State of the Art Process of End-of-Life Treatment for SF_6 Medium Voltage Equipment

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Abstract In a world where recycling is a word commonly used in our everyday life, it is important to explain that not all processes dealing with obsolete Medium Voltage equipment (end-of-life management, scrapping or destruction) have the same impact on the environment. This paper highlights the key points that differentiate a state of the art process of end-of-life treatment for SF_6 Medium Voltage equipment from a basic dismantling process. It shows that it is necessary to analyze every phase performed in order to limit SF_6 emissions to the lowest possible value.

Keywords Sulphur hexafluoride · Global warming · Environmental impact · Recovery

1 Introduction

Sulphur Hexafluoride (SF_6) gas is a well known insulating and breaking medium used for decades for transmission and distribution equipment. It is also a very powerful greenhouse gas with a GWP (Global Warming Potential) of 23,500 [1]. In Europe, legislation requires owners of equipment to recover residual gases prior to its disposal, as stated in Regulation (EU) No 517/2014 [2]. It is, however, mainly

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for the environmental impact that special care must be taken during the disposal of Medium and High Voltage Equipment. Owners of equipment should be aware that not all end-of-life treatment processes are the same from an environmental point of view. Although regulations and standards set rules and guidelines for this type of service, modern technology, experience and knowledge enable us today to go beyond regulations, namely a step further towards a greener, low carbon world.

The aim of this paper is to inform on the latest know-how and technological progress for the disposal of MV equipment.

It will be necessary to analyze every step of the process in order to reach an optimized and *state of the art* disposal process for SF_6 Medium Voltage equipment. From the moment the equipment is decommissioned up to its disposal, it will go through the following 5 main steps:

- Transportation
- SF_6 Recovery
- Dismantling
- SF_6 Reclaiming or destruction
- Storage of cylinders containing used SF_6.

2 Transportation

Before transporting the equipment from the location where it was installed to the workshop where it will be dismantled, special care must be taken on how the equipment is strapped to the pallet to avoid dangerous movements during transportation. It is necessary to avoid equipment from tilting and dropping, because this can create cracks in the SF_6 enclosure and therefore leaks (Fig. 1).

It is advisable to gather as many units as possible in order to optimize transportation and avoid unnecessary carbon emissions.

But why shall the equipment be transported away? Can't it be treated on site? This is because for MV equipment it is recommended to perform the dismantling process in a closed but ventilated workshop, particularly for safety reasons.

During the recovery of gas, we will reach low pressures of the SF_6 inside the gas chamber. This can lead to implosion (particularly with stainless steel compartments), with the risk of flying objects hitting workmen present in the workshop. Also, performing this operation outdoors may disturb operators' concentration level due to wind, rain and other meteorological conditions.

It is universally accepted that SF_6 presents no danger to life apart from the fact that, since it is denser than oxygen, a prolonged exposure to an environment rich in SF_6 could lead to asphyxiation. This danger is avoided by adequate ventilation. An O_2 detector shall be available for the operator to inform about risks due to accumulation of SF_6.

Fig. 1 Correct strapping of equipment to wooden pallets

3 SF_6 Recovery

International Standard IEC 62271-4 [3] states that residual pressure during recovery should be below 2 kPa (20 mbar). Modern SF_6 pumps can operate well beneath this value, without the operator having to wait too much time. Let us compare the amount of SF_6 which we will avoid releasing to the atmosphere if 0.1 kPa (1 mbar) had been reached instead, and most of all, its CO_2 equivalent.

Let's assume your equipment has an SF_6 filling pressure of 130 kPa (1300 mbar) absolute and the filled SF_6 mass is 2.5 kg.

If recovery is processed up to 2 kPa (20 mbar) vacuum level, only 98.46% of SF_6 will be recovered from the equipment, which means 38.5 g lost per unit. For 100 units, the equivalent CO_2 emission will be 90 tonnes!

With 0.1 kPa (1 mbar) vacuum level, CO_2 equivalent emission will be reduced to 4.5 tonnes, with 99.92% SF_6 recovery rate.

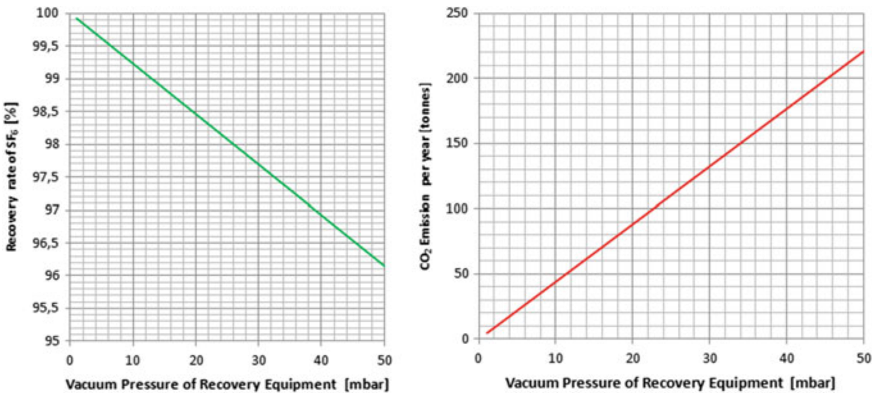

Fig. 2 On the *left*, Recovery rate of SF_6 versus Vacuum pressure of recovery equipment. On the *right*, CO_2 emissions per year versus Vacuum pressure of recovery equipment. Both graphs have been drawn by assuming 130 kPa (1300 mbar) initial pressure, 2 kPa (20 mbar) final pressure, 2.5 kg of SF_6 initially inside the equipment and 100 units of equipment

The graph on the left of Fig. 2 shows how the recovery rate of SF_6 increases with decreasing vacuum pressure of the recovery equipment. It is therefore best to reach a low vacuum pressure inside the obsolete equipment. On the right, the CO_2 emissions increase as the vacuum pressure of the recovery machine increases. Once again, it is recommended to reach the lowest possible vacuum pressure when recovering SF_6.

As stated in the paragraph on transportation, certain equipment may not withstand low pressure during recovery and may implode. Membranes, gaskets, welded joints and even sheet metal compartments may not bear the pressure. As a consequence, the recovery operation may not be completed and residual SF_6 gas may escape to the atmosphere. To avoid this from happening, specific cabinets exist. The principle is to lower the pressure inside and outside the equipment at the same time. Therefore it will be possible to reach low absolute pressures inside the equipment, in order to evacuate all residual SF_6 gas, and at the same time avoid stress on mechanical sealing parts. Potential flying parts which could cause injuries will also be avoided (Fig. 3).

Each equipment needs specific tools to connect the pump to the SF_6 container. The manufacturer has the best knowledge and experience of its products and will be able to provide the right connections that will avoid leaks. Furthermore, it is necessary to verify that the recovery equipment (i.e. the pump) is free of leaks. An SF_6 leak detection unit, also called “sniffing probe”, can be used to perform a leakage check during SF_6 recovery. The tool shall be set at a threshold of 10^{-6} mbar.l/s.

In the European Union, SF_6 recovery can only be performed by operators having followed the specific training and holding a certificate released by an approved

Fig. 3 A cabinet used for gas filling and recovery for MV equipment

certification body of a Member State. This measure, which came in force in July 2008 with the additional Regulation (EC) No. 305/2008, has been extended to other activities in the most recent implementing Regulation (EU) No. 2015/2066 [4]. From the 1st July 2017, operators performing filling operations, installation of manometers, transfer of SF_6 between compartments and all other SF_6 handling operations, including of course recovery, shall also be certified.

4 Dismantling

Inside used SF_6 equipment, there is a high probability of finding gaseous and solid SF_6 decomposition by-products, which are dangerous for operators in case of contact, due to their toxicity and corrosiveness.

For this reason the equipment shall be handled and opened with care after recovery of SF_6 from the equipment. Any risk for the health of the operators shall be avoided. The molecular sieve, an object whose main aim is to absorb humidity contained in the equipment and SF_6, will have absorbed a big part of the by-products. It shall therefore be sorted and put in a specific bin for toxic substances. The inside of the SF_6 tank must be cleaned with an industrial dry vacuum cleaner (H dust class). The tank shall also be neutralized with a caustic soda solution.

5 SF_6 Reclaiming or Destruction

Once the SF_6 is recovered from obsolete equipment and is pumped in correctly labelled cylinders, there are 2 options to choose from for its future: reclaiming or destruction.

Reclaiming gives a new life to SF_6. Experience shows that in 99% of the cases, the used SF_6 which has undergone the specific treatment process (a series of filtrations) can be fully reused. In fact, the treatment process allows it to reach IEC 60480 [5] or even IEC 60376 [6] requirements.

Another choice is to proceed to SF_6 destruction. There exist several processes to destroy SF_6; from discharge activation, like in the non-thermal plasma process [7], to the decomposition at hot surfaces, to thermally activated SF_6 reactions with metals and metal oxides [8]. These processes transform SF_6 in environmentally compatible fluorides, sulphides and sulphates.

However, the most common is the destruction in high temperature dump combustors (temperatures >1000 °C). Although this solution is economically favourable compared to reclaiming, it has several ecological drawbacks:

- The recycling loop is broken. There will be no reuse of the decomposed SF_6 molecule. New, valuable resources will be pulled out of the earth, processed in factories, shipped around the world, and then wasted in incinerators.
- Emissions: even the most technologically advanced incinerators release thousands of pollutants that pose considerable risk to the health and environment of neighbouring communities [9].
- Climate change: all incinerators emit carbon dioxide (CO_2). According to the U.S. EPA, "waste to energy" incinerators contribute far higher levels of greenhouse gas emissions and overall energy throughout their lifecycles than source reduction, reuse and recycling of the same materials [10].
- Energy: in order to reach high temperatures (combustion at 1000 °C and post-combustion at 1200 °C), a considerable amount of energy will be needed.

The recommendation purely from an environmental point of view is to reclaim the SF_6 and close the SF_6 life cycle loop.

6 Storage of Cylinders Containing Used SF_6

Cylinders containing used SF_6 should not be kept longer than 2 years before they are checked and newly certified, in order to avoid any leakage. They must have an orange or yellow strap around the bottleneck and should be properly labelled (check with an SF_6 gas recycler for the proper label codification). Once the cylinder is emptied in order to recycle the SF_6 gas, it should be cleaned inside and outside and newly certified before using it again.

Cylinders leakage test should be performed frequently (frequency to be adapted locally to the period of storage) to ensure leakage rates below 1×10^{-6} mbars.l/s

Fig. 4 Example of a "Zero Emission" coupling valve, which avoids the SF_6 loss of the dead volume

during the whole period of storage (including during filling up of the drums at the workshop).

SF_6 cylinders are generally equipped with valves (DIN 477—Part 1: Type A, 1" No. 8 [11]) and screw-in fittings, which are different from those used in containers for new gas to prevent inadvertent filling and contamination of new SF_6. The valves are made of stainless steel to withstand corrosive decomposition products [12].

New generation "Zero Emission" coupling valves have been recently designed to dramatically reduce SF_6 loss during connections and disconnections. Thanks to this new concept, the so-called "dead volume" loss is avoided (Fig. 4).

7 Conclusions

Modern tools, technologies and know-how are today available. This *state of the art* end-of-life treatment for SF_6 Medium Voltage equipment will increase the safety of personnel while considerably limiting the environmental impact. All of the process steps will contribute to it:

- Transportation: caution during handling and strapping of the equipment to avoid tilting, dropping and damaging of equipment, and hence potential leaks.
- SF_6 recovery: it is now economically possible to go beyond regulations and standards to limit emissions. A recovery cabinet which reaches a vacuum pressure of 0.1 kPa is the utmost technological standpoint. It is recommended to perform the end-of-life treatment through the equipment manufacturer. The operators handling the gas must hold a certification in Europe.
- Dismantling: the molecular sieve contains the most toxic substances. It must be disposed of according to toxic wastes regulations.
- SF_6 reclaiming or destruction: reclaiming enables up to 99% of the gas to be reused in future applications. During destruction, although this is generally economically more interesting, the ecological impact is higher since the recycling loop is broken, leading to emissions of CO_2 and pollutants.
- Storage of cylinders containing used SF_6: regularly check the cylinders for leaks. Avoid dead volume leaks thanks to "Zero Emission" coupling connections.

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