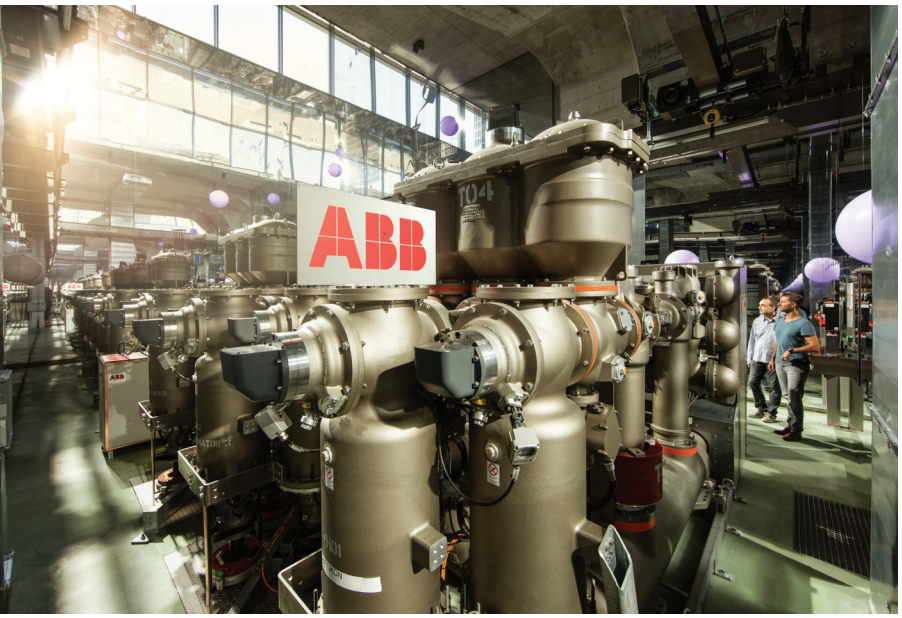
TECHNICAL PAPER

Breakthroughs in switchgear technology with eco-efficient gases as an alternative to SF_6



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

With global warming and climate change becoming worldwide concerns, products are increasingly being developed that have the lowest environmental impact possible. To this end, research is ongoing to find alternatives to even well-established technologies. This is the case with SF_6, a man-made gas developed in the early 20th century which, due to its excellent properties for electric insulation and arc interruption is used extensively as the dielectric medium in high and medium-voltage switchgear. In addition to enabling safe and reliable operation, it has also made it possible to significantly reduce the size of switchgear installations, and SF_6 will remain as the main insulation medium for years to come.

However, SF6 is a greenhouse gas and its lifecycle management requires careful handling and can entail substantial costs, particularly when decommissioning aging substations. As the demand for electricity rises worldwide, especially in emerging countries, demand for high-voltage switchgear is also rising. Thus, the search for alternative gases to SF_6 for reduced environmental impact continues.

A new fluoroketone-based gas mixture

ABB has achieved a recent breakthrough with a new alternative to SF_6 by commissioning the world's first high- and medium-voltage pilot gas-insulated switchgear (GIS) bays with a new eco-efficient gas mixture. This fluoroketone-based gas mixture is a chemical compound developed for switchgear applications in collaboration with 3M. The GIS bays for 24 kV and 170 kV voltage ratings are installed in a pilot substation in Zurich operated by leading Swiss utility ewz, which was inaugurated on August 24, 2015.

This new gas mixture contains:

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

This fluorinated molecule has a chemical composition that decomposes under ultraviolet light in the lower atmosphere. Therefore, the molecule's atmospheric lifetime is extremely short (less than 15 days versus 3,200 years with SF_6) and it

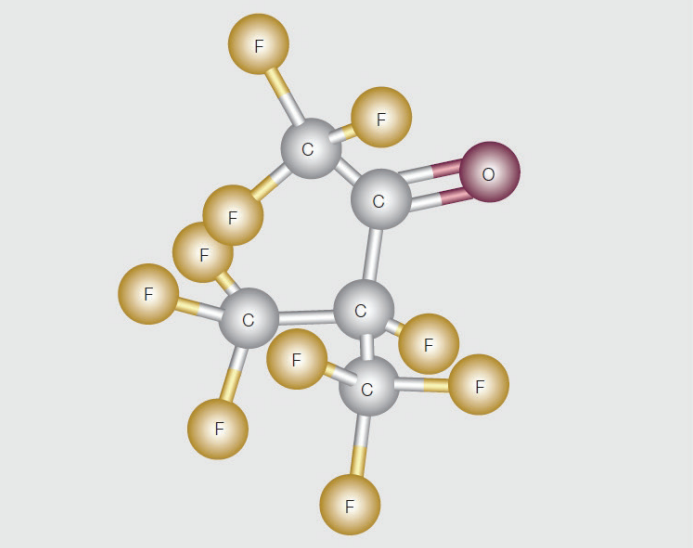


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Figure 1

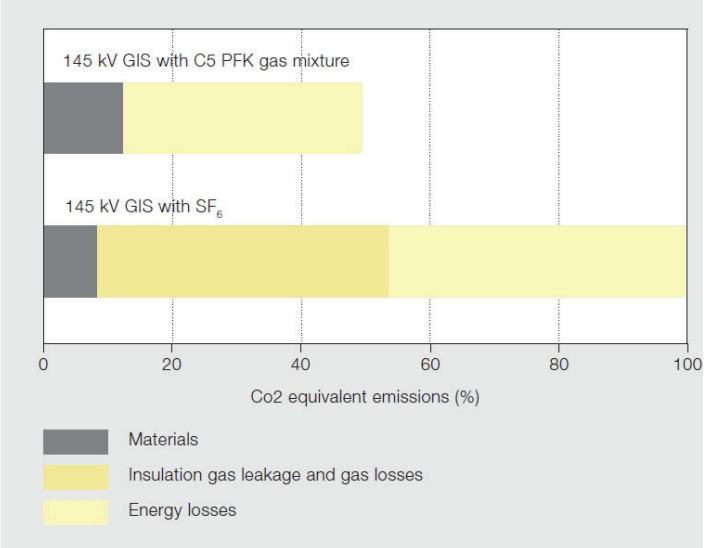

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Figure 2

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Figure 1: Molecular model of $C_5F_{10}O$

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Figure 2: Relative contributions to CO_2-equivalent emissions

decomposes into negligible quantities of CO_2 that are not harmful for the environment. Because of this, its Global Warming Potential (GWP) is less than 1, even lower than CO_2 (GWP=1). In addition, the fluorinated molecule is practically non-toxic, non-flammable and neither the substance itself nor the effects of decomposition would deplete the ozone layer.

This GWP is almost 100 percent lower than that of SF_6, without any compromise on equipment quality and reliability. The new gas mixture is the only one available so far, meets performance criteria after being type tested according to IEC standards and has a GWP <=1. In addition, as per the lifecycle analysis (LCA) of the product, deployment of high-voltage GIS with this new gas mixture can lower CO_2 equivalent emissions by up to 50 percent through the lifecycle of the equipment, the other half being attributable to raw materials, manufacturing and thermal losses.

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

- Materials
- Insulation gas leakage (SF6 losses)
- Energy losses (at 50% rated current flow over 30 years)

Boundary conditions:

- Lifetime of equipment: 30 years
- Assumed gas leakage rate: 0.1% p.a. accumulated over a period of 30 years, 1% loss during handling, 1% loss during decommissioning

Despite the known challenges, in the search for alternatives, gas mixtures composed of fluoroketones with technical air or CO_2 as a carrier gas have shown acceptable insulation and switching capabilities where this mixture has only a GWP <=1, no ozone depletion potential (ODP), is non-toxic and non-flammable.

In the insulation regime, testing performed at ABB laboratories has shown that transmission and distribution ratings can be addressed with a fluoroketone-based admixture, where the lower ratings (sub transmission) are also feasible with constituent gases of the atmosphere such as N_2 and CO_2[1]. Power testing performances have also shown the high potential of fluoroketone-based admixtures for indoor applications as a switching and arc interruption medium.

An acceptable interruption performance has been established using a standard high-voltage circuit breaker. For lower ratings and low temperature applications, CO_2 may be used as an alternative[2]. As well as contributing to the efforts of reducing global warming, the new technology also brings end-users the possible benefits of simplified operations, as the use of SF_6 entails significant regulatory work like inventory management and other logistic requirements.

The use of atmospheric components

Carbon Dioxide (CO_2)

One alternative that has been developed and deployed is to use CO_2 as the insulation medium. While CO_2 is also a greenhouse gas, its GWP is lower than that of SF_6 by almost 100 percent – SF_6 has a GWP of 23,000 compared to 1 for CO_2. ABB offers the high-voltage LTA, a scalable platform which uses CO_2 as the insulation and arc-interruption medium for live tank and disconnecting circuit-breakers. This platform is also suitable for low temperature applications.

Environment LCA of the product indicates that a 72.5-kilovolt (kV) LTA breaker has the potential to reduce CO^2 equivalent emissions by 10 tons through the product lifecycle – which is 18 percent less than the SF_6 breaker of the same rating. When the LTA is combined with an ABB disconnecting circuit-breaker, the potential to reduce CO_2 equivalent emissions over the equipment lifecycle goes up to 60 percent compared with conventional air-insulated technology. A pilot project at 145 kV has been running successfully since 2010 and other installations are also in progress, including one recently completed in Sweden for European utility E.ON.

Dry Air

Another alternative is to use dry air as the insulation gas. ABB has developed a ring main unit (RMU) – called SafeRing Air as part of its medium-voltage switchgear offering. This is as compact as the traditional SF_6 insulated RMU, but uses an insulating gas that consists of atmospheric components, thus avoiding intensive use of epoxy materials. The switchgear design is based on a completely sealed system with a stainless steel tank containing all live parts and switching functions.

SafeRing Air is available for up to 12 kV in circuit breaker and load-break switch configurations and is ideal for use in compact secondary substations, light industry, building and infrastructure applications, for both new installations and retrofits. Its design is based on the existing SafeRing/SafePlus portfolio, providing the same user interface, footprint, spare parts and operation in retrofits.

With these alternatives to SF_6, ABB is therefore applying its research and innovation to the aim of lowering environmental impact.

References

[1] Mantilla J.D., Claessens M., Gariboldi N., Grob S., “Investigation of the Insulation Performance of a New Gas Mixture with Extremely Low GWP”, IEEE 2014 Electrical Insulation Conference, Philadelphia PA, USA, pp. 469-473

[2] Åkesson U., Lidholm J., Söderström P., “Suitability evaluation of improved high voltage circuit breaker design with drastically reduced environmentally impact”, CIGRE Session 2012, A3-302.

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