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170 kV pilot installation with a ketone based insulation gas with first experience from operation in the grid

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SUMMARY

The high electric strength of sulfur hexafluoride (SF_6) and its excellent current interruption performance allowed for the development of compact and cost-efficient electrical equipment. As a stable gas with zero ozone depletion potential, SF_6 is the standard insulation medium for high voltage metal enclosed gas insulated switchgear (GIS). However, SF_6 has a CO_2 global warming equivalent of 22'800. An alternative to SF_6 could further reduce the carbon footprint of the electric grid.
ABB investigated the use of an alternative candidate to SF_6 based on a perfluorinated ketone with 5 carbon atoms (C5 PFK) with a systematic name 2-Butanone, 1,1,1,3,4,4,4-heptafluoro-3-(trifluoromethyl)-. With a CO_2 equivalent of one and an ozone depletion of zero, the C5 PFK is an ecofriendly alternative to SF_6.

To examine the impact of the alternative insulation on the environment, a life cycle assessment of the GIS insulated with C5 PFK has been conducted. Method and results are presented in this paper.
As the vapor pressure of C5 PFK is significantly lower than the one of SF_6, the insulation medium consist of a mixture of CO_2 and O_2 to increase electric strength and current interruption performance. This gas mixture allowed for the development of a GIS with 170 kV rated voltage based on an ELK-14 C, 245 kV GIS.
During the development a cooperation with ewz, a large Swiss utility was started to bring the new technology into the grid in a pilot installation. After completing all relevant type tests, 8 bays of a 170 kV switchgear were installed in a new ewz substation in the city of Zurich. The indoor substation comprises all components of a typical GIS with cable terminals. The paper explains the experience made during type testing and manufacturing of the GIS as well as installation and commissioning of this 170 kV GIS substation pilot. Filling and reclaiming of the gas mixture is done with dedicated gas handling equipment.
While the gas handling of the gas mixture requires additional equipment compared to SF6, the reporting of the new insulation media is not necessary. This simplifies the administrative burden of customers.
The installation is an important milestone to gather long-term operational experience with the technology.

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Compared to the four decades experience with SF6, this technology is still in the starting phase. Further investigations are required to reach a similar maturity grade than SF_6 based switchgears and to clarify the application range of this SF_6 alternative.

Introduction

For decades, sulfur hexafluoride (SF_6) has been the predominant insulation medium for gas insulated switchgear due to its technical properties. However, as it is a greenhouse gas, ABB has been developing and deploying alternatives on the path towards greater eco-efficiency and lower environmental impact and has now commissioned the world's first pilot gas-insulated switchgear installation with a new eco-efficient gas mixture.

With rising awareness and concerns of global warming and climate change, products that have the lowest environmental impact possible are increasingly being developed. To this end, scientists have been searching for alternatives to SF_6, a man-made gas developed in the early 20th century. Due to its excellent properties for electric insulation and arc interruption, it enables safe and reliable operations, while making it possible to significantly reduce the size of switchgear installations.

However, SF_6 is a greenhouse gas and its lifecycle management requires careful handling and can entail substantial costs, particularly when decommissioning substations at the end of life. As the demand for electricity rises worldwide, so is the demand for high-voltage and medium-voltage switchgear. For decades, researchers and scientists have been searching for alternatives that can fulfil the technical requirements of SF_6 but with a lower environmental impact.

A fluoroketone-based gas mixture

The key technical requirements for an insulation gas in switchgear are its dielectric strength and in case of the circuit breaker its arc quenching capabilities. Specifically for usage in GIS, there are other less obvious but equally important properties such as; low boiling point, low toxicity, low flammability, zero ozone depletion potential (ODP) and very low Global Warming Potential (GWP*)[1]. Considerable efforts have been made by research groups around the world to find a suitable alternative for SF_6 [2][3][4]. So far, no one-to-one replacement that fulfils these properties has yet been discovered.

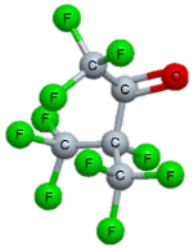
An efficient computational procedure to screen molecules for high-voltage insulation has been developed [5][6][7]. The process involves virtual screening of molecules on the parameters of GWP, toxicity, flammability among others, then estimating their breakdown field and boiling point. A family of compounds from Fluoro-alkenes, -alkylsulfides, -alcohols and -alkylamines were considered as a source from which a possible candidate could emerge[5].

After many years of research, a suitable alternative to SF_6 has been identified that meets the required properties[1][8]- perfluorinated ketone with 5 carbon atoms (C5

PFK) based on a molecule compound from the company 3M, called Novec™ 5110 Dielectric Fluid. In collaboration with 3M, a fluoroketone-based gas mixture for switchgear application was developed.

The new gas mixture contains:

- Fluoroketone (C5 PFK), carbon dioxide (CO_2) and oxygen (O_2) for high-voltage (HV) GIS
- Fluoroketone (C5 PFK), nitrogen (N_2) and oxygen (O_2) for medium-voltage (MV) GIS



Molecular model of the fluoroketones $C_5F_{10}O$

This fluorinated molecule has a chemical structure that decomposes under ultraviolet light in the lower atmosphere. Therefore, the molecule's atmospheric lifetime is short (less than 15 days versus 3,200 years with SF_6) and it decomposes into negligible quantities of CO_2 that are not harmful for the environment. Because of this, its GWP is less than 1, which is even lower than CO_2 (GWP=1). In addition, the fluorinated molecule is practically non-toxic, non-flammable and neither the substance itself nor its decomposition products deplete the ozone layer.

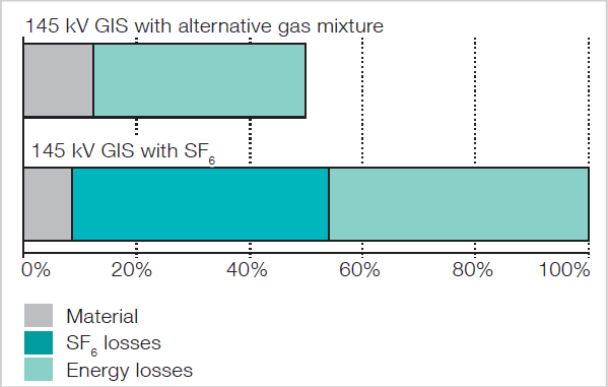
Power testing performances at our laboratories have shown the high potential of fluoroketone-based mixtures as switching and arc interruption medium for transmission and distribution rating. With a GWP that is almost 100 percent lower than that of SF_6, the gas does not compromise on equipment quality and reliability. The new gas mixture is the only insulation available so far that has been type tested according to IEC standards and meets the mentioned performance criteria, with a GWP ≤1.

Customer benefits

In addition, the deployment of HV GIS with this new gas mixture can lower CO_2 equivalent emissions by up to 50 percent according to lifecycle analysis. The remaining half is attributed to raw materials, manufacturing and thermal losses.

Lifecycle Analysis (LCA)
According to ISO 14040, the LCA takes three major contributors into consideration:

- Materials
- Insulation gas leakage and gas handling losses
- Energy losses



Boundary conditions:

- Lifetime of equipment: 30 years
- gas leakage rate: 0.1% p.a., 1% loss during handling, 1% loss during decommissioning
- operations at 50% rated current flow over 30 years

Also in MV with lower gas pressure and quantity, the new gas contributes to reduce the CO_2-equivalent emissions over the switchgear lifetime. Especially in cases where gas handling is out of manufacturers' responsibility, the new gas mixture assures that the climate impact of any escaping gas is reduced by almost 100%.

The new technology brings the following benefits to end-users:

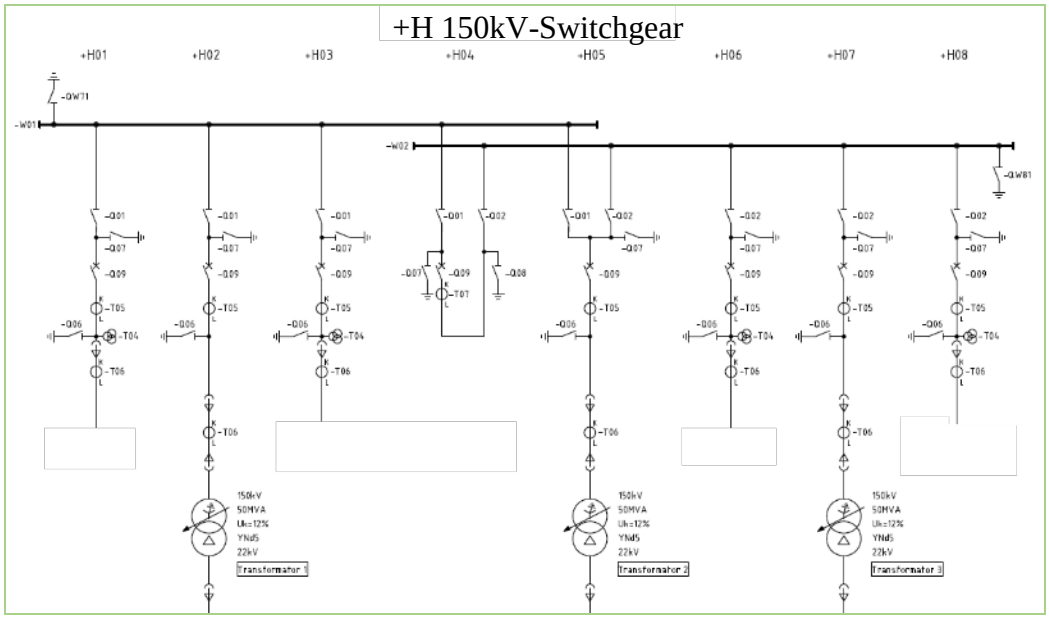
- Regulatory procedures specially required for SF_6 such as maintaining inventory records, special requirements in gas handling, filling and decommissioning the equipment will be avoided
- Savings can be made in SF_6 related taxes which are applicable in some countries
- Compliance with existing or future gas regulations regarding fluorinated gases

World's first GIS installation with ECO-EFFICIENT gas mixture

When the development of the new technology began, ewz (Elektrizitätswerke Zürich) was in its early planning phase for a new substation to replace an existing air-insulated switchgear (AIS) installation in the heart of Zurich (Substation Zürich Oerlikon), that was built in 1949. ewz had set a goal to utilize innovative technologies with low carbon footprint in the substation, in line with its vision to provide sustainable energy. New technologies that were not yet available on the market were taken into account.

The new technology was the perfect fit – reliable GIS with a compact footprint and low environmental impact, both on HV and MV side. Together, both companies collaborated to integrate the new technology into the grid in a pilot installation. The newly comissioned substation in Oerlikon consists of 8 high-voltage GIS bays and 50 medium-voltage GIS bays. The substation comprises all components of a typical GIS with cable terminals.

170 kV high-voltage GIS and 24 kV medium voltage GIS with eco-efficient gas mixture



A single line overview of the HV switchgear installed in ewz substation

The GIS bays were energized in summer of 2015, and started transmitting and supplying electricity to the city of Zurich in fall of 2015.

ewz substation in Oerlikon Zurich – the world's first pilot switchgear installation with eco-efficient gas mixture (right) replacing an aged air insulated switchyard with a 5x bigger footprint (left)

The pilot substation is an important milestone for SF_6 alternatives and helps to gather long-term operational experience in the grid. In the coming years, the experience with this new technology will be used to allow further improvements of the carbon footprint of switchgear installations.

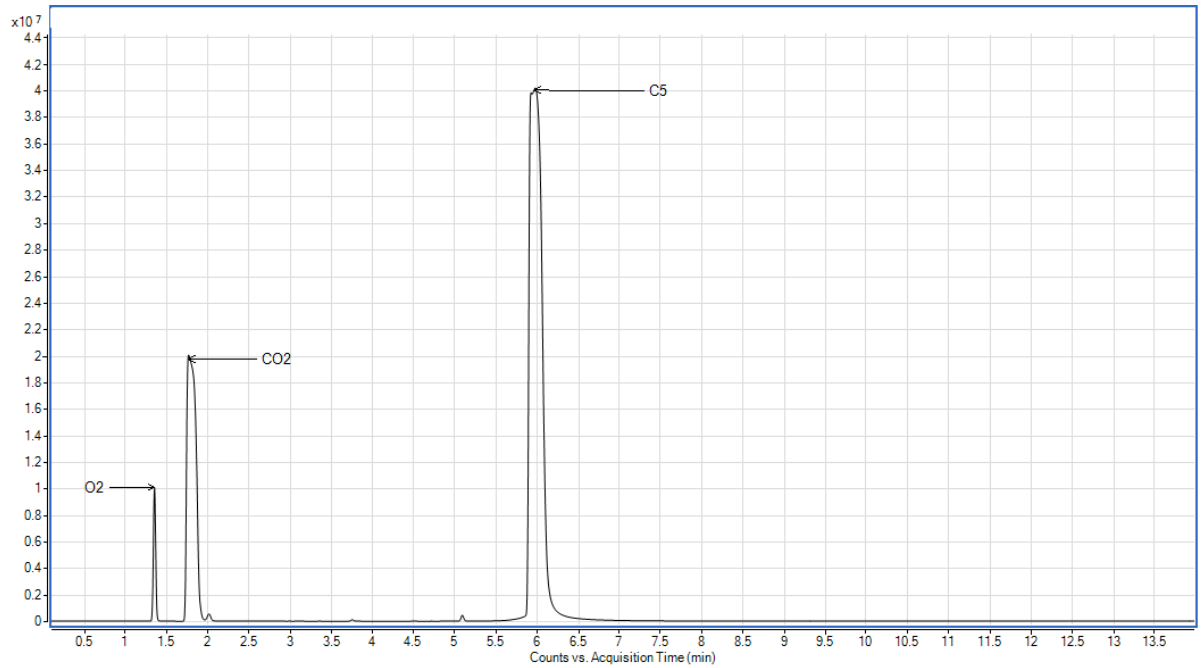
Commisioning and First Operational experience

On site the gas was mixture was filled using a specially developed mixing device. The device simulatenously injects all the components of the gas into the gas compartments.

The on-site high voltage test with partial discharge measurement of the 170 kV HV GIS was successfully passed in March 2015 and the GIS was ready to be energized.

Since the substation was stepwise energized during summer and fall 2015, it runs without any problems. Gas samples are taken regularly to verify the high quality and stability of the gas mixture in the daily operation. These gas samples are then being analysed and the data compared to expected stability data to prove, that the stability of the gas mixture performs as predicted.

A plot of one of the spectra is shown in the Figure below. The gas sample shown was taken 9 months after filling the gas mixture into the GIS compartments and after the substation was high voltage tested and in operation for three months.



Relative abundance of species in GC-MS resulting from gas analysis

So far no irregularities have been detected, but it needs to be said, that the observation interval is still short.

Additionally, one bay of the pilot installation is equipped with a monitoring system for pressure, density and temperature [10]. With these three measurement data, one can calculate a composition of the mixture to an accuracy of +/- 5%. Analysis of these results show up to now no changes in the ketone content of the insulation gas.

We continue to take samples and monitor in the 170 kV GIS bay using the pressure, density and temperature signals. This is important, as it is the first of this type of installation in the grid. The intervals for sampling are gradually increased over time.

CONCLUSION

In conclusion, SF_6 switchgears have been used for decades and are well accepted in the industry. Their compact design and the low environmental impact make GIS a sustainable solution.
The closed-loop handling and low leakage rates result in a small carbon footprint over the lifetime of the GIS. For this reason, SF_6 will remain the main insulation medium for GIS for years, however an alternative could further reduce the carbon footprint of the grid.

*GWP: The global warming potential describes how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. GWP is expressed as a factor of carbon dioxide

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