High Voltage Laboratory

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ECOFYS
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Concept for SF_6-free transmission and distribution of electrical energy

Executive summary of the final report

Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety

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1 Summary

In electrical energy technologies, the gas sulphur hexafluoride (SF_6) currently plays a central role as an insulation and extinguishing medium, particularly in switchgear. In addition to its many advantages in terms of technical properties, SF_6 has the disadvantage of having a very high global warming potential (GWP). It is the most potent greenhouse gas known.

Since the Kyoto Protocol of 1997, there have been discussions of measures that aim to reduce emissions of SF_6. One example is the voluntary commitment within the industry in Germany. On the European level, a ban on specific instances of use was discussed in 2014 in the context of the F-gas Regulation (EU, No. 517/2014), but ultimately rejected. The revision in 2020 provides for the examination of the availability of alternatives for SF_6 in specific switchgear in the medium-voltage range.

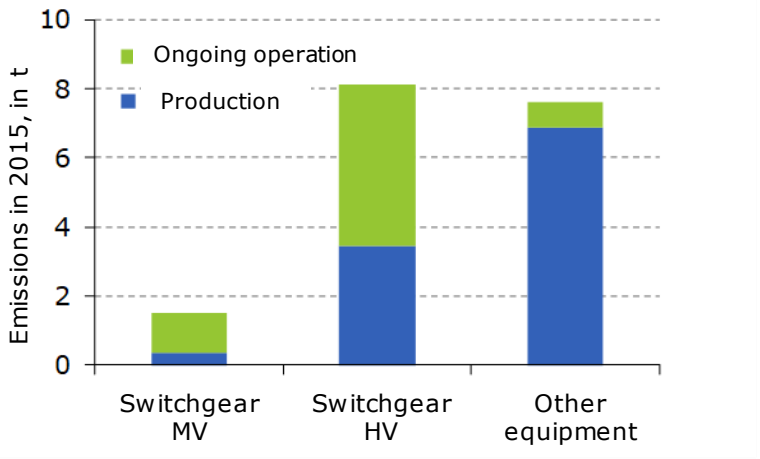
Against the backdrop of these climate policy-motivated efforts, Ecofys - a Navigant Company and ETH Zurich have been commissioned to identify and categorise technological alternatives and specific courses of action for replacing or reducing the use of SF_6 in newly constructed electrical operating equipment. The report focusses on switchgear, measuring transformers and electrical lines in the medium- (1 ≤ 52 kV) and high-voltage (>52 kV) ranges in Germany.

Specifically, we tested the existing SF_6 alternatives regarding their implementability, advantages and limitations, as well as environmental impacts. The insights gained also help scientifically determine the climate protection potential of replacing SF_6 in medium- to high-voltage installations. For the potentials that have been identified for replacing SF_6, the possibilities as well as the limitations of a European withdrawal, the timeframe this would require, as well as proposals for accompanying measures should be worked out. In conclusion, we have inventoried, systematised and comparatively analysed instruments and measures for reducing the use of SF_6. During the study, our own research was linked with an intensive dialogue with manufacturers and users in the form of multiple interviews and expert discussions.

1.1 Findings and Conclusions: Status Quo

The highest SF_6 emissions in the distribution and transmission of electrical energy are emissions in the production of 'other' operating equipment as well as operational emissions from high-voltage switchgear.

Existing emissions in the high-voltage (>52 kV) sector exceed those in the medium-voltage sector many times over, although more SF_6 is installed in medium-voltage installations. Emissions during production are also high. The high reported emissions in the production of "other equipment" (e.g. measuring transducers, bushings and capacitors) are not always traceable in detail. A precise analysis and validation of the reported figures is currently handled by the trade associations and the SF_6 work group.



Research by Ecofys, based on [UBA, 2016]

Figure Z1: SF_6 emissions during the production and in running operation; emissions in disposal are negligible (2015). Source: Own research, based on [UBA, 2016].

In the medium-voltage range, alternative solutions are available on the market, whereas in the high-voltage range, further developments are needed.

In the medium-voltage range, there are established alternatives to SF_6. Some of these alternatives have been used successfully in commercial settings in other European countries for years. However, there are no alternatives that are equal to SF_6 in every technical respect, or that outmatch it. Depending on the area of application, air-insulated switchgear or switchgear with alternative insulation media like solids, liquids or alternative gases can be considered. In the medium-voltage range, vacuum circuit-breakers are the state-of-the-art switch medium.
In the high- and extra-high-voltage range, the selection of technically practical alternatives is more limited in terms of both insulations as well as switch media. In addition to using vacuums as switch media, practically the only considerable alternatives for insulation or switching media are gases and gas mixtures.
Industry representatives assume that alternatives in the high voltage range can reach a level of performance similar to SF_6 installations, though this will still require several years of development.

The F-gas Regulation and voluntary commitments have already resulted in significant reductions in SF_6 emissions.

Since initial implementation of the F-gas Regulation, the industry is working to reduce its SF_6 emissions in production processes, as well as in the utilisation phase in medium- and high-voltage. In Germany, this led to a voluntary commitment within the industry (first in 1997, renewed in 2005) [SOLVAY et al., 2005]. This resulted in a reduction in SF_6 emissions related to electrical operating equipment from 50 t of SF_6 in 1997 to 17 t of SF_6 in 2015.

1.2 Findings and Conclusions: Further Developments

Further potentials for reduction are available, but exploiting them will require additional efforts.

Through ambitious efforts, it will also be possible in the future to achieve significant reductions in SF_6 emissions despite a rising number of installations. However, reduction potentials are more difficult to tap into than in the past, and they continue to depend heavily on voltage, use/type of operating equipment and area of application.

- *High-voltage switchgear:* New installations already have a very high containment level. Product processes have already been greatly optimised. All possibilities for further reduction through improving operational processes must be considered. Substantial reduction in emissions will require the bold introduction of existing and future alternatives.
- *Medium-voltage switchgear:* Newly installed medium-voltage switchgear already features very low emissions rates (<0.1% p.a.). These leakage rates can be seen as technical feasibility limits. Therefore, further reduction potentials in medium-voltage installations can only be exploited if SF_6-free solutions are used increasingly for MV switchgear in the future. The actual reduction potential cannot be reliably quantified based on the model approach in the course of actual monitoring.
- *'Other' Electrical Operating Equipment:* The origin of the high absolute emissions in the production of 'other' electrical operating equipment has not been sufficiently explained. Existing reporting does not allow the precise sources of these emissions to be identified, nor does it point conclusively to the type of operating equipment in question. The technical feasibility of alternatives or emission reductions thus remains unclear for now.
- *Decommissioning and Disposal:* The first major series of SF_6-containing operating equipment are fast approaching the ends of their technical lifespans. Therefore, decommissioning and disposal will be relevant topics for controlling emissions in the near future. General requirements are in place for the proper recycling of gases at the end of the equipment's lifespan. These are also part of voluntary commitments adopted by the industry. Considering the widely scattered locations of the operating equipment and the non-registered allocation of operating equipment, manufacturers and users, it remains to be seen whether all parties will carry out the processes with the necessary care.

Further substantial reductions in emissions could ultimately depend fundamentally on a widespread change to alternative technologies/gases. For such a change to take place, challenges for the reliability, safety and environmental soundness of new solutions must be carefully tested and comprehensively evaluated.

The industry requires regulatory and technical certainty

Pressure to further reduce the use of SF_6 brings with it adoption costs and a wide range of uncertainties for the industry. A reliable regulatory framework is a precondition for sustainable efforts.

Setting a mandatory target for further minimisation of the use of SF_6 is just as important for the industry as a consistent evaluation of the properties of relevant alternatives. In this area, there are still many uncertainties. Especially the

regulated network industry has a need for reliable statements on how the extra costs associated with alternatives are to be handled in the regulations.

Further development of voluntary commitments offers chances for continued progress

It is up to policy-makers to set the targets. The further reduction of emissions is increasingly difficult to realize. Mandatory reduction targets should therefore be regulated by the policy. The implementation of industry-wide targets however, can generally continue to stay with the industry itself; e.g. in the context of ongoing voluntary commitments.

SF_6 monitoring requires further development

If effective measures are to be established and carried out by policy-makers or the industry itself, it is necessary to know where emissions are actually occurring. Current methods and aggregation levels of SF_6 monitoring within the framework of voluntary commitments in the industry do not sufficiently allow for an independent evaluation and comparison of the performance levels achieved, or the identification of specific emissions sources. However, there are many difficulties associated with further improvements in monitoring. Three areas of monitoring deserve particular attention:

- *Emissions monitoring and reporting* (bottom-up), Possibility of differentiated identification of potential main emission sources (above-average emission rates).;
- An *SF_6 register* in the form of a database for constant monitoring of the quantity, location, age and possibly the emissions rate of individual SF_6 switchgear.
- *Atmospheric emissions measurement* (top-down).

Considering the Replacement of Old Installations

The subject matter of the studies was new operating equipment. Selectively replacing old installations can presumably reduce a large portion of operational emissions, both in the medium-voltage and high-voltage ranges. However, there are no simple, generic and reliable indicators (e.g. the age of the installation) through which the emission level of a specific switchgear can be discerned. The total potential, efficiency and effectiveness of these measures are therefore uncertain and difficult to assess in advance. Again, improved monitoring would help.

1.3 Recommended Actions

Policy and Regulatory Framework

- We recommend the specification of clear policy goals for further reduction in the use and emission of SF_6. Without setting clear policy goals, further reductions in SF_6 emissions by the industry will lag behind what is possible.
- Policy-makers must define the criteria for a consistent evaluation of the non-technical properties of the alternatives. These include the evaluation of climate relevance, health risks, consideration of additional costs in the incentives scheme and other similar topics.
- In our opinion, these clarifications should preferably be issued on the European level. National rules promise only limited efficiency and effectiveness.
- We consider normative specifications or financial incentives in favour of certain alternatives in individual applications to be less useful. An integrated specification of volumes for the industry as a whole (usage, emissions) is more effective, in our view. An expanded, voluntary commitment by the industry can serve as a suitable framework for this.
- Should a voluntary commitment fail to reach its goals, policy instruments that have deeper impacts must be considered and promptly worked out. If such courses of action are known, it increases the credibility and clout of the policy. It is part of the certainty that the industry demands.
- As a supplement to voluntary commitments adopted by the industry, specific instruments can be implemented. They allow 'low-hanging fruit' to be seized that would otherwise only be attainable with delays.
- One option would be to impose targeted sanctions on inadequate gas recovery and recycling. Effective sanctions must clearly exceed the costs of disposal.
- Furthermore, incentives systems can be useful in specific areas. However, these must be applied with moderation due to the risk of market distortion and deadweight effects. A: Supporting the replacement of leaky equipment. B: Supporting the market launch of alternatives by buffering against additional costs and risks.

Developing voluntary commitments further

In this context, we consider the following aspects particularly worthy of attention:

- *Efforts to achieve ambitious targets must be shared fairly:* the efforts required to further reduce emissions will naturally increase as emissions decrease. Ongoing efforts by individual enterprises seeking to advance low-SF_6/SF_6-free technologies cannot count on a commercial base at this time. A clear code of conduct, combined with a consistent means of sharing the efforts within the industry, can strengthen security, even in a competitive playing field.
- *Greater efforts must be made to address 'other' operating equipment.* It is indispensable for the industry to broaden its level of knowledge and develop a bold strategy. To a large extent, this aspect will affect only a small number of manufacturers. Even still, the distribution of efforts within the industry itself will be essential for facing the oncoming challenges.
- *Emissions - Not Emissions Rates:* The development of emissions in the field of medium-voltage installations shows that successes in reducing emissions rates are insufficient from an environmental policy perspective.

In light of the immense increase in the number of installations, absolute emissions have once again been on the rise recently, despite the fact that emissions rates have been cut to the technical minimum. Therefore, we find it reasonable to demand that targets be focussed on absolute emissions. This will stimulate the introduction of alternatives.

- *Substitution Road Map:* Ideally, the industry will work out a road map for further reduction in the use and emissions of SF_6, as well as the introduction of alternatives, and actively coordinate this with the policy level. We consider it expedient to quantify the interim steps along the way towards achieving the goal. This will support in evaluating the progress and increase the possibility of making targeted readjustments whenever difficulties occur, without the need for immediate action on the policy level. With all due reservations, such a road map would also provide an additional degree of certainty to all parties involved.
- *(Voluntary) Commitment by Users to Functional, Technology-Neutral Tendering:* In current practice, tendering documents for new operating equipment regularly refer 'out of habit' to SF_6 installations. A requirement to generally avoid this specification in tendering and, in the future, to tender according to functionality would provide suppliers of alternative solutions with at least an equal competitive position, while also increasing product diversity.
- *Decommissioning and Disposal:* Proper recycling, reuse, disposal and destruction of SF_6 from decommissioned operating equipment is already regulated in general. A detailed agreement on the processes and their monitoring seems appropriate, in light of the volumes to be dealt with in the medium term. The handling of operating equipment from which the gas currently cannot be recycled without excessive effort (e.g. measuring transducers) should be given particular attention at this time.
- *European Coordination:* An expansion of voluntary commitments to all of Europe would have an explicitly positive influence on the effectiveness of the measures. At the same time, we consider it appropriate to incrementally standardise individual points (selected topics in which it is possible to reach a consensus; individual Member States who are leading the way in specific areas). Otherwise, we are concerned that this coordination will take place at a very slow pace.

Further Development of SF_6 Monitoring, Emissions Oversight and Reporting

We consider it necessary to adjust the monitoring system in the following respects:

- *Make disaggregated data accessible to public authorities:* less aggregated data would help authorities to identify the worst emitters and to implement effective, efficient measures based on this, as well as to monitor progress towards reaching targets.

- *Standardise reporting systems on the EU level in all relevant respects:* the introduction of a coherent European monitoring system would be useful for comparison purposes and necessary in case of future EU-wide measures. Industry experts expect that the establishment of an EU-wide methodology will take at least a decade. However, this is no reason not to get started and to push for an incremental harmonisation of reporting practices, as needed.

- *Expanding the Responsibilities of Gas Producers and Suppliers:* Currently, gas producers do not report on SF_6 volumes. Involving them in reporting would simplify the entire process. The confidentiality and anonymisation of market-relevant data must indeed be given particular consideration, considering the limited number of market players. However, this could be maintained by limiting access to the data. The various import

and export streams of European and non-European suppliers would, of course, also need to be depicted adequately. This is an additional argument in favour of a coordinated European approach.

- *Eliminate Lack of Clarity Surrounding the Term 'Other' Operating Equipment:* There are uncertainties regarding the distinctions between categories of operating equipment, voltage levels and the definitions upon which monitoring is based. These should be eliminated to identify potential options for reduction.
- *Atmospheric Emissions Measurement:* We recommend, in addition to existing bottom-up inventorisation activities by industry associations, top-down oversight through atmospheric measurements and reverse modelling. Top-down analyses can supply very specific findings as to the regions and timeframes in which emissions originated. This may help to verify progress achieved in emissions reduction, to refine emissions modelling for the bottom-up inventory and to identify sources in need of attention. Even if some relevant emitters are missing or less reliably registered in the reporting (e.g. soundproof windows, military, non-EU countries), it would be useful to understand the volumes that are not measurable in order to bring top-down and bottom-up analyses closer in line with each other.

Developing and Introducing an SF_6 Register

- An SF_6 switchgear register in the form of a database to continually monitor the number, location, age and possibly the emission rate based on maintenance data would facilitate emissions reporting and unify bottom-up and top-down approaches. Such a register could be created for the high- and extra-high-voltage sector without excessive effort. In the medium-voltage sector, the pros and cons would need to be balanced:
- The precondition for data gathering is consensus on collection processes as well as on which data is to be collected and in which format. Such coordination among stakeholders would be a question of years rather than months, even on the national level. Individual companies have already introduced SF_6 registers in the course of their asset management activities, and have tested appropriate methods. Much can be learned from these companies as the discussion of a Germany- or EU-wide register continues. Furthermore, the experiences of EU Member States with regard to refrigerating plant registers can also be used as a reference.

Considering the Replacement of Old Installations

- If a significant portion of operational emissions can be reduced by selectively replacing old installations, incentives and socialisation of costs are justifiable.
- A clear inventorisation of existing installations, which also serves as a basis for reliably identifying worthwhile installations, is a precondition for implementing such measures. This can only be achieved by the industry itself. Sophisticating monitoring helps.

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