

Life Cycle Assessment

Electricity Supply Using SF₆ Technology

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Abstract Whereas there are known technical and economical advantages of using SF₆-technology in electricity supply systems, the potential environmental effects of applying this technology has not been quantified in detail up to now.
From this background, a comparative Life Cycle Assessment (LCA) on the supply of electricity using different switchgear technology has been carried out, which showed the following main results :

- * Already on the level of switchgear bays the use of SF₆-technology results in reductions of the area needed and energy losses and thereby also in a decrease of emissions contributing to acid rain and nutrification of rivers and seas. The total global warming potential can be decreased subject to low SF₆ losses and in bays with a high loading.
- * For an electricity supply grid of a city with 140,000 inhabitants the use of SF₆-technology showed to be favourable in all environmental aspects studied (area used, energy needed, acid rain, nutrification and global warming potential) as compared to conventional SF₆-free-technology.
- * SF₆-technology provides particular flexibility in the basic design and in case of extension or re-arrangements of electricity supply grids. Thus, the length of the medium-voltage-cables can be reduced resulting in lower transmission losses. This fact is the main reason for the environmental advantages of SF₆-technology, provided the SF₆ losses are adequately controlled.

The study has been performed and critically reviewed according to ISO 14040.

1. INTRODUCTION

Electrical energy is generated in power plants, and supplied to the consumers by means of transmission and distribution systems. In a simplified view, the electrical power systems consist of switchgears, transformers, and power lines (underground cables and overhead lines). The nodes of these networks are the switchgears.

The current state of the art for switchgear-technology is represented by:

- High-voltage switchgear, open type, with air as the insulating medium (AIS, air-insulated switchgear)
- Gas-insulated metal-enclosed high-voltage switchgear with SF₆ as the insulating and quenching medium (GIS, gas-insulated switchgear)
- Medium-voltage switchgear (indoor type), enclosed design, with air or SF₆ as the insulating medium.

The advantages of SF₆ result from its high dielectric strength compared to air and its superb quenching property for electric arcs.

2. ENVIRONMENTAL ASPECTS

The gas SF₆ is colorless and odorless, as well as non flammable. It is an extremely stable gas which is chemically inert as well as physiologically/biologically not very reactive. To the best of our knowledge, pure SF₆ has no toxic properties.

However, SF₆ has a high material-based global warming potential (GWP) ^{/1/}.

For this reason it is included in the six gas basket of the Kyoto Protocol.

Calculations based on atmospheric measurements show that the total worldwide emissions of SF₆ contribute only about 0.1 percent of the overall anthropogenic greenhouse effect. This includes both the SF₆ emissions from the major area of use in electricity transmission and distribution systems (about 70-80 % of the global SF₆ production is used in this sector) and those from all other uses.

3. DESIGN OF THE LIFE CYCLE ASSESSMENT ^{/2/}

The motives for carrying out the study arose from the possible conflict between the known advantages of sulfur-hexafluoride (SF₆) technology, such as a reliable and economical power supply, and the environmental profile of the use of SF₆ in power supply systems, which has not been quantified in

detail until now. The previous one-sided focus on the material-based global warming potential of SF₆ must be replaced by an analysis of all the relevant environmental criteria in the context of the application of SF₆ - in this case the electric power supply.

The associates in the project, which compares different types of switchgear, with and without SF₆ technology, at the levels of switchgear bays and of a practical power supply system, were ABB, PreussenElektra Netz, RWE Energie, Siemens and Solvay Fluor und Derivate GmbH.

The life cycle assessment was performed according to the specifications of the international standard DIN EN ISO 14040^{13/}, and was followed and evaluated by an external independent expert from TÜV NORD.

3.1 Scope of investigation

Object of the life-cycle assessment is the supply of electric power using different switchgear technologies. First, switchgear bays for the voltage levels 380 kV, 110 kV and 10/20 kV were studied.

Based on this, a practical urban power supply system was assessed. The functional unit is the useful electrical energy per year. The studies are based on conditions in Germany. The technologies considered reflect the current state of the art. The power output in the various scenarios is equal; for this reason, its generation was ignored.

3.2 Impact categories

The impact categories considered in the present study belong to the environmental criteria which are considered by the general debate today to be relevant to sustainable development. The following environmental criteria are of particular importance for the systems considered: the global warming potential (GWP), acidification potential (AP) and nutrification potential (NP). The impact assessment also covers the cumulative primary energy consumption and the area required.

3.3 Data requirements

Data on the composition of the respective materials (e.g. copper, steel, aluminum, SF₆) and on the utilization (e.g. service life, ohmic losses, rate of

SF₆ losses) of the various defined switchgear bays, cables and overhead lines were provided by the manufacturers of electric switchgear (ABB, Siemens) and power utilities (PreussenElektra Netz, RWE Energie) participating in the project. The process data for the production of SF₆ gas were obtained from the project participant Solvay Fluor und Derivate. The data concerning the power supply system considered, and the calculation of the system's variants were provided by ABB.

The processes for manufacturing the materials used in the switchgear, underground cables, and overhead lines are represented by means of publicly available sets of data that are recorded in databases or life-cycle assessments. The most current version of the databases used was employed in each case. The processes used and their sources were described in the extended version. A special computer program was used to draft the present life-cycle assessment.

3.3.1 Data basis for components

Service life

The service life of the components considered ranges from 25 (parts of AIS installations) to 50 years (overhead lines).

SF₆ losses

A survey by the VDEW ^{/4/} shows that the SF₆ emissions from high-voltage and medium-voltage switchgears in Germany amount to 0.9 % per year of the quantity of SF₆ installed due to leaks and handling losses. This figure refers to all installations in operation that employ SF₆ technology, and thus includes older, first-generation installations that are still in operation. By the use of high-grade vessel materials, modern manufacturing methods, tried-and-tested sealing systems, and of sealed or hermetically sealed pressure systems only, it has become possible to reduce the leakage losses of new GIS installations to less than 0.5 % per year. In future, a further reduction in SF₆ emissions may be expected, since modern compact units have volumes that are up to 75 % smaller. In the present study, an average rate of SF₆ losses of 0.5 % for all switchgear bays considered (high-voltage and medium-voltage level) was assumed.

Transmission capacity and amperage

For switchgear bays the current intensity corresponds to approx. 50% of the switchgears' nominal currents: 1250 A for the 380-kV high-voltage level, 630

A for the 110-kV high-voltage level, and 315 A for the 10/20 kV medium-voltage level.

3.3.2 Data basis for power supply networks

At the system level, two alternative supply models were compared (figure 1), based on the given load profile of a German city about 40 km² large, with about 130,000 inhabitants, a peak load of 120 MW, and a consumption of 400 GWh during the first year of the period (and an annual increase in load of 1.5 percent) :

- The electric power is fed into four air-insulated 110/20-kV transformer substations (AIS) on the outskirts, occupying a corresponding surface area, and distributed via the 20-kV network. The 110-kV transformer substations are connected by means of overhead lines.
- The electric power is fed via 110-kV cables into three SF₆-insulated 110/20-kV transformer substations (GIS) close to the consumers, and distributed via the 20-kV network.

In both cases, the electric power is taken from the regional grid in a 380/110-kV transformer substation on the outskirts. Both systems are designed such that the quality of supply to the consumers is equal.

The systems were optimized from the commercial point of view. The period considered is thirty years, the typical service life of air-insulated high-voltage switchgear. SF₆-insulated switchgear can usually be used for at least ten years more.

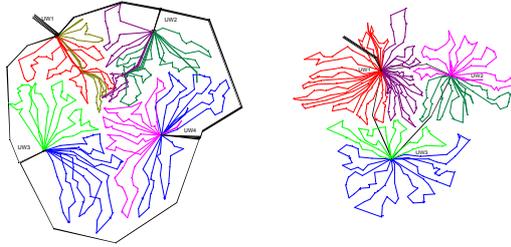


Figure 1 :

Topology of the power system variants: System with AIS technology (left) and system with GIS technology (right) for a distribution voltage of 20 kV. "UW" stands for transformer substation. The left hand illustration shows that, in the AIS version, the four air-insulated substations are located on the outskirts. In the GIS version shown on the right, the three SF₆-insulated substations are positioned within the city, and thus close to the consumers. – Thick lines represent 110-kV high-voltage overhead lines or underground cables; thin lines stand for 20-kV medium-voltage cables. While the 110-kV overhead transmission lines of the AIS version (without SF₆) circle the city, the 110-kV cables of the GIS version (with SF₆) stretch into the city, resulting in a reduction in transmission losses.

4. RESULTS

4.1 Components level

Even at the switchgear bay level, the use of SF₆ technology offers advantages for four of the five criteria of the life cycle assessment study (Figure 2) :

Primary energy consumption, area required, acidification potential, and nutrification potential. Switchgear with a high utilization factor and/or the low rates of SF₆ loss achievable today provide an ecological advantage even for the greenhouse potential.

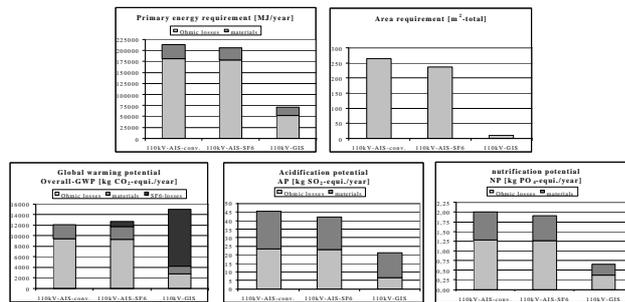


Figure 2: Potential environmental impacts from the use of various switchgear technologies at the 110-kV high-voltage level

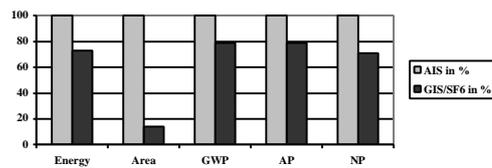
The absolute values from the calculation of the assessment for the switchgear bays listed are shown, divided into the individual components: ohmic losses, material input (= materials), and SF₆ losses from "leakage" and "handling".

4.2 Systems level

At the level that counts in the end, namely the power supply system considered, the following results were obtained (figure 3) : designing a power supply network with GIS technology (using SF₆) results in a reduction of about 27 percent in the primary energy consumption, of about 86 percent in the area required, of about 21 percent in the greenhouse potential (GWP), of about 21 percent in the acidification potential (AP), and of about 29 percent in the nitrification potential (NP), compared to designing the same network with AIS technology (without SF₆). The transferability of the results from this sample network had been tested in extensive scenario calculations.

The major reasons for this reduced environmental impact are : since SF₆ has considerably better insulating and quenching properties than air, substations and equipment can be made with less material and energy than in the SF₆-free AIS alternative. Furthermore, due to the compact design of the GIS components, the 110/20-kV transformer substations can be built directly at the (downtown) load centers. So the energy is transmitted at high voltage with low losses to the city centers, and distributed from there to the consumers via short medium-voltage lines.

The use of GIS switchgear in the power supply system considered reduces all the potential environmental impacts studied. The diagram shows the relative environmental impact potentials during the first year of use of the power system variant (gray bars = AIS version, black bars = GIS/SF₆ version). An increase in the system's supply capacities by about 50 percent (i.e. increased utilization of the system) results in a further reduction of about 5 percent each in the parameters primary energy consumption, greenhouse potential (GWP), acidification potential (AP), and nitrification potential (NP), due to SF₆



technology.

Figure 3: Reduction of potential environmental impacts studied by use of GIS (SF₆) switchgear in the power supply system considered compared to AIS switchgear technology.

5. CONCLUSIONS

The use of SF₆ technology leads to considerable environmental advantages over the use of SF₆-free switchgear. Therefore, SF₆ technology makes sense for electric power supplies, even from the environmental viewpoint. This requires the use of GIS installations that ensure appropriately low SF₆ emissions, on the one hand, and rigorous application of the SF₆-ReUse-Concept of a closed SF₆-cycle, on the other. The technical and logistical prerequisites for this effort are already available.

It is also very clear that an environmental view limited to the greenhouse potential of a unit of weight of SF₆ cannot provide an environmental assessment of the use of SF₆ in high-voltage and medium-voltage equipment. A comprehensive consideration of an entire power supply system with the help of a life cycle assessment, directed to all relevant environmental criteria, provides dependable results that are positive for SF₆ use.

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