SF_6 in the Electric Industry, Status 2000

by

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Abstract

A survey is given of the present situation concerning the environmental implications of SF_6 used in electric power equipment. Recently published data on global SF_6 production and emission are evaluated and extrapolated. They show that the efforts of the electric industry, namely, original equipment manufacturers (OEM) and users of electric power equipment (utilities) to reduce SF_6 emissions are successful and that a substantial further emission reduction can be expected.
It is also shown that the environmental impact of SF_6 can not only be judged by its global warming potential (GWP) but that several other factors have to be taken into consideration which are reviewed in detail. Recommendations are made for providing a basis for a rational discussion of the issue.

1. Introduction

The high global warming potential of SF_6 became known in 1995 as a consequence of which the gas was put on the list of greenhouse gases in the Kyoto protocol 1997 [1]. The high GWP of SF_6 triggered various efforts to reduce its emissions from SF_6-insulated transmission and distribution (T&D) equipment. These efforts range from improved sealing of equipment over improved gas handling procedures, systematic gas reuse and voluntary emission reduction programs in the electric industry to governmental regulatory actions. Key issues in the ongoing discussion on the environmental impact of "electric" SF_6 are the *quantitative* facts of atmospheric SF_6 emissions, the success of ongoing SF_6 emission reduction efforts and the role of the SF_6 used in the electric industry in the frame of a more general environmental consideration. This note summarizes the presently known facts, tries to extrapolate them to the future and presents, as conclusion, suggestions for supporting a rational discussion of the SF_6 issue.

2. Facts and trends of atmospheric SF_6 emissions

A key information for an evaluation of the environmental impact of the SF_6 used in the electrical industry (OEM and utilities) is the global SF_6 balance, which is controlled by production, banking of gas in newly installed electric equipment and release into the atmosphere by leakage and handling.

The **global SF_6 production** can be inferred from the annual SF_6 sales worldwide, which have been compiled in a recent survey comprising the seven largest SF_6 producers worldwide [2]. These data do not include the SF_6 production in Russia and China and the losses at the SF_6 producers themselves. The production in Russia and China was estimated in [4] to be 400 t/y in 1992 and 880 t/y in 1996. We tentatively extrapolate these figures to 400 t/y before 1995, a linear rise from 1995 to 1998 and a constant value after 1998. As the gas producers claim to have SF_6 release rates 0.5 % to 8 % of their sales [3], we will account for these by adding an average of 3 % to the sales. The thus corrected total production is represented as uppermost curve in **figure 1**.

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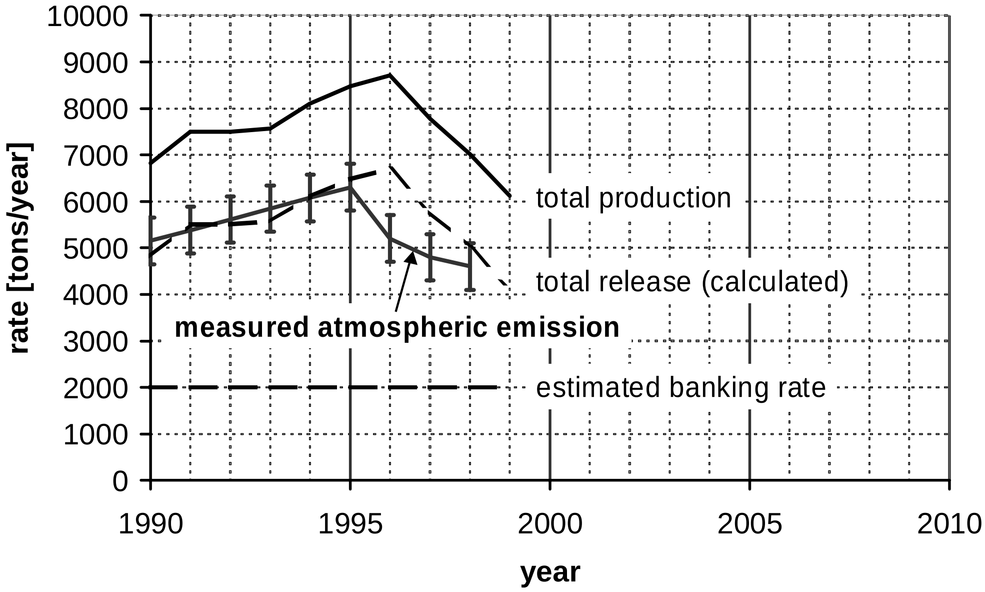

Figure 1: Elements of global SF_6 balance: The total atmospheric release rate (dot-dash curve) can be calculated as the difference between the total production rate (uppermost curve) and the banking rate in newly installed electrical power equipment (broken curve). This calculated release is seen to roughly coincide with the measured atmospheric emission rate (curve with error bars).

The annual rate at which SF_6 is **banked in newly installed electric power equipment** was estimated to be 2000 t/y in 1995 [4]. This figure is roughly consistent with an estimate of the banking rate in GIS, which is presently being prepared by the CIGRE WG 23-02. As the rate at which electric power is being installed worldwide has been approximately constant over the last decade [5], we assume that the rate at which new SF_6 equipment is being installed between 1995 and 2000. This is a conservative assumption in that the quantity of SF_6 required per performance will in tendency go down in the future due to improved design and other factors. We therefore can expect that the banking rate will decrease in the following decade.

The gas purchased for **non-electric applications** is usually not recoverable like in electric applications. Most of this gas is immediately released (e.g. cover gas in the magnesium industry, semiconductor industry, military applications) and a smaller fraction of it is released with some delay (e.g. tires, sport shoes, insulation windows). For simplicity, we approximately assume immediate release of all this “non-electric” SF_6. We then obtain the **calculated global atmospheric release rate** as the difference between the total production rate (uppermost curve in figure 1) and the rate of banking in newly installed electrical power equipment (broken curve). This calculated release rate is represented by the dash-dot curve in figure 1 and can be checked against the measured atmospheric SF_6 emission rate represented by the curve with attached error bars. This curve is determined independently from the increase of the SF_6 concentration in the atmosphere, which is monitored by various atmospheric research institutions (e.g. [4] [6]). It is seen that this experimental emission rate roughly coincides with the calculated release rate, which confirms the approximate consistency of the assumptions that had to be made above.

The global annual SF_6 sales data given by the SF_6 producers in [2] provide a **breakdown by application fields** and give, in particular, the SF_6 purchased by the electric industry for OEM and utilities separately. The total sales to the electric industry are shown in **figure 2** as uppermost curve and the sales to the utilities as broken curve. The difference between both curves are the sales to the OEM which are partly banked in newly installed equipment and partly lost during testing, manufacturing and commissioning. Note that the banking of gas in new equipment at commissioning is normally handled under the responsibility of the OEM.

The purchases by the utilities cover leakage and handling losses during equipment operation and are therefore all released. In a detailed data discussion for 1995 doubt was expressed that *all* the utility purchases are released from electrical equipment [4] [25]. If we nevertheless assume this to be the case we come to estimate **worst case upper limits for the fraction of SF_6 used for electrical applications.**

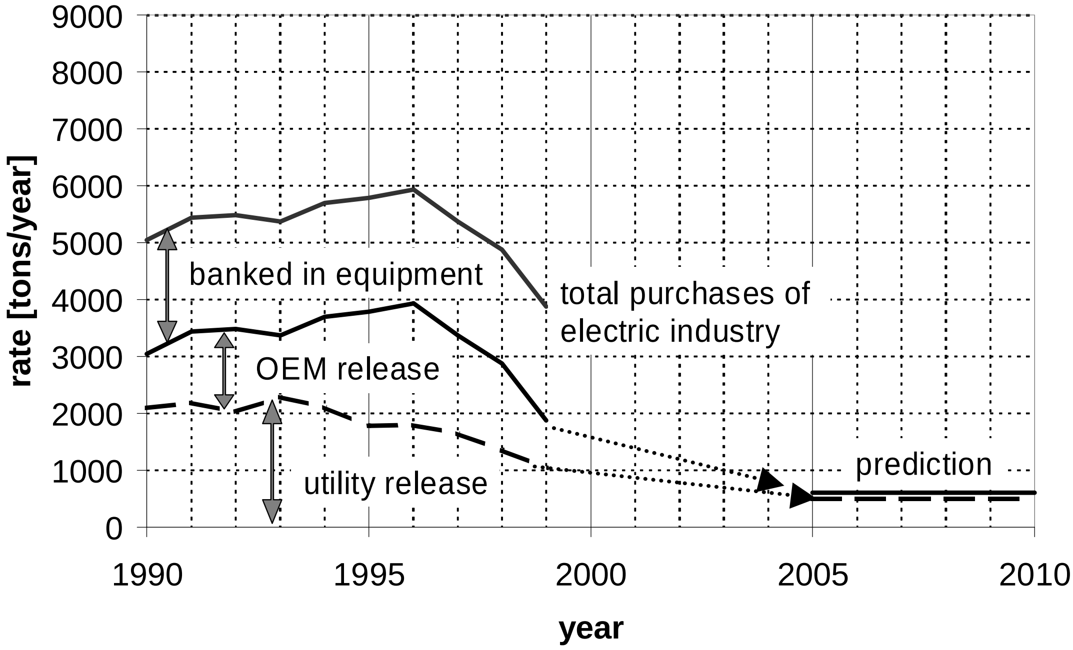

Figure 2: Global SF_6 balance of the electric industry: Total (uppermost curve) reduced by banking rate (2000 t/y) yields the total release by the electric industry (middle curve). This is further broken down into the releases by utilities (broken curve) and OEM. A prediction of the future emissions from the electric industry (without "non-electric" applications) is indicated by the levels labeled "prediction".

Subtracting the gas banked in newly installed electric equipment from the total purchases by the electric industry one obtains the **total release from the electric industry**. The result is represented by the middle curve in figure 2. As the SF_6 purchased by the utilities is given separately (broken curve) and as they are released the **OEM release** can be inferred as the difference between the total release of the electric industry and the utility release.

From the data in figures 1 and 2 the following **conclusions** can be drawn:

- The **electric industry is the main SF_6 user**. In 1999 it purchased less than 70 % of the total SF_6 production. Previous estimates for 1995 yielded lower percentages [25].

- There is a clear decreasing trend in total production and release from the electric industry since 1996. **From 1996 to 1999 the electric industry has almost halved its release with a further falling trend,** although new SF_6 equipment keeps being installed.

- It has to be noted that this **reduction trend of "electric" SF_6 release starts** in 1996, i.e. **only one year after the high global warming potential of SF_6 became known** in 1995. This indicates a **rapid reaction of the electric industry to the problem**.

- The continuing downward trend of the "electric" SF_6 emissions since 1996 is proof that **the electric industry is in the course of successfully implementing conservative SF_6 handling practice worldwide.** It should be noted that such an implementation is a tedious process, which requires substantial capital investment in improved handling equipment, time for personnel formation and world-wide logistic efforts.

- In [4] the SF_6 banked in electric power equipment is estimated to have been about 27 000 t in 1995. With the average annual banking rate of 2000 t/y, the SF_6 banked in equipment in 1999 results about 35 000 t. With utility losses of about 1000 t/y in 1999 this results in a world average **release rate from operating equipment (leakage + handling) of < 3 %/y.** This value is roughly consistent with the data retrieved by CIGRE for high voltage GIS [7]. These data indicate that leakage losses from high voltage

GIS, were in the range 0.5 …1 %/y and handling losses are around 1…2 %/y. For medium voltage distribution equipment of the sealed-for-life type losses are much lower, typically below 1%/y total.

- It is seen from figure 2 that the **OEM have more than halved their emissions in only 3 years time** (from 1996 to 1999) with a **further downward trend for the future**.

It has to be underlined that all the above statements refer to global averages and that the figures are worst case limits with respect to the electric industry. The figures may strongly vary from region to region, though. As an example, the total emission from the electric industry in the European Union in 1995 was only 3 % of the global emission whereas 15 % of the "electric" SF6 was banked in this region [25]. More precise and regionally differentiated statements will only become possible after more detailed data will have become available.

As conservative SF_6 handling in the electric industry is presently still in the process of implementation, it is justified to **extrapolate the "electric" SF_6 emissions to the future.** For this purpose, we make the following **conservative assumptions,** which are all based on *presently* established power equipment technology and gas handling practice and do not account for future improvements:

- The utilities reduce their emissions to a total (leakage + handling) of < 1 %/y. Figures of this order have already been reported in the past from some countries (e.g. [8]) and are part of voluntary emission reduction efforts in other countries (e.g. [3]). The figure of 1 %/y has also been proposed in the draft of the international electrotechnical standard IEC 60517 [9]. Extrapolating, as described above, the quantity of SF_6 banked in electric equipment will reach about 50 000 t in 2010. With the target utility loss rate of < 1 %/y this would result in future emissions from operating equipment of < 500 t/y.

- The original equipment manufacturers (OEM) have the potential to reduce their loss rate to less than 4% of the SF_6 they install in new equipment. This figure is composed of 1 % for development tests, 1 % for factory testing, 1 % at commissioning and 1 % at decommissioning which are typical data for high voltage GIS. For medium voltage distribution equipment of the sealed-for-life type still lower losses are already presently achieved. The above figures have already been agreed upon in some voluntary emission reduction commitments (e.g. [3]). If we assume that the OEM will reduce their rate of banking in new equipment to less than 1500 t/y, this would result in future OEM emissions of < 60 t/y.

The resulting future emissions are represented in figure 2 as levels between 2005 and 2010. They are approximately equal to the reduction potential estimated in [4]. With these figures we come to the following **prospective conclusion**:

- **The electric industry** (OEM + utilities) **has the potential to reduce its emissions to the order of 500 t/y which is a reduction of the 1995 value by more than 85 %.** Note that the Kyoto protocol only requires reductions in the 5 to 10 % range, typically.

3. Ongoing SF_6 emission reduction efforts

Voluntary programs for the reduction of SF_6 emissions from the electric industry were initiated briefly after the high global warming potential (GWP) of SF_6 had become known. These activities were organized by the electric industry (electrotechnical committees, OEM and utilities), SF_6 producers and manufacturers of SF_6 handling and recycling equipment. They consisted in:

1) **Promotion of conservative SF_6 handling by international committees**:
   - Issuing of recommendations for environmentally responsible SF_6 handling in the electric industry (e.g. CAPIEL/UNIPEDE [10], IEC [9, 11], CIGRE [12,13,14])
   - Preparation of SF_6 handling guides for the electric industry (IEC [11], CIGRE [13,14]).

2) Activities of **OEM (Original equipment manufacturers)**:
   - Improved equipment design to reduce the quantity of SF_6 required per performance and to reduce leakage

- Implementation of conservative SF_6 handling practice in test laboratories, factories and on erection sites. These measures have caused the halving of OEM emissions between 1996 and 1999, shown in figure 2
- R&D activities to explore the feasibility of SF_6 substitution (e.g. [16] [22] [23])
- Environmental evaluation of SF_6 insulated electric power equipment by environmental lifecycle assessment (LCA) [18] according to the standard ISO 14040 [15].

3) Activities of **electric utilities** including:
   - Improvement of gas handling procedures
   - Introduction of SF_6 inventories
   - Signing a memorandum of understanding for emission reduction with a government authority (e.g. USA [15], Japan [3]).

   These measures have already caused the halving of OEM emissions between 1996 and 1999, as shown in figure 2.

4) Activities of the **SF_6 manufacturers**:
   - Establishment of global SF_6 production inventories [2]
   - Offering take-back services for used SF_6
   - Research for SF_6 substitution [16].

5) Manufacturers of **SF_6 handling and recycling equipment**:
   - Performance improvement and cost reduction of SF_6 handling and recycling equipment
   - Support of personnel instruction.

4. SF_6 in a general environmental context

Although SF_6 is one of the strongest greenhouse gases by its molecular properties, it is important to put it into a general environmental context and to do this in a *quantitative* way. In this respect, the following aspects are of particular importance for electric power equipment:

(1) SF_6 is one of many other man-made greenhouse gases and is emitted in comparatively small quantity. Its contribution to global warming is best assessed in terms of CO_2 - equivalent emission rates. A CO_2 - equivalent emission rate is the actual emission rate multiplied by the global warming potential (GWP) of the gas. At present (1999), the SF_6 emission rate from the electric industry is about 2000 t/y (see figure 2) which, with a GWP of 22 000 for SF_6, corresponds to 44 Mt/y CO_2 equivalent. The total equivalent emission rate of the other man-made greenhouse gases is presently 43 000 Mt /y CO_2 equivalent [5]. **The present share of "electric" SF_6 in man-made greenhouse gas emissions** thus results

$$44\ \text{Mt/y}\ (CO_2\ \text{equivalent}) / 43\ 000\ \text{Mt/y} \sim 1\ 10^{-3} = \mathbf{0.1\ \%\ (1999)}$$

As estimated above, the full implementation of conservative SF_6 handling in the electric industry will reduce the "electric" SF_6 emissions to about 500 t/y corresponding to ~ 10 Mt/y CO_2 equivalent. Considering that the global emission rate of all man-made greenhouse gases will be approximately 50 000 Mt/y CO_2 equivalent in 2010 [5], the share of the electric SF_6 emission in relation to the total greenhouse gas emissions will then be

$$10\ \text{Mt/y}\ (CO_2\ \text{equivalent}) / 50\ 000\ \text{Mt} \approx \mathbf{0.02\ \%}$$

It can thus be concluded that the **"electric" SF_6 emissions, which are already now quantitatively insignificant, will become irrelevant in the future**. This conclusion may seem against intuitive expectation, which considers only the *molecular* property GWP and does not account for the *quantitative* emission data.

(2) It has to be noted that the above estimate does not yet account for the *positive* environmental value of SF_6 when it is viewed in the context of an *integral* environmental evaluation. Because of its high functional efficiency SF_6 allows to design very compact equipment. This allows to save materials and energy losses, both of which substantially contribute to the integral environmental impact. These savings have to be balanced against the negative impact of the SF_6 losses. The standardized procedure for such a balance is **LCA (environmental lifecycle assessment)** according to the

international standard ISO 14040 [15]. LCA evaluates the integral environmental impact of a technology and allows, in particular, to assess the relative contribution of SF_6. Applying LCA to a regional electric power supply system [18] has led to the result that the use of SF_6-insulation ***reduce*s** the environmental impact of the over-all system. Material savings, lower energy losses and other equipment features enabled by SF_6 over-compensate the negative impact of the SF_6 emissions. It has thus to be concluded that **SF_6, in spite of its high GWP, may even reduce the integral environmental impact of electric power equipment due to its extraordinary functional performance.**

(3) In contrast to many other greenhouse gases, the SF_6 used in electric power equipment is, by its very function, enclosed and is practically always handled by expert personnel. In contrast to consumer products, it is therefore relatively easy to implement conservative gas handling, once the necessary investments in gas handling equipment and personnel instruction have been made. **The electric industry has already proven that it is able to implement conservative SF_6 handling worldwide.**

(4) Several decades of intense and comprehensive research have shown, that **a functionally equivalent substitute gas for SF_6 does not exist** for physical reasons (e.g. [16] [22] [23]). As a consequence, SF_6 substitution, if enforced, would become technically difficult, economically unacceptable and environmentally critical, particularly for high voltage transmission equipment. Nevertheless, the OEM are continuing research and development work to identify performance niches (mainly low voltage and low current) in which SF_6-free equipment might become feasible.

The 1997 **Kyoto protocol** for the reduction of greenhouse gas emissions [1] explicitly lists SF_6 as the gas with the highest global warming potential. This **obliges all participating countries to achieve SF_6 emission reduction.** The methods by which governmental institutions try to achieve this goal and the reduction levels they have as targets are at the choice of the countries. Presently, three major concepts of governmental action can be recognized:

(a) Establishment of national SF_6 inventories (e.g. in EU, D [19] [20], J [3], CH, Brazil [8])

(b) Voluntary agreements on SF_6 emission reduction between government and electric industry (e.g. in US [17], J [3], D [24])

(c) Straightforward taxation of SF_6 as greenhouse gas and/or programmed phase-out (e.g. DK [21], NO, AU)

Whereas the establishment of national SF_6 inventories is necessary and voluntary emission reduction agreements have already proven to be efficient, **straightforward taxation and/or phase-out are considered inappropriate** for several reasons:

- Such measures are solely based on a material specific property (the global warming potential) and disregard functional aspects, the role of the gas in the frame of an integral environmental impact assessment (LCA) and the economic consequences. They thus do not hit the intended target of global emission reduction.
- Such measures will have several (probably not intended) counterproductive consequences. They will cause a cost increase for maintaining and retrofitting the already existing SF_6 power equipment. They will enforce technologies with increased cost and (integral) environmental impact. They may even make it impossible to provide certain vital functions in the T&D system, which can not be realized technically without SF_6, unless one would resort to historical technologies which were phased out decades ago, not only for economic but also for safety and environmental reasons.

5. Recommendations

Based on the facts and figures presented in this paper it is recommended that

(1) Information of the kind presented in this document is made available on the CIGRE SF_6 net-site and regularly updated

(2) CIGRE includes instructions on the establishment of SF_6 inventories into the planned practical SF_6 handling guide (to be published in 2002)

(3) CIGRE develops a sample form for a voluntary SF_6 emission reduction agreement between government and electric industry. This form could be oriented at already existing documents of this type (e.g. US [17], Japan [3], D [24]).

(4) Background information of the kind presented in this document is made available to governmental institutions and their consultants and to all relevant international and national organizations in order to provide information on the ***quantitative*** aspects of SF_6 use in the electric industry. This is expected to help putting the ongoing SF_6 discussion on a rational basis.

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