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IN DEPTH



In search of an SF₆ replacement

Environmental concerns drive new development

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CLIMATE CHANGE G³ SF₆-FREE SOLUTIONS

Sulphur hexafluoride (SF₆) boasts many useful properties, especially for the high voltage electricity sector. It also suffers from a significant disadvantage – it is a powerful greenhouse gas. Hence the need to find a suitable alternative.



10 comments



1. SF₆ is a versatile gas used in various industries, such as magnesium and aluminium casting and insulated window glazing. But by far its most important application, and one that was first proposed by Vitaly Grosse of AEG (a GE Renewable Energy's Grid Solutions ancestor company), is in high voltage power transmission equipment. Some 10,000 tonnes per year of SF₆ are used for this purpose (around 80 % of the total). Air- and gas-insulated substations exploit the gas in circuit breakers, instrument transformers, surge arrestors, bushings and busbars, while gas-insulated substations also rely on it in disconnectors and earthing switches.

“SF₆ stands out for its remarkable arc quenching capability and dielectric insulation,” says Grid Solutions Materials and Eco-Design R&D Manager, Yannick Kieffel. “Moreover, it is stable, non-toxic and non-flammable. It allows manufacturers to design switchgear that is compact and insensitive to climatic conditions, has minimal environmental impact and requires little maintenance.” However, SF₆ is one of the 6 gases included in the Kyoto Protocol aimed at reducing greenhouse gas emissions. Its global warming potential ⁽¹⁾ (GWP) is 23,500 times greater than CO₂ (IPCC 2013) and it has a lifetime in the atmosphere of 3,200 years, putting it at the top of the Kyoto Protocol list. So, while SF₆ switchgear is

generally safe for the environment, if just one kilogramme of SF₆ leaks into the atmosphere it has the equivalent global warming impact of around 23.5 tonnes of CO₂.

(1) Calculation mode of GWP: please refer to the sidebar in [**Think Grid article “The impact of “F” gas regulation”**](#)

1 __ Persistence reaps rewards



Research has been on-going for a long time to find an alternative to SF₆ but it has not been successful in finding a suitable solution for transmission networks. Until now.

After 4 years' research, GE Grid Solutions, together with the 3M Company, has developed an SF₆-free solution that is much more environmentally sustainable yet meets all the very tough specifications for HV switchgear:

- high dielectric strength;
- good arc quenching capability;
- low boiling point;
- high heat dissipation;
- compatibility with existing switchgear materials;
- easy handling;
- design compactness, etc.

It also meets health and safety prerequisites (low toxicity, no flash point) and in particular environmental requirements such as:

- low GWP;
- no Ozone Depletion Potential (ODP);
- and minimal environmental impact⁽²⁾.

“We looked at simple, non-greenhouse gases such as nitrogen and air,” explains Kieffel, “but their dielectric strength is only a third that of SF₆.

SF₆/nitrogen mixtures would have higher dielectric strength, but their GWP is still too high. The same is true of perfluorocarbons



(PFCs). On the other hand, trifluoroiodomethane (CF₃I) presents dielectric strength greater than SF₆, with a GWP of less than 5 and a lifetime in the atmosphere of only a few days. On the down side, CF₃I is classified as carcinogenic, mutagenic and toxic; it cannot be used for industrial purposes.”

(2) Reach Annex VII testing

[Think Stock/GETTY]

2 __And the winner is...



Not a simple gas as SF₆ is, but a gas mixture named g³ (pronounced g-cubed) based on 3M™ Novec™ 4710 Dielectric Fluid from the fluoronitrile family specially developed by 3M for that purpose and used as an additive to a complementary gas. Among other candidates, fluoronitriles were studied extensively as the most promising chemical family. Among the different candidates tested, some have a high dielectric strength, but toxicity was an issue. So, new molecules were developed to resolve this problem, chemists and physicists manipulating molecular architecture to combine the advantages of previous candidates while eliminating drawbacks. Finally, one specific

molecule, marketed as Novec™ 4710 fluid, was designed and selected as the best compromise for its excellent combination of properties:

- significantly lower GWP compared with SF₆;
- boiling point: -4.7;
- dielectric strength: 2.2 x that of SF₆;
- high thermal transfer capability;
- low toxicity.

“However,” notes Kieffel, “Novec™ 4710 fluid cannot be used alone due to its liquefaction at low temperature. It was found that the best compromise is achieved by mixing it with CO₂ (for its arc quenching capability) to create g³, a gas mixture suitable for disconnect and circuit breaker applications.” As a result, the GWP of the g³ mixture of fluoronitrile with CO₂ can be brought down by well over 98 % compared with SF₆.

3 __ Moving ahead



But what of the other properties of g³?

Toxicity: g³ is non-toxic ⁽³⁾ and in the same category as SF₆.

Insulation: dielectric performance was tested on 145 kV gas-insulated switchgear. The results showed it to be between 87 % and 96 % of SF₆ performance. The difference can be compensated by minor design modifications or a dielectric coating on high-stress electrodes.

Temperature rise: the thermal conductivity of the gas mixture is slightly lower than SF₆, but significantly higher than pure CO₂. Tests show that the temperature rise difference is 5 or 6 °K.

This can be compensated by adding cooling fins to the enclosure or slots on conductors to improve convection cooling.

Switching: the gas mixture has a good capability of switching bus transfer current and is suitable as a substitute for SF₆.

Arc quenching: tests carried out on a 145 kV live tank circuit breaker show very encouraging results. The plan is to use the new gas mixture in the arcing chamber but, due to its different behaviour such as gas flow, the design of the arcing chamber has to be optimised for g³.

(3) Based on GHS and CLP classifications.

4 ___ A suitable substitute



The insulation, thermal conductivity and switching performance have now been validated. Current interruption capability also shows positive progress, and g³ is safe for operators. Therefore, g³ is suitable for developing a new generation of clean equipment from 72 kV up to ultra-high voltages with extremely low global warming potential.

* g³: trademark application owned by ALSTOM Grid SAS

* 3M and Novec are trademarks of the 3M Company

Next steps

Philippe Ponchon, Grid Solutions VP Marketing and AIS Marketing Director, offers a roadmap for its ground-breaking SF₆ replacement.

“Our objective of replacing SF₆ in our high voltage equipment stems from our customers’ concern for the environment, as well as present or future pressure from the authorities. The breakthrough we have

made is to engineer and test a family of gas mixtures for high voltage switchgear applications. We call it g^3 . It uses a molecule, developed by 3M in cooperation with GE Grid Solutions and according to Grid Solutions' specifications and guidance, which we have combined with CO_2 .

"We have already started the development of new products for both GIS and AIS arrangements. In a not too distant future, i.e. from March 2015 we will announce the first specific g^3 product.

"Retrofit – to replace SF_6 with g^3 , while adapting some components – is also of major interest for some customers who want to reduce the environmental footprint of their assets as fast as possible. Even if it is only possible in specific cases, we are currently assessing pilot applications with precursor customers.

"The technical foundations are laid; opening the door to the development of new ranges of high voltage equipment comparable to SF_6 in terms of performance and footprint, but much more environmentally friendly. It is, from my point of view, the beginning of a major change similar to the move from oil or compressed air to SF_6 in the early '70s. The speed of the move will depend on many parameters – economical, technical and societal.

"On the technical side, in the insulating domain this will enable fast development for all voltages from 72 kV to ultra-high voltages. Circuit breakers are a more complex domain. We have tested some prototypes, with satisfying results. But we are aiming at solutions for all types of circuit breaker on the full range of voltages. This implies modifications to a number of components and exhaustive testing, which will take more time.

"The key parameter will now be how far customers are ready to move to solutions with a global warming potential reduced by up to 98 % and how strong will be the regulatory incentives to protect the planet against climate change!"

Read more: Developing a new gas

John G. Owens, Lead Research Specialist at 3M, talks of the cooperation with Grid Solutions to find an SF_6 alternative.

Think Grid: GE Grid Solutions came to you with its specifications. What led you to this particular molecule?

John Owens: 3M's long history in researching fluorinated materials provided insight into the structure of materials needed to meet GE's specifications. The unique

combination of performance, safety and environmental properties drove our research in new directions. A large number of compounds were evaluated for this application. An understanding of the types of material that did not work was as helpful as those that did work, by directing the synthesis towards materials that showed greater promise.

TG: How is this molecule different from existing ones?

JO: This is the first material to combine all the required properties into one compound. All rejected candidates displayed a serious deficiency in one category or another. An improvement in one property often led to deleterious effects in a different property. This molecule's structure allowed for the right combination of properties with no significant sacrifice in one of them.

TG: Which other application domains do you see for this molecule?

JO: This material was developed specifically as a dielectric medium. At present, it is best utilised to replace high global warming potential materials such as SF₆.

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