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ZVEI: Die Elektroindustrie

Scenario for reducing SF_6 operating emissions from electrical equipment through the use of alternative insulating gases

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Content

Key messages

- SF_6 operating emissions have been steadily reduced in recent years.
- The SF_6 technology for electrical equipment is technically optimised to a large extent with regard to emission rates.
- Due to the increase in the plant population against the background of the energy turn-around, electromobility, digitization and urbanization, hold on SF_6 technology alone would lead to a further increase in SF_6 stocks and not to a sustainable reduction in SF_6 emissions.
- A further reduction of SF_6 emissions in the area of electricity supply is possible mainly through the use of alternative technologies.
- Alternative products are already available and in use for individual application areas/voltage levels. However, an area-wide application for new plants across all voltage levels requires appropriate transition periods:
  - For each area of application, products adapted to the requirements must be developed and brought to market readiness; if there is sufficient supply, they can be used throughout the country;
  - Secure grid operation and security of supply must be guaranteed at all times: The speed and sequence of measures in electrical power supply networks must take this into account.
  - For these reasons, a transition period of 5-10 years should be applied, e.g. for the secondary medium-voltage level (≤ 24 kV).
- For extensions and repairs as well as for very special solutions (borderline applications) SF_6 will still be necessary beyond 2050.
- The use of SF_6-free solutions can be substantially supported by clear and reliable European frameworks for manufacturers and operators.

1 Motivation

The SF_6 and Alternative Gases[1] working group has developed two future scenarios on how the introduction of new technologies to replace sulphur hexafluoride (SF_6) in the field of electrical energy supply can help to achieve the EU Commission's ambitious goals of making Europe the first climate-neutral continent by 2050. In addition to the technical feasibility, the scenarios also consider the challenges of providing appropriate products in sufficient quantities and integrating them into the existing power grid while ensuring the energy supply at all times.

It also takes into account the fact that the demand for switchgear will continue to rise until 2050 against the background of the energy turnaround, electromobility, digitalization and urbanization. The objective is to show the potential for future reductions in SF_6 emissions and the banked SF_6.

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[1] AK SF6 and Alternative gases: The cross-association working group SF6 and Alternative Gases is composed of representatives of German manufacturers, operators, gas producers and suppliers of gas accessories. The following associations are also represented as associate members: BDEW, FNN, VIK, ZVEI.

2 Technical background

SF_6 - sulphur hexafluoride - is a gas, non-toxic but with a high climatic impact if it is released into the atmosphere. In the electrical industry it is used as an insulating and switching gas in medium and high voltage electrical products. The switchgear and switchgear devices based on SF_6 technology available on the market have proven themselves, are safe and very reliable.

The data collected by the Federal Environment Agency show that SF_6 (calculated in carbon dioxide equivalents) from all emitter's accounts for about 0.5 % of total greenhouse gas emissions in Germany [1]. Less than one-tenth of this is accounted for by the electrical industry [1] [2].

Over the last ten years, all major manufacturers of switchgear and controlgear have continued to invest in research and development of SF_6 alternatives. Already today, there are alternatives available in some fields of application of medium and high voltage. Some of them are already in use, some are being tested under real conditions in the network [3]. However, none of the alternatives available so far is a complete and equivalent replacement for SF_6 across all its applications.

The replacement of switchgear is usually carried out when the technical service life has been reached in order to always maintain the security of supply. Many SF_6 switchgear products in substations from the early days have already been replaced by SF_6 products with lower SF_6 quantities and SF_6 emissions. Further SF_6 products are increasingly being replaced and will thus contribute to a further reduction in SF_6 emissions.

3 Description of assumptions and scenarios

In this report, the effects of sticking with SF_6 technology and introducing alternative technologies in medium and high voltage are considered and evaluated on the basis of a model. The final results show which significant reduction potentials can be tapped for SF_6 emissions and for the banked SF_6 quantities in the systems („inventory").

Within the framework of a feasibility analysis, the current boundary conditions are also considered and a conclusion defined.

The member companies of the ZVEI have developed a model, using and combining public data and anonymous extrapolation of manufacturer figures, which shows the development of banked SF_6 quantities from the introduction of the technology to the present day. All high-voltage products (gas-insulated switchgear, instrument transformers and circuit breakers in outdoor installation) as well as gas-insulated medium-voltage switchgear (GIS) of the primary and secondary distribution level are taken into consideration. The figures for the installed quantity and the annual operating emissions of SF_6 were verified in the officially reported report figures (BMU, UBA) [2] and the model was adjusted accordingly.

According to the experts' estimates regarding the future development of the plant and substation population (cf. Section 3.3) regarding the replacement of existing plants and the construction of new plants that correspond to the expected network expansion, the future development of the existing plant population and operating emissions are considered in two scenarios. Scenario 1 considers the new construction and planned replacement of SF_6 plants with plants using the latest SF_6 technology (smaller gas volumes, lower SF_6 emissions). Scenario 2 describes the gradual use of alternative technologies. The development of SF_6 quantities in the system and SF_6 emissions in both scenarios are compared.

3.1 Estimation of banked SF_6 quantities in high voltage plants

As no detailed, publicly accessible information on the number of installations and products in the network is available, but the individual associations only have aggregated data on SF_6 quantities and SF_6 emissions, an expert estimate was made and validated with the report data.

The entire range of technology in all voltage levels (72.5 to 420 kV) was taken into consideration, i.e. gas-insulated switchgear (GIS) or instrument transformers and switchgear that are otherwise installed in air-insulated systems. Different gas volumes were exploited for the different technologies. The first plants from the 1960s are larger and therefore designed with a significantly larger amount of SF_6 than modern plants. The dimensioned and real leakage rates were also significantly higher in the early days than today. Over the decades, there has been an improvement from 3%/year to 0.1%/ year, which represents the technically feasible state of the art.

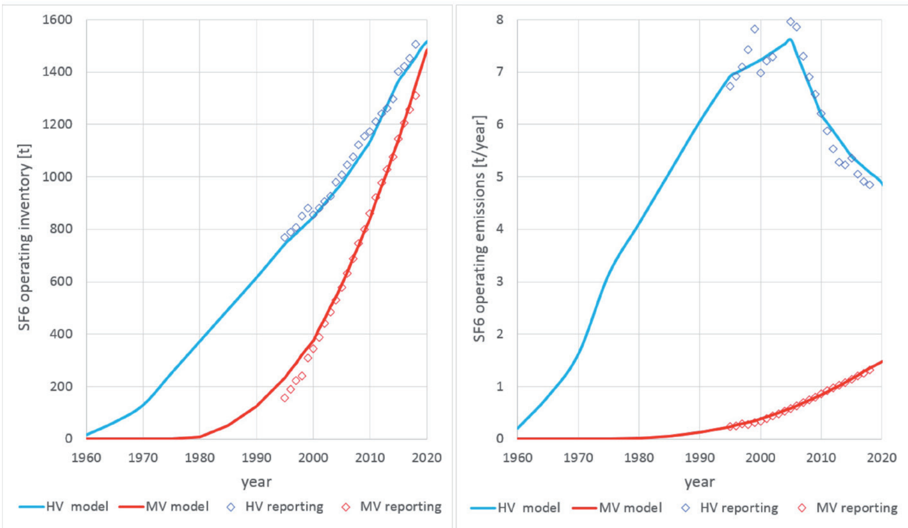
The products placed on the market were derived by one producer on the basis of the units supplied and the estimated market share in each case. The plausibility of the assumptions was checked and confirmed. The model is based on the summed SF_6 quantities used in the categories of the different leakage rates. In order to comply with the compliance guidelines, it is therefore not possible to draw any conclusions about production volumes or market shares of individual manufacturers.

Entered into the model, this results in the inventory quantities for the high voltage with the same product coverage as the reported figures. Since the reporting figures do not use theoretical leakage rates, but rather exemplary leakage rates of selected plants of each generation, these are also included in the model. This gives the annual leakage rates.

Since no public data on the exchanged plants and products in the grid is available, the model took into account the replacement of the first products after 40 (instrument transformer, circuit breaker) or 50 (GIS) years of operation with an exchange with products of the latest technology (lower gas volume and lower leakage rate).

The model now available could be compared with the inventory figures and emissions reported in the years 1995 to 2018.

Fig. 1: Comparison of the SF_6 inventory or SF_6 operating emissions in Germany according to the model and according to reporting for high voltage (blue) and medium voltage (red) - (Source: annual reporting to the BMU and UBA)



Source: annual german reporting to the environment ministry and environment federal office

The respective graphs show a correspondence between the model and reported figures and confirm the model.

3.2 Inventory data of medium voltage plants

For medium voltage, publicly available figures are not available as well, but the complexity of the product range is also lower. Only GIS are considered, divided into primary and secondary energy distribution systems (Ring-Main-Units - RMU). As this technology was developed much later and was not used until the 1980s, the first plants were already able to benefit from the experience gained in the high-voltage sector. These were already very compact and had a low leakage rate (< 0.5 %/year). To date, there are usually only two, rarely three, generations of systems that differ significantly less from one another than those in the high voltage sector. The range of covered operating voltages from 12 to 24 or 36 kV is also rather small, so that the differences due to the design are small. Some plant types are even largely identical in construction for the voltage levels 12, 24 and in some cases even 36 kV. For the analysis in the medium-voltage range, an analogous approach to determining the plant population is chosen as for high-voltage plants.

Based on the total production figures of a manufacturer for primary and secondary switchgear, produced until 2017, the total amount is extrapolated by assuming the market share. The share of this installed base in Germany is estimated and confirmed. The increase in the plant population is assumed to be similar to that of the high voltage. As the plants have only been installed since the 1980s and their service life has been estimated at approx. 40 years, a relevant deinstallation of old plants is neglected at present. The amount of SF_6 used per unit is averaged based on published data. As in the annual reporting to the BMU and UBA, a leakage rate of 0.1 %/year is assumed throughout.

3.3 Prediction of future development

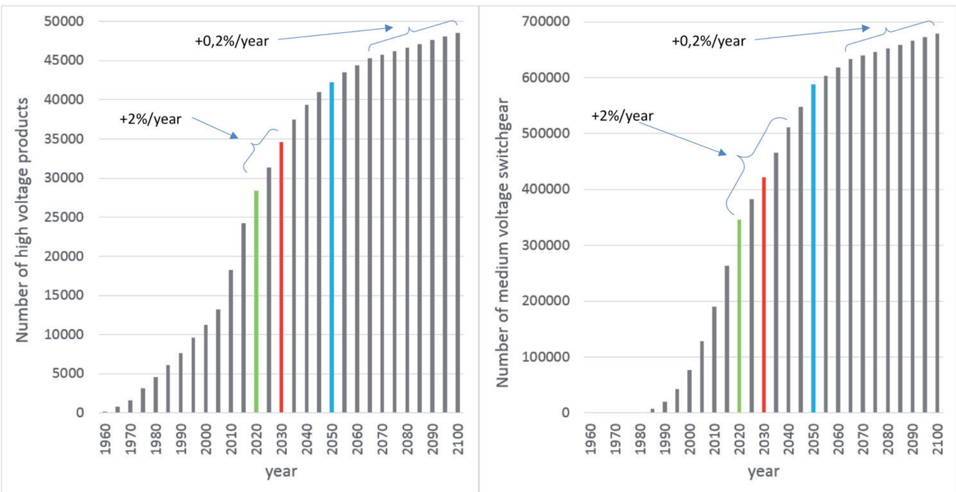
According to industry opinion, the SF_6 technology is mature in high and medium voltage and corresponds to the technological optimum. Lower leakage rates or reduced SF_6 quantities in new installations are in future not to be expected.

In the opinion of the experts represented in AK SF_6 and Alternative gases, especially on the operator side, lower growth rates will result for high voltage. However, the connection of renewable energy production (e.g. offshore wind farms) requires further expansion measures.

In medium voltage an increased demand in the area of distribution networks and generation needs to be considered. Another reason for the increase is the regenerative, decentralized energy generation, which requires considerably more switchgear than centralized generation. The digitalisation and electrification of transport is also expected to lead to an expansion of switchgear in the medium-voltage networks. Growing urbanisation also contributes to this. Overall, an annual growth rate of 2 % is assumed for the period until around 2050.

Extrapolating the data up to the year 2100, the following predictions result on the basis of the assumptions made:

Fig. 2: Prediction of the expected plant population until 2100 for medium and high voltage in Germany.



Source: own description

The graphs show the described trend of a smaller, but still steady expansion of switchgear for high voltage compared to the last 20 years and a continued expansion of medium voltage. The green bar indicates the present in each case, with the basic data on the development of the plant stock to date shown to the left and the forecast of future development to the right.

4 Considered scenarios

The aim of this work is to compare SF_6 emissions and the SF_6 inventory in two scenarios:

- Scenario 1 considers the new construction and planned replacement of SF_6 plants with plants using the latest SF_6 technology (lower gas quantities, lower SF_6 emission rates).
- In Scenario 2, new construction and planned replacement of SF_6 plants are carried out step by step using alternative technologies. The replacement is carried out according to technical requirements when the technical life of the existing equipment is reached („end of life" = 40 or 50 years).

As the technology for SF_6-free products is not yet available in complete product portfolios, but is currently still partly in development/pilot testing, assumptions have to be made as to when these products will be available in the individual market segments. These time periods take into account not only the pure product development times, but also corresponding verification tests, pilot installations, industrialization and finally homologation by the network operators.

For repairs and system expansions, the operation of SF_6 products must continue over many years.

The basis for a move to SF_6-free solutions is clear political incentives for the network operator or end customer. If this is not required, it is only partially or even very little used and the identified impacts are not felt. If the systems are not used on the market and there is no demand for their use, there will be no widespread development and it is even possible that the development process will not only slow down but will be discontinued due to a lack of demand.

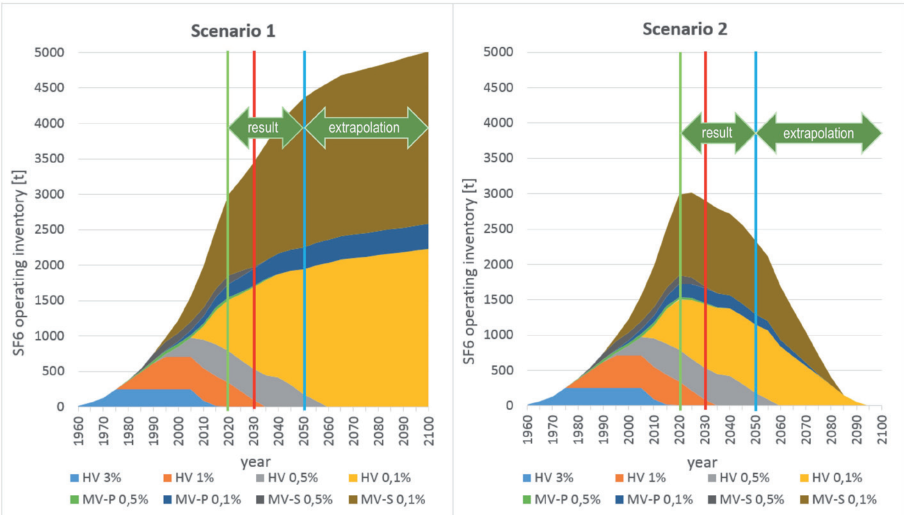
However, if appropriate incentive measures are taken, alternative technologies may develop and become widely used in the coming years. Based on this basic assumption, it is assumed for Scenario 2 that in the high-voltage sector about 5 % of new installations will be SF_6-free by 2025, about 40 % by 2030 and about 90 % by 2050. A similar development is expected in the secondary medium-voltage level until 2025. By 2030, 60 % of new installations could be SF_6-free, and by 2050 this should apply to all new installations. For the primary medium-voltage level, it is assumed that the share of SF_6-free technology will be somewhat higher by 2025 (approx. 10 %), as products are already available for individual voltage levels in this segment. By 2030 half of all new installations in this segment could be SF_6-free, and by 2050 almost all new installations (approx. 98 %). These assumptions reflect that for extensions and repairs as well as for very special solutions (borderline applications) SF_6 will still be necessary beyond the year 2050.

5 Results

The banked SF_6 in the installed base (see Figure 3) has increased in recent years, especially in the high-voltage range, despite the move to more compact systems with lower SF_6 volumes. There is also a significant increase in medium voltage, due to new installations by the above mentioned drivers. The scenarios considered show that the total banked SF_6 inventory in scenario 1 will continue to increase significantly in the future.

In future, the banked SF_6 in medium-voltage systems would exceed that in high-voltage systems.

Fig. 3: Comparison of the expected SF_6 stock (in t) in Germany based on the two scenarios



Source: graphical interpretation of the model

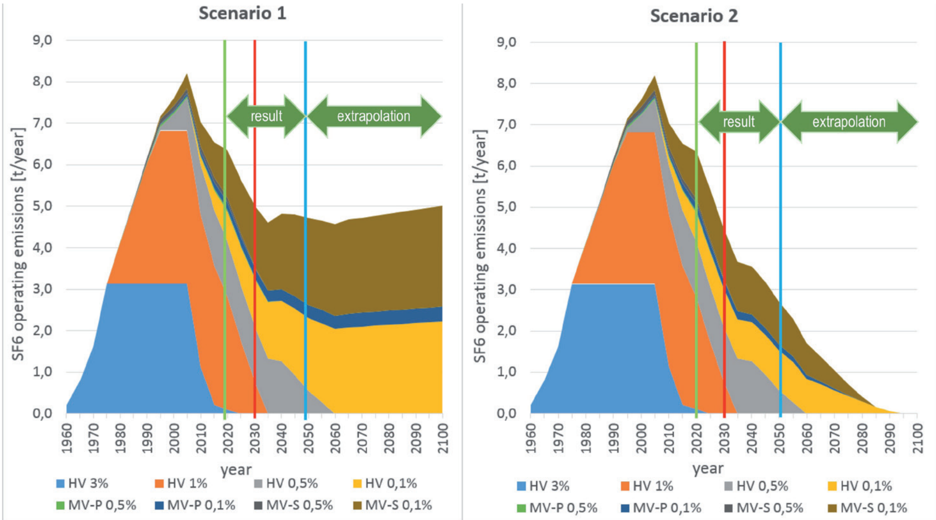
Scenario 1: Execution of the products in SF_6 technology latest state of the art
Scenario 2: Gradual use of SF_6-free alternatives
Result: Model result based on the selected premises
Extrapolation: Extrapolation of the model with analogous premises

Scenario 2, on the other hand, shows that, if SF_6-free technology is introduced immediately, the banked SF_6 can be reduced to an increasing extent, as more and more new plants are designed to be SF_6-free and old SF_6 plants and product are replaced by new SF_6-free plants. However, since the plants will - sensibly - be used for several decades, the decline in the amount of SF_6 used will take a long time period. The extrapolation shows that, under the above assumptions, even in scenario 2 the installed SF_6 quantity will not approach zero until the turn of the century.

If we now look at the resulting operating emissions (see Figure 4), we can see first of all that the measures taken in recent years have been successful, particularly the voluntary commitment of 2005 and the resulting measures taken by manufacturers and operators. Due to the progressive replacement of second- and third-generation high-voltage old plants with leakage rates of 1% and 0.5%/year respectively by newer and more compact plants, SF_6 emissions will continue to decrease in the coming years. Once this replacement is completed, the increase in installations will tend to lead to an increase in SF_6 emissions if scenario 1 (continued use of SF_6 technology) is pursued.

A phaseout of SF_6 with a gradual entry into SF_6-free solutions will continue the downward trend. Extrapolation shows that this will enable operating emissions to be reduced to zero by the turn of the century.

Figure 4: Comparison of the expected SF_6 emissions (in t/year) in Germany in the two scenarios



Source: graphical interpretation of the model

Scenario 1: Execution of the products in SF_6 technology latest state of the art
Scenario 2: Gradual use of SF_6-free alternatives
Result: Model result based on the selected premises
Extrapolation: Extrapolation of the model with analogous premises

6 Conclusion

The model developed gives a sufficiently accurate picture of the past with regard to the stock of SF_6 and operational emissions. Extrapolation into the future up to the year 2100 is associated with a large number of uncertainties.

However, if one assumes the availability of the product portfolios as well as the early application of SF_6-free solutions and if the predictions for the plant population - as stored in the model assumptions - are correct, it becomes clear that only a rapid and comprehensive changeover to SF_6-free installations can further reduce the stock and emissions of SF_6.

This transition to SF_6-free solutions can be accelerated by clear political measures and boundary conditions. If these fail to materialise or are not effective, a slower development can be expected, which lies between the two scenarios. If the switch to SF_6-free technologies is not made (extreme case), the development of SF_6 quantities and SF_6 emissions described in scenario 1 must be assumed.

7 Literature sources

[1] Umweltbundesamt (2019): Greenhouse gas emissions in Germany, online at https://www.umweltbundesamt.de/daten/klima/treibhausgas-emissionen-in-deutschland#textpart-1 (query 14.01.2020, 09:00 a.m.)
[2] Data reporting ZVEI / VDE FNN in accordance with the voluntary self-commitment to SF6 in power engineering to the BMU and UBA
[3] T&D Europe Guide „Technical report on alternative to SF6 gas in medium & high voltage electrical equipment

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