SF_6 Reporting Challenges

The U.S. Environmental Protection Agency (EPA) requires that owners and operators of electric power transmission and distribution equipment report emissions of sulfur hexafluoride (SF_6) and/or perfluorocarbons (PFC) for systems that have a total nameplate capacity exceeding 17,820 lbs. (7,838 kg) of those gases. Regulatory agencies in California and Massachusetts require reporting as well. The formula for calculating and reporting emissions to the EPA and state agencies is as follows:

> User Emissions = (Decrease in SF_6 Inventory) + (Acquisitions of SF_6) − (Disbursements of SF_6) − (Net Increase in Total Nameplate Capacity of Equipment Operated)[1]

Where 'Net Increase in Total Nameplate Capacity of Equipment Operated' = the nameplate capacity of equipment installed during the year – the nameplate capacity of equipment retired during the year.

In order for the actual quantity of user emissions to equal the other side of the above formula, not only must the reporter be able to accurately calculate each of the variables, but the amount of SF_6 contained in each piece of equipment must be identical to the stated nameplate capacity in cases of installed or retired GIE, or where the gas is transferred between a GIE and a storage cylinder. The Electric Transmission & Distribution SF_6 Coalition (the Coalition) has published this paper to identify common scenarios in which the weight of SF_6 contained in gas-insulated equipment (GIE) may be different than the figure on the nameplate; explain why nameplate accuracy, until recently, has not been an emphasis for the manufacturer (OEM) or user communities; and explain what GIE users, OEMs, and regulatory agencies can do to promote accurate reporting.

Definitions

- (Gas) Volume: the amount of gas that can be contained in a space enclosed by gas-insulated equipment, measured by length, width, and height and expressed in terms of cubic feet (ft^3)
- Mass of SF_6: weight in terms of pounds (lbs.)
- (Gas) Density: the ratio of mass to volume expressed in terms of pounds per cubic feet ($lbs./ft^3$) and achieved by filling a space with a given pounds per square inch (psi) gauge at a given temperature

Nameplate background

Contrary to what some stakeholders believe, the nameplate figure on a GIE is not intended to indicate the maximum amount of SF_6 that a particular piece of equipment can hold. Rather, the nameplate is meant to indicate the approximate mass of SF_6 that the GIE will hold once it is filled to the proper density.

To facilitate proper filling, OEMs have historically provided a temperature-pressure curve—a chart that provides the end user with the gas pressure that is necessary, at a given temperature, for the GIE to be properly and safely insulated against unintentional electric arcing. It has then been left to the utility to use the chart to fill (or complete filling, in cases where the GIE arrives partially filled) the GIE. The actual mass of SF_6 in a GIE is ancillary for insulation purposes; density is much more important, which is why OEMs have provided and continue to provide precise instructions for filling to the proper density. But

[1] For a more detailed summary of the GHG Reporting Requirements, see Annex 1 to this document, entitled "Subpart DD: U.S. EPA Greenhouse Gas Reporting Rule"

because GIE users typically acquire and dispose of SF_6 in units of pounds, the nameplate figure is provided in units of pounds for inventory and recordkeeping purposes.

Much like GIE and its subcomponents, the information on a nameplate is the result of an industry standard. Standards for high- and medium-voltage equipment are coordinated through the Institute of Electrical and Electronics Engineers (IEEE) with input from the OEM and user communities. The current equipment standards do not have an accuracy requirement for the nameplate insulation values.

Reasons for discrepancy

There are generally two reasons why the amount of SF_6 in GIE might differ from the amount listed on the nameplate: changes in equipment design and field errors.

Changes in Equipment Design

Minor changes in equipment design (i.e. tank and bushing wall thickness) have changed the exact volume of gas that particular models of GIE can hold. Because a change in volume necessarily affects the mass at a constant density, in many cases these changes have resulted in a disparity between the nameplate figure and the pounds of SF_6 actually contained in GIE when filled to the proper density. For example, suppose a particular piece of GIE is manufactured to a gas volume of 200 ft^3 with a required density for insulation of 0.38 lbs./ft^3. When filled to the proper density, this GIE would contain a mass of 526.3 lbs. of SF_6. Now, suppose slight design changes to the GIE model result in a decrease in gas volume to 195 ft^3. Since the equipment still requires the same density to be properly insulated (0.38 lbs./ft^3), the mass of SF_6 in the GIE when filled to that density is 513 lbs., a 2.5% difference.

SF_6 technicians in the field (who typically follow the temperature-pressure guidance in filling GIE) usually assume that when the proper density is attained they will have also attained the stated nameplate capacity in terms of weight. While this assumption does not create any safety issues—as explained above—it does create a reporting issue, since GIE users are required to use the nameplate figure in calculating emission.

Field Errors

As the name implies, a field error occurs when the GIE is in the possession of the end user (e.g., in the "field") and can occur anytime gas is put in or removed from the GIE during commissioning, maintenance, and de-commissioning.

<u>GIE Commissioning and Maintenance</u>

While some OEMs now ship GIE fully charged with SF_6, it has been a common historical practice to ship some types of GIE with minimal or no SF_6, requiring the end user to fill it. As mentioned previously, each GIE is accompanied by a users' manual that contains a temperature-pressure curve, indicating how much SF_6 pressure the GIE requires at each point along a range of temperatures to achieve proper density. Because the gas temperature is difficult to gauge, field technicians often rely on ambient temperature, which can differ up to 40 degrees Fahrenheit from the gas temperature[2]. This disparity leads to a miscalculation of gas density and, consequently, mass. Of course, even if the gas temperature is measured accurately, it is possible for the gas pressure to be improperly measured if, for example, the pressure gauge is not calibrated correctly.

[2] The SF_6 Coalition recommends use of a precision temperature gauge (accuracy +/- 1.0°F)

Anecdotal evidence also indicates that SF_6 field technicians will regularly overfill the GIE by a few pounds of gas just to ensure there is a sufficient amount. While this is a perfectly acceptable practice for purposes of safety, it is apparent how this would lead to a different amount of gas in the GIE than the amount that appears on the nameplate.

GIE Decommissioning

When GIE is removed from service, the SF_6 is removed and stored in a cylinder. While the objective is to completely remove the gas, due to a variety of factors, some of the gas (i.e. potentially up to 10%) may remain trapped in the recovery system and/or the hose that connects the recovery system to the cylinder. Not realizing this, the technician may simply report the "missing" SF_6 as an emission. But in reality, the gas could remain in the hose until it is used again, at which point the SF_6 would be (unknowingly) siphoned into another cylinder or pushed into a different GIE, depending on what the hose is used for. Accordingly, the technician would have reported a phantom emission (explained below).

Negative impact of nameplate discrepancy

In cases where the weight of the SF_6 in the GIE is less than the stated nameplate capacity, owners and operators of GIE are forced to record "phantom" emissions (i.e. emissions that did not occur) if the GIE at issue is involved in a reportable event[3]. For example, installation or retirement of GIE is considered a reportable event since the emissions calculation formula requires an input for the gas in any GIE installed or retired over the calendar year.

The formula also requires an input for the decrease in SF_6 inventory and/or any SF_6 disbursements. Consequently, SF_6 that is syphoned from a storage cylinder into GIE or, conversely, from GIE into a cylinder and stored on-site, would be a reportable event since either scenario impacts the 'SF_6 Inventory' variable of the formula. The same holds true if the gas is syphoned into a cylinder and sent offsite; it would be reported as part of the SF_6 disbursement variable. In any of these scenarios, if the weight of gas in the GIE is less than the nameplate, the reporting entity is forced to calculate an emission for that event.

The following example helps to clarify the scenario:

Status January 1	Status December 31
GIE: Nameplate 100 lbs	GIE: Nameplate 100 lbs (Actual: 105 lbs)
Cylinder A: Empty	Cylinder A: 100 lbs
Cylinder B: 105 lbs	Cylinder B: Empty

Emissions Calculation Formula: (5) + (0) – (0) – (0) = 5 lbs

In the above example, at some point during the year the gas in the GIE is emptied into Cylinder A and, shortly thereafter, the gas in Cylinder B is syphoned into the GIE. This results in a reportable event since the first variable in the formula calls for a calculation of the decrease in the SF_6 inventory (the combined total between both cylinders). In this case, the inventory decreased from 105 lbs to 100 lbs. Assuming other variables remain the same, it appears there has been an emission, even though all of the gas from Cylinder B is safely inside the GIE on December 31.

[3] In cases where the weight of SF_6 exceeds the stated nameplate capacity, this could lead to the reporting of a negative or "hidden" emission.

While the EPA does not currently have an emissions reduction requirement, its corollaries in California and Massachusetts do, and utilities located in those states could be subject to fines and other civil penalties if reported SF_6 emissions for a given year exceed the allowable amount. This amount is expressed as a percentage of Total Nameplate Capacity of Equipment Operated. The allowable emissions for California and Massachusetts are as follows:

California		Massachusetts	
2016	5%	2016	3.0%
2017	4%	2017	2.5%
2018	3%	2018	2.0%
2019	2%	2019	1.5%
2020	1%	2020	1.0%

Prevalence of discrepancy

While current data is somewhat limited, empirical information suggests that a large percentage of GIE currently in service and containing the target density of SF_6 contains a different mass of SF_6 compared to what is indicated on the nameplate. Data collected by DILO Inc. showed that out of 221 high-voltage circuit breakers—ranging from 34.5 kV to 500 kV—tested over a period of 36 months, only six (6) contained actual SF_6 mass that was within 1% of the figure on the nameplate.[4]

How to determine SF_6 weight in GIE

There are two (2) possible processes to determine the exact amount of SF_6 in any vessel: pressure/mass calculation and complete SF_6 recovery.[5] The former process entails removing a small amount of SF_6 that is then weighed while monitoring the initial and final pressure. This process takes about 30-60 minutes per GIE, depending on the size. The latter process entails removal of all the SF_6 and then precise weighing of the gas during the process; this takes significantly longer but has a lower margin of error. Because both processes require de-energizing the GIE, the Coalition recommends that they be performed only during commissioning, maintenance, or decommissioning.

What are OEMs doing to help?

GIE manufacturers are certainly willing to expend effort to help the utility community increase reporting accuracy. Specifically for older equipment, OEMs are prepared to work with their utility customers to formulate a streamlined process wherein nameplates can be amended or replaced with a more accurate figure. The details of such a process are yet to be determined, but it would likely entail the utility customer undergoing one of the processes described above (and discussed in detail in Annex 2) to calculate SF_6 weight and providing corresponding documentation to the manufacturer. For new equipment, OEMs have begun to communicate an "as-filled" value on the GIE, which indicates the precise weight of SF_6 when it leaves the OEM facility. For logistical and safety reasons, not all GIE is shipped while fully charged with SF_6. Providing the "as-filled" information would provide a verifiable baseline to the utility from which it could make the reporting calculations once the GIE is in service. Finally, as of July 2016, OEMs have proposed including a nameplate accuracy standard to several IEEE subcommittees.

[4] DILO, Inc. is an SF_6 management and maintenance firm that services hundreds of utilities across North America

[5] For a complete description of pressure/mass calculation and complete SF_6 recovery, please see Annex 2, "Recommended Processes to Support Accurate Reporting of SF_6 Emissions"

How can regulatory agencies help?
The Coalition does not believe that any new requirements or mandates are necessary to encourage more accurate reporting. However, we do believe that reporters will be more likely to accurately measure SF_6 weight if they are allowed to use that figure instead of the nameplate figure for reporting purposes should they so choose. Absent such a formal allowance, the coalition hopes that state and federal regulatory agencies will at least be open to considering evidence—derived from an agreed-upon process with the corroboration of the OEM—that the reported figure does not reflect actual emissions.

About the Coalition
The SF_6 & Alternatives Coalition is comprised of 17 members who are producers and distributors of SF_6 and SF_6 alternatives, manufacturers of gas-insulated equipment, a California utility, and other SF_6 stakeholders. Our mission is to:

1) provide a forum for equipment manufacturers using SF_6, SF_6 producers and distributors, and transmission and distribution equipment owners for discussion of environmental concerns of SF_6 as a greenhouse gas;
2) develop best practices and recommendations related to sustainable SF_6 usage in electric power transmission and distribution;
3) advocate the Coalition positions to federal, state, and local policymakers;
4) educate public and private stakeholders on SF_6 alternatives; and
5) maintain liaisons with government and industry groups such as U.S. EPA, Institute of Electrical and Electronic Engineers (IEEE), EEI, IEC, CIGRE, and EPRI.

Annex 1

Subpart DD, U.S. EPA Greenhouse Gas Reporting Rule

The following is meant to be a brief explanation of the U.S. reporting process and requirements for owners and operators of gas-insulated equipment.

Who Is Required to Report?

Owners and operators of electric power transmission and distribution equipment with a total nameplate capacity exceeding 17,820 lbs (7,838 kg) of sulfur hexafluoride (SF_6) and/or perfluorocarbons (PFC) are required to report emissions of these gases from their electric power transmission and distribution systems.

- SF_6 and PFC insulated equipment includes gas-insulated substations, circuit breakers, other switchgear, gas-insulated lines and power transformers containing these gases.
- An electric power system is defined as the collection of SF_6 and/or PFC insulated equipment linked through electric power transmission or distribution lines and operated as an integrated unit by one electric power entity or several entities that have a single owner.

What is the Reporting Cycle?

Subpart DD took effect January 1, 2011. Reporting years correspond with calendar years. Reports must be submitted by March 31st for the prior year information.

How Are Emissions Calculated?

Owners and operators of these systems use a mass-balance process accounting for the following factors:

- Decrease in SF_6 Inventory: The SF_6 stored in containers at the beginning of the year minus the SF_6 stored in containers at the end of the year.
- Acquisitions of SF_6: The sum of the amount of SF_6 that is: 1) purchased from distributors; 2) purchased from equipment manufacturers; and 3) returned to the facility after offsite recycling.
- Disbursements of SF_6: The sum of the amount of SF_6 that is: 1) in bulk and contained in equipment that is sold to other entities; 2) returned to suppliers; and 3) sent off site for recycling or destruction. (NOTE: Facilities returning containers to a supplier either weigh the containers themselves or have the supplier weigh the containers, obtaining a detailed monthly account, within 1%. The scale used in this process is certified to be accurate within 1% of the true weight and recalibrated at least annually.)
- Net Increase in Total Nameplate Capacity of Equipment Operated: The nameplate capacity of new equipment minus the nameplate capacity of retiring equipment.

(NOTE: Nameplate capacity refers to the full and proper charge of gas specified by the equipment manufacturer rather than the actual, which may reflect leakage.)

Emissions = Decrease in SF_6 Inventory + Acquisitions of SF_6 – Disbursements of SF_6 – Net Increase in the Nameplate Capacity of Equipment

What Information is Reported?

In addition to reporting emissions, owners and operators are required to report the following:

- Nameplate capacity of: 1) equipment containing SF_6 at the beginning of the year; 2) new equipment purchased during the year; and 3) equipment retired during the year.
- Transmission miles (length of lines carrying voltages at or above 34.5 kV).
- SF_6 sales and purchases.
- SF_6 sent off site for destruction.
- SF_6 sent off site for recycling.
- SF_6 returned to site after recycling.
- SF_6 stored in containers at the beginning and end of the year.
- SF_6 with or inside new equipment purchased during the year.
- SF_6 with or inside equipment sold to other entities.
- SF_6 returned to suppliers.

Are there any States that Require Reporting?

California and Massachusetts require unique reporting at the state level for owners and operators located within those states, in addition to federal reporting requirement.

California

California Air Resources Board (CARB) has enacted Subarticle 3.1 to Title 17 of the California Code of Regulations. Subarticle 3.1 is titled Regulation for Reducing Sulfur Hexafluoride Emissions from Gas Insulated Switchgear.

- Gas Insulated Switchgear (GIS) is defined as all electric power equipment insulated with SF_6 gas regardless of location. This includes switches, stand-alone gas-insulated equipment, and any combination of electrical disconnects, fuses, electrical transmission lines, transformers and/or circuit breakers used to isolate gas insulated electrical equipment.
- The methodology used to calculate annual emissions is the identical mass balance model used in Subpart DD of the U.S. EPA Greenhouse Gas Reporting Rule.
- The table below shoes the maximum annual SF_6 emission rate for each calendar year for each GIS owner.

Calendar Year	Max Allowable Emission Rate
2011	10.0%
2012	9.0%
2013	8.0%
2014	7.0%
2015	6.0%
2016	5.0%

2017	4.0%
2018	3.0%
2019	2.0%
2020 and each Calendar Year thereafter	1.0%

- Emergency Event Exemption:
  - A GIS owner may request emissions from an emergency event to be exempted from the calculation of the maximum allowable emission rate if it is demonstrated to the Executive Officer's satisfaction that the release of SF_6:
    - Could not have been prevented by the exercise of prudence, diligence and care; and
    - Was beyond the control of the GIS owner.
  - The GIS owner must submit the request within 30 calendar days after the occurrence of the emergency event and must provide a detailed description of the emergency event.

Massachusetts

Massachusetts Department of Environmental Protection (Mass DEP) has enacted 310 CMR 7.72: Reducing Sulfur Hexafluoride Emissions from Gas-Insulated Switchgear.

- Gas-insulated switchgear of FIS means all electrical power system equipment insulated with SF_6 gas. Gas-insulated switchgear (GIS) includes switches, stand-alone gas-insulated equipment, and any combination of electrical disconnects, fuses, electrical transmission lines, transformer and/or circuit breakers used to isolate gas-insulated electrical power system equipment.
- The methodology used to calculate annual emissions is the identical mass balance model used in Subpart DD of the U.S. EPA Greenhouse Gas Reporting Rule.
- The table below shows the maximum annual SF_6 emission rate for each calendar year for each GIS owner.

Calendar Year	Max Allowable Emission Rate
2015	3.5%
2016	3.0%
2017	2.5%
2018	2.0%
2019	1.5%
2020 and each Calendar Year thereafter	1.0%

- Emergency Event Exemption:
  - A federal reporting GIS owner may exempt emission from a sudden and unforeseen event form the calculation of the maximum allowable emission rate if the federal reporting GIS owner demonstrates the release of SF_6:
    - Was caused by an emergency event, such as a fire, flood, earthquake, or act of vandalism; and
    - Could not have been prevented by the exercise of prudence, diligence, and care; and
    - Was beyond the control of the federal reporting GIS owner; or
    - Was necessary to avoid an immediate electrical system outage.

- In order for emissions to be exempted from the calculation of the maximum allowable emission rate, Mass DEP requires a detailed description of the emergency event.

Annex 2

Recommended Processes to Support Accurate Reporting of SF_6 Emissions

While current data is somewhat limited, empirical information suggests that a large percentage of currently installed gas insulated equipment (GIE) contains a different amount of SF_6 compared to what is indicated on the nameplate. Data collected an SF_6 management and maintenance firm shows that out of 221 high voltage circuit breakers – ranging from 34.5 kV to 500 kV – tested over a period of 36 months, only six (6) contained actual SF_6 mass that was within the 1% of the figure on the nameplate. This discrepancy is attributable either to filling error or an inaccurate stated nameplate capacity. The purpose of this document is to provide GIE users with a step-by-step process to determine actual SF_6 weight and to verify nameplate accuracy.

Section 1 – Reporting Requirement

GIE users are required to report SF_6 emissions by the U.S. Environmental Protection Agency's Greenhouse Gas Reporting Rule Subpart DD. Regulatory agencies in California and Massachusetts require reporting as well. The formula for calculating emissions to all three entities is as follows:

> User Emissions = (Decrease in Storage Inventory) + (Acquisitions) - (Disbursements) – (Net increase in Total Nameplate Capacity of Equipment Operated)

To ensure better accuracy when reporting greenhouse gas emissions, and to eliminate the reporting of "Phantom Emissions", users of GIE not only must have a way to accurately determine the actual charge of SF_6 in any given GIE within their inventory, but also must be able to identify whether the stated nameplate capacity is accurate. And in cases where the nameplate is not accurate, users should be able to correct the nameplate value for purposes of reporting (e.g. substitute the correct nameplate capacity for the stated). The Electric Transmission and Distribution SF_6 Coalition hopes that state and federal regulatory agencies will be open to allowing operators the option to use the figures derived from these processes for reporting purposes should they choose to do so.

In order to reduce the likelihood of error we strongly recommend that operators use the following tools:

- Temperature/Pressure curve or chart provided by GIE OEM
- Precision Temperature gauge (accuracy +/- 1.0°F)
- Precision pressure gauge (accuracy +/- 0.5% of complete scale) – requires at least 2 digits past decimal point – should read in absolute values
- Mass flow scale (Accuracy +/- 0.1 lbs.) – requires at least 2 digits past decimal point
- SF_6 Recovery System capable of achieving a blank-off pressure of 3.5 Torr or less

For each of the following processes, it is highly recommended that the GIE be de-energized. After the process is complete the user should follow the manufacturer's instructions to re-energize or de-commission the GIE, as appropriate.

Section 2 – How to Identify Exact Weight of SF_6 in GIE

There are two (2) possible processes to determine the exact amount of SF_6 in any vessel:

1. Pressure/Mass Calculation. This process entails removing a small amount of SF_6 that is then weighed, while monitoring the initial and final pressure.)

Procedure:

Step 1. Record the initial system pressure (a) using a precision pressure gauge
Step 2. Connect evacuated hose (no longer than 3' with ¼" diameter) to primary side of mass flow scale / use inline T-piece with precision gauge
Step 3. Connect secondary side to evacuated cylinder
Step 4. Open GIE valve (or connect to GIE quick connect) and remove a minimum of 2 lbs. as well as a minimum differential of 2 psi (c) (Note: Record all readings with a minimum of two (2) digits past decimal point).
Step 5. Record final system pressure (b) using precision pressure gauge
Step 6. Calculate total mass of SF_6 in the vessel per the following formula:
Total mass of SF_6 in vessel = c x a/ (a-b) where:
a = Initial system pressure (psi absolute)
b = Final system pressure (psi absolute)
c = Amount of SF_6 removed

2. Complete SF_6 Recovery: This process entails removal of all the SF_6 either during GIE maintenance or decommissioning and then precise weighing of the gas during the process. Based on feedback from some members of the utilities industry, this option seems to be preferred.

Procedure:

Step 1. Record the initial system pressure using precision pressure gauge
Step 2. Connect evacuated hose to primary side of mass flow scale, and another hose from the secondary to the inlet of the SF_6 Recovery System
Step 3. Recover the SF_6 to a blank-off pressure of < 3.5 Torr
Step 4. Verify that GIE pressure is < 3.5 Torr after a 5 minute hold
Step 5. Record the final system pressure using precision pressure gauge
Step 6. Mass shown on mass flow scale is the total amount of SF_6 in the vessel

Note: Amount of SF_6 (mass) weight is to be measured at the GIE's fill valve and on the primary side of any recovery system. As cylinder tare weights are known to be inaccurate, using conventional gas/cylinder weighing scales is not recommended.

Section 3 – How to Verify Nameplate Accuracy of GIE

This process is similar to "Complete SF_6 Recovery" discussed in the previous section, but adds a new step (2) and follows a formula as indicated below.

Procedure:

Step 1. Record the initial system pressure (a) using precision pressure gauge
Step 2. Convert the initial system pressure to temperature compensated initial system pressure (d) by accurately measuring the vessel temperature and using the OEM temperature/pressure curve or filling data to compensate the initial system pressure to rated fill temperature (usually 68◦F (20◦C))
Step 3. Connect evacuated hose to primary side of mass flow scale, and another hose from the secondary to the inlet of the SF_6 Recovery System
Step 4. Recover the SF_6 to a blank-off pressure of < 3.5 Torr (c)
Step 5. Verify that GIE pressure is < 3.5 Torr after a 5 minute hold
Step 6. Record final system pressure (b) using precision pressure gauge
Step 7. Determine the corrected nameplate value using the following formula:
Corrected nameplate mass value = c x a/(a-b) x (e/d) where:
a = Initial system pressure (psi absolute)
b = Final system pressure (psi absolute)
c = Mass of SF_6 recovered
d = Temperature compensated initial system pressure (psi absolute)
e = Rated fill pressure at rated temperature (psi absolute) – taken from nameplate

Note: Amount of SF_6 (mass) weight is to be measured at the GIE's fill valve and on the primary side of any recovery system. As cylinder tare weights are known to be inaccurate, using conventional gas/cylinder weighing scales is not recommended