SF6 Free Switching Alternatives Current and Future Trends for HV and MV GIS

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Abstract

This paper presents an overview on the research for the alternative gas to SF_6 used for transmission and distribution and on the worldwide developments to support this technology. In high voltage and medium voltage applications Sulphur hexafluoride (SF_6) gas has been utilized as electrical insulation and /or for current interruption due to its strong electronegative properties. However, even if SF_6 Switchgears are safe for the environment, the SF_6 insulating gas has potential significant environmental impacts if it leaks into the atmosphere. Indeed, SF_6 is one of the six gases listed in the Kyoto Protocol, with a global warming potential that is 23,500 times greater than CO2. Potential applications of SF6-free gas mixture, called g^3 and based on 3M^{TM} Novec^{TM} 4710 Dielectric fluid for dielectric insulation and arc switching into high voltage apparatuses are reported with the aim to be low in toxicity and to reduce the global warming potential of the new mixture to typically less than 2% of the SF_6 equivalent with no or minor design modification by respect to typical SF_6 design. This paper presents the research conducted with fluorinated compounds to qualify a new gas to be used into high voltage equipment as SF_6 alternatives with properties significantly improved with respect to typical SF_6/N_2 mixtures or others already in use as well as use of vacuum interruption with air for medium voltage applications. We expect this new gas mixture and use of vacuum interruption with air to allow a major move towards a new generation of environmentally friendly switchgears for medium and high voltage applications.

Keywords: SF6 Switchgear, SF6 Free Switching Alternatives for Switchgear, Future Trends in Medium and High Voltage GIS

I. INTRODUCTION

Sulphur hexafluoride (SF_6) gas has been extensively used in various gas-insulated applications such as circuit breaker, transformers and switchgear, due to its outstanding properties in both dielectric strength and arc-quenching. SF_6 is also a strong electronegative or electron attaching gas. Due to the electronegative properties of its molecule, it captures free electrons and produces a low mobility negative ion, thus making the electron avalanches development retarded.

However, in Kyoto Protocol 1997, SF_6 has been recognized as one of the greenhouse gases which contribute to the global warming issues, thus need to regulate its usage and emission to the atmosphere. Nevertheless, SF6 has the major drawback of presenting a global warming potential (GWP) of 23500 (relative to CO2 over 100 years), and it has a lifetime in the atmosphere of 3200 years, thus placing it amongst the gases presenting the most potent greenhouse effect. Therefore, 1kg of SF_6 released into the atmosphere has therefore the equivalent global warming impact as 23.5 tons of CO2. Since then, enormous efforts and studies were carried out to find the alternatives of SF6 gas, including SF6 gas and its mixtures with buffer gas of N2 or CO2.

A recent scenario analysis has clearly shown that only a transition to SF_6-free technologies will lead to a steady decrease of SF_6 emissions. Even the exclusive use of the most advanced technologies with minimum emissions would lead to steadily increasing SF_6 emissions (almost doubling today's emissions in the coming 80 years) due to the ever-increasing installed basis and with it the banked amount of SF_6. The legal frameworks must, thus, be urgently adapted and set to support and ensure a complete transition as fast as technically and economically possible

Due to the long development and even longer investment horizon, a dependable change is a mandatory requirement for manufacturers and users.

II. EXISTING ALTERNATIVES

In electric power equipment, SF_6 serves three main technical purposes: insulation of high electric field strengths, cooling (heat removal), and arc quenching (current interruption).These three functions must be fulfilled by any SF6-free system, which can also be non-gaseous alternatives, specifically solid, liquid or vacuum. Research was done in past decades on substitutes to SF_6, covering different candidates including common gases (Nitrogen, air, CO_2), perfluorocarbons, and vacuum. All these technologies present advantages and drawbacks.

Available or recently developed technologies include

1) Traditional gases such as dry air, Nitrogen, CO_2 or their mixtures have the advantage of low global warming potential but very limited dielectric strength up to approximately 40% or less compared to SF6.Use of such a gas as insulating or current

interrupting medium would lead to drastic changes in term of high voltage product design – i.e. either filling pressure or apparatus dimension would be increased by a factor of at least 2.5. Increasing the pressure too much would impact vessels and enclosure design and safety. Increasing the size would directly impact the dimensional footprint and cost of the product making it unsuitable as a replacement product in existing substation. In circuit breaker applications, CO_2 has a higher thermal interruption capability relative to N_2 or Air.

2) CF3I – trifluoroiodomethane - presents the advantage to combine high dielectric strength and current interruption capability with a low global warming potential below 10 relative to CO2, but it is suspected to be mutagenic hence it is not suitable for larger applications in industrial equipment in contact with the public.
3) Vacuum is widely used in the medium voltage domain as current interruption medium. The technology is now well established and has proven to be reliable. Application in high voltage domain at 72,5 kV is now state of the art with pilot application at 145 kV. But due to the intrinsic insulating characteristics of vacuum, its insulation capability being not directly proportional to the insulating gap as it can be for pressurized gas, there is a saturation of the insulation capability for large gaps in vacuum making unlikely to use vacuum interrupters for higher voltage. As a result, the application of vacuum at UHV does not appear to be economically competitive.

Therefore, none of these technologies is economically and technically viable as an alternative to SF6 across all the voltage ranges from 72,5 kV to UHV with the same reliability and safety for the network and workers.

III. DEVELOPMENT OF NEW ALTERNATIVE TO SF_6 WITH LOW GWP

The main specifications for the new alternative gas to be used should have high dielectric strength, high thermal dissipation, low boiling point, low toxicity, arc switching capability, compatibility with materials used in the switchgear, high stability versus temperature and time and to be easily handled on site for gas filling or topping up. GE's developed gas with 3M named g^3 based on 3M™ Novec™ 4710 fluid and CO2, has been specifically.

Developed to drastically reduce global warming potential relative to SF6 and to comply with the stringent specifications of switchgears.3M™ Novec™ 4710 fluid cannot be used alone due to liquefaction at low temperature and has to be consequently diluted into a buffer gas, The gas remains homogeneous over long periods of time even if the temperature cools down to minimum temperature. Experiments were performed as well by mixing several fluorinated gases with low vapor pressure but high dielectric strength to get optimal insulation performance, but the liquefaction temperature was drastically modified.

It was clearly concluded that a single fluorinated gas with high dielectric performance and low boiling point in addition to CO2 is preferable to a fluorinated gas mixture.

A. GWP and toxicity of mixtures.

Considering a typical GIS with a 6.3 bar relative filling pressure with Novec 4710 fluid/CO2 mixture for -25°C, then the total GWP for the mixture is less than 500 instead of 23,500 for SF6, reducing the GWP by 98%.

Considering then a Live Tank Circuit Breaker with a Novec 4710 fluid/CO2 mixture for -30°C, then the total GWP is 360 instead of 23,500 reducing the GWP by 98.4%. The gas mixture is classified as nontoxic and requires no specific label.

B. Dielectric strength under power frequency

The dielectric strength of the gas mixture was measured under AC voltage on a 145 kV GIS with Novec 4710 fluid ratio from 0 to 20% by volume into CO2. The dielectric strength of pure CO2 (0%vol Novec 4710 fluid) was found to be equivalent to about 40% of SF6. Adding only 6 to 7%vol of Novec 4710 fluid to CO2 doubles its dielectric strength. For roughly 18 to 20%vol, the dielectric strength of the mixture is equivalent to SF6

C. Switching performance

The switching bus-transfer current capability under 1600A and 20V was tested over 100 C/O operations on a 420 kV disconnector designed for 5.5 bar of SF6. The disconnector was filled with a mixture Novec 4710 fluid/CO2 for -25°C at a total pressure of 5.5 bar. It showed that arcing time is stable over the 100 operations and the average arcing time is about12 ms compared to a typical value of 15 ms for SF6. This means that the gas mixture tested has a good capability of switching bus-transfer current and can be used as a substitute to SF_6 for this application. Arcing contacts present a similar electrical wear to SF6.

IV. DEVELOPMENT OF COMBINED VACUUM INTERRUPTION AND AIR INSULATION

A better and safer SF6-free solution has been developed for switch disconnectors with vacuum interrupters and air insulation for medium voltage applications upto 36Kv
The advantages of the solution include:

- environmental friendliness and no need for end-of-life gas recovery.
- safety for people and ease of operation.
- same or similar compact footprint as SF6 and interchangeability.
- long life expectancy, under normal service conditions.

A. *Breaking with Vacuum Interrupters in Series with 3-Position Disconnector*

The traditional approach for vacuum interrupter switching consists of placing a vacuum interrupter in series with a 3-position disconnector. This solution is already applied in RMUs using SF6 for insulation and vacuum interrupter for circuit breaker functions. For the switch-disconnector functions, the vacuum interrupter must ensure short-circuit closing, dielectric withstand, admissible short time withstand current (including its peak value) and carry rated continuous current (heating). The only difference between the two types of VIs is the breaking capacity. As a consequence, VI for load break switches have the same dimensions and a similar cost as VI for VCB.

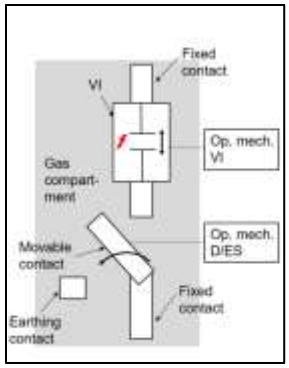
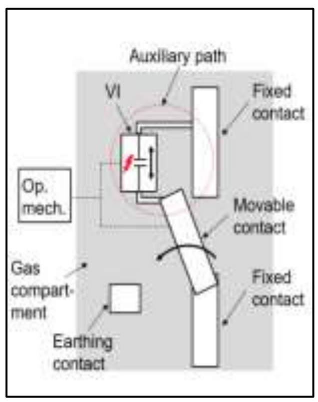


Fig. 1: VI in series with disconnector

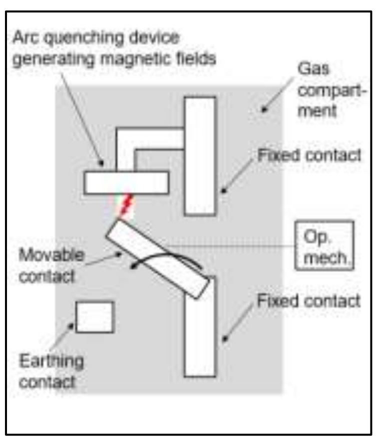
However, it presents three main drawbacks:
- The solution's cost is high.
- Low reliability with increased components.
- Opening/disconnecting takes place using 2 operations.

B. *Alternative load break switching principles for medium voltage switchgear.*

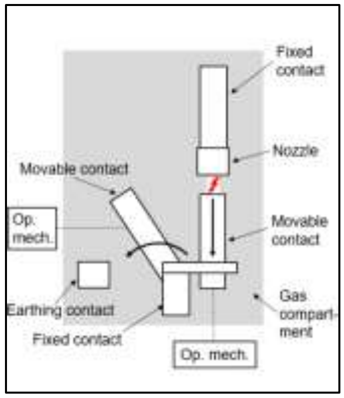
1) VI in auxiliary path



2) Rotating Arc



3) Puffer Type



C. Evaluation with Different Switching Principles

Criteria	*VI in main current path*	*VI in Auxiliary path*	*Rotating Arc*	*Puffer Type*
Breaking Capability	*High*	*High*	*Low*	*Medium*
Technical complexity	*High*	*High*	*Low*	*High*
Cost	*High*	*Low*	*Not evaluated*	*Low*
Overall Space	*High*	*Low*	*Not evaluated*	*Low*
Industrialization degree	*High*	*Low*	*High*	*Low*
Operating philosophy	*Medium*	*Simple*	*Simple*	*Simple*
Overall Assessment	*Not favored*	*Viable*	*Not suitable*	*Possible solution*

V. CONCLUSION

This paper presents g3, a new potential alternative gas mixture to replace SF_6 for high voltage switchgears. g^3 is based on $3M^{TM}$ $Novec^{TM}$ 4710 fluid used as an additive to CO_2 and presents the advantage of a significant reduction of its Global Warming Potential of more than 98% compared to SF_6. Moreover, with a dielectric strength higher than SF_6, the addition of a few volume percent of Novec 4710 fluid to CO_2 significantly increases the dielectric strength of the mixture to be almost equivalent to SF_6 even for operating temperature down to -25°C.

This is a clear advantage when compared to other alternative solutions such as N2, CO2, or air, allowing designers to keep the volume and/or the filling pressure of switchgears close to the current values to remain compact and safe for workers and surroundings particularly suitable for high voltage applications.

For medium voltage applications, the only solution known today is breaking with a vacuum interrupter, which is a proven and reliable technology. The solution currently used, which consists of setting a VI in series with a disconnector, is expensive and has a large footprint. Moreover, the operating mode is different from traditional SF_6 switches.

A new proposed solution that positions a VI alongside the main contacts as well as puffer type provides a compact and cost-effective solution. It is completely environmentally friendly, safer for people, eliminates the need for end-of-life gas recovery, and uses the same operating mode as existing switches. It also has a long-life expectancy, the same footprint, and is fully interchangeable with the currently used SF6 switches. It is well adapted for both AIS and GIS equipment for line switching as well as transformer protection.

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