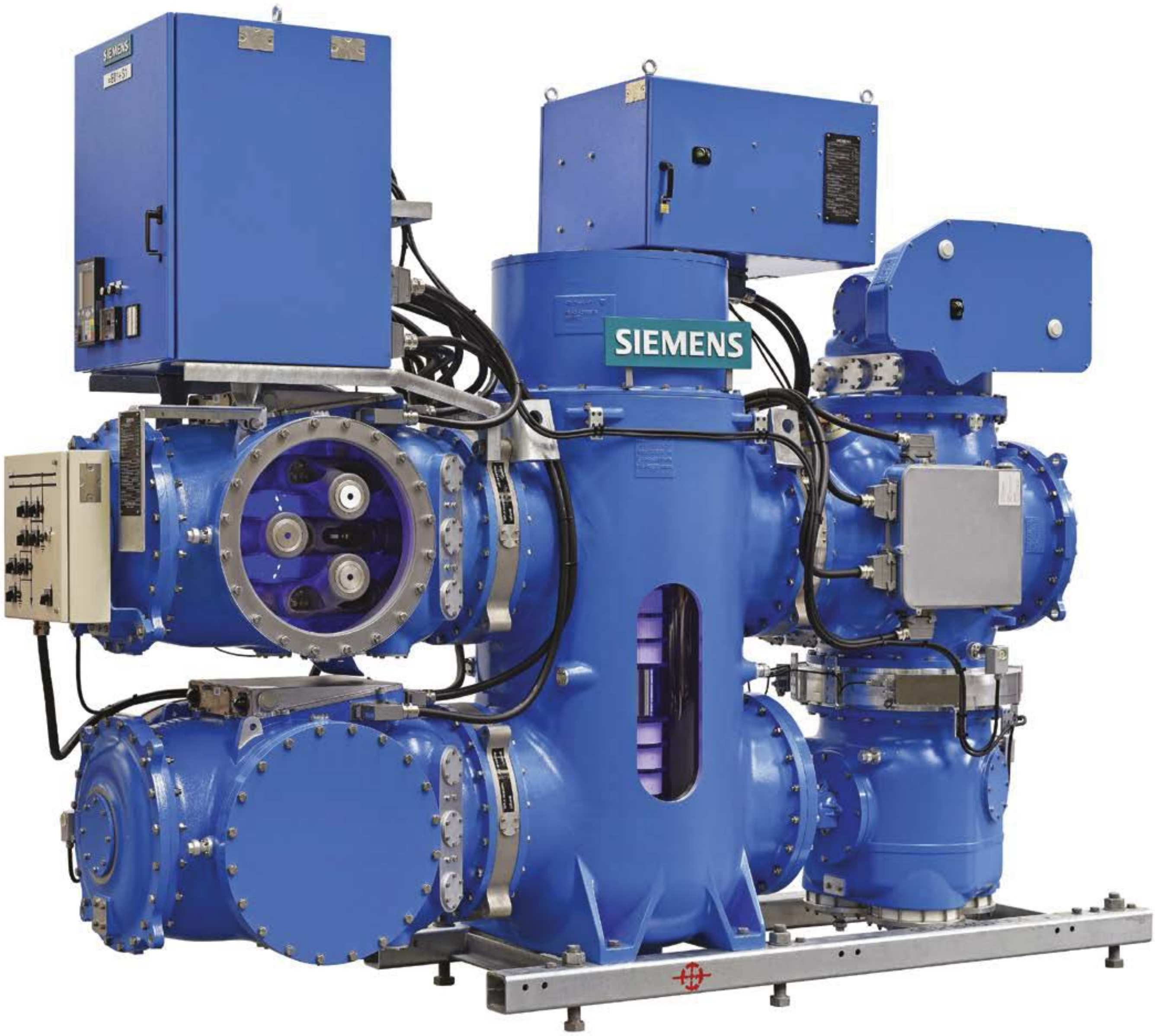
SF_6, the most commonly used arc extinguishing and insulating gas in gas-insulated switchgears, is a greenhouse gas with high global warming potential, requiring careful handling throughout its life cycle



ABSTRACT

SF_6, the most commonly used arc extinguishing and insulating gas in gas-insulated switchgears (GIS), is a greenhouse gas with high global warming potential, requiring careful handling throughout its life cycle. In order to reduce the GIS-related global warming impact, innovative solutions using alternative gases have been developed by different manufacturers, especially the blue GIS from Siemens – available for 145 kV / 40 kA / 3150 A – with clean air insulation and vacuum switching technology shows many technical advantages.

KEYWORDS

High voltage gas-insulated switchgear, GIS, vacuum interrupter, clean air, SF_6 alternatives

Technically advanced and SF_6-free 145 kV blue GIS

Clean air- and vacuum-based interrupter technology

1. Introduction

Today, SF_6 is by far the most globally used medium for arc extinguishing and insulating gas in high-voltage switchgears. Its excellent technical properties have been proven in high voltage applications for more than 50 years.

SF_6 requires careful handling throughout its life cycle to prevent gas leakage into the atmosphere, as it is a high global warming potential (GWP) greenhouse gas with a very long lifetime.

In order to improve the sustainability of the energy supply and to reduce the GIS-related global warming impact, research on SF_6 alternative solutions have been worked on internationally for years [1-12].

The alternative solutions offered today are clean air, CO_2 and fluoroketones or fluoronitriles, with mixtures of N_2, O_2 or CO_2, which are used as arc extinguishing and insulating media. On this basis, different products were developed, and first grid applications were started. Consequentially, the first modified draft of the IEC 62271-4 (Edition 2 / CD from 04/2019, [20]) including SF_6 alternatives gases has been worked out and is currently in distribution.

In this article, the status of the alternative solutions is summarized from the high-voltage switchgear point of view. On the other hand, the SF_6-free 145 kV blue GIS 8VN1 based on clean air and vacuum switching technology is also represented.

2. Status and evaluation of the SF_6 alternative gases

The alternative gases available today and their main properties, as well as pros and cons, are discussed in different papers, e.g. [1 - 12]. The decision to use clean air as insulating gas is grounded upon the following core clean air facts:

Clean air in high voltage application consists of 80 % N_2 and 20 % O_2, is cleaned from CO_2 and almost free of moisture (synthetic air). Clean air has neither global warming potential ((GWP) = 0) nor ozone depletion potential ((ODP)) = 0).

Clean air is extremely stable, whereas SF_6 alternative fluorinated insulating gases have a lower long-term stability and a higher tendency of irreversible decomposition under the influence of electric arcs [2, 3]. Under the influence of electric arcs, e.g. when switching bus transfer current (BTC), or switching busbar commutation currents with circuit breakers, partially fluorine-containing gaseous decomposition products such as hydrogen fluoride, cyanogen and carbon monoxide could be detected. If solid decomposition products with a high proportion of carbon are deposited on insulating parts, the voltage stresses can lead to arcing of the insulating surface and finally to a reduction of the dielectric surface strength. In addition, the fluoronitrile content is reduced from e.g., 4.7 % to 3.6 % [13]. Although design measures can be taken to minimise spark formation and soot formation, the proof of long-term stability must be provided in the pilot applications.

The decomposition products must also be taken into account, with regards to environmental protection and health and safety at work. Only with clean air are there no toxicological aspects to consider when operating switchgear. For the fluorinated alternative gases, cost-relevant additional measures regarding environmental, health, and occupational safety reasons must be taken into account [13, 19].

Not only do the SF_6 emissions play a role regards to the global warming impact, but to a lesser extent, the dimensions and/or the material input and the GIS design (e.g. gas tightness) is important as well. Over the last few decades, improvements have primarily been achieved through reduced gas quantities, less material, no welding and design related lower leak rates of CO_2-eq. Consequently, the greenhouse impact caused

In order to reduce the GIS-related global warming impact, innovative solutions using alternative gases have been developed by different manufacturers

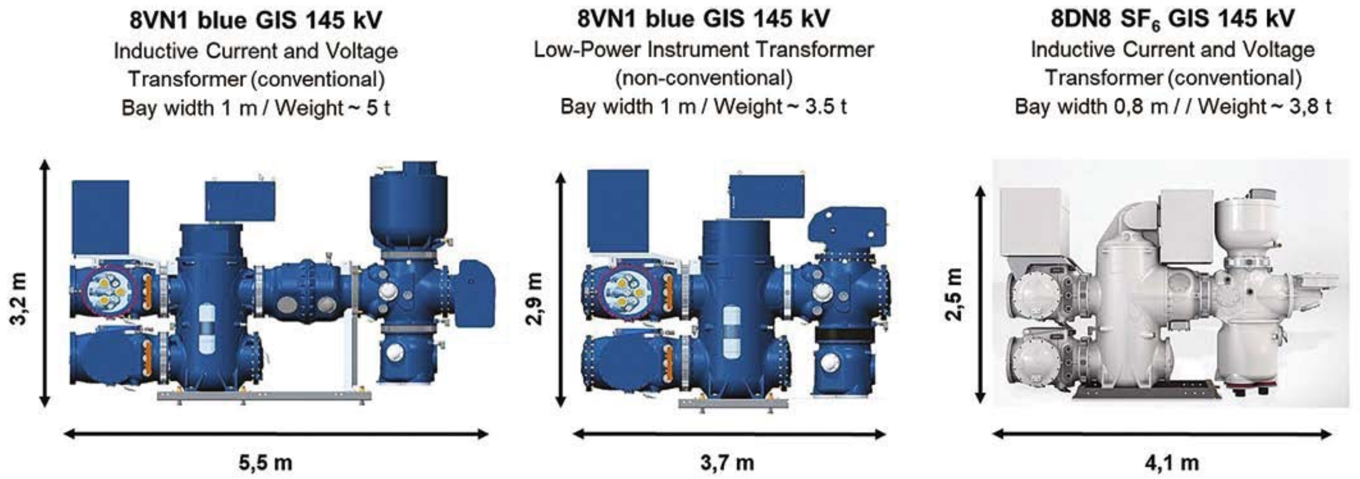


Figure 1: Impact of clean air and LPIT to size and weight of a typical 145 kV GIS bay

Siemens' blue GIS, available for 145 kV / 40 kA / 3150 A, with clean air insulation and vacuum switching technology shows many technical advantages

by GIS could already be significantly reduced today by replacing the old inventory with modern SF_6 GIS facilities. Further reductions can be achieved by using non-conventional measurement methods (LPIT: low-power instrument transformer) for current and voltage measurements. The LPIT has been extensively tested and all relative type tests have been carried out without any objections. The functionality of this technical solution was successfully confirmed in various pilot applications [14]. Against the background of digitalisation, there has been a noticeable increase in interest in both the LPIT and Sensgear® [15, 18] solutions, which is expected to continue. The LPIT application is a successful countermeasure to reduce the slightly larger GIS dimensions because of the weaker dielectric strength capabilities [e.g. 1 - 4] of clean air compared with SF_6, Figure 1.

The basis for clean air as an insulating gas is through the use of vacuum switching technology for short circuit interruption. Vacuum switching has been used successfully for more than 40 years [13]. It is characterized above all by its constant properties over the entire life cycle. The vacuum interrupter tube is hermetically sealed and excludes any external influence. On the other hand, environmentally damaging decomposition products do not occur in the vacuum. Further advantages result from the lower burning voltage and energy conversion in the switching path as visible in Figure 2. The shorter arcing time (around 5 ms faster than in SF_6) results in less wear of the contacts, resulting in less material erosion and more nominal and more short-circuit current switching capabilities (up to 30, with SF_6 usually up to 8).

The high performance and proven vacuum switching paired with the clean air insulation allows the ecological footprint to be reduced to the highest safety level, without having to sacrifice performance and economy. For a customer in Norway, the overall CO_2 reduction was calculated resulting in an overall saving

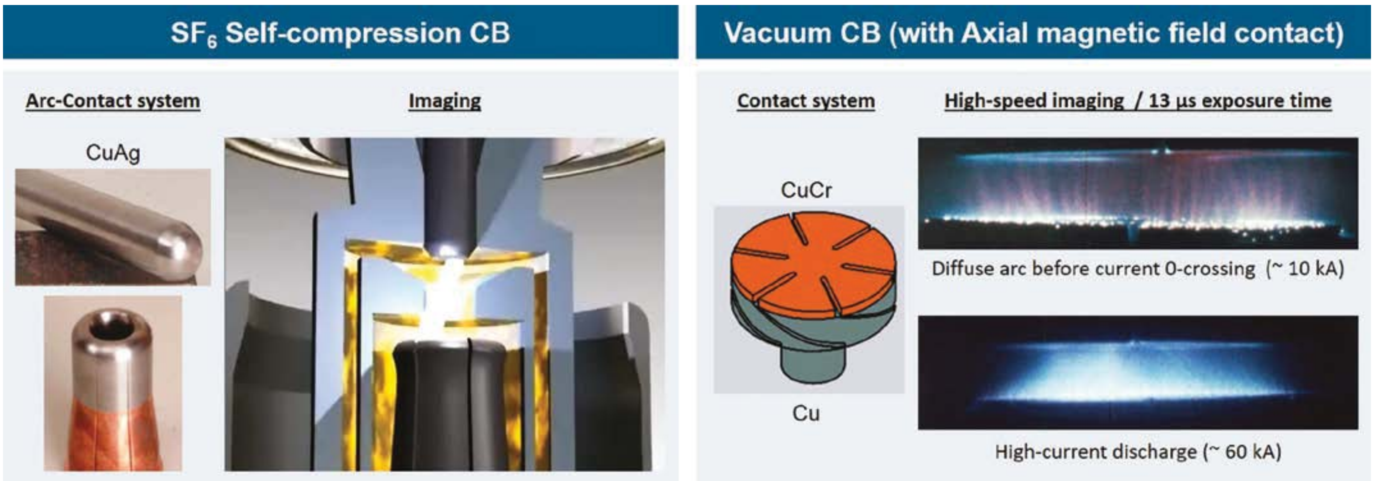


Figure 2: Comparison of arc behaviour in high voltage gas and in vacuum interrupter circuit breaker (CB)

of around 86 % CO_2-equivalent in comparison to nowadays used SF_6 GIS [17]. A lower CO_2-eq. impact can be also recognized in comparison to a comparable SF_6 GIS using Fluoronitrile instead of SF_6 as insulating gas, Figure 3. As an outcome for an average 145 kV substation with 7 bays, a total reduction of around 14 000 kg CO_2-eq. environmental impact can be achieved per year. In fact, this approximately corresponds to the CO_2 compensation of about 1200 adult beech trees.

Figure 4 summarises an overall assessment of the currently discussed SF_6 alternative solutions. It becomes obvious that clean air combined with vacuum interruption in total is an excellent alternative to SF_6. Beside the environmental advantage, it also has a technical performance improvement.

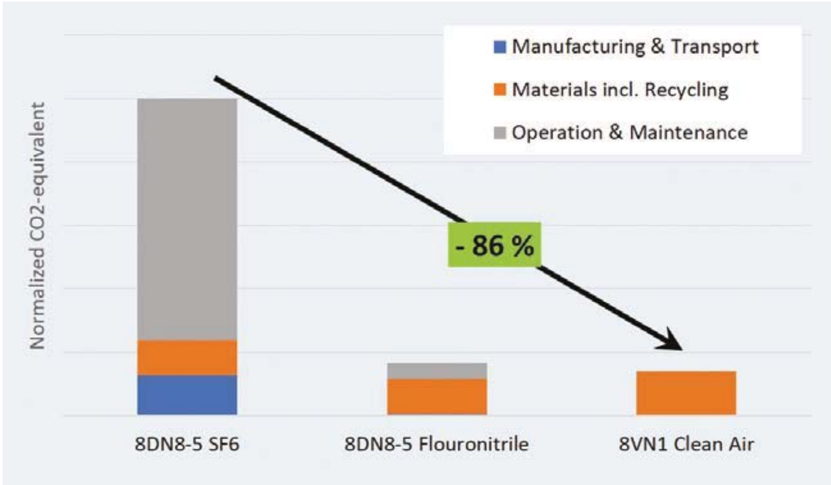


Figure 3: Carbon footprint for the entire life cycle based on LCA according to ISO 14040/44

Main boundary conditions: lifetime 50 years, 1 maintenance after 25 years, manufacturing/development gas losses 0.71 %, operational gas losses 0.1 % per year, maintenance gas losses 0.01 %, Norwegian energy mix (99 % renewables) -> almost no direct CO_2 impact from ohmic losses during operation, Clean Air = 80 % N_2 + 20 % O_2, Nitrile Gas Mixture = 4.6 % Novec4710 + 95.4 % CO_2

3. Concept / Qualification of 145 kV 8VN1 blue GIS

The basis of 8VN1 is the modification of an existing SF_6 product for 170 kV / 63 kA (8DN8). The product has a modular design and enables all customer-specific circuit requirements to be met, e.g. Figure 5 shows an exemplary, so-called, H configuration.

Despite the slightly larger dimensions compared to SF_6 due to the weaker dielectric performance of clean air, the advantages far outweigh the disadvantages

With extensive simulations based on finite element methods (FEM) being carried out, significant modifications have been made to the circuit-breaker by integrating the vacuum interrupter into the design. The vacuum tube was developed in such a way that it meets the requirements of outdoor circuit breakers and GIS for a short-circuit breaking current of 40 kA and a rated voltage of 145 kV even up to -50°C w/o liquation and specific additional measures (e.g. heating mats). All development, as well as all type tests according to IEC and IEEE including seismic IEEE tests, were passed w/o any objections [13].

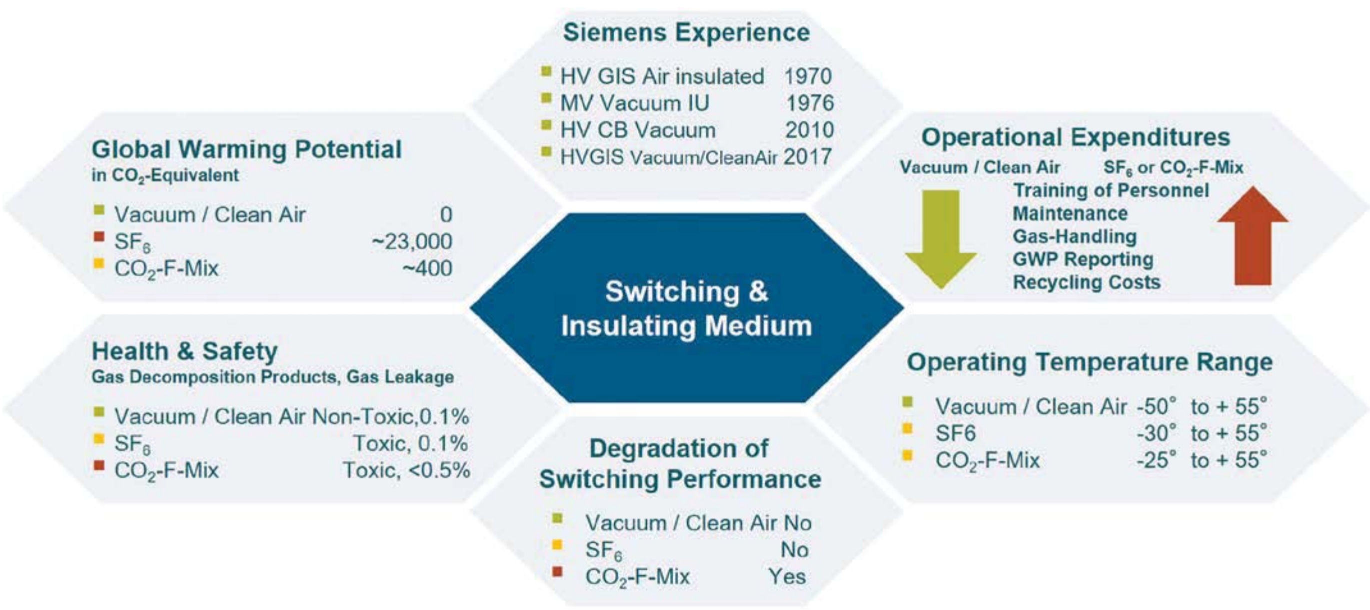


Figure 4: Summary of the advantages and disadvantages of currently discussed SF_6 alternative solutions

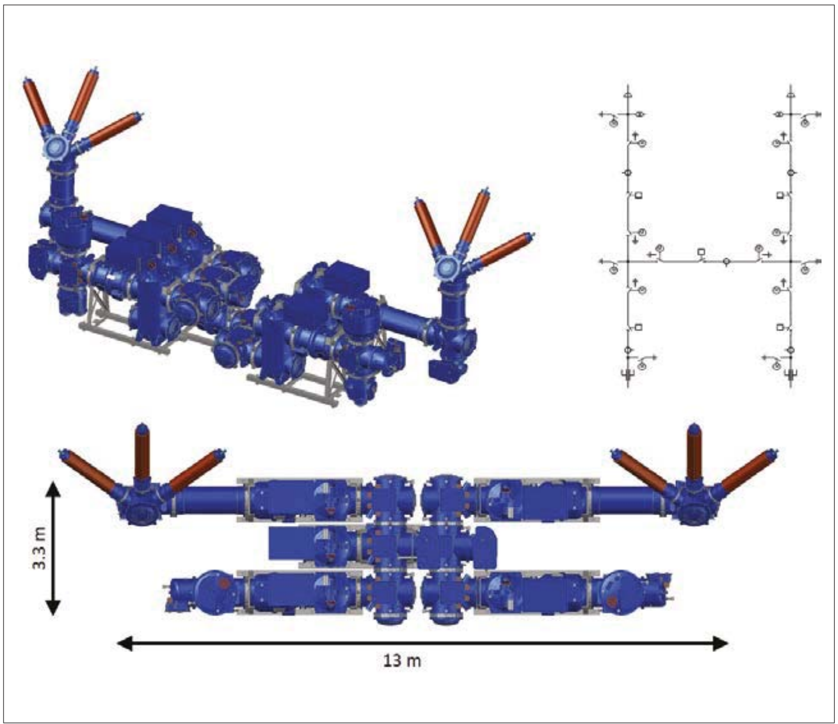


Figure 5: Modular design of 8VN1 using the example of an H-circuit configuration with conventional instrument transformers

Blue GIS is reliable, maintenance-free and long-term stable, hermetically sealed without any external influence, suitable for frequent switching, with excellent switching characteristics over the entire service life

Of special interests are the high-power tests. All switching conditions were safely mastered [16, 17]. This also applies to the inductive loads (e.g. choke). In particular, the following behaviour has been determined:

- The breakaway current of the vacuum switch is constantly independent of the arc time, with SF_6 it increases with increasing arc time.
- The maximum overvoltage due to current break for SF_6 and vacuum switch is in the same order of magnitude as for SF_6 and vacuum switch.
- Both switching media have a re-ignition-free window, which can be used e.g. with PSD (Point-on-Wave) switching.

8VN1 is the next clean air and vacuum interrupter-based product for high voltage applications. All operational experience with clean air and vacuum interrupter technology, in detail 72.5 kV GIS & Live Tank (LT) as well as 145 kV LT, facilitate quick easy on-site handling and high reliability as well as positive customer feedback. Meanwhile more than 900 bays of orders from different parts of the world have been placed, demonstrating a high confidence regarding the SF_6 alternative solution and leading to a reduction of around 2000 tons of CO_2-eq. impact per year.

The development of the technology continues. At last year's Paris Cigré exhibition, a vacuum interrupter for 245 kV / 63 kA respectively 170 kV / 50 kA was presented and first results were published [16].

Conclusion

Despite the slightly larger dimensions compared to SF_6 due to the weaker dielectric performance of clean air, the advantages far outweigh the disadvantages.

All in all, the 145 kV GIS 8VN1 fulfils the strict criteria to be marked as "blue" and offers many technical advantages:

- Sustainable, highly reliable with excellent long-term stability
- No fluorinated gases, use up to low temperature (-50 °C) without additional measures
- No greenhouse gas emissions during operation and all other handling processes such as maintenance or recycling
- Use of environmentally friendly materials
- Lowest operating, maintenance, and recycling costs (clean air can be released into the environment while F-gases are time-consuming to evacuate)
- No toxicological aspects during operation to consider
- No emission compensation costs over the lifetime of the device

Further advantages result from the use of vacuum switching technology:

- Reliable, maintenance-free and long-term stable, hermetically sealed without any external influence
- Suitable for frequent switching: high number of short-circuit interruptions with excellent switching characteristics over the entire service life
- Perfect for low temperatures, no liquefaction of the switching medium, no additional heating required
- No CO_2-equivalent emissions, switching medium (vacuum) with zero global warming potential

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