Green Switching - Opportunity to avoid SF_6 emission from electrical networks

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Keywords: green switching, SF_6, medium voltage, MV switchgear

ABSTRACT: SF_6, the most potent greenhouse gas with a Global Warming Potential (GWP) of 23.900 CO_2 equivalents, is one of the substances that have been banned for almost all applications, except for high voltage and medium voltage switchgear. The reasoning for this exception is that there would be no alternatives available. However, there is good news on the horizon: Eaton has developed very compact and environmental friendly MV switchgear, called Xiria, which is based on vacuum technology and solid insulation for voltages up to 24 kV. With this green solution utilities can choose a sustainable alternative and therefore reduce the use and emission of SF_6 in their distribution networks. This green alternative – launched in 2002 – is now finding a wide acceptance due to the fact that many utilities in Europe have decided to use this SF_6-free switchgear in their networks.

The philosophy of Eaton is very simple: to prevent is better than to cure. The best way to limit emissions is just not to use any fluorinated greenhouse gases. Based on this principle Eaton has taken the initiative, together with several utilities in the Netherlands to start the Green Switching platform which is also supported by the Dutch government and by SenterNovem, being the agency for sustainability and innovation of the Ministry of Economic Affairs in the Netherlands. This Green Switching initiative has created a lot of awareness around this subject and supports the policy to reduce the use of Non-Carbon Greenhouse Gases.

1 INTRODUCTION

As global warming is now high on the political agenda and there is a growing concern about the impact of climate change, policy makers are looking for ways to reduce the emission of greenhouse gases. The greenhouse gas that contributes the most to global warming is CO_2. Although there are a lot of policies in place to reduce the CO_2 emission on a global scale, as described in the Kyoto protocol, implementation of these measures appears to be more complex and time consuming. The CO_2 emission is highly related to energy consumption and for this reason the economic development of a country. A quick win can be realized by reducing Non-Carbon Greenhouse Gases like SF_6, especially when alternative processes and technologies are available and the incremental costs for these measures are low. In this paper the authors will point out the need for a more stringent and proactive policy to reduce the emission of SF_6.
The features of SF_6 are described and an overview of its applications as switching and insulation medium in electrical switchgear is provided. The authors will give an overview of switchgear developments over time and they will present the environmental and health & safety aspects of SF_6 and its by-products. After an overview of current legislation and voluntary reduction programs, alternative technologies for SF_6 as applied for Medium Voltage switchgear in the electro technical industry are presented. Recommendations for more stringent legislation and financial stimulation measures will be proposed.

2 PROPERTIES OF SF_6

2.1 *Chemical features*

Sulphur hexafluoride (SF_6) is a man-made gas that is chemically inert, non-toxic, non-flammable, non-explosive and thermally stable at temperatures less than 500°C. SF_6 is colourless and odourless and heavier than air. One of the main characteristics of SF_6 is its high chemical stability due to the six covalent bonds of its molecule. SF_6 is usually transported in the liquid form. The pressure required to liquefy SF_6 at 21°C is about 2,100kPa and it is therefore normally liquefied by compression.

2.2 *Electrical features*

SF_6 has been commonly used for application in electrical switchgear in the power transmission and distribution sector since the 1960's. The reasons for its use are its good insulation and interruption capabilities. SF_6 is strongly electronegative at room temperature and at temperatures well above ambient. SF_6 has a fast dielectric recovery time and is self-healing after being dissociated under high-pressure conditions in an electrical discharge or an arc. In addition SF_6 has good heat transfer and arc quenching properties. The electrical breakdown strength is approximately three times higher than air at atmospheric pressure.

2.3 *Applications of SF_6*

SF_6 is the largest and heaviest gas molecule that exists at room temperature and it has very good insulation properties. Due to this SF_6 was up till recent used as a filling and insulation gas for sport shoes, tennis balls, car tires and double glazing. SF_6 is also used for medical applications, in the defence industry, for semi-conductor production and as blanket gas for magnesium production to prevent oxidation. SF_6 is also used as a switching and insulation medium in High- and Medium Voltage switchgear in electricity networks.

3 ELECTRICAL SWITCHGEAR

3.1 *The Energy Line*

Switchgear is used to control and distribute the electrical power flow from the power generation plant to the end user. For economical and technical reasons, it is advantageous to do the bulk transport of electricity at a high voltage (HV, > 52kV) level, transform to medium voltage (MV, 1- 52kV) level in dedicated, primary substations and continue to distribute the power at the MV level to smaller transformer stations which are situated locally and widespread in industrial and residential areas, close to the end-users. At this point the power is transformed from the MV level to the low voltage level (LV, < 1kV) for the end-user (Fig.1).

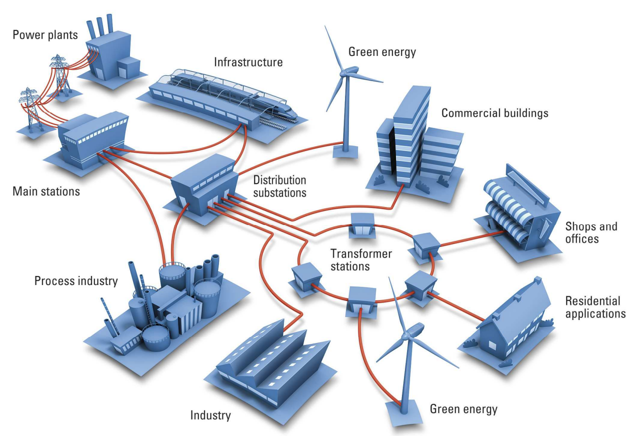

Figure 1. The Energy line: flow of electrical energy from generation to end-user

3.2 *Modern switchgear technologies*

Switchgear, as applied in primary-, sub-distribution and transformer stations, is a combination of several active and passive components, interconnected by conductors. All primary parts, intended to be energized should be insulated from the outside world. SF_6 gas is generally pressurized at 1.3 Bar for MV insulation purposes, where for HV a pressure of 3 to 5 Bar is quite normal to obtain even higher breakdown levels, up to a factor 10, compared to atmospheric air. This has resulted in very compact and cost-effective solutions compared to conventional technologies, especially for HV applications.

Several manufacturers – mainly active at the MV level – have looked for solutions based on vacuum switching technology in combination with solid or air insulation as alternative for SF_6. This has resulted, amongst others, in modern compact Ring Main Units (RMU's), as used in utility networks and the smaller industrial and commercial applications worldwide.

Both SF_6 and vacuum technology are used in state of the art switchgear. SF_6 can be used both as interrupting and insulation medium inside the switchgear. Vacuum is very commonly used as switching medium in combination with air insulation or in combination with solid insulation. The application area for vacuum as interrupting medium is expanding now to voltage levels of 110 kV.

An overview of the applied switching and insulation technologies is shown in table 1. For HV applications above 110 kV, there are currently no technical and commercial viable alternatives for SF_6 as interrupting and insulation medium in compact switchgear.

Switching & insulation technologies		Voltage level (IEC)		
		Up to 36kV	50-110kV	>110kV
Switching medium	SF_6	Yes	Yes	Yes
	Vacuum	Yes	Yes	No (not yet)
Insulation medium	SF_6	Yes	Yes	Yes
	Air / solid insulation	Yes	No	No

Table 1. Switching and insulation technologies for compact switchgear

4 ENVIRONMENTAL ISSUES OF SF_6

4.1 *Most potent greenhouse gas*

According to the Intergovernmental Panel on Climate Change (IPCC), SF_6 is the most potent of the six main groups of greenhouse gases. Its global warming potential (GWP) varies between 22,800 and 32,600 dependent on the timescale. In general, a 100 years horizon is considered with a corresponding value of 23,900 [1]. For this reason SF_6 has been put on the Kyoto list of substances of which the use and emission should be minimized [2]. Although the contribution of SF_6 to global warming at present is estimated to be only 0.01%, scientists are concerned because of its long term environmental impact. If production and leak rates of SF_6 are maintained at current levels it is expected that in 100 years its relative contribution to global warming would become as high as 0.15%. SF_6 is an efficient absorber of radiation, in particular at wavelengths around 10.5 µm. In addition, unlike most other greenhouse gases, SF_6 is largely immune to chemical and photolytic degradation. Therefore its contribution to the greenhouse effect is expected to be cumulative and virtually permanent. The lifetime of SF_6 in the atmosphere is estimated at 3,200 years [3].

4.2 *Annual global emission*

Approximately 8,000 metric tons of SF_6 are produced annually, of which about 80 percent is used by the electrical power industry for arc interruption, cooling, and insulating [4]. Production of SF_6 is still increasing worldwide, although this greenhouse gas is listed in the Kyoto protocol. According

to recent studies, the annual rate of increase of SF_6 in the atmosphere is 8% ±0.7%, the highest rate of increase found of all of the potent greenhouse compounds [5].
This equals an annual emission of over 1500Mton CO_2 equivalent. This will increase if no additional measures are taken. Although there are now inspection, leakage prevention and recycling policies in place in most of the western countries, it is still doubtful if most of the used SF_6 outside these countries will be prevented from escaping into the atmosphere. Also in the western countries, leakage does happen, on a structural basis or by incidents.

5 HEALTH AND SAFETY ASPECTS OF SF_6

5.1 *Asphyxiation*

As indicated SF_6 is a very heavy gas with a density of about five times the density of air. Because of the fact that SF_6 is colourless and odourless, the risk is that personnel not aware of the presence of SF_6 will be asphyxiated. It is highly recommended that personnel should be made aware of this danger and, that equipment and buildings should be adequately ventilated if the substation is entered without breathing apparatus. If there is any doubt about the presence of SF6 in a switching room, it is essential to verify the presence of sufficient oxygen by using a portable analyzer.

5.2 *Toxic by-products*

Under normal conditions SF_6 is an inert, non-toxic and thermally stable gas. However on incineration or when an electric arc in the switchgear occurs, SF_6 breaks down into highly toxic substances like HF, SOF_2, SF_4 and S_2F_{10}. The quantity and type of reaction products depends on the types of material in contact with the SF_6, the humidity and also on the content and type of gas impurities. When the discharge is cleared the gas will recombine to a large extent but not completely. These reactions also occur in normal use under partial discharges or whenever an arc is cleared as result of a switching operation. The toxic residues will then remain in the housing, as a result of which special precautions are required when dismantling the system at the end of its service life.

5.3 *Critical failures in the public domain*

In the event of an internal arc caused by a critical failure, SF_6 gas and its toxic by-products are released into the atmosphere. This will lead to unacceptable health and safety risks, not only for operators, but also for the general public when installed in residential areas or public buildings. This is especially the case when MV equipment is used in commercial buildings, shopping malls, railway stations, hospitals and other large buildings that are freely accessible by the general public. These toxic by-products are even more dangerous when SF_6 switchgear is used in underground applications like subways, railway tunnels and mines.

6 CURRENT LEGISLATION & MEASURES ON SF6 EMISSION REDUCTION

6.1 *F-gas regulation*

As a consequence of the outcome of the IPCC studies and the fact that SF_6 is a greenhouse gas listed under the Kyoto-protocol of which emissions should be mitigated [6], the European Union passed legislation that bans SF_6 for almost all applications, except for electrical switchgear. The reasoning for this exception is that no viable alternative would be available. Under the F-gas regulation (2006) the use of SF_6 is now prohibited for most applications, like in sport shoes, car tires, tennis balls and for double glazing [7].

The F-gas regulation prescribes a lot of precautions to limit the emission in HV and MV switchgear applications. Utilities and switchgear manufacturers have to take special measures to limit the emission during the production, use, maintenance and end of life of equipment containing SF_6. Technicians involved in regular inspections, maintenance, refilling and recycling of switchgear containing SF_6, need to be trained and certified. Besides, there are three IEC standards that prescribe how to deal with SF_6 for HV and MV switchgear applications.

6.2 *EPA voluntary program*

As climate change is now also becoming a growing concern in the USA [8], the US government and several large users of SF_6 participate in a voluntary program to reduce emissions of SF_6. This has resulted in the Environmental Protection Agency's (EPA's) SF_6 Emission Reduction Partnership for electrical power systems. Over 80 US utilities are taking measures to reduce SF_6 emissions and the results are reported on an annual basis [9]. This has led to an average emission reduction for the partners from 15.1% in 2000 to 8.3% in 2005 of the banked SF_6 gas in the installed base.
The annual SF_6 emission for the participating utility companies has been reduced from 6.32 Mton CO_2 eq. per year in 2000 to 4.50 Mton CO_2 eq. in 2005, which means a reduction of over 30%. The cumulative emission reduction that has been avoided since the start of the program is 6.88 Mton CO_2 equivalent. One of the outcomes of the EPA annual report is that emission rates seem to vary between 0% and over 45%, which illustrates that the SF_6 emission prevention is very much related to conscious behaviour, leakage monitoring and periodical inspections.
Although this EPA Partnership program is a great success story, it also indicates that the annual emission rate for utility companies that don't participate can be expected to be still significant both by percentage and as absolute emission in Mton CO_2 equivalent. Further measures, like a ban on SF_6 for those applications where alternative technologies exist, and legislation that forces all utilities to participate in this emission reduction program, are recommended.

6.3 *Developing countries*

The above-mentioned case shows that SF_6 emissions can vary significantly, dependent on the consciousness of behaviour, type of equipment and inspection & maintenance interval. For developing countries SF_6 emission prevention can be a problem, as the know-how is not always available and procedures are not in place to limit SF_6 emissions. Especially in countries where the daily temperature cycle shows extreme values, leakage of SF_6 is more difficult to prevent due to the expansion and contraction of materials, like seals. The developed countries have the obligation to lead by example and to share best practices, i.e. providing knowledge how to prevent this leakage and sharing technology, especially where alternatives exist.

6.4 *Total ban on SF_6*

Due to a severe lobby campaign by SF_6 producer Solvay and several of the larger switchgear manufacturers, SF_6 is still not banned for HV and MV switchgear applications. The reasoning they use is that there are no economically and/or technically viable alternatives for SF_6 in HV applications. This might be the case for HV, but certainly not for MV applications. It is important to be more specific on this voltage level definition.
Within the international IEC standards, the term high voltage (HV) is used for all voltages above 1000 Volts (1kV). However, the term medium voltage (MV) is generally used in practice and, now also recognized by IEC [10], for systems with voltages above 1 kV and up to and including 52 kV, leaving HV for above 52 kV.
For HV switchgear the claim is that HV switchgear based on SF_6 technology is more compact, cost-effective and technically superior to other technologies. Although there are solutions based on vacuum technology under development now, this statement can be in general judged as true. For MV applications however, there are good alternatives available on the market, e.g. based on vac-

uum switching and solid insulation. These compact solutions are technically equivalent and economically attractive, especially when the Total Costs of Ownership are taken into account.

7 SF_6 FREE SWITCHGEAR TECHNOLOGIES EXIST

7.1 *Global trends in MV switchgear*

In the 1980's oil was still predominant as the interrupting medium in breakers, since then vacuum and SF_6 took over very quickly. However, since the 1990's the worldwide awareness about the disadvantages of SF_6 has grown, resulting in an even faster growth of vacuum [11] particularly in MV switchgear applications (Fig. 2).

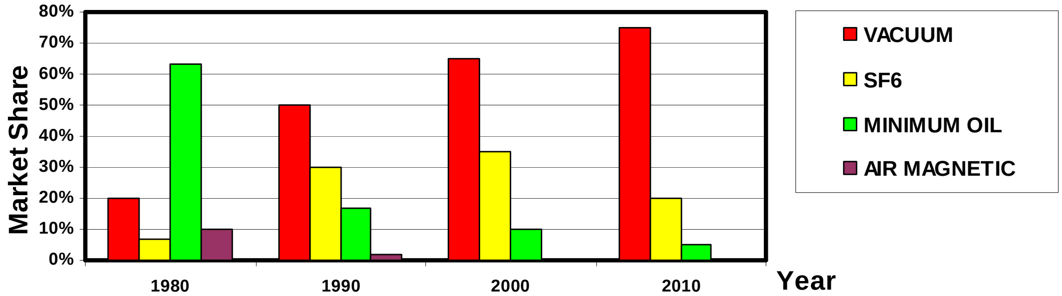

Figure 2. 3.3 – 38kV circuit-breaker technology – global shares by percentage

Worldwide the number of vacuum circuit breakers is growing fast. Most designs are claimed to be maintenance free and this technology is widely used within the electrical energy distribution sector. SF_6 free switchgear is nowadays recognized as a very safe and reliable technology.

7.2 *Design criteria for SF_6 free switchgear*

Constructing switchgear without SF_6 as insulation poses special demands on the dielectric design. Especially where the transition from energized part to earthed parts cannot be covered by solid insulation material (e.g. open gap as disconnecting facility), emphasis on optimized electrical field layout is necessary. However, with modern software (Finite Element Methods) this is very well practicable. In general, vacuum circuit breakers have the same dimensions as SF_6 type breakers. As vacuum circuit-breakers are maintenance free, this technology can also be used for fixed type switchgear with even smaller dimensions. With regard to the Life Cycle Cost, SF_6 free switchgear has an equal or better profile than switchgear containing SF_6, as the Total Cost of Ownership is lower for SF_6 free designs. This is especially the case when the additional cost for training, inspection, maintenance and recycling of SF_6 switchgear are taken into account.

7.3 *Eaton policy*

7.3.1 *Company profile*

Eaton is a global diversified company active in the electrical and industrial market. Eaton has production facilities all over the world and is serving customers in more than 150 countries. Eaton is a world leader in vacuum technology and one of the largest manufacturers of SF_6 free switchgear. Eaton is developing and producing MV switchgear according to IEC, GB (China) and ANSI (USA) standards and has production facilities for MV switchgear and circuit-breakers in the United States, Puerto Rico, Brazil, the Netherlands, Australia and China. Eaton has a wide range of withdrawable and fixed type switchgear that can be used for primary or secondary distribution.

7.3.2 *Motivation to choose for SF6 free switchgear*

In the 1980's Eaton Holec made the fundamental choice not to apply SF_6 in its MV range of switchgear. Eaton Holec did have SF_6-technology in house, as a manufacturer of HV switchgear. The main reasons not to apply SF_6 for MV applications were the complexity of handling and the need for extra safety measures related to SF_6, when installing switchgear 'just around the corner' in residential areas. In addition the fear of a new PCB's or asbestos type environmental issue played its role. Eaton Cutler Hammer, the market leader in the United States with NEMA/ANSI switchgear, has used the same reasoning to design only SF_6 free switchgear [12].

7.3.3 *Xiria – a modern compact SF6 free Ring Main Unit*

Ring Main Units (RMU's) are used in the MV network in the transformer substations near the end user. Although the use of SF_6 for Ring Main Unit applications is still very common, Eaton took the challenge and developed the first SF_6 free 24kV Ring Main Unit, called Xiria, which is based on vacuum technology and solid insulation (Fig. 3). With this green switchgear solution, utilities and other end users can choose a sustainable alternative and therefore reduce the use and emission of SF_6 in their distribution networks.

Figure 3: Xiria – a modern compact SF_6 free Ring Main Unit

8 THE GREEN SWITCHING INITIATIVE

In 2005, due to a growing concern about the impact of global warming, several utilities and Eaton started the Green Switching initiative in the Netherlands. Green Switching is a platform of users, manufacturers and other participants who are concerned about the growing use of SF_6 for MV applications. The participants share the idea that the use of SF_6 should be prevented wherever there are alternatives available on the market. The Green Switching initiative is supported by SenterNovem, an agency of the Ministry of Environment in the Netherlands.

The Green Switching platform has published a position paper and several related publications. It also presents scientific and technical articles about SF_6 and its alternatives on a website [13].

As a result of this Green Switching initiative there is a growing consciousness in the energy distribution market about the use of SF_6. Utility network companies, industrial users, owners of railway- and underground infrastructure and public private investors in the healthcare sector are becoming more aware of the health & safety aspects of SF_6 and its toxic by-products as well as its impact on global warming. This has resulted in a growing concern about the use of SF_6 for MV applications.

Asset managers within the larger utilities take the use of SF_6 also into account from a financial point of view. They calculate a certain percentage as penalty to compensate the potential risks of SF_6 and its by-products over the lifetime, and also reward SF_6 free technology with a 5% to 10% benefit as a consequence of the potential savings during the life cycle. This has led to a more well-balanced decision making process within the utilities, as not only the initial investment cost are taken into account.

9 NEXT STEPS

Taking into account the growing concern about global warming, policy makers within the European Union and the national governments should take further measures to limit and even prohibit the use of SF_6 where not really needed, like in MV switchgear. The measures that should be taken –

amongst others – are: green taxes on the use of SF_6 for utilities and other end users; subsidies for the development of SF_6 free MV and HV switchgear and finally a ban on SF_6 in MV switchgear on a intermediate time scale, for example 2012. This will stimulate the development of SF_6 free switchgear within the T&D sector for both MV and HV applications and will lead to more innovation by switchgear manufacturers [14].
Additional measures should be taken to prevent unnecessary emissions of SF_6 in the current installed base. As the impact of SF_6 emissions is a global problem, governments, international bodies and NGO's should take their responsibility and work together with the goal to set up a legal framework that prevents the use of any SF_6 in MV switchgear for the near future.

CONCLUSIONS

SF_6 is the most potent greenhouse gas and for this reason put on the Kyoto list of substances of which the use and emission should be minimized. Because of this, SF_6 is currently banned for all applications where alternatives are available. However, an exception was made for HV and MV switchgear in the electrical industry. The reasoning for this was that it was believed there was not a viable alternative available on the market – this, as pointed out in this paper, is not the case for MV switchgear. There are alternatives, based on vacuum technology and solid insulation, which are technically and commercially viable.
Policy makers should consider forcing further legislation with the purpose to ban SF6. This will stimulate the development of SF6 free solutions, not only for MV switchgear, but also for HV applications. These measures will contribute to a significant reduction in emissions of SF6 against a relative low marginal cost level.

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