RESPONSIBLE USE OF SF$_6$ IN ELECTRICAL DISTRIBUTION SYSTEMS

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INTRODUCTION

Sulfur-Hexafluoride (SF$_6$) is used in electrical transmission and distribution since the early 1960’s. After the first years of experience in high voltage equipment, the first medium voltage switchgears using SF$_6$ for insulation were launched in the world market in the early 1980’s. The excellent dielectric properties made it possible, that SF$_6$ is used today in all voltage ranges beginning at 12 kV. The market share of products filled with this gas in electrical distribution is steadily growing. In some segments, such as secondary distribution about 50% of all delivered ring main units (RMU) are using SF$_6$. The environmental problems caused by the increase of world wide industrialization and an increasing public interest in environmental issues led to a survey to find out which gases could have caused the global rise of temperature. After this study it was agreed in the Kyoto Protocol [1], that the industrial countries shall reduce the amount of gases, that are contributing to the green-house effect. One of the gases contributing is SF$_6$.

CHARACTERISTICS OF SF$_6$

Today SF$_6$ is used in medium voltage systems (rated voltage between 1 kV and 52 kV) mainly for electrical insulation. In this application the thermal effects of an electrical arc do not stress the gas. The reasons for the use of this artificial gas are:

- High dielectric withstand
- Good thermal transportation capability
- Inertia
- Non toxic
- High thermal stability
- Good recombination characteristics
- Recyclable and re-useable

Most of the characteristics are due to the electron bonding structure between the most electro-negative of all elements, Fluorine and Sulfur. Sulfur forms an extremely stable octahedron structure with the six fluorine atoms.

Another advantage of switchgear, that uses SF$_6$ for insulation, is, that this type of gas insulated switchgear (GIS) is independent from the surrounding environment. The encapsulation needed to maintain the gas pressure enables the GIS to be installed even under severe climatic conditions. This kind of switchgear is not sensitive to moisture, pollution, animals and high altitude; it can be even operated when fluted. The reduction up to 80% of required space in the substation building for the GIS medium voltage switchgear, compared to conventional air insulated switchgear is also significant for this technology. All this advantages made it possible, that medium voltage GIS are widely used also for electrical distribution. Meanwhile the installed amount of SF$_6$ in medium voltage switchgear is no longer negligible. The large numbers of advantages offered by Sulfur-Hexafluoride are countered by one disadvantage. SF$_6$, although a gas which is not harmful to the ozone layer, is considered as a greenhouse gas.

The effect of active greenhouse gases is shown schematically in figure 1. Due to the strong absorptive properties of gases like CO$_2$, methane (CH$_4$), nitrogen oxides (NO$_x$) or SF$_6$ the infrared radiation (IR) reflected from the earth’s surface is blocked in the atmosphere. By this the heat dissipation from the earth is reduced and causes a temperature rise in the troposphere. In addition to this general effect to be a greenhouse gas, SF$_6$ features the drawback that its absorptive power of infrared radiation is much higher than any other gases. This is expressed in a high global warming potential (GWP) factor of 22,200 for 100 years [2].

This environmentally detrimental effect, however, is partially offset by the following facts:

- Electrical switchgear contributes to the emissions to a very minor extent, contrary to applications like for window thermal insulation, as an inert gas for military purposes and also as an inert gas for process engineering.
- In spite of its high GWP factor, SF$_6$ is responsible worldwide for approximately only 0.1% of the total man-made greenhouse effect due to its extremely low concentration in the atmosphere (concentration in the range of parts per trillion) [3].

After a long time of sorrow-less handling all industries, not only the electrical, are asked to provide solutions to stop the further increase of SF$_6$ in the atmosphere. Meanwhile the manufacturers of GIS have considered alternatives for SF$_6$ for insulation and switching purposes.
THE USE OF SF₆ IN ELECTRICAL DISTRIBUTION

The design of high voltage switchgear above 1 kV is described in the relevant standards of the International Electrotechnical Commission IEC [4] [5] and dedicated test procedures are given with the respect to their particular design features. The main differences in the use of SF₆ in high voltage switchgear up to 52 kV are

- use for insulation only
- use for arc extinction only
- use for insulation and arc extinction

With respect to the environment the application where SF₆ is used for insulation only is the most preferable. The gas is not subjected to the temperature of an electrical arc and therefore no by-products are generated. Further measurements have shown, that in ring main units (RMU), where the gas is also used for arc extinction, the interruption of load currents does not lead to a significant decomposition of the insulation gas.

The gas compartments used in this equipment are specified according to the following categories [4]:

- controlled pressure system
- closed pressure system
- sealed pressure system

All categories except the sealed pressure system need refilling of SF₆ during the entire life of the switchgear. A sealed pressure system, see example in figure 2, is filled with a certain amount of gas when it leaves the factory and needs no gas processing during its expected operating life.

In the design concept of such switchgear all primary parts (such as switches, support insulators etc.) are built in gas tight tank. Openings needed for the cable connections are assembled with gaskets to ensure the required leakage rate. Beside this static seals, dynamic seals are used for the moving of the switching devices as well. In this case normally two gaskets in series are used to provide a gas-tight assembly. The design of modern medium voltage switchgear is fully in line with the requirements of the Coordinating Committee for the Association of Manufacturers of Industrial Electrical Switchgear in the European union (CAPIEL) [6].

The filling mass of the gas takes into account the leakage rate of the compartments and is specified as such, that the gas density would reach the minimum level necessary for operation at the end of the expected operating life. Only for this kind of switchgear it is possible to determine exactly the losses and to provide the possibility to the end-user to have a proper inventory of the installed amounts in the network. Another advantage of sealed pressure systems is, that they can be fully routine-tested at the manufacturer. Additional tests and measurements on site after commissioning are not required.

THE POLICY OF ALSTOM

ALSTOM launched its first gas insulated medium voltage switchgear in 1983. The first designs were very close to the high voltage applications, which mean cylindrical tanks with relatively high filling pressures to achieve the rated insulation level. The main switching device was a vacuum circuit breaker as used for the conventional air insulated cubicles. Beside a lot of static seals to connect the welded tank modules each panel had at least 4 dynamic seals (three for the circuit breaker and 1 for the three position switch). The single panels were factory pre-tested and assembled together on site. During the erection phase the main busbars compartment had to be finalized. The most difficult job was to evacuate and fill the busbar compartments on site and to check the system for leakages. For this designs a leakage rate of 1.5 % per year was usual. During the last two decades the technological development of welding processes and advanced sealing materials in combination with more sophisticated designs made it possible to reduce the amount of SF₆ used per function, see figure 3, and the possible leakage rate dramatically.
After the Kyoto meeting the discussion about the reduction of greenhouse gases began and also the use of SF\textsubscript{6} was in public discussion. With a delay on some years the wave reached Europe and the European manufacturers were asked for alternatives. In general all insulation media had to be considered [7]. In particular
- liquids,
- gases,
- solid insulation materials and
- vacuum

were investigated. Balancing all ecological and economical aspects during the life cycle, not only these after manufacturing the switchgear, no real alternative to SF\textsubscript{6} switchgear could be shown up.

In addition to the ecological aspects the expectation of the most customers is totally different. The client expects to buy switchgear according to the state of the art, mainly according to IEC standards, and is specifying more and more functional. Things like maintenance free and long expected operating life time are obvious. Taking into account all this aspects, at the end the selling price will be the most important decision criteria as long as there is no restriction of any technology. Especially the market for RMU’s is such a business. The switchgear specification for secondary distribution is mainly:
- rated voltage 12 kV, 15/17.5 kV or 24 kV,
- rated short circuit current 16 kA or 20 kA,
- rated current 400 A or 630 A,
- transformer protection with fuses,
- expected operating life 40 years
- maintenance free
- recyclable at the end of life

Taking into account the market specification and the ecological needs the response of ALSTOM is the new FBX range. The main focus of the design is to reduce the gas emission.

Therefore as much functions as possible are integrated in one gas tank. The tank consists of chromium-nickel steel and has a minimized welding length. This could be reached by using a single bended sheet metal, see figure 4. To the left an right side the sheet is welded to the side walls. The tank is designed as a sealed pressure system according to IEC 60694 [4], that needs no maintenance of the gas filled compartment. The only apertures are for the connection of the high voltage cables and for the operation mechanism.

The functions interruption of the load current and earthing of the cables are combined in a three position switch. By this measure the apertures for the mechanisms could be reduced by a factor of two. In one tank up to four functions can be realized, incoming and transformer feeders as well. If more functions are needed, the extensible version of this ring main unit can be expanded on the bus bar by a plug system. This system consists out of two inner cone bushings an one double outer cone per phase, see figure 5. The extension of such a ring main unit can be done without any gas-handling on-site, by simply pulling two tanks together and fixing them on the ground frame of the building. The dielectric properties of the connection can be checked by a power frequency withstand test.

Beside the insulation task of the gas, it is also needed to interrupt the load currents of the cable rings and to interrupt the connected transformer under all operational conditions. From no-load currents up to the rated current by the switch disconnector itself and up to the short circuit current of the network in combination with the high voltage fuse (transfer current of the fuse). The switch disconnector, see figure 6, is using the Deion principle for the arc extinction. If the switch is opened, the blades are lengthening the arc. Driven by the thermal force the arc is moving in the Deion sheets and split up in several small arcs in series. One captured in the specially designed Deion sheets the arcs are cooled down and they will extinguish when the next current zero is following. If the current is passing the zero, the blades have reached already a position at which the transient recovery voltage (TRV) can be withstood. With this principle the arcing time can be limited to less than 10 ms.
The blades of the switch disconnector are mounted on a plastic part, that also acts as switching shaft. The switch is designed for a maximum of ten making operations with the full short circuit current without any maintenance. The same blades are also used for the earthing of the connected high voltage cables. The design of this special three position switch makes it possible to have only one radial stressed gasket for two independent switching duties. Further the switch is able to interrupt and make more than 100 times the rated current and has an inductive switching capability up to 1400 A.

In the case when high voltage fuses protect the connected distribution transformer; the fuse links are also placed inside the gas tank. They are housed in three gas-tight glassfiber-reinforced tubes. The outer insulation is done by SF\textsubscript{6}, the insulation of the fuse itself is in air. The fuse container is protected against the environment by a sealing system too. This seal enables also the operation of the RMU under water, up to a water height of three meters.

All materials used for connecting parts between SF\textsubscript{6} and atmosphere, e. g. sealing systems (elastomers), fuse-housing (filament winding epoxy tubes), spouts (epoxy) are improved, to avoid loss of SF\textsubscript{6} and migration of moisture inside SF\textsubscript{6}. (increasing of the dew point):
- lowest permeation for water and for SF\textsubscript{6}
- stability against decomposition products of SF\textsubscript{6}
- long-life property without decreasing of mechanical and electrical demands

With the described measures it is possible to ensure and guarantee a leakage rate of less than 0.1% per year.

**PROCESSING THE GAS**

In the past most emission of the insulation gas occurred during the manufacturing process and the erection on site. For the FBX ring main unit the whole process was designed to handle SF\textsubscript{6} in a totally closed system. The main process steps are
- assembling of all components into the gas tank,
- final inspection of the built in components,
- assembling of the switching mechanism,
- closing of the gas tank (welding),
- evacuation of the gas tank,
- filling of the gas tank,
- tightness test and
- test of the dielectric system (partial discharge and power frequency withstand test).

In addition to this pre-cautions the CAPIEL SF\textsubscript{6} inventory methodology [8] was introduced to allow all parties to calculate the true emission of SF\textsubscript{6}. The aim of this method is to measure the SF\textsubscript{6} emission in particular caused by the handling of switchgear. The comprehensive method developed by CAPIEL covers all sorts of use of SF\textsubscript{6} in the electrical sector from the moment of acquiring the gas till the end of life of the equipment. Further it defines the principles of chain management, ensuring that the total chain of use of SF\textsubscript{6} is covered, from production of SF\textsubscript{6} via application in switchgear, the operation in the electrical network, its use and maintenance, to the End of Life of the switchgear and the return/destruction of the SF\textsubscript{6}. Further it defines as well the principles of “Ownership” and “Transfer of Ownership” to ensure a clear responsibility in any stage of the process of handling SF\textsubscript{6}. The inventory Methodology is comparing the input and the output of SF\textsubscript{6} on a calendar year basis. In fact it is the only practical way to determine emissions with a reasonable precision. The principle is shown in figure 7.

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If there is a bigger leak and the system pressure cannot reach a certain value, the process is stopped immediately. After the evacuation process the control volume, surrounding the ring main unit, is filled with Helium gas. A spectral analyzer is controlling the amount of Helium in the second gas volume. With this measuring device a minimum leakage rate of 0.01% per year can be detected. After passing the leakage test and when it is confirmed, that there is definitely no leak in the tank, the tank is filled with the insulation gas. After this final manufacturing step the gas quantity is recorded and put on the nameplate of the RMU. With all this measures it is guaranteed, that the emission during the all the processes is minimized and in line with all valid environmental recommendations.

SUMMARY

In a market, that is more and more sensitive to the environmental behavior of electrical equipment, a sulfur-hex fluoride still can be used. As SF₆ has no relation to the Ozone hole in the earth’s atmosphere and as it not subjected to legal restrictions is has still its justification. The key factor is the restricted and careful use of the gas during all industrial steps. Already in the design stage of the equipment all measures must be taken to minimize the gas amount an to reduce the possible leakage sources. The careful use continues during the manufacturing process and during the service life of the switchgear and ends with the disposal at the end of life. There is no real alternative to the use of SF₆, that enables the use of distribution equipment under all environmental conditions.

REFERENCES


[5] IEC, 1990, IEC 60298 “A.C. metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to an including 52 kV”

