AirPlus™

An alternative to SF_6 as an insulation and switching medium in electrical switchgear

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For decades, the unique properties of sulfur hexafluoride (SF_6) have made it popular as an insulation and switching medium for electrical switchgear. However, SF_6 is a greenhouse gas and there are life-cycle management costs associated with its use. For some years, ABB has been conducting research into alternatives with lower environmental impact but with insulation and arc interruption properties similar to those of SF_6. This mission has now been accomplished and the world's first gas-insulated switchgear (GIS) pilot installation to use a new gas mixture has recently been commissioned in Switzerland.

An SF_6 alternative is needed that can be used in all cases.

Across utilities and industry, rising awareness of global warming and climate change is driving the replacement of many products by more environmentally friendly alternatives. The ubiquitous insulation and switching medium, SF_6, a manmade gas developed in the early 20th century, is no exception to this trend. Due to its excellent properties for electric insulation and arc interruption, SF_6 enables safe and reliable operations while making it possible to significantly reduce the size of switchgear installations.

Title picture
SF_6 has proven its worth as an insulating medium in electrical switchgear. However, the global warming implications of SF_6 are coming under scrutiny. ABB has now developed an alternative that in certain cases comes close to the performance of SF_6. Shown is high-voltage GIS.

However, SF_6 is a greenhouse gas and the life-cycle management costs incurred when handling SF_6, particularly when decommissioning aging substations, are increasing. These costs will rise further as the demand for electricity, and, thus, for gas-filled high-voltage and medium-voltage switchgear, increases. This factor makes the search for an environmentally friendly alternative to SF_6 all the more urgent.

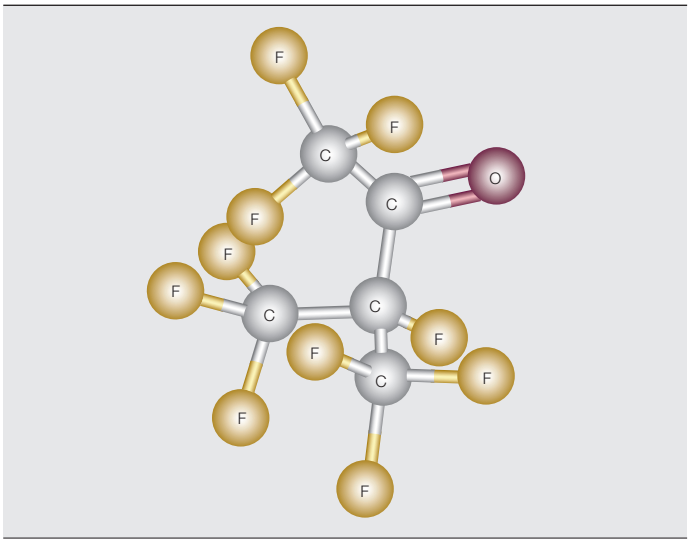
ABB has already developed and commissioned air-insulated high-voltage circuit breakers that use carbon dioxide (CO_2) as an insulating and arc-quenching medium, and medium-voltage ring main units (RMUs) that utilize air in a gas-insulated switchgear design. However, these solutions are only part of the picture – an SF_6 alternative is needed that can be used in a wider field of applications.

The search for an insulating and switching medium

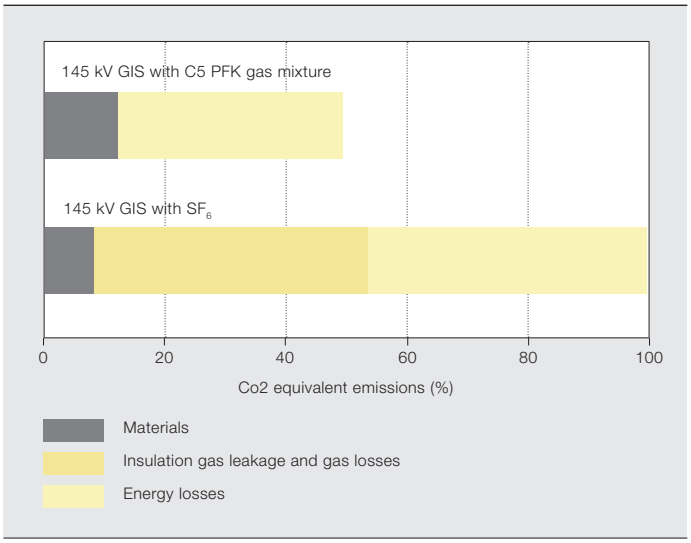
The key technical parameters for an insulation gas in switchgear are its dielectric strength and arc-quenching capabilities. For use in GIS, there are other, less obvious, but equally important properties – such as low boiling point, low toxicity, stability, low flammability, zero ozone depletion potential (ODP) and very low global warming potential (GWP) [1]. GWP is expressed as the ratio of the amount of heat trapped by a certain mass of the gas in question to the amount trapped by a similar mass of CO_2. It is calculated over a specific time interval – commonly 20, 50 or 100 years.

Considerable efforts have been made by research groups around the world to find a suitable alternative for SF_6 → 2 – 4. Until now, no one-to-one replacement that fulfills all the required properties has been discovered.

1 Molecular model of $C_5F_{10}O$



2 Relative contributions to CO_2-equivalent emissions



After many years of research, ABB has identified a gas mixture that is a suitable alternative to SF_6 and that matches all the required properties.

A fluoroketone-based gas mixture

To assist the search for an SF_6 replacement, efficient computational procedures were developed (by third parties) to screen molecules appropriate for high-voltage insulation [5]. These procedures involve virtual screening of molecules for GWP, toxicity, flammability, etc., followed by a study of their breakdown field and boiling point. Early on, a family of compounds based on fluoro-alkenes, fluoro-alkyl sulfides, fluoro-alcohols and fluoro-alkylamines was considered as a promising source from which a possible candidate could emerge [5].

After many years of research, ABB identified an environmentally friendly alternative to SF_6 that matches all the required properties. The gas mixture is based on a product from the company 3M called Novec 5110 Dielectric Fluid – a perfluorinated ketone with five carbon atoms (C5 PFK) [1,6] → 1. Delivered as a fluid, it is vaporized and mixed during the filling process. The fluoroketone-based gas mixture for switchgear applications was developed in collaboration with 3M and has been named AirPlus.

The new gas mixture contains:
- Fluoroketone, carbon dioxide and oxygen for high-voltage (HV) GIS
- Fluoroketone, nitrogen and oxygen for medium-voltage (MV) GIS

This fluorinated molecule rapidly decomposes under ultraviolet light in the lower atmosphere. Therefore, the molecule's atmospheric lifetime is short (around 15 days, versus 3,200 years for SF_6). It decomposes into CO_2 that remains in the atmosphere and other molecules that are washed out. Quantities of both are low so global warming contributions are negligible. Because of this, the GWP of the new gas mixture is less than 1, which is even lower than CO_2 (GWP = 1). Also, the fluorinated molecule is practically nontoxic, noninflammable and neither the substance itself nor its decomposition products deplete the ozone layer.

Demonstrations in ABB laboratories have shown the high potential of the fluoroketone-based mixtures as a switching and arc interruption medium at transmission and distribution power ratings. The gas mixture does not compromise equipment quality and reliability, and has an extremely low GWP. It is the only insulation available so far with a GWP ≤1 that has been type tested according to IEC standards and that meets performance criteria similar to those set for SF_6.

Life-cycle assessment (LCA)

According to the ISO 14040 environmental management standard, LCA considers three major contributors to CO_2-equivalent emissions:
- Materials
- Insulation gas leakage and gas handling losses
- Energy losses

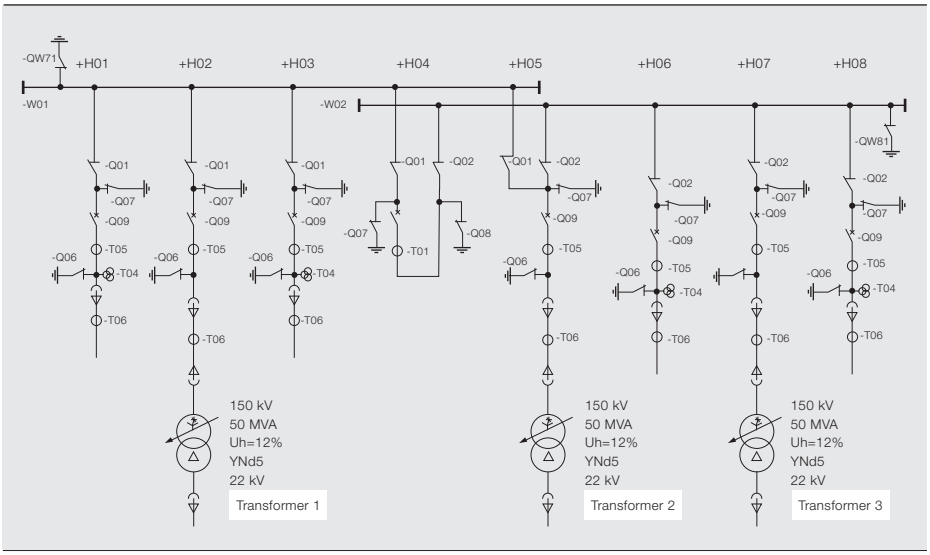
The boundary conditions assumed for HV GIS are:
- 30-year equipment lifetime
- A gas leakage rate of 0.1 percent per annum, 1 percent gas loss during handling and 1 percent loss during decommissioning

3 GIS with the new gas mixture installed in Zurich

3a 170 kV HV GIS

3b 24 kV MV GIS

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



The gas mixture is based on a perfluorinated ketone with five carbon atoms and was developed in collaboration with 3M.

– Operation at 50 percent of the rated current flow over 30 years

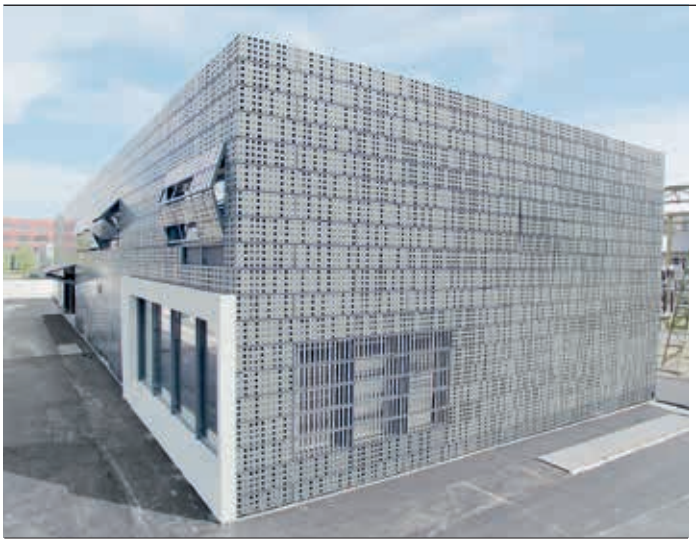
LCA indicates that the deployment of high-voltage GIS with AirPlus can lower CO_2 equivalent emissions by up to 50 percent. The 50 percent remaining is attributed to raw materials, manufacturing and thermal losses.

Although the contribution of materials to the CO_2-equivalent emissions is slightly higher for the PFK gas mixture GIS, the energy losses are lower and the leakage and handling losses disappear almost entirely ➔ 2.

Also, in MV equipment, which has lower gas pressures and gas quantities, AirPlus helps reduce the CO_2-equivalent emissions over the switchgear lifetime. Further, in cases where gas handling is outside of the manufacturer's responsibility or control, the new gas mixture ensures that the climate impact of any escaping gas is reduced by almost 100 percent.

The new technology brings other benefits too:
– Regulatory procedures specifically required for SF_6 – such as maintaining inventory records, special handling requirements, and measures to be taken when filling and decommissioning equipment – are avoided.
– The SF_6-related taxes that are applicable in some countries can be avoided.

5 ewz substation in Zurich – the world's first pilot switchgear installation with the SF_6-replacement gas mixture



5a The Oerlikon substation building

5b The ABB HV GIS factory can be seen behind the substation.

World's first GIS installation with the new gas mixture

When the development of the new technology began, Swiss utility ewz was in the early planning phase of a new substation to replace a 1940s air-insulated switchgear (AIS) installation in Zurich. The utility had set a goal to utilize innovative technologies with low carbon footprint in the substation, in line with its vision to provide sustainable energy wherever possible. New technologies that were not yet available on the market were also taken into account.

ABB's new technology was the perfect fit for ewz – reliable GIS with a compact footprint and low environmental impact, both on the HV and MV side. Both companies collaborated to integrate the new technology into the grid in a pilot installation. The newly commissioned substation in Zurich consists of eight HV GIS bays and 50 MV GIS bays → 3-4. The substation comprises all components of typical GIS with cable terminals.

While the MV panels come from ABB's modern GIS factory in Ratingen, Germany, the HV GIS was manufactured in ABB's state-of-the-art GIS factory in Oerlikon, Switzerland, located next door to ewz's new substation → 5. The GIS bays were energized in the summer of 2015 and started transmitting and supplying electricity to the city of Zurich a couple of months later.

The pilot substation is an important milestone in the path to an SF_6 alternative and it will provide long-term operational experience of grid operation. In the coming years, ewz and ABB will use this experience to further improve the carbon footprint of switchgear installations.

Future grid carbon footprint

SF_6 switchgear has been used for decades and is well accepted in the electrical power industry. Its compact design and low environmental impact make GIS a sustainable solution. 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 to come. However, an alternative such as AirPlus could further reduce the carbon footprint of the power grid.

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