

g³: THE SF₆-FREE SOLUTION IN PRACTICE

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In August 2014, GE unveiled g^3 (g cubed), its ground-breaking solution for replacing SF_6 in high-voltage equipment. Since then, g^3 products have been installed successfully in several countries (Figure 1), and g^3 lifecycle assessments have underscored the huge environmental benefits of the new gas mixture.



Figure 1: CERIOUS' F35-72.5 kV g^3 gas-insulated substation, including six circuit-breaker bays, is located in Denmark

g^3 Equipment Portfolio

For about 50 years, SF_6 has provided the high-voltage equipment industry with good service, thanks to its exceptional arc-quenching and voltage-withstanding capabilities. Now, with the sustainability of the planet becoming an overriding, universal concern, the power transmission sector is looking for a replacement.

This is due to the global warming potential (GWP) of SF_6 being 23,500 times higher than that of CO_2 , and the fact that it remains in the atmosphere for 3,200 years. Moreover, its atmospheric concentration has increased by 20% over the past five years.

The time is now to find and scale the adoption of a reliable and sustainable SF_6 substitute. After several years' research, GE has done just that, with its g^3 solution – a gas mixture made up of CO_2 , O_2 , and Novec™ 4710 fluoronitrile developed by the 3M™ Company. This revolutionary gas mixture has the power to reduce the gas impact on climate change by more than 99%, in comparison to SF_6 .

This performance is achieved through only limited modifications to the original equipment. The breaker remains a single-chamber, self-blast breaker, using the same spring drive, and an overall unchanged footprint.

The g^3 equipment portfolio to date ranges from 145 kV gas-insulated switchgear (GIS), to 420 kV gas-insulated lines (GIL) (Figure 2), a 145 kV live tank breaker, and both 123 kV and 245 kV air-insulated switchgear (AIS) instrument transformers (Figure 3). All subsequent products will be made for g^3 and released to the relevant industry in their g^3 version. Such was the case with the latest developments shown at CIGRE in 2018 where the new 72.5 kV GIS and 145 kV live-tank circuit breaker were introduced.



Figure 2: A 420 kV gas-insulated line filled with g^3 at National Grid's new Sellinglee substation in the UK



Figure 3: An SF_6 -free 245 kV current transformer using g^3 installed at a TenneT substation in Germany

Grid operators globally who are concerned about the environmental impact of their operations have chosen the SF_6 -free, g^3 technology from GE, ultimately reducing both their overall physical and economic footprint. g^3 adoption is increasing, given its equally reliable performance in comparison to SF_6 , and the tremendously vital environmental benefits it delivers.

From SF_6 to g^3 : A Smooth Transition

Customers do not have to be concerned about mixing the g^3 components on site. Delivery of g^3 is just like that of SF_6 , so the user is not required to combine the different components of the gas mixture. Instead, GE has established partnerships with leading industrial gas suppliers, including Air Liquide, DILo, Inventec, etc. These gas handling experts have developed specialized equipment and processes for g^3 mixing. They ensure the precise percentages of the different elements when transferring to cylinders, which are then shipped either to the customer factory or directly to the site.

Each large B50-size cylinder contains approximately 22 kilos of the gas mixture in liquid state, and is used for large volumes such as GIS and GIL applications. The mixture is also available in gas form in 2 kg cylinders for gas-to-gas operations, such as topping up or filling instrument transformers. GE's partners have also developed special gas carts (for both small and large volumes) for the filling and recovery of gas mixtures, similar to the SF₆ equipment standards that users are already familiar with (Figure 4). A typical GIL or GIS installation can require anywhere between 10 and 50 B50 cylinders (Figure 5).



Figure 4: Air Liquide's g³-filling cart in service at a National Grid site in the UK



Figure 5: g³ cylinders being delivered to the customer site

For liquid-to-gas transfers, homogeneity of the gas mixture must be achieved to ensure the right ratio of the CO₂, O₂, and Novec™ 4710. Specialized service carts enable this process, without operator interaction, by heating the cylinders through an automated process of induction or resistive heating (Figure 6). This is the only significant change when compared to SF₆ gas handling, where heating was required only in cold climate conditions.



Figure 6: g³ cylinder with warming system

The same devices used for monitoring SF₆ gas purity and humidity have been adapted for g³ oversight applications, now designed to verify the percentage content of g³ components. Operators have been using these same tools for the past 40 years. Although they have been adapted, the principles are the same. It is also important to note that g³ is non-toxic like SF₆, and safe for equipment-handling staff.



Figure 7: WIKA g³-gas quality analyzer and a DILO g³-gas quality analyzer

End-of-Life Management

Disposal and recycling are important concerns for grid operators. Since there are insufficient quantities of the g^3 mixture around today to warrant recycling, all decomposed products are disposed of by specialized partner companies. Any new gas can be re-used in the mixing plant. This highlights a clear parallel with SF_6 in its early days, when disposal was the norm as well. Over time, processes were introduced to separate the components, and now, even polluted products can be recycled. The same is expected to happen with g^3 . GE is currently investigating two different approaches to recover the Novec™ 4710, both of which have shown some promise for the recycling and re-use of those mixture components in the future.

Lifecycle Assessment: A Positive Comparison

According to EU green procurement guidelines, the environmental impact of the whole product throughout its complete lifecycle should be evaluated in the sourcing and procurement phase (as opposed to only considering the gas global warming impact).

Lifecycle assessments (LCA) were performed on 420 kV GILs and 145 kV double busbar GIS – both SF_6 -based and g^3 -based – to compare their results. The aim was to evaluate:

- the reduction of impact on climate change, considering not only the gas itself, but the complete product over its whole lifecycle, from raw material extraction to end-of-life;
- the environmental impact of the g^3 solution on the other environmental indicators, compared to SF_6 .

The assessments were carried out according to ISO 14040 and 14044 using SimaPro 8.3.0. and the International Life Cycle Data (ILCD) method, covering 16 environmental impacts, including climate change, ozone depletion, resource depletion, and toxicity, among others. The following entries were taken into account:

- manufacturing, including all materials contained in the complete switchgear bays, and accounting also for surface treatments and painting
- transportation (1,000 km on the road and 6,000 km on the sea)
- 40 years of service use, considering both power losses and gas leakages
- The end-of-life phase, taking into account that the gas is removed from the GIS and treated separately

Comparative LCA of 145 kV GIS with SF_6 and with g^3

In Figure 8, the results for the 145 kV GIS show that, compared to the SF_6 version, the SF_6 -free product had a significantly lower negative impact on climate change (72.5% reduction) and resource depletion (18% reduction), respectively.

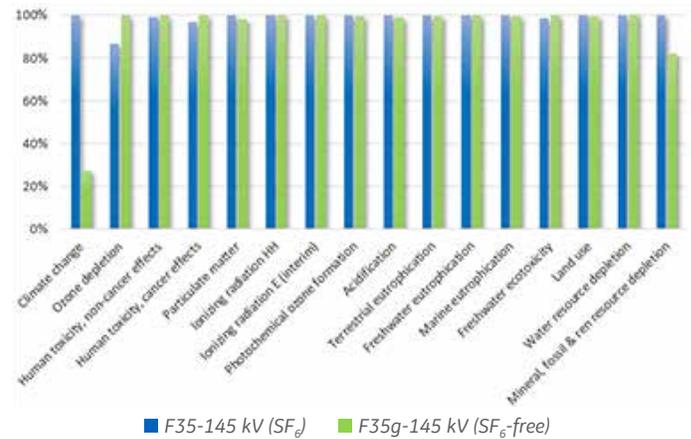


Figure 8: LCA comparison of F35-145 kV (SF_6) in blue, and F35g-145 kV (SF_6 -free) in green

With respect to the climate change indicator reduction of 72.5%, it is worth considering that aluminum (due to its production process) has the largest impact in the GIS manufacturing phase. Aluminum represents 65% of the product using SF_6 , and only 4.4% more in GE's SF_6 -free version. One of the main specifications for g^3 product design was to keep the same equipment size at equivalently-rated voltage. Had the GIS been designed any larger, the impact on climate change would have been even greater.

In terms of g^3 's global warming potential, it has a GWP reduced by 98% compared to SF_6 . When applied in the GIS, the GWP of the gas is further reduced by more than 99%, simply because the necessary gas mass of g^3 for one bay is half the necessary mass required for SF_6 .

The g^3 -GIS yields a 15% increased impact on ozone depletion. This is due to the greater use of polytetrafluoroethylene (PTFE) material in the circuit breaker to cope with the characteristics of the alternative gas. However, since PTFE quantities are very low, this increase is negligibly small (only 2.8 g of CFC-11 equivalent over the whole life cycle).

On the other 13 indicators, the difference is less than 5% between all other indicators, keeping them in the range of uncertainty of the LCA analysis. In other words, these environmental indicators remain virtually unchanged compared with those of state-of-the-art SF_6 GIS.

Switzerland

This project using g^3 was delivered and tested onsite in March 2018 at an Axpo site in Switzerland (Figure 12). It features four bays of three-phase encapsulated 123 kV GIS and can operate, just like SF_6 -GIS, down to $-25^\circ C$. It was the first project featuring a circuit breaker using g^3 as the arc-quenching medium.

The gas mixture was delivered onsite, premixed in cylinders. The filling or evacuation procedure is similar to the procedure with SF_6 directly from the cylinder. A g^3 -dedicated gas handling cart is used to fill or recover the gas from/to the GIS compartment (Figure 13). Gas quality analyzers, densimeters, filling valves, and the sealing system are adapted to g^3 , but work the same way. Even the maintenance cycles remain the same. The site was energized in August 2018 (Figure 14).



Figure 12: Axpo's Etzel substation in the Swiss Alps



Figure 13: DILO's g^3 -service cart used at Axpo's Etzel substation



Figure 14: 123 kV GIS with g^3 installed and energized at Axpo's Etzel substation in 2018

France

RTE, the French transmission system operator, ordered seven GIS bays at 72.5 kV rated voltage for its substation at Grimaud in France (Figure 15). This project is so far the largest F35 GIS, with g^3 installed at the customer site in September 2018. A dedicated g^3 service cart containing a cylinder heating facility was used to fill the GIS. The gas handling of g^3 is similar to the gas handling of SF_6 ; it needs an additional step of heating the cylinder to bring the mixture from liquid into the gaseous phase. After filling, the C_4F_7N content, O_2 content, and humidity in each compartment was confirmed using a g^3 analyzer (Figure 7).



Figure 15: 72.5 kV F35 GIS using g^3 installed in RTE's Grimaud substation in France

Conclusion

These first applications demonstrate that the g^3 gas handling tools work reliably, even under adverse weather conditions, and that the gas filling process compared to SF_6 is practically unchanged.

Various g^3 projects are currently in their execution phase. They demonstrate how straightforward g^3 high-voltage products can be implemented throughout the manufacturing, engineering, project execution, installation, and commissioning phases. As shown in Figure 16, GE's g^3 products have already been adopted by 16 different utilities around the world.

g³ Adoption



16 LEADING UTILITIES
have decided to use
equipment with g³



386,000 tons of CO₂ equivalent
were not installed on the electrical
network thanks to g³ projects

UK/SCOTLAND
UK/ENGLAND
FRANCE
SPAIN

DENMARK
NETHERLANDS
GERMANY
SWITZERLAND

SOUTH KOREA

	<p>g³ Gas-Insulated Lines 420 kV, -25 °C 5 sites - 2033 meters</p>
	<p>g³ Gas-Insulated Substations 145 kV, -25 °C 12 sites - 70 bays</p>
	<p>g³ AIS Instrument Transformers up to 245 kV, -30 °C 3 sites - 6 CT - 3 CMU</p>
	<p>g³ Live Tank Circuit-Breakers 123 kV, -30 °C 1 site - 2 CBs</p>

Figure 16: g³ worldwide adoption

GE Grid Solutions

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