SF_6 Nameplate Inaccuracies and their Impact on Greenhouse Gas Reporting

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***Abstract* – With emission reporting now being mandatory for many SF_6 users, reports of nameplate discrepancies have become quite common. This paper will identify the different types of emissions, discuss the possible reasons for some of the inaccuracies, as well as the difficulty faced by both SF_6 users and regulatory agencies alike while trying to gather accurate data. A simple method to determine the exact amount of SF_6 in a vessel at any given time will also be discussed.**

***Index Terms* – Nameplate; amount of SF_6 (in kg or lbs) that is contained in the equipment when properly charged, as indicated by the OEM. GIE (Gas Insulated Equipment); any equipment, which as its dielectric or arc quenching medium, uses SF_6. Phantom Emissions; any accounting-only emission that didn't actually occur.**

I. Introduction

The Mandatory Greenhouse Gas Reporting Rule (40 CFR Part 98) subpart DD applies to users of medium to high voltage SF_6 insulated transmission and distribution electrical equipment, and subpart SS applies to Original Equipment Manufacturers (OEM's) of that equipment. The US Environmental Protection Agency (EPA) now requires users with in service SF_6 nameplate capacity of at least 17,820 lbs to report their gas emissions annually. Certain States - most prominently the State of California through its Air Resources Board (CARB) - have enacted similar mandatory reporting regulations. With the increase of different entities now having to track and monitor their SF_6 emissions, so have the reports of nameplate discrepancies leading to so called "phantom emissions".

II. Mass Balance Equation

The Mass Balance Equation used to determine leakage rates (Eq. DD-1) is as follows:

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

The last component of the equation is determined by taking the nameplate capacity of new equipment, including hermetically sealed-pressure switchgear, and subtracting the nameplate of retiring equipment, including hermetically sealed-pressure switchgear. Nameplate capacity refers to the full and proper charge of equipment, in pounds (lbs) of SF_6, rather than the actual charge, which may (amongst other things as described below) reflect leakage.

Using the above equation, it can easily be determined that if the capacity of retiring equipment is underestimated (Example: true value is 300 lbs but the nameplate Label reads 280 lbs) it will lead to showing a negative SF_6 emission - and the emission rate subsequently will be underestimated. If the capacity of retiring equipment is overestimated (Example: true value is 280 lbs but the nameplate label reads 300 lbs), it will lead to a "phantom emission" of 20 lbs - this means that the user will end up having to report a 20 lbs SF_6 loss that didn't actually occur.

To date accurate data isn't available, however anecdotal evidence suggests this being a major problem with some electric utilities reporting a "large percentage" of their GIE having inaccurate nameplate information. Not surprisingly the reported instances of nameplate capacities being overestimated far exceed those of it being underestimated as the latter generally will be used to simply offset other SF_6 losses.

III. Reasons for nameplate inaccuracies

Numerous reasons and events can be the cause for the actual amount of SF_6 to differ from the listed nameplate capacity. Generally they can be separated into the following categories:

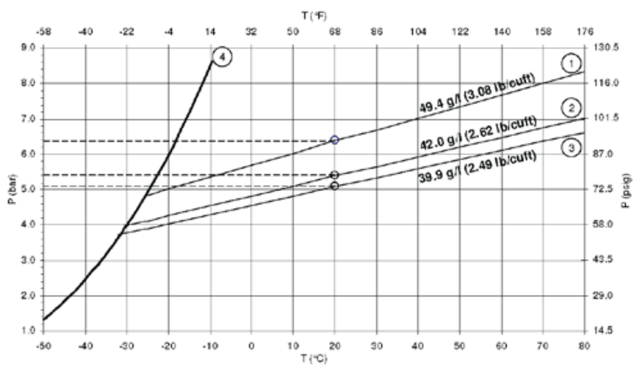
- SF_6 Leakage from GIE
- GIE Equipment issues / SF_6 handling
- SF_6 Maintenance Equipment issues / SF_6 handling
- GIE Inaccurate Nameplate

III.A SF_6 Leakage from GIE

In theory it should easily be determined if the amount of SF_6 recovered from GIE is lower than its nameplate if the gas is removed from a known leaker. Unfortunately – especially with large volume and/or slow leaking equipment – it can be extremely difficult to determine that the GIE is losing SF_6 due to a leak. A large volume compartment (common on high voltage circuit breakers) may need to emit in excess of 30 lbs of SF_6 before any noticeable change on its pressure gauge can be detected.

III.B GIE Equipment Issues

The operating instructions for GIE usually contain a temperature/pressure curve (as illustrated below) that is used to determine the operating pressure at any given temperature. This information is utilized by personnel to set the secondary (fill) pressure of the regulator. In order for the GIE to be filled with the correct amount of gas, any temperature and pressure gauges used during this process will have to be extremely accurate, as due to the high density of SF_6 any deviation of the temperature or pressure reading will lead to a discrepancy in the amount of SF_6 being filled. Gauge inaccuracies (both on temperature as well as pressure gauges) are quite common – especially on older equipment or lower cost pressure regulators. Some OEM's install temperature compensated pressure gauges on GIE that do not provide an actual pressure reading. Once the needle moves from the red part of the indication to the green section, it confirms that the gas pressure is sufficient. This type of gauge is not conducive to be used to accurately measure SF_6 amounts.



III.C SF_6 Maintenance Equipment Issues

Anecdotal evidence suggests that a good portion of reported phantom emissions in fact are due to recovery systems not being able to achieve an acceptable blank off pressure (vacuum generated during the recovery process), field personnel not understanding residual pressures, or a combination of both. The percentage of SF_6 that has been recovered from GIE can easily be calculated using the following formula:

$$\left(\frac{P_I - P_F}{P_I}\right) \times 100 = \% recovered$$

P_I = Initial System Pressure in mmHg absolute
P_F = Final System Pressure in mmHg absolute

Using the above formula, one can easily see the impact on the amount of SF_6 being recovered from GIE if the recovery process is terminated before a solid vacuum has been generated in the GIE. Thanks to improvement in recovery system technology, > 99.9% SF_6 recovery from any vessel is now technically feasible. It is therefore of utmost importance for the personnel operating this equipment to understand how residual pressure affects the recovery rates.

GIE is generally filled directly from compressed gas cylinders either with a fill kit (regulator and hose assembly) or by using an SF_6 Recovery System (Gas Cart). Any pressure gauge inaccuracies on this type of equipment will have a similarly negative impact as outlined under III.B.

When determining the current temperature for filling GIE, it is generally assumed that the ambient and SF_6 gas temperature will be identical, which in reality is rarely the case. Due to its high density, one of the properties of SF_6 is that it generates tremendous heat loss while vaporizing in a storage cylinder. This potentially results in the gas temperature being substantially colder than ambient as it is being filled directly from a cylinder. The other extreme is when an evaporator (commonly used on large SF_6 Recovery Systems) is used during the filling process. Evaporators generally are automatically set to a minimum of 85 F to expedite the filling process and to ensure that only gaseous SF_6 enters the GIE.

Both filling processes outlined above can cause the SF_6 gas to enter the GIE at either higher or lower temperatures than ambient. While the pressure of the GIE will initially be correct, this can lead to an unknown over- or under fill of the equipment on any GIE that is not equipped with temperature compensated gauges.

EPA as well as the California Air Resources Board has exact and stringent requirements for both weight scale accuracy and calibration frequency. But even a highly accurate weight scale in calibration cannot account for residual SF_6 that remains in connecting hoses or the tubing/filtration system of an SF_6 Recovery System once the gas has been removed from GIE.

To determine the amount of SF_6 in a compressed gas cylinder, it has to be weighed and then the tare weight (stamped on each cylinder; Example: TW 115) is deducted from the displayed weight. Some cylinder testing facilities have recently reported incorrect cylinder tare weight stamps being quite common, which undoubtedly will lead to additional discrepancies.

III.D GIE Inaccurate Nameplate

Over the last 6 months, DILO has collected data from numerous utilities on nameplate discrepancies. Additionally, controlled tests on out of service equipment have been performed to determine the impact of different filling and recovery procedures on the amount of SF_6 in a piece of GIE. During all the testing, NIST calibrated weight scales and mass flow scales, as well as high precision pressure and temperature gauges were used to precisely measure the amount of SF_6 that was added or removed. Not surprisingly these tests simply confirmed what a lot of SF_6 users have been reporting: Actual gas amounts differing from the nameplate seemed to be the norm and not the exception – even when the SF_6 work was performed in a controlled environment.

While some of the nameplates simply contained inaccurate information – possibly due to design changes on later models yet original gas quantity information was never updated – the way the equipment was originally filled seemed to have the biggest impact on the resulting phantom emissions.

Example: GIE that according to its nameplate needs to be filled with 200 lbs of SF_6 gas, which corresponds to a pressure of 87 PSIG at 68 degrees Fahrenheit. If due to human error or gauge inaccuracy the GIE was only filled to 85 PSIG, the equipment will only hold 196 lbs of gas. Assuming less detailed past recordkeeping, this could lead to a phantom emission of 4 lbs whenever the GIE has to be degassed for maintenance or decommissioning.

IV. How to Determine Exact SF_6 Weight in Any Vessel

The Recovery Formula pictured under III.C can also be used to determine the *exact* amount of SF_6 contained in any piece of GIE at any given time. In order to calculate the mass of the SF_6 correctly, only a small amount of gas will have to be removed from the GIE. It is however extremely important that both the initial as well as the final system pressure will be measured with a highly accurate gauge. To eliminate inaccuracies (cylinder tare weight, residual SF_6 in service hoses, ect.) only highly accurate mass flow scales should be used to measure the mass (weight) of the SF_6 being removed. As the formula is strictly dependent on the correlation between pressures and mass – both of which have to be precisely measured – the temperature at which the testing is performed is irrelevant.

Only (3) variables are needed to determine the exact amount of SF_6 in a vessel:

a) Initial system pressure / PI
b) Final system pressure / PF
c) Amount of SF_6 recovered

$$\left(\frac{a-b}{a}\right) \times 100 = \%\ recovered\ (y)$$

$$\frac{c \times 100}{y} = lbs\ of\ SF_6$$

A high voltage circuit breaker is currently pressurized to 87 PSIG. 5lbs is then removed, which brings the system pressure to 82 PSIG.

First, the PSIG values have to be converted to mmHg absolute:

$$\left(\frac{87PSIG + 14.7}{14.7}\right) \times 760 = 5258mmHg\ absolute$$

$$\left(\frac{82PSIG + 14.7}{14.7}\right) \times 760 = 5000mmHg\ absolute$$

Then, calculate the percentage recovered:

$$\left(\frac{5258 - 5000}{5000}\right) \times 100 = 5.16\%$$

Finally, the total amount of SF_6 can be calculated:

$$\frac{5lbs \times 100}{5.16} = 96.9lbs$$

Using proper equipment, the time to complete this process will not exceed 30 minutes per piece of GIE (example: 500 kV circuit breaker); substantially less when working with smaller volume equipment (example: 242 kV or lower voltage circuit breaker). *SF_6 users required to report their emissions should be given a certain timeframe to perform this type of verification on all their GIE where nameplate inaccuracies have been reported, and if necessary use this to correct their baseline inventory numbers.*

V. Conclusion

It is apparent that discrepancies in the amount of SF_6 recovered from GIE can be the result of a number of events and failures, in addition to the possibility that a nameplate may or may not be incorrect. Generally there are too many variables and potential failures –either caused by equipment issues or human error - to expect anything but potentially substantial differences between OEM nameplate and the actual amount of SF_6 that can be recovered.

Entities that are required to report their SF_6 emissions should have a way to account and correct for discrepancies when having to provide authorities with their annual emission figures. This will be especially desirable when degassing older equipment that was used to determine their initial inventory. Following the procedure outlined under IV would make this relatively easy and very accurate. New equipment installations (or filling existing GIE after maintenance has been preformed) will require exact measurements using only properly calibrated equipment which should lead to better accuracy in the future. Having only specially trained personnel handling the SF_6 should lessen future reporting problems and inconsistencies and will ensure that users required to reporting emission rates are in compliance of local and federal laws.