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IN DEPTH

Gas-insulated substations are switching to g^3, the SF_6-free solution

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CLEAN GRID   G3   GIS G^3 SF6-FREE SOLUTIONS SF_6

Deployment of the g^3 gas mixture as a replacement for SF_6 has taken a major step forward: the F35-145 kV gas-insulated substation (GIS) is now SF_6-free too. It has the same physical footprint as its SF_6-based GIS predecessor and can operate at ambient temperatures as low as -25 °C.

3 comments

It was just two years ago that GE announced a breakthrough in developing a substitute for SF_6 in gas-insulated equipment. Such a substitute had become necessary because SF_6, despite its undeniable qualities—its arc-quenching and dielectric capabilities—has a global warming potential (GWP) 23,500 times that of CO_2, with a lifetime in the atmosphere of over 3,000 years. With g^3, a fluoronitrile and CO_2 gas mixture, GE was able to develop a suitable operational alternative with a GWP brought down by 98% compared with SF_6.

1__g ³ as an electrical insulation and switching medium

First, the gas mixture properties, behavior and capabilities required for use as an alternative insulation and switching gas were investigated (**read Think Grid article on g³ properties**). Research was then made on material compatibility to identify the adaptations that would be needed in high voltage equipment.

2__Material compatibility with g ³

In gaseous state, the fluoronitrile contained in g³ is compatible with most of the metals and hard plastics used in HV equipment. For example, gas in contact with copper, aluminum, brass, nickel, steel or stainless steel for several months at elevated temperature (120 °C) shows no change in purity.

Particular attention was then paid to the gasket material: permeation of the gaskets for CO_2/fluoronitrile mixtures was investigated in accordance with ISO 2782-1:2012. EPDM is a typical elastomer used as gasket material in SF_6-filled HV equipment. The combination of its material properties, together with the gasket design, allows gas-insulated substations to be reliably gas-tight during their entire lifetime and meet the maximum allowed leakage rate of 0.5% per compartment and per year, as specified in IEC 62271-203. As the CO_2 molecule is much smaller than that of SF_6, standard EPDM was found not to be the most appropriate rubber material to ensure a low permeation rate for a g^3 gasket. A variation of butyl rubber, an elastomer material widely used in the automotive industry for tires, was successfully tested. Test results clearly showed that the permeation rate of the g^3 mixture was suitable. Beyond that, the new gasket material was qualified to withstand environmental stresses such as heat, humidity and ozone.

In the meantime, several “pioneer” products have been developed with g^3 as the insulation medium, with the active support of several TSOs committed to environment-friendly power grids. These products are:

- A 420 kV gas-insulated line (GIL); this product has undergone real-life tests at the UK National Grid’s Sellindge site and has demonstrated its operational qualification. Watch the video.

Gas-insulated line project with g^3 at Sellindge UK

- A 245 kV gas-insulated current transformer; several of these products have been delivered and are now being installed at a customer's site for testing in the network.
- A 145 kV gas-insulated substation, in which g3 is applied not only as an insulation medium but also as a switching and arc-quenching gas. This article is mainly about this product.

3__ Voltage withstand and temperature rise

Voltage withstand tests were performed on individual components as well as on the fully equipped bay.
The lower dielectric performance of the g^3 mixture, compared with SF_6, is easily mitigated by a higher filling pressure, set at 7 bar (relative). This pressure level allows the GIS to operate with no heating at temperatures down to -25 °C.

Temperature rise tests were performed on a fully equipped bay. The test results showed that the g^3 mixture has a slightly lower performance than SF_6, though better than pure CO_2. The difference has been compensated for by design modifications.

4 __Switching by disconnector and earthing switch

Several tests were carried out to verify the switching characteristics of the g^3 mixture. The results of the bus-transfer current switching tests at 1600 A/10 V showed that the mean arcing times using g^3 and SF_6 are almost identical for the tested slow-moving disconnector, with a slightly higher standard deviation with g^3. In the end, both gases perform quite similarly. In addition to the 1600 A/10 V tests, the performance at 80% of the nominal current (2520 A/10 V) was successfully validated.

Bus-charging tests and capacitive switching tests were also performed—with successful results—on the combined disconnector/earthing switch. Furthermore, electrostatically induced current making and breaking tests were performed on an encapsulated make-proof earthing switch (fast-moving switch) by an independent laboratory. The results showed that the arcing times and contacts were identical for g^3 and SF_6.

David Gautschi, Manager of Technical Services at GE Grid Solutions, explains: "*These results show that the existing* *disconnectors and switches require only minor modifications to operate perfectly well on the 145 kV GIS with g^3."*

5__Circuit breaker

The development of g^3 technology began with a live tank circuit breaker for application in air-insulated substations. All the necessary type tests were successfully completed on prototypes and this experience served as input for the g^3 GIS circuit breaker.

Simulation tools were used to simulate arc-quenching and flow behavior with g^3. The 2D CFD code was used for numerical simulations of the electric arc. A 1D macroscopic tool, AMASIS, was used to predict pressures, mass flows and arc voltage, helping to optimize the design of the circuit-breaker chamber. To date, AMASIS has produced calculations for both SF_6 and g^3. The results are positive, especially in calculating the arc voltage. Gautschi adds: "The process is self-feeding: the more results we have, the more precise we will be, and so the more g^3 breakers we test, the better AMASIS accuracy will become."

The data from the 1D and 2D simulations are then used as input for 3D flow calculations, in particular to assess the quantity, direction and temperature of hot gas in the tank. "*This allows us to assess hot gas flows, particularly during three-phase operations.*"

The breaking performance of the g^3 gas mixture is largely influenced by its CO_2 content. Compared with SF_6, CO_2 is a small molecule with a lower thermal breaking performance. The size of the CO_2 molecule influences the gas flow and significantly diminishes the pressure build-up inside the arcing chamber. With adaptations to the heart of the chamber, it is possible to keep enough pressure in the thermal volume during the full arcing window. Tests on an adapted chamber have shown successful results in all relevant test duties, such as terminal faults, short-line faults and capacitive switching tests. The size of the adapted chamber is comparable to existing SF_6 self-blast chambers.

6__A g^3-ready GIS

To adapt the existing F35-145 kV GIS to the new gas mixture, the test and simulation results showed that some adaptations were needed—mainly to the circuit-breaker chamber—to produce equivalent arc-quenching performance. For instance, the compression volume, some valves and some of the gas flow channels have been adapted.

However, the main housing and footprint of the g^3-GIS have the same dimensions as its SF_6 predecessor. It thus remains the most compact GIS on the market.

It is also possible to fill gas-insulated lines, bushings and transformer connections with the same gas. Since ambient temperature can be as low as -25 °C, outdoor installation is perfectly possible.

With g^3, based on a full life-cycle evaluation, the CO_2 footprint of gas losses is cut by 98%. Taking the entire substation into account, more than 50% of the CO_2 footprint can be saved. GE's F35-145 kV GIS therefore offers today the lowest CO_2 footprint of any 145 kV GIS in the world.

7__ g^3 tools and handling

A new gas also means new tools. Gas monitoring and handling equipment has been developed or adapted in parallel with the work on the switchgear itself.

g^3 monitoring

Gas monitoring is done with g^3 as it was with SF_6. Traditional sensors (temperature-compensated pressure switches) have only to be adapted to the updated pressure. Digital sensors for on-line monitoring do not require changes; just the software needs updating according to the physical properties of the g^3 mixture.

Digital density sensor

g^3 quality check

GE has worked closely with gas equipment suppliers to develop quality checking equipment. This equipment accurately measures the gas composition (CO_2 and Novec™ percentages) and the gas humidity.

g^3 gas quality monitoring

g^3 delivery

Gas handling is made very easy for the customer. The mixing of Novec™ 4710 and CO_2 is carried out by a qualified GE Grid Solutions partner. The g^3 is therefore delivered to the site already mixed in bottles in a liquid pressurized state—as for SF_6—ready to be used with the help of a gas-handling cart.

g^3 bottles delivery

g^3 handling

Filling is done directly from the bottle containing the g^3 mixture, using a new, specifically developed gas-filling device. The standard SF_6 device was not suitable, so GE worked closely with gas equipment suppliers to develop a dedicated g^3-filling cart.

The key difference between g^3 and SF_6 is that g^3 is a gas mixture while SF_6 is a single gas. Elodie Laruelle, GE Grid Solutions Eco-design Engineer, explains: "*The critical point for a gas mixture is to maintain the homogeneity of the two components (Novec™ and CO_2) throughout the filling process. To ensure this homogeneity, the filling equipment needs to directly heat up the g^3 bottle to a specific temperature, to reach the supercritical state of the gas mixture. In this way the mixture becomes homogenous, which results in the filling of the correct gas ratio in the*

GIS compartment.

g^3 bottle heating system

One of the challenges was to develop a software solution that checks the entire process to maintain the right conditions (temperature and pressure inside the bottle) and to ensure homogeneity of the final gas mixture."

g^3 Filling cart

g^3 Recorvery cart

g^3 recycling

In parallel, development of solutions for g^3 recycling is ongoing with a number of partners. The target is to use g^3 in a closed loop as is already the case for SF_6. "*However, for g^3, the process is more challenging since it is a gas mixture,*" explains Yannick Kieffel, GE Grid Solutions Senior Expert, Materials and Eco-Design Manager. "*Besides removal of the by-products, we have two main options under investigation: either to reuse the gas and keep the ratio of the original gas; or separate the components and subsequently re-mix them for further use. We already have long-term experience with gas mixtures, such as N_2/SF_6 or CF_4/SF_6, so a similar process is foreseen.*"

COMMENTS

3 comments

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