systems, a volume is replenished only periodically by manual connection to an external gas source. High-voltage (above 72.5 kV) SF₆ single-pressure circuit breakers are examples of closed-pressure systems.

It is recommended that:

- Leak checks are performed to meet standard requirements.
- When SF₆ conditions are checked, that gas be recaptured from analysis equipment.
- Appropriate record-keeping procedures are used.

4.3.3 Sealed-pressure system

Sealed-pressure systems have gas volumes that are completely sealed. It is not expected that any gas or vacuum processing will be performed over the expected operating life. Sealed-pressure systems are completely assembled and tested in the factory.

Much state-of-the-art MV electric power equipment uses a sealed-pressure system. These systems are commercially designated “sealed for life,” as they require no on-site gas handling for their entire life duration, typically 40 years. End-of-life disposal is performed under the responsibility of the user and is supported by the manufacturer. Third parties, such as service companies, may also carry out end-of-life disposal.

During the product life of these systems, SF₆ is handled in a controlled environment only twice: for gas filling at the beginning and for gas recovery at the end. Given the limited handling, handling losses can be considered to be of the same order of magnitude as leakage losses. Today a typical leakage rate is lower than 0.1 % per year for each gas compartment

4.3.4 Description of the installed system

Among all characteristics defined by the current IEC Standards in force and given in the instruction manual from the manufacturer, those most relevant to SF₆ handling are highlighted in [Table 1](#).

Table 1—Equipment characteristics related to SF₆ handling

Equipment characteristic	Closed-pressure systems	Sealed-pressure systems
SF ₆ mass per compartment/substation	X	X
Volume per compartment/substation	X	X
Rated SF ₆ filling pressure at 20 °C (68 °F)	X	X
Leakage rate in % p.a. per gas compartment	X	X
Designation of different compartments (e.g., breaker, disconnector, and bus bar)	X	X
Number of separate compartments	X	X
Location of safety overpressure control means	X	X
System used to observe the pressure in each containment	X	When relevant
Precautions when handling SF ₆ containments	X	—
Record-keeping	X	When relevant
Typical time between two consecutive maintenance operations in years	X	—
Typical time between two consecutive SF ₆ measurements in years	Required	—
Location of SF ₆ valves	X	When relevant
Location of gas-tight spacers	X	When relevant
Pressure levels and number of alarms/indicators	X	When relevant

4.3.5 Description of the monitoring system for controlled and closed-pressure systems

In order to operate safely, switchgear needs a minimum gas pressure/density. In the case of controlled or closed-pressure systems, visual indications and/or acoustic alarms are set as a function of that threshold. If the gas pressure/density reaches its minimum threshold, standard operations can no longer be maintained and, according to specific users’ requirements, appropriate countermeasures (e.g., alarm, automatic lockout, or switching features) come into effect.