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A3

PS2 – Decarbonisation of T&D Equipment

SF_6-free Solutions for 420 kV Networks using Gas-Insulated Substation (GIS)

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SUMMARY

Leading utilities in Europe are putting a strong focus to reduce their greenhouse gas emissions. GIS manufacturers have been working during the last decade to implement GIS solutions using alternative gases to SF_6 to help utilities in that direction.

Solutions have existed since 2016 at 420 kV level using passive components like GIL (Gas Insulated Lines). The first reference has been in service in south of England, with four additional projects, totalling more than 2500 meters of GIL, now installed. The next major steps are the validation of the alternative gas solution for switching components, like circuit-breakers and disconnectors, for this 420 kV voltage level and for short-circuit current up to 63 kA. Projects are under development and first validation of the technology is progressing well.

The user, SSEN Transmission – the electricity transmission network owner for the north of Scotland – have clear goals for reduction in greenhouse gas emissions and an approved Science Based Target. The use of SF_6 alternatives is key to support these and so they selected a, fluoronitrile based, SF_6-free GIS solution and awarded a contract in December 2020 for the manufacturing and delivery of the world's first SF_6-free 420 kV gas-insulated substation.

This paper details the reason for the choice of this SF_6-free solution and its expectations for performances and technical requirements. It also details progress made by the manufacturer, GE Grid Solutions, to develop and validate this first 420 kV SF_6-free solution. The benefit in term of architecture, accessibility and environmental footprint is described. The move from one gas like SF_6 to multiple gases brings some new requirements in terms of gas management during installation and maintenance. The user's expectations and the manufacturer solutions are detailed.

KEYWORDS

GIS – 420 kV – SF_6-free – Alternative gases – C_4F_7N – C4-FN – Fluoronitrile – Life cycle assessment

1 INTRODUCTION

SSEN Transmission are responsible for the electricity transmission network in the north of Scotland. We own and maintain AC (mainly 132 kV (145 kV), 275 kV (300 kV) and 400 kV (420 kV)) and DC transmission network in our licence area. Our network extends over a quarter of the United Kingdom's (UK) land mass across some of its most challenging terrain. The operating area is home to vast renewable energy resources, and this is being exploited by wind, hydro and marine generation.

Delivery of net zero brings challenges to the electricity industry beyond generation: transmission asset owners must also look at their own CO_2e emission, and SF_6, with its extremely high global warming potential (GWP), is key part of this. Users and manufacturers have for years been looking for alternatives to SF_6 and progress has been made. There is in service experience with passive components like GIL at 420 kV and with active components at 145 kV. This paper will present the development and utilization of 420 kV entirely SF_6-free GIS.

2 REASON FOR SSEN TRANSMISSION TO CHOOSE SF_6-FREE GIS

2.1 General

Connecting the renewable, low carbon, generation to the demand centres – 100s km away – naturally requires the construction of transmission infrastructure, which by its very nature has a CO_2e footprint. Therefore, our environmental commitment extends beyond our role of connecting and transporting this renewable energy and includes a responsibility to act for our own impacts on climate change.

We have therefore committed to a science-based emissions reduction target which is consistent with delivering a pathway to net zero emissions – the world's first networks company to have our target independently accredited by the Science Based Target Initiative (SBTi) [1] [2]. Our SBT includes:

1. Reduce our absolute Scope 1 and 2 GHG emissions 46% by FY 2029/2030 from 2018 base, by:
    a. making our substations more energy efficient
    b. replacing our operational vehicle fleet with electric vehicles
    c. tackling SF_6 emissions.

   This builds on the commitment to reduce emissions by one third by the end of the current regulatory period in 2026 as part of our Business Plan: A Network for Net Zero.
2. Reduce Scope 3 Transmission Losses GHG emissions 50% per gCO_2e from losses/kWh by FY2029/2030 from a 2018 base year, by implementing a Transmission losses strategy and connecting more renewable electricity to our network.
3. Work closely with our supply chain so that two thirds of our suppliers by spend will have a science-based target by FY2024/2025 and so reducing our indirect emissions.

Even if excessive leakage is prevented, natural leakage from SF_6 assets is inevitable and permitted by applicable standards like IEC 62271 series; hence, for newly installed assets, the best way to avoid SF_6 emissions is to install SF_6-free assets. We have stated this in our Strategy for the Management of Insulation & Interruption Gases: "where is it technically and commercially viable, we will no longer install assets containing SF_6. [3]"

2.2 Technical performance and reliability

The environmental case for avoidance of SF_6 is clear and justifies the change in technology but there is no technical benefit expected from this move. It is critical for network owners to have confidence that an SF_6-free solution has the equivalent performance – in both short and long term – as SF_6.

The technical development and testing of the manufacturer's SF_6-free GIS is explained in later sections of this document. The ratings of the GIS aligned to the user's requirements.

Accepting that experience is limited, the user's own experience with SF_6 alternatives – already installed 145 kV GIS and 420 kV GIL using the same technology – does not show any specific reliability concerns; this is supported by publications such as [4].

The change of gas within the switchgear is clearly significant but, when reviewing overall performance and reliability of switchgear, it was necessary to consider that many elements are either not materially affected by this change or the change can easily be handled by during the design and testing process. Therefore the same performance and reliability is expected in these areas. For example operating mechanism are essentially unaffected by gas type and sealing systems to prevent gas leakage can be designed for the new gas and the effectiveness tested.

2.3 420 kV GIS Development

The adoption of 420 kV GIS entirely without SF_6 represents a significant step in the development of the technology. Confidence was needed that the development would be completed intime for project execution.

Close collaboration between the user and manufacturer assisted with this – a large amount of information on the existing “research” testing was shared. The user supported the manufacturer in the application for the European Union (EU) LIFEGrid programme to perform this research in a collaborative way. This showed the benefit of users and manufacturers working collaboratively in improved development times – a topic discussed again at the CIGRE 2021 Session.

The development of the 420 kV fluoronitrile CB self-evidently presented the highest technical risk; it was shown a solution using an SF_6 CB could be accommodated, without change to basic GIS design, in the unlikely event the fluoronitrile CB was not ready. While not desirable, and with CO_2e implications, this reduced technical risk in achieving project deadlines for wider network upgrades.

As with reliability, confidence in the development was supported by published research and user’s own experience with the same technology. Some of this research is summarized in the later sections.

Overall there was sufficient information to demonstrate that development and testing would be completed within the project programme.

2.4 Operational Issues

The introduction of gas and gas mixtures other than SF_6 self-evidently imposes new operational challenges for users; while these are not to be overlooked, with correction mitigations, they do not prevent the adoption of SF_6 alternatives. Some of the mitigations are explain later in this document.

2.5 Overall Selection

Switchgear technology choice has typically been limited to air insulated switchgear (AIS) and SF_6 GIS. The advantages and disadvantages of each are well known.

As explained, the user had confidence in the ability to deliver 420 kV SF_6-free GIS, which would be reliable over the lifetime, in line with project timescales (with suitable risk mitigation). This allowed 420 kV SF_6-free GIS to be considered as a “third option”.

A holistic evaluation of each of the three technologies was performed – examining factors including site footprint, programme, cost, CO_2e impact and technical risk. The constraints of the site were such that GIS was preferable to AIS, but with SF_6 GIS the CO_2e impact of the SF_6 would be contrary to the above explained target to reduce this; the third option of SF_6-free GIS provided the benefits of SF_6 GIS but with a much-reduced CO_2e impact.

Hence the choice to implement SF_6-free GIS as opposed to other technologies. There was some inherent technical risk in this choice, but it was felt that these are adequately mitigated and offset by other benefits.

Fundamental to successful implementation of this selection was an adequate technical specification for SF_6 alternatives, taking account of existing experience; this is explained in the next section. Specific maintenance and condition assessment procedures are under consideration by the user.

3 LESSONS LEARNT FOR SPECIFICATION

The user has already installed 145 kV GIS, 145 kV AIS and 420 kV GIL without SF_6 on its network; the lessons learnt from this have been incorporated into specifications for the procurement of more recent fully and partially SF_6-free switchgear. The main topics are as follows:

3.1 Environmental requirements

Aligned to section 2, the user's specifications state a requirement for gases or gas mixtures used in all new switchgear to have a GWP of less than 1000 – making SF_6 switchgear no longer specification compliant. A GWP of 1000, which applies to mixtures as used in service, was selected to permit all known SF_6 alternatives available or immediately foreseen. While each of the alternatives have some inherent advantages and disadvantages, there is at present insufficient information to allow a objective comparison between these technologies within the scope of a specification.

3.2 Technical requirements

The user's specifications build upon international standards; mainly IEC 62271 series. It is recognized that while the majority of the standards are not related to gas type, some parts of these standards do not fully address the requirements of gases and gas mixtures other than SF_6 [4], as they were written either explicitly for SF_6 or based on knowledge related to SF_6. This is typical of the introduction of any new technology and the development of is progressing at a good pace. However, several specific gaps were identified and included in the specification:

3.2.1 Cable terminations

It is readily apparent that type testing a cable termination immersed in SF_6 does not demonstrate its performance in a gas other than SF_6. As these tests are, in general, performed by the cable system supplier it is necessary to mandate the cable system supplier performs these tests with a gas or gas mixture representative of the one to be used in service. This is example of the, CO_2e reduction driven, change in the switchgear impacting upon the scope of another manufacturer.

On technical review it was determined that repetition of the full suite of tests required by standards (IEC 60840 / IEC 62076) was not necessary to transfer the homologation of the cable termination from SF_6 to an alternative gas. It is not necessary to repeat tests intended to stress the cable termination. As such, a reducing type testing regime, principally consisting of dielectric tests (including partial discharge) and a single heating cycle voltage test, is required.

3.2.2 Electrical endurance / gas mixture composition

Asset owners rely extensively on type testing according to applicable standards to demonstrate the performance of network equipment. For SF_6 gas filled switchgear the approach of testing at the minimum functional pressure is well proven and defined in standards. However, for alternative gases, the gas composition is slightly changing during the lifetime of the products and this phenomenon needs to be considered during the development and testing of the switching devices [4]. Hence the introduction of new terminology like gas (mixture) composition for normal operation and gas (mixture) composition for type-tests. CIGRE working group A3.41 "Current Interruption in SF6 alternatives" is expected to publish more information on this topic and a new CIGRE joint working group JWG B3/A3.60 "User guide for non-SF_6 gases and gas mixtures in Substations" has been set up and is working to further clarify these aspects.

At this stage it is necessary for users to require manufacturers to demonstrate that the conditions used for type testing adequately represent the worst-case operating condition, including any allowable tolerances on the ratios of gas in the gas mixture. This topic will require continued attention as more knowledge is gathered.

3.2.3 Dielectric performance below minimum functional pressure

It has been established custom and practice for the user, and other UK network owners, to require that SF_6 switchgear can withstand rated voltage at atmospheric pressure of SF_6 (0 bar gauge). It is known however that SF_6-free switchgear, regardless of gas used, cannot meet this requirement without a dramatic increase in equipment dimensions and this requirement has subsequently been relaxed. This requirement could be relaxed as it is not considered as an operational requirement (any equipment operated at lower pressure than minimum functional pressure puts the equipment at risk and must be de-energized as soon as possible).

3.2.4 Parameters not subject to change

It is to be expected that new switchgear is designed to meet the requirements of international standards. It is therefore necessary for users to define any requirements that are beyond those stated in these standards. Use of SF_6-free GIS does not change this – with the development of any new product this is an essential requirement – however, these topics become particularly important where users are engaged earlier in the development process. It is also important for users to avoid “over specification”, ie requirements that are not technically justified. Examples of two topics considered in the user’s specification are:

- Service continuity – maintenance, repair and extension (MRE) levels – the same level is required in SF_6-free GIS; this is stated in specifications and manufacturers are required to demonstrate that it is achieved during the design stage. The user has continued to define this using historic practices but intend to update to align with CIGRE B3.51 and the next revision of IEC 62271-203 which will better clarify these requirements.
- Specific ratings or duties linked to network requirements – due to the design of the user’s network the required induced switching rating for earthing switches is well in excess of the standard class B requirements stated in IEC 622271-102. This is stated in the specification so manufactures design and test their product accordingly.

3.3 <u>Monitoring requirements</u>

As SF_6-free GIS is a new technology, the user has decided to fit all installations with the most comprehensive available online monitoring. Hence the specification mandates the provision of continuous online monitoring of gas density (GDM) and partial discharge (PD).

GDM is installed to allow early detection of leakage and suitable intervention. It is important to note that while the CO2e impact of SF_6-alternative leakage is lower than SF_6 it is not always zero and, even in cases where it is, there are still implications for network availability.

PD monitoring is a proven technique for early detection of defects within GIS. For established SF_6 GIS the installation of continuous monitoring is not always justified on a cost-benefit analysis, but for new technology it is considered appropriate. It is recognized that available research into PD in gases and gas mixtures other than SF_6 is limited, however early research shows that PD technic is effective [5]. Further research in this area is considered valuable.

3.4 <u>Operational requirements</u>

Management of the variety of different gases and gas mixtures used in switchgear now available is a key operational challenge for users. This is further discussed in section 5. While consensus at both national and international levels is beginning to develop, there are currently no defined standards to govern this and it is therefore critical to define requirements within specifications, including:

- Unique identification of mixtures – specific names that identify each mixture individually, rather than reliance on manufactures’ brand or trade names
- Labelling – explicit requirements to include all the details of the gas or gas mixture used, eg what gases and in what ratio.
- Mandating types of filling point – the user, after consultation with switchgear and gas handling equipment manufacturers, have defined the requirements shown in Table 2-1 and included this into specifications for all applicable equipment. Currently there are multiple different SF_6 connections; SF_6 has been added to this table with the intention that this is standardized for future installations.

In addition, the use of gases other than SF_6 introduces some other operational challenges that needed to be addressed in the specification, such as:

- Provision of handling equipment, leakage detection equipment etc
- Option to obtain gas mixtures in pre-mixed cylinders – key operational need
- Requirements for information to be supplied on gases other than SF_6, eg details on: storage of the gas or gas mixture; availability now and future; recovery; disposal (preferably via an environmentally friendly process).

Table 2-1 – Requirements for Gas Connections

Gas / Gas Mixture	**Colour**	**RAL**	**Connection**
SF_6	Pure Orange	2004	DN8 with M26 thread or DN20 with M45 thread
N_2 / O_2 mixtures	Light Blue	5012	DN20 with M50 thread
Mixtures containing C4-FN (C_4F_7N)	Yellow Green	6018	DN8 with M28 thread or DN20 with M48 thread
Mixtures containing C5-FK ($C_5F_{10}N$)	Telemagenta	4010	DN8 with M24 thread or DN20 with M43 thread
CO_2 / O_2 mixtures	Dusty Grey	7037	Malmquist valve with M32 thread

3.5 Health requirements

The potential health risks associated with equipment are the most important concern on network operators. The risk associated with SF_6, including in its arced decomposition form, are well known; but as alternatives are introduced it is necessary for users to assess the implications of these from a health perspective. One part of this to ensure manufacturers supply necessary information; key parts being:

- Classification under CLP regulation (Classification, labelling and packaging; European Regulation (EC) No 1272/2008).
- Acute toxicity level.
- Safety data sheet covering non-arced, normally arced and heavily arced gas (ie containing decomposition products) and including as a minimum PPE required and emergency procedure.

4 DEVELOPMENT 420 KV GIS

4.1 Gas selection for the GIS

Before starting the development of the GIS product, the selection of the gas if of prime importance. First SF_6-free solutions based on fluoronitrile gases were based on 4% fluoronitrile and remaining gas is CO_2 only for the GIL and based on 6 % fluoronitrile and remaining gas is 5% O_2 and remaining is CO_2 for 145 kV full GIS. In order to optimize the layout and performances of the new gas system, decision has been made to implement such solution. CIGRE papers [4] and [6] disclosed standardized fluoronitrile-based gas mixtures for different applications and product which have the same minimum operation temperatures. A 5% mol C_4F_7N / 13% mol O_2 / 82% mol CO_2 mixture is defined for -25°C application, therefore used for the development of the 420kV SF_6-free GIS.

4.2 Development of the GIS bay components

One of the major advantages of using alternative gas mixture based on fluoronitrile is to keep the overall dimensions of the GIS equipment as designed today with SF_6 gas. This gives real advantage for users as the architecture is very similar, accessibility is maintained and modular assembly in the factory is maximized. The complete footprint of a GIS substation based on fluoronitrile is similar to the footprint of the same substations based on SF_6.

As a result, GIS based on fluoronitrile may not have a negative impact on the complete environmental assessment as it can have with some other alternative gas solutions (where GIS dimensions are significantly increased for the 420 kV application). Section 4.4 gives an example of such assessment. To reach this equivalent GIS footprint, it is necessary to design a product with enclosures having the same size as the current one. An appropriate mixture has been determined to meet this objective while respecting technical requirements (dielectric strength, thermal capacity, switching performances, minimum temperature, pressure scale comparable to SF_6). Some adjustments are necessary on active parts design to fulfil dielectric design criteria. Only the GIS circuit breaker (CB) cannot have same dimensions as for SF_6. Indeed, to achieve the high 63 kA breaking performances, a double chamber design is required and so its length is more compared to current SF_6 mono-chamber CB.

Even though compartments have the same size as for SF_6, an architecture optimization has been done to compensate the CB size and keep an equivalent if not lower GIS footprint (depending on the single line diagram selected). This optimization has been studied in several single line diagrams arrangements. Figure 4-1 shows a simulation of Kintore substation with SF_6 and C4-FN mixture products has been made. An equivalent GIS footprint is obtained. This new architecture has been chosen to keep GIS footprint and at the same time a high level of accessibility and ergonomics for operation, maintenance and repair. Drives, gas filling valve, gas monitoring, disconnector/earthing switch viewing windows and control cubicle have been modelled in CAD and their accessibility checked. Coworking with the user has validated this.

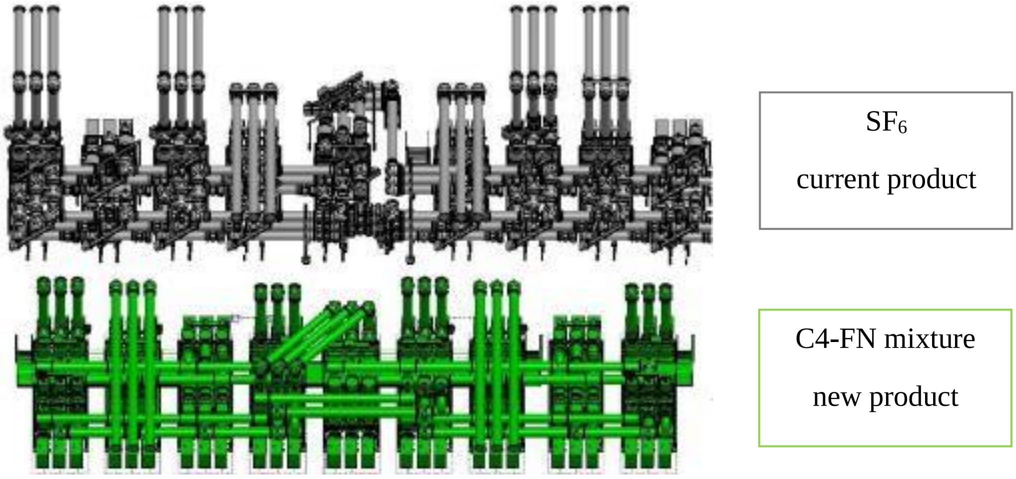

Figure 4-1 – Kintore substation simulation with SF_6 and C4-FN mixture products to the same scale

Once general dimensions and architecture had been chosen for this product, an investigation test campaign is mandatory to check performances and capability. For the following C4-FN GIS components, the tests have been passed in accordance with latest IEC standards; Figure 4-2 gives an overview of two of these tests. More details on the development of GIS components are given in [7].

- GIB: Dielectric strength; temperature rise for 4000 and 5000 A; internal arc for 63 kA
- Disconnector: Bus transfer current switching and bus charging current switching
- Fast earthing switch: Induced current switching; short-time current withstand; short-time current making proof

Figure 4-2 – 420 kV GIS devices during dielectric test (left) and bus transfer test (right)

4.3 Development of the GIS circuit-breaker

A key technical challenge with introduction of 420 kV SF_6-free GIS is the development of the 420 kV CB having full performance required at this voltage level. This part of the paper details the approach followed to selection the different technologies that enable the requirements to be fulfilled.

One by-product induced by power arc interruption originated from CO_2 decomposition is solid graphite. This solid graphite could lead to equipment failure due to its conductive properties. Investigations showed that the addition of O_2 inside the gas mixture leads to the removal of the graphite from the solid by-products induced by switching, ensuring the equipment reliability [8] [9] . CO_2 and O_2 content in the mixture could lead to contact corrosion by the presence of oxygen. As traditionally implemented with SF_6 technology, silver plating on permanent contact for current flowing avoids contact corrosion [10].

To accelerate the development of high voltage SF_6-free switchgears, the European Commission is currently funding the development of the fluoronitrile based 420 kV 63 kA GIS CB under its LIFE Climate action program called LIFEGrid (LIFE18 CCM/FR/001096) aiming at the completion of the 420 kV 63 kA GIS CB. This highlights EU confidence in fluoronitrile technology [11].

Revised CIGRE 2021 paper [4] disclosed that recent research demonstrates the single break interrupter capability at 245 kV 63 kA using standardized gas mixture. This was already a major step towards the full high voltage deployment of the gas mixture. 420 kV CB uses double-break technology and is taking benefit from the progress obtained on 245 kV 63 kA single break performances. Thanks to grading capacitors, all the breaking capability performances demonstrated at 245 kV are scalable for the 420 kV application, ensuring a good confidence for the completion of the 420 kV CB. The following table gives the tests performed on 245 kV CB solutions and validating the performance at this level and opening the door to achieving the performance at 420 kV level.

Table 4-1 – Tests performed on CB

	Making	LC/CC	OP2	T10	T30	L75	T100a	T100s
245 kV single-break breaking capability	✓	✓	✓	✓	✓	✓	✓	✓
420 kV double-break breaking capability using grading capacitor	✓	✓	✓	✓	✓	✓	✓	✓

✓ (green)	Demonstrated breaking capability
✓ (yellow)	Extrapolation

420kV breaking capability will then be re-demonstrated in 420 kV double-break full-scale relevant mock-up. Full dielectric performance according to IEC62271-203 has already been demonstrated with margin (see Figure 4-3). More details on the development of circuit-breaker are given in [7].

Figure 4-3 – CB dielectric test

4.4 EHS assessment of the 420 kV GIS solution

First EHS aspect to consider is the toxicity of the gas mixture based on the fluoronitrile for new and used gas. The acute toxicity level of new and arced gas was determined with the LC50 4h on mice (females and males) according to OECD 403 “Acute toxicity inhalation guideline” [12] . The test was performed by Laboratoire de Pharmacologie et de Physiopathologie Expérimentales – CNRS UMR

5247 at the University of Montpellier, France. Both new and arced C4-FN mixtures were not classified in a hazard class according to the CLP regulation due to its low toxicity [13] [8].

Second aspect of EHS is the eco-design and life cycle assessment. As the main goal of SF_6-free alternative is to limit global warming, the solution provided shall demonstrate a significant CO_2e footprint reduction. The evaluation of the impact shall not be limit to the gas contribution but also to the complete CO_2e footprint of the solution. The C4-FN solution is providing 99% reduction on the gas contribution. To validate the efficiency of the solution regarding climate change mitigation, you must make sure that the technical solutions implemented on the GIS components are not jeopardizing the benefit of the gas. For instance, a GIS using lower dielectric performance gas, like technical air, may have a degraded global life cycle assessment compared to a solution using fluoronitrile with same size of GIS compared to SF_6. This was demonstrated with papers comparing the life cycle assessment of 145 kV GIS [14] and 145 kV DT [15]. The benefit on climate change should not be taken as a single indicator of good environmental performance.

For this full 420 kV GIS, the complete life cycle assessment will be performed when product development is completed. However, based on previous studies performed on 420 kV GIL and 145 kV GIS, summarized below, we can already estimate the benefit on climate change indicator will be similar and there will be no degradation of other indicators. Some specific work is also done to limit total sealing length, hence limiting the possible operational constraint linked to tightness of GIS.

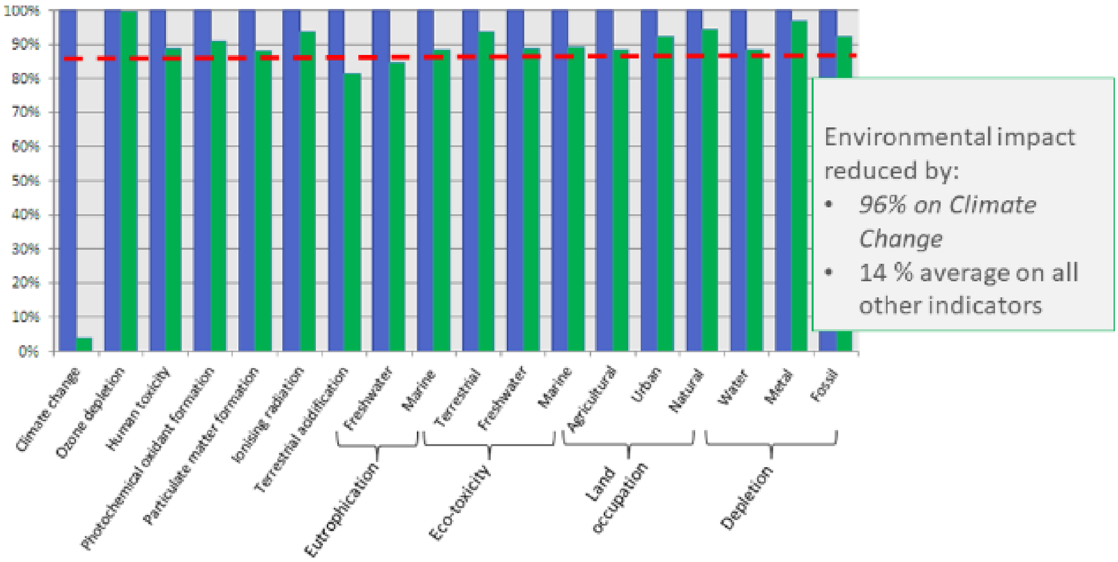

Figure 4-4 – Life Cycle Assessment (LCA) comparison for GIL 420 kV – SF_6 in blue versus C4-FN mixture in green

Table 4-2 – GIS 145 kV Life Cycle Assessment

	SF_6 GIS	Equivalent SF_6-free GIS
Gas mass (kg)	374	178
Gas loss over 40 years (kg)	30	14.3
CO_2 equivalent of 1 kg gas (t)	23.5	0.46
CO_2 equivalent of the bunkered gas (t)	8796	82
CO_2 equivalent of the gas loss (t)	704	6.6

5 GAS HANDLING

The identification and handling of various gases and gas mixtures – still including SF_6 – is a key challenge to asset owners and operators. Since first installation in 2016, some significant experience has been cumulated with various types of components installed and various types of tools developed or adapted to facilitate the first filling and also the end-user life when handling different gases.

5.1 Gas filling

As detailed in previous sections, the GIS and GIL equipment based on fluoronitrile alternative gas looks very similar to the GIS and GIL designed for SF_6 (footprint, access, installation, operation, etc.). The significant change between the two technologies is related to the gas handling. Users are used to handling only one gas, SF_6, for all high voltage and medium voltage equipment. With alternative gases, manufacturers are developing solutions based on different gases and based on different gas composition for the same gas mixture (linked to type of equipment and performances). As a consequence, end-users will have to manage various gases in their assets; slightly increasing complexity compared to only SF_6. Manufacturers had this constraint in mind from the beginning and decided to work closely with two partners and experts in gas handling: one who has a long and worldwide recognized expertise in tools for handling SF_6 gas for HV equipment and another who has a worldwide expertise in handling specific gas mixtures, like the ones containing CO_2.

For past applications of gas mixture based on SF_6, like SF_6 and N_2 mixtures used for GIL, gas mixing was performed on site using a specific gas mixer. This equipment was not that simple to use on site and required the separate delivery of each gas contained.

For the gas mixture made of fluoronitrile, CO_2 and O_2, the manufacturer has taken the decision not to mix components on site, but to bring directly to site already pre-mixed gases in containers like B50 bottles or C500 containers (as shown in Figure 5-1). Due to the specific properties of the gas mixture, specific gas carts for filling and recovery have been developed with the partners.

Figure 5-1 – Gas mixture delivery to site in pre-mixed B50 bottles or C500 containers

Due to the nature of the CO_2 buffer gas, homogeneity of the gas mixture needs to be ensured to meet the ratio requirement between the fluoronitrile and the CO_2. This is achieved through heating of the bottles to bring the gas mixture in the supercritical phase where all gases can be well mixed together. This is one significant change compared to handling SF_6 bottles where heating was required only in case of specific cold climate conditions.

For the first 420 kV GIL pilot project at Sellindge in England, about 40 bottles of B50 type have been used; more than 750 kg of C4-FN mixture. This represented a total of about 38,000 liters distributed in 15 compartments from 120 liters to 4600 liters. GIL equipment was filled with ambient outdoor conditions around 10 to 15°C. The process was slightly longer than with SF_6 as heating is required [16].

The second GIL project in service is in the south of Scotland, at Kilmarnock substation. This is a new substation developed with three GIS bays. On one bay has SF_6-free GIL solution, like the one used at Sellindge. During the installation of this second GIL, weather conditions were less favourable with heavy rain, snow, wind and temperatures below 0°C. Gas filling from 30 bottles (more than 600 kg of gas) was done successfully using the same filling gas cart as used for the first application. Despite the more severe weather conditions, similar filling duration where recorded which confirmed the process of filling whatever the ambient conditions [4].

The next two projects were in Scotland for the same user, at New Deer and Fort Augustus; both substations are energized. Compared to the first two GIL projects, these two projects have high quantity of gas mixture, as all feeders connected to overhead lines have been filled with alternative gas, totalling more than 1500 meters of GIL. For instance, New Deer has 63 compartments, containing more than 2400 kg of gas. To speed-up gas handling, gas mixture was delivered in C500 containers.

The gas cart has the facility to handle such containers and it was used at New Deer for the first time.

After finetuning of the equipment parameters, the gas filling operation was performed with the flowrates as expected and gas quality (percentage of fluoronitrile gas) was as per criteria and measured using the commercially available gas analysers.

Figure 5-2 – 420 kV substations at New Deer (left) and Fort Augustus (right)

5.2 Users Operational Approach

Like most utilities, the user, has well established practices for the handling of SF_6. Handling equipment is readily available at all sites with SF_6 GIS and most operational staff trained and certified in its use. Initially the approach to alternatives to SF_6 has been similar.

However, from initial experience, it has become apparent that the adoption of alternatives to SF_6 requires a rethink of this approach – this is still evolving as experience increases and more sites are equipped with SF_6-free switchgear. However, the increased cost and complexity of handling equipment for SF_6-alternatives, including C4-FN mixtures, and inherent complexity in handling the various mixtures means that it may be more appropriate to have fewer sets of equipment, stored in strategic geographic locations, and specialist “gas handling” teams. This approach will be coupled with continuous GDM to allow for planned interventions rather than a wholly reactive approach.

This has to be supported by increasing general awareness in the different technologies. There is broad support for CO_2e reduction and changes to operational approach are recognised as needed for this.

5.3 Manufacturer solutions to facilitate gas handling

The manufacturer has from beginning implement some specific precautions to avoid confusion between C4-FN mixture and SF_6, like specific M48 thread on filling valve with specific green cap colour. We are now working on additional solutions to ease gas handling in future and to address the user’s expectations as detailed in previous section. The two main areas are:

- Development of a training programme on the different tools to be used
- Development with gas cart manufacturers of a technical solutions to limit the risk of wrong operation like the use of specific QR code and labelling for the different gas mixtures.

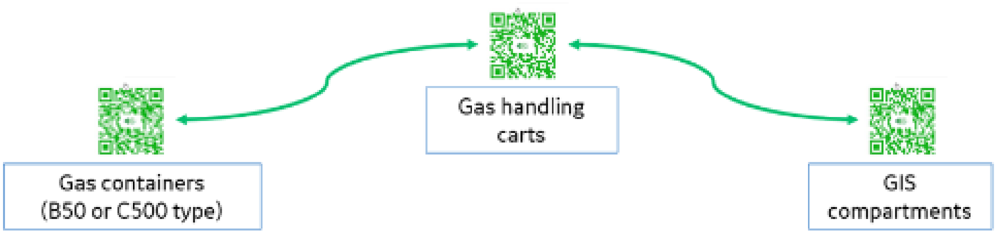

Figure 5-3 - Principle of QR-code based identification

6 CONCLUSION

The case for reduction in CO_2e emissions to limit climate change is clear. Electricity transmission has a key role to play in this: not just by transmitting low carbon generation from centers of generation to centers of load, but also by transmission system owners reducing our own CO_2e emissions. Reduction in the use of SF_6 has a significant part to play in this reduction.

The first generation of 420 kV GIL and 145 kV GIS using $CO_2/O_2/C_4F_7N$ gas mixture have been in service since 2017 and are giving positive feedback. Next step for adoption of SF_6-free high voltage equipment is the full GIS at 420 kV and 63 kA performance where quantities of SF_6 are high. Manufacturers are now working actively at this voltage level and have taken commitment with some users to deliver suitable solution to help them reducing their environmental impact. The recent positive tests on circuit breaker 245 kV 63 kA single break are demonstrating the scalability of the $CO_2/O_2/C_4F_7N$ gas mixture to the 420 kV 63 kA level.

For 420 kV SF6-free GIS is now an option that users can select – providing the known advantages of SF_6 GIS but with a much reduce CO_2e impact.

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