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WHITE PAPER

“Alternative Gases” and Gas Mixtures Part 1

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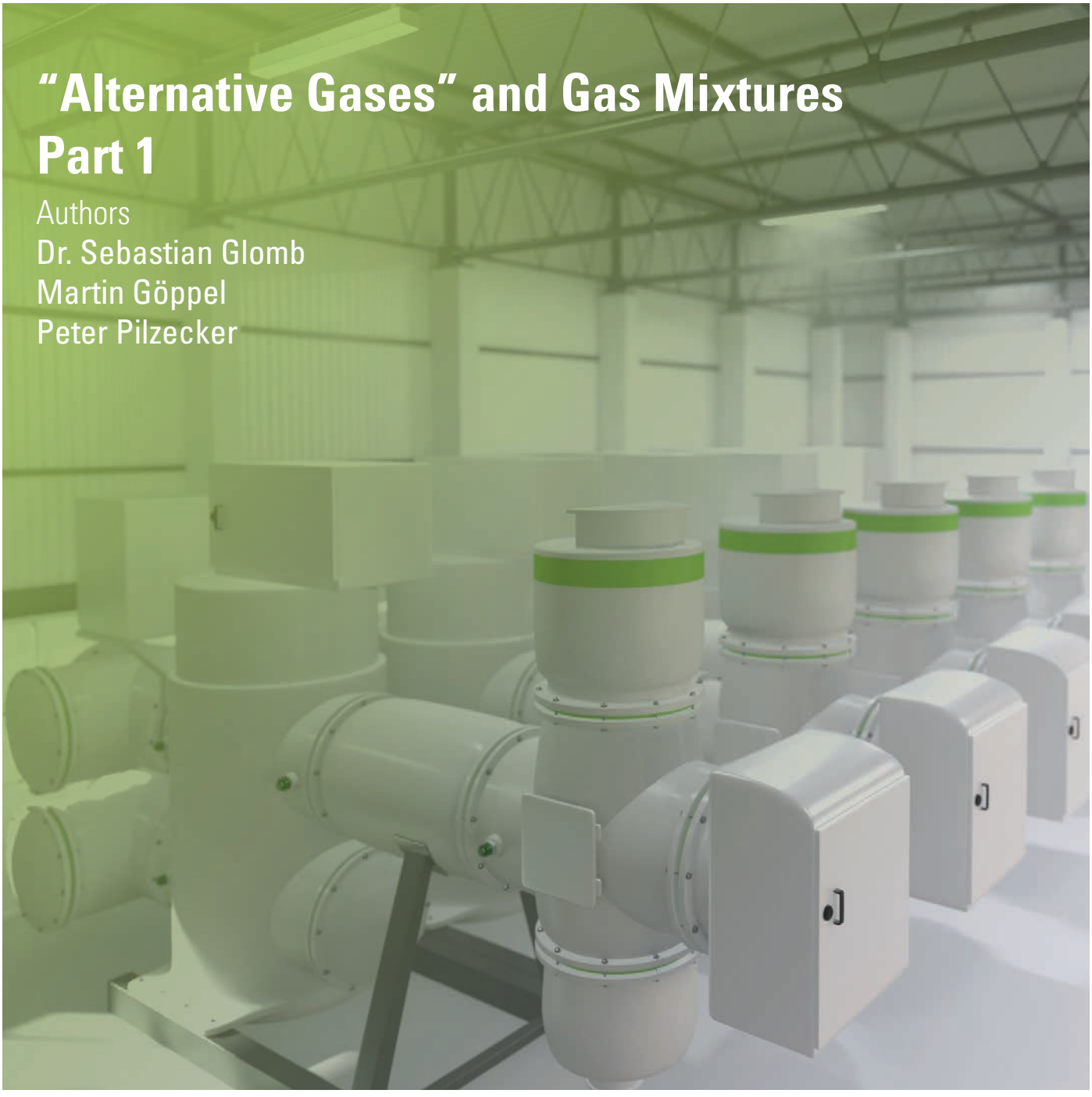

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Table of contents

Introduction:

Several editions of this guide will become available and will deal specifically with the problems and uncertainties that users and operators of SF_6 gas-insulated equipment are faced with. The problems and uncertainties are associated with changing from sulphur hexafluoride to new, Alternative Gas mixtures and the current, technical status of the implementation of Alternative Gas handling. Here you will get an up-to-date overview of Alternative Gas mixtures and reasons for the changeover in future editions. Special attention is paid to the mixing and availability of gas mixtures. Also, the handling, measurement, preparation and reconditioning, including regulatory requirements. Furthermore, insights are provided to what extent the life cycle of Alternative Gases is, comparable to that of SF_6 and how far this is already covered today.

1. Overview "Alternative Gases" and Gas Mixtures

Despite all the efforts, regulations and prohibitions in the use of sulphur hexafluoride gas (SF_6) (prohibited to use in car tyres, windows and trainers; compulsory certification for the handling of SF_6 gas in switchgear etc.), the proportion of SF_6 in the atmosphere has risen continuously worldwide to over $10 \cdot 10^{-12}$ mol·mol^{-1} (Figure 1).[1]

Although the amount of SF_6 seems low compared to the total carbon dioxide (CO_2) in the atmosphere (~$400 \cdot 10^{-6}$ mol·mol^{-1}), SF_6 has a high global warming potential (GWP) value of 22,800 over 100 years compared to CO_2 due to its longevity (3200 years). This means that each kilogram of SF_6 released over a period of 100 years is just as harmful to the environment as the release of 22.8 tonnes of CO_2. In Germany, the SF_6 emissions in CO_2 equivalents currently are about 0.5 % of the total emissions.[2]

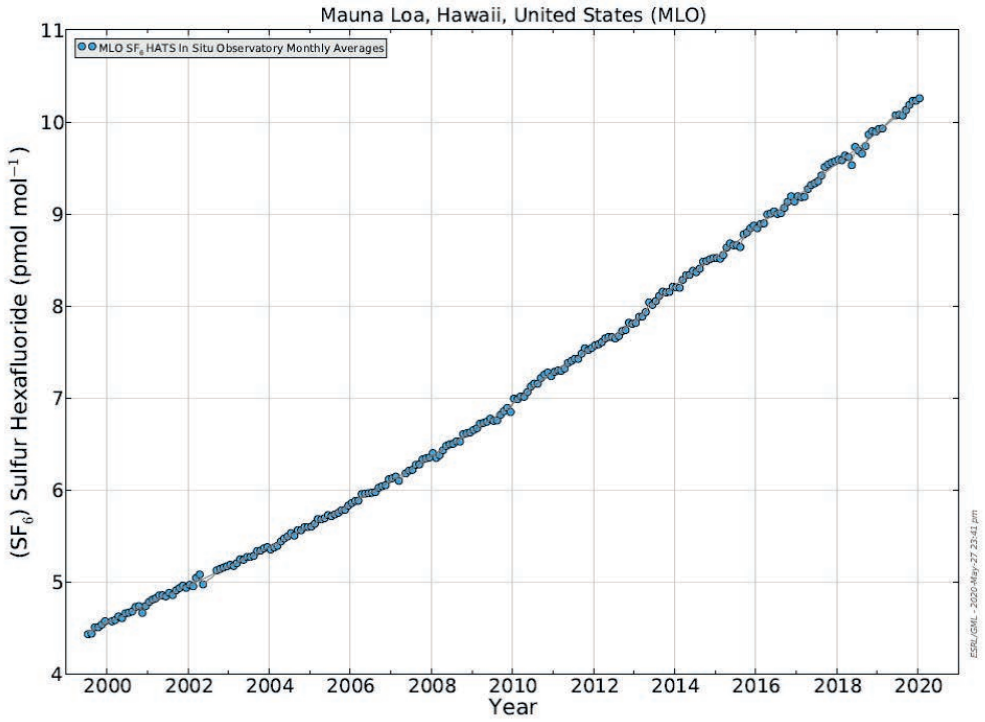


Figure 1: Measured values of the proportion of SF_6 in the atmosphere of the Mauna Loa measuring station in Hawaii (27/05/2020).[1]

Due to its excellent insulating and switching properties and despite a reduction in the quantity of SF_6 gas emitted since 2016, a large proportion of SF_6 produced in Germany today is still used in the electrical industry and apparatus engineering (> 75 %).[3]

Although the share of operational emissions has been steadily decreasing in recent years, the global share of SF_6 in the atmosphere has continued to increase. The SF_6 technology used in electrical equipment is, with regard to the emission rates, largely optimised and further reduction at this point is only possible by replacing existing units or systems with the latest generation or by using alternative technologies. When replacing the units or systems, the focus should be on the sustainable use of SF_6 by preparation or reconditioning and reuse. As the majority of SF_6 is still used in the electrical industry, the search for alternatives to SF_6 in this field is well advanced. Changing over in all voltage levels to Alternative Gases or technologies is considered inevitable.[4]

The guidelines are focused regionally on the current technical status of implementation in Europe and North America. The focus is on the "Synthetic Air" gas mixture ("CleanAir", "DryAir") and gas mixtures with the insulating gases 2,3,3,3-tetrafluoro-2-(trifluoromethyl)-propannitrile, commercially available under the names 3M™ Novec™ 4710 (hereinafter referred to as „C4") and 1,1,1,3,4,4,4-heptafluoro-3-(trifluoromethyl)butan-2-one, available under the name 3M™ Novec™ 5110 („C5", Figure 2). All alternative gases and gas mixtures will be referred to as „Alternative Gases".

In contrast to the SF_6 gas handling, where SF_6 is usually present and handled as a single component and only rarely as gas mixture (with N_2 or CF_4), Alternative Gases consist of two or more single gas components which together form the insulating gas mixture. The theoretical background and the chemical and physical properties with regard to insulating and quenching properties of the possible Alternative Gases and gas mixtures to SF_6 have already been discussed in detail in the known literature.[5-8] There are already explicit recommendations of the CIGRE working groups on the use of SF_6-free gases or gas mixtures in medium and high voltage switchgear as well.[9]

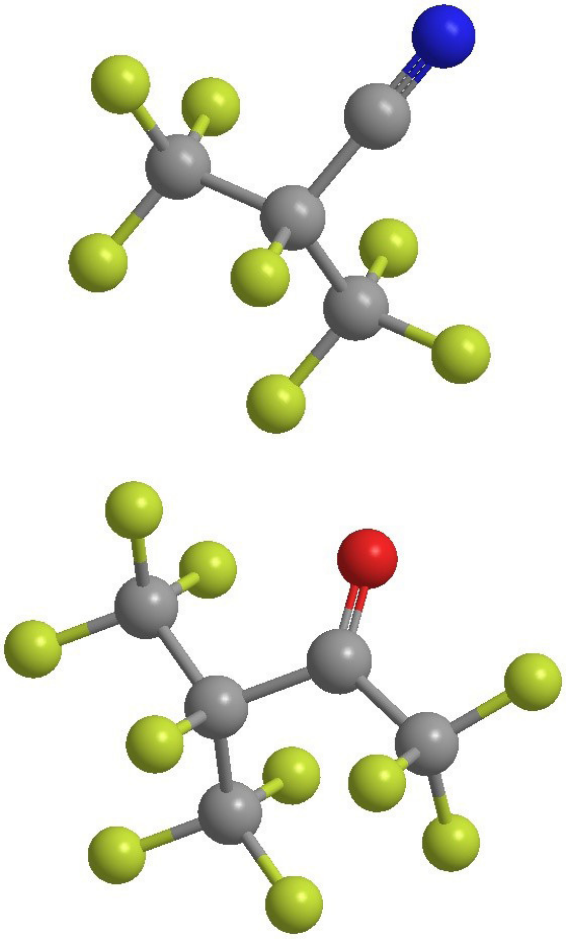


Figure 2: Illustration of the chemical structure of C4 (above) and C5 (below) Grey: carbon atoms,
olive: fluorine atoms, blue: nitrogen atom, red: oxygen atom.

Different gases or mixtures with different ratios of the single components are used for the various applications in high voltage technology:

Novec™ is the registered trademark for special chemicals and gases of the 3M™ company. The syntheses of the chemicals C5 (chemical name: 1,1,1,3,4,4,4,-heptafluoro-3-(trifluoromethyl)butan-2-one) and C4 (2,3,3,3-tetrafluoro-2-(trifluoromethyl)propannitrile) have been known since the 1960s for C5 and 1970s for C4.[10,11] Nevertheless, for both gases only 3M™ is currently registered as an authorised seller in the European chemicals database in Europe.[12] Contrary to the SF_6 gas, C4 and C5 are used, due to their higher boiling points (table 1) at atmospheric pressure in mixtures with additional carrier gases such as carbon dioxide (CO_2) or nitrogen (N_2). In these cases, carrier gas refers to the component that is predominantly present in the mixture in percent. Oxygen (O_2) is often used as a further component to reduce the soot production in case of arcing or switching operations in switchgear. The concentrations of the single components, with the exception of the carrier gas, are generally in the range of 0 - 15 %.

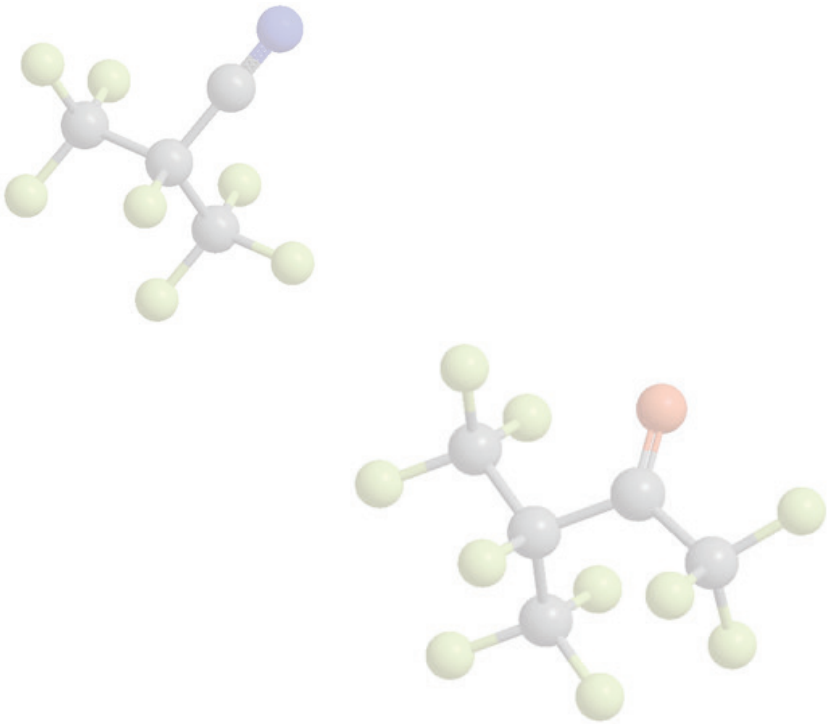
g³ comprises the solution from General Electric and includes mixtures with C4. AirPlus is the equivalent of the ABB company and includes mixtures with C5 as insulating gas. Depending on the required application, different mixing ratios are used in both cases. Synthetic air is a mixture of approx. 20 % oxygen (O_2) and 80 % nitrogen (N_2) and is mainly used in switchgear in combination with the vacuum switching technology up to 145 kV from Siemens.[13] It can only be liquefied at temperatures lower than -183 °C and is also stored at room temperature in a homogeneous state under high pressure (> 200 bar) (table 1). Due to their partly toxic properties, other gases traded as alternatives, such as trifluoroiodomethane (CF_3I)[14] or hydrofluoroolefin ($C_3H_2F_4$), are currently no longer in the broad focus of the industry. However, their handling is based on C4/C5 or synthetic air, similar to the mixtures.

Table 1: Overview of Alternative Gases and their mixtures compared to SF_6.

	Sulphur hexafluoride SF_6	2,3,3,3-tetrafluoro-2-(trifluoromethyl)-propannitrile C4	1,1,1,3,4,4,4-hepta-fluoro-3-(trifluoro-methyl)butan-2-one C5	Synthetic Air/ CleanAir/DryAir
Trademark	SF_6	3M™ Novec™ 4710	3M™ Novec™ 5110	
Chemical formula	SF_6	C_4F_7N	$C_5F_{10}O$	O_2/N_2
CAS number	2551-62-4	42532-60-5	756-12-7	7782-44-7; 7727-37-9
Boiling point	-63.8 °C	-4.7 °C	+26.9 °C	–183 °C; –196 °C
Atmospheric dwell time	3200 y	30 y	0.04 y	-
Global warming potential	22800	2100	< 1	0
Properties of the gas mixtures				
Common trade names		g³ (GE)[a]	AirPlus (ABB)	CleanAir (Siemens)
Used gas mixtures	Pure SF_6	C4: < 10 % with CO_2	C5: < 15 % in Synth. Air	~ 20 % O_2 in N_2
	SF_6 with N_2 or CF_4	C4: < 10 % with O_2/CO_2	C5: < 15 % in O_2/CO_2	
Minimum operating temperature	Pure SF_6: < –30 °C	Depending on the exact mixture:		< -50 °C
	SF_6 with N_2/CF_4: < -50 °C	–30 °C - –5 °C		
Global warming potential		< 760	< 1	0

[a]) Common mixtures of g³ have a C4 mole fraction ≤ 6,3 % (GWP: ≤ 500).

Although there is still no prohibition on the use of SF_6 in existing or new gas-filled power transmission equipment, some concrete alternatives have emerged. In some projects, different approaches have already been implemented in practice, but solutions for the implementation for all fields of application are not yet available.
The next edition of the guide will focus on the properties and the different ways to produce mixtures of Alternative Gases.



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