g3 – In the air

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CLEAN GRID G3 GIS
SF6-FREE SOLUTIONS SF_6

The latest developments to GE's SF_6 gas replacement for transmission equipment, g^3, have got a lot of attention. To keep all stakeholders up to date and satisfy their curiosity, this article aims to respond to the numerous questions and comments that g^3 continues to generate.

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The introduction of three g^3-filled products (GIB, GIS and current transformers) at the CIGRE Session in August 2016 followed by the delivery and energization of the first equipment using g^3 instead of SF_6 raised considerable interests. Several questions and comments were transmitted to GE experts through the social media and the *Think Grid* feedback facility.

Some of the very encouraging comments were: "g^3 is a remarkable solution for removing the global warming potential disadvantages of SF_6"; "I am amazed by the new gas called g^3. I would like to discuss it with my colleagues at our national meeting. Of particular interest are switchgear and instrument transformers."

Think Grid spoke with Philippe Ponchon, Executive Product Manager, Grid Solutions. In answering the different questions asked through social media, he provided further insights and some technical explanations that should be helpful to a wide spectrum of readers, and especially those with

projects that are more environmentally driven to meet increasingly stringent regulatory requirements.

What are the environmental advantages of g^3?

Philippe Ponchon: There is a major advantage – its global warming potential (GWP). SF_6 is one of the six gases listed in the Kyoto Protocol due to its very high GWP, which is 23,500 times greater than CO_2. So potentially, it has a heavy impact on climate change. g^3 (a mixture of CO_2, O_2, and fluoronitrile called Novec™ 4710 developed by the 3M™ company) has a GWP lower than SF_6. The reduction is even 99% when the difference in gas density is taken into consideration. Also, the lifetime of SF_6 in the atmosphere is 3,200 years. This means that if 1 kilogram of SF_6 leaks into the atmosphere today, there will still be 200 grams present in 5,000 years – that is, 165 human generations. And the amount of SF_6 entering the atmosphere has been measured at an increase of 20% during the last five years.

To illustrate the potential impact on climate change, it can be said that replacing SF_6 by g^3 in all high voltage equipment in the UK would be equivalent to taking 150,000 cars off the road!

If equivalent results can be achieved under the same economic conditions, it is much more responsible to use a green solution. That is exactly what we have done with g^3.

What if the ambient temperature is lower than -25°C in AIS applications?

Philippe Ponchon: We have developed g^3 with our key markets in mind – GIS down to -25°C and AIS to -30°C – which represent some 90% of our marketplace. For these temperatures, we'll be able to deliver g^3-insulated GIS and AIS with the same footprint, the same performance and at similar or at slightly higher cost compared to SF_6-based equipment (depending on the equipment type).

There is still a possibility that g^3 might be extended beyond the -30°C mark, but economic performance would be reduced, so developing g^3 for this sector is not planned. For specific applications like dead-tank circuit breakers and operating temperature down to -40°C, g^3 could be used with a heating belt to avoid liquefaction below -30°C (as is sometimes the case with SF_6).

g^3 is a remarkable solution for mitigating the GWP disadvantages of SF_6. Can you provide details of the electrical characteristics comparison between g^3 and SF_6?

Philippe Ponchon: The important point to remember is that g^3 can achieve the same electric performance as SF_6 with a slightly higher gas pressure.

We have published a number of technical articles giving detailed comparisons of the electrical characteristics such as power frequency, lightning and switching impulse withstand. I suggest reading CIGRE article No. D1-204: "Characteristics of a Fluoronitrile/CO_2 Mixture – An Alternative to SF_6." You will also find some useful information in the *Think Grid* article "In search of an SF_6 replacement."

What is the difference between the fluoronitrile used by GE and the fluoroketone used by the competition? Or are they both the same product by 3M with slightly changed properties? Are they based on 3M Novec 612?

Philippe Ponchon: The GE solution, g^3, is based on CO_2, O_2 and Novec 4710, a fluoronitrile that offers the benefits of high dielectric strength and a low boiling point. The competitor solution for high voltage applications, as publicly disclosed, is based on CO_2, O_2 and Novec 5110, which is C5-FK, a fluoroketone. The GE solution has the advantage of being applicable for minimum operating temperatures down to -30°C for AIS and -25°C for GIS. It is therefore suitable for both indoor and outdoor operation. The fluoroketone solution is limited to temperatures down to 0°C and consequently to indoor application. This is important to our customers who want to cover all their needs with a single standard solution.

Note also that thanks to the high dielectric strength of fluoronitrile, the GE solution is a g^3-insulated product with the same footprint for the same performance. This is not the case with other solutions.

The Novec 612 mentioned in the question is something quite different; it is another fluoroketone with a boiling point of +49°C, which means it would quickly liquefy in HV equipment. Novec 612 is used to replace SF_6 in the magnesium casting process.

Is retrofit by gas replacement in existing GE switchgear and gas-insulated lines possible?

Philippe Ponchon: Direct retrofit is not possible. However, retrofit could be possible in some specific cases, though not with strictly identical performance or operating conditions. In any case, equipment modification will be necessary.

Due to the differences of the gas characteristics between g^3 and SF_6, the design of today's circuit breakers needs to be adapted to the new gas mixture, and then they must undergo intensive type tests. It is therefore not possible to simply replace SF_6 by g^3 in circuit breakers.

As far as gas-insulated lines are concerned, retrofit could be considered on a case-by-case evaluation with different operating conditions and equipment modifications.

How do g^3 and SF_6 behave in a short circuit, at a high temperature and under high pressure, and what decomposition products result?

Philippe Ponchon: Overall, g^3 is equivalent to the current SF_6 solution in these respects. g^3 has been proven to be very stable at high temperature and high pressure.

When subjected to an electrical arc, decomposition by-products are generated. These mainly come from the CO_2 in the g^3 gas mixture. As regards toxicity of the by-products, comparative tests have been performed with g^3 and SF_6 during interruption within the circuit breaker.

The by-products have been analyzed by independent pharmaceutical laboratories and by-products from arcing in g^3 are in the same toxicity class as those generated by SF_6 under the same conditions.

What happens in case of a leakage in a substation? Are the new and aged gases toxic?

The leakage rates with g^3 will be equivalent to the leakage rates with SF_6 thanks to specific gaskets with adapted design and material.

Since g^3 is qualified nontoxic and aged g^3 is in the same toxicity class as polluted SF_6, i.e., nontoxic in normal operating conditions, the same procedures must be used in case of leakage in a substation as with SF_6. In case of a small leakage, reduction of oxygen levels must be checked to avoid suffocation. Both Novec 4710 and CO_2 have, like SF_6, their own occupational limits for workers and they must not be exceeded. For both Novec 4710 and CO_2, detectors are available on the market.

In case of a pressure release device opening and the subsequent release of polluted g^3, the substation must first be ventilated to remove polluted gases and workers must wear appropriate autonomous breathing equipment, as is the case with heavily polluted SF_6 today.

Currently, how do manufacturers work with g^3 in GIS and circuit breakers?

Philippe Ponchon: g^3 is GE's solution to replace SF_6. It is made up of three components, CO_2, Novec 4710 and O_2. Both GE and 3M recognize the sustainable nature of the Novec 4710 dielectric fluid and as such are supportive of offering this material to a broader audience. An example is the cooperation with LSIS in South Korea to jointly develop SF_6-free power equipment. GE benefits from being the first company to work with Novec 4710.

As greenhouse gas regulations become ever more stringent, so the demand for alternatives such as g^3 will increase.

Do you want to try any test sites for replacing SF_6 with g^3? I have some 34 kV GE circuit breakers that may be a good platform.

Philippe Ponchon: It must be remembered that we initiated research into an SF_6 replacement as AREVA T&D. Later, the business was acquired by Alstom, the latter being dedicated to high voltage, with no medium voltage switchgear activity. Work on g^3 for medium voltage was discontinued at that time, allowing us to focus entirely on the high voltage sector. Furthermore, alternative technologies for medium voltage exist, such as dry air for insulation and vacuum for circuit breakers.

We already have some references of substations using g^3. The 420-kV gas-insulated lines (GIL) at the UK National Grid's Sellindge site were energized in April 2017. The second 420 kV GIL will be energized beginning of 2018. The world-first full 145-kV gas-insulated substation using g^3 successfully passed the site high voltage tests in November 2017 and will be energized in April 2018. In total, nine utilities have confidence in GE's solutions and have decided to implement g^3 solutions on their network. The registered contracts now total approx. 400 meters of 420 kV GIL, 23 bays of F35-GIS, 6 SKF 245 kV current transformers. And this is just the start...

Can g^3 be applied to railroad electrification applications – 15 kV, 25 kV, 50 Hz. Are there any plans to develop a technology demonstrator for this market?

Philippe Ponchon: The railroad electrification sector is not a priority for g^3 development, so there is no application available today. Our initial focus covers high voltage equipment for voltages above 50 kV, more specifically 145 kV, 245 kV and 420 kV. At CIGRE 2016, we introduced the 420 kV GIL, 145 kV GIS and a 245-kV current transformer. Further products will be developed in accordance with the market demand. We observe a growing interest for 420 kV GIS. We will further develop the GIS range at other voltage levels as well as the current transformer range, moving then to the air-insulated live-tank and dead-tank circuit breakers.

What other potential applications exist?

Philippe Ponchon: g^3 is a gas mixture designed for HV switchgear. One of its components is a fluoronitrile, which could be considered as a replacement for SF_6 in other applications such as special manufacturing processes (especially the magnesium industry), radar, laser and military applications that are out of GE Power's Grid Solutions' portfolio.

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