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F-GASES

Awareness Raising on Environmentally Friendly Alternatives to F-Gases

Industry Guideline for the Switch Gear Sector

April, 2019

Technical Assistance for Increased Capacity for Transposition and Capacity Building on F-Gases

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GFA CONSULTING GROUP

CONTENTS

LIST OF ABBREVIATIONS

AC	Air Conditioning
CapEx	Capital expenditure
CFC	Chlorofluorocarbon
CO_2	Carbon Dioxide
CO_2 e	Carbon Dioxide equivalent
EC	European Commission
EU	European Union
F-gas	Fluorinated Gas
GHG	Greenhouse Gas
GWP	Global Warming Potential
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HF	Hydrogen fluoride
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
HP	Heat Pump
KA	Kigali Amendment
kW	Kilowatt
LT	Low Temperature
MP	Montreal Protocol
MT	Medium Temperature
N_2	Nitrogen
NH_3	Ammonia
O_2	Oxygen
ODP	Ozone Depleting Potential
ODS	Ozone Depleting Substances
PFCs	Perfluorocarbons
RAC	Refrigeration & Air Conditioning
R&D	Research and Development
RRR	Reclaim, Recovery, Recycle
TFA	Trifluoracetic
TCO	Total cost of ownership
SF_6	Sulfur hexafluoride

Aim of the Guideline

This guideline is prepared to guide the Turkish switchgear sector in the process to adopt the changes ahead of the upcoming new National F-gas Regulation in line with the Kigali Amendment and Regulation (EU) 517/2015, with an emphasis to the low global warming potential (GWP) alternatives to the F-gases.

It is particularly important to make the necessary transitions to the F-gas free alternatives at a time when global temperatures are in constant rise due to accumulation of the greenhouse gases (GHGs) in the atmosphere. Failing to reduce GHG emissions will potentially result in catastrophic consequences.

This guideline is aimed at manufacturers, end users and service companies of SF_6 insulated switchgear to raise awareness of the environmentally friendly alternatives to fluorinated gases (F-gases). For this reason, it includes information on:

- The low global warming potential (GWP) alternatives to F-gases in the switchgear sector,
- The international and national F-gas regulations, potentially impacting businesses.

The information in this guideline grouped into four sections:

- **Introduction** with background information on the **climate change, the Montreal Protocol and the Kigali Amendment.**
- **Information on the provisions** of the **EU F-gas Regulation and Turkish National F-gas Regulation**
- Switchgear sector specific section on the **low GWP alternatives** with information on the equipment types, safety, pricing, barriers to adoption and the availability of low GWP and SF_6 free alternatives
- **Recommendations** for a successful transition to low GWP alternatives.

Further information can be found through the links provided in the refences.

1 Introduction

As a signatory country to Montreal Protocol (MP) Turkey is working towards updating its national fluorinated gases (F-gases) regulation in line with Kigali Amendment (KA) and the Regulation (EU) No. 517/2014. This guideline is prepared to guide the Turkish switchgear sector in the process to adopt the changes ahead, with an emphasis to the low global warming potential (GWP) alternatives to the F-gases. This transition requires a phase-out period of the use of F-gases, improved monitoring and reporting, enhanced legal structures and increased national and local capacity.

1.1 Climate change, greenhouse gases and low GWP alternatives

Climate change is the large-scale and long-term changes in the weather patterns and rising temperatures, both of which are damaging life on Earth. Climate change is caused by the greenhouse gases (GHGs) in the atmosphere. Manmade gases such as CFCs, HCFCs, HFCs and SF_6 are potent GHGs and have a significant impact on climate change. They have high GWPs[1] that can be thousands of times higher than GWP of CO_2. In fact, SF_6 is the most potent greenhouse gas that it has evaluated, with a global warming potential of 22,200 times that of CO_2.

1.2 Montreal Protocol and Kigali Amendment

The Montreal Protocol:

The Montreal Protocol (MP) phases out the consumption and production of the ODSs gradually, meeting predefined and agreed targets at different stages, with different timetables for developed and developing countries (Figure 1).

Under the MP, all parties have specific responsibilities related to the phase out of the different groups of ODS, control of ODS trade, annual data reporting, national licensing systems to control ODS imports and exports, and other matters.

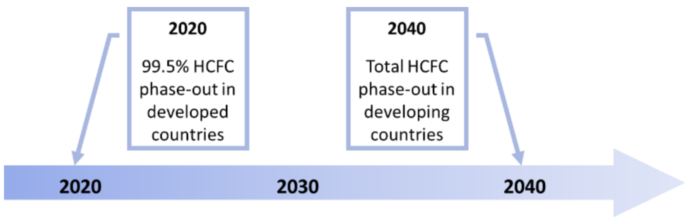

Figure 1. Timeline for the HFCF phase out under the Montreal Protocol.

The Kigali Amendment:

The Kigali Amendment (KA) to the MP adds the phase-down of the production and consumption of HFCs to the existing controls of ODS under the MP. It was agreed by all 197 Parties in 2016 and entered into force on 1 January 2019. This landmark international agreement sees that developed countries take the lead on phasing down HFCs, while developing countries (A5 countries such as Turkey) are allowed to have a delayed start, as shown in Figure 2 with green line.

[1] GWP is expressed as the ratio of the amount of heat trapped by a certain mass of the gas in question to the amount trapped by a similar mass of CO_2

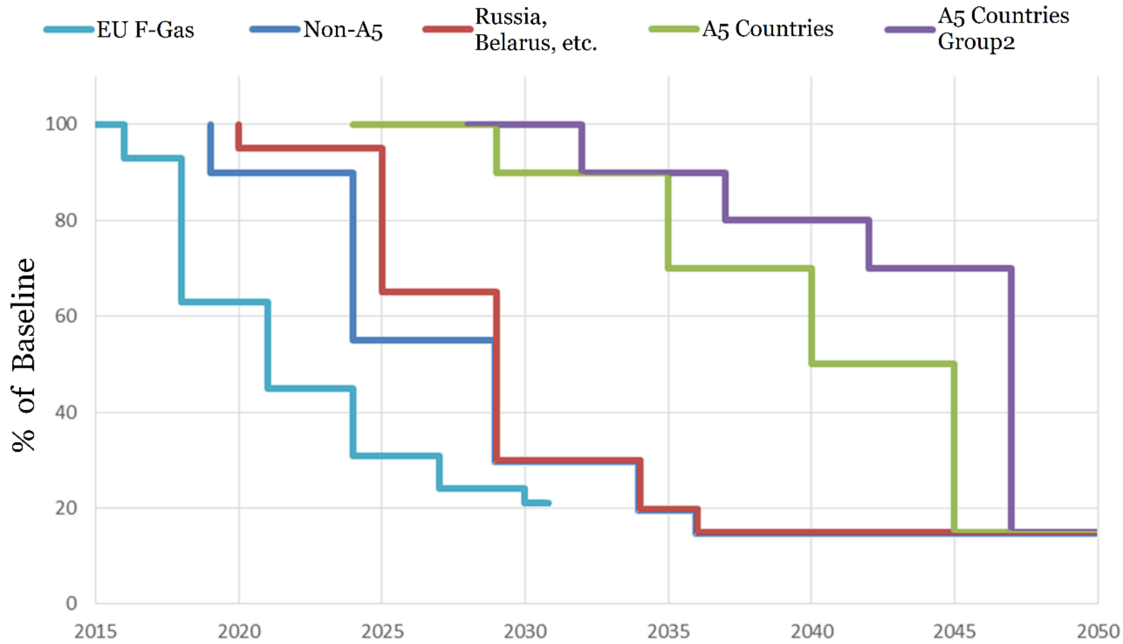

Figure 2. Kigali Amendment HFC phase-down schedules

2 Provisions of the EU and Turkish National F-gas Regulation

EU F-gas regulation:

The EU's F-gas legislation was among the world's first actions to phase down HFCs in favor of low GWP alternatives. In 2014, Regulation (EC) No 842/2006 was replaced by a new regulation (EU) No 517/2014 on fluorinated greenhouse gases. It aims to decrease the EU's F-gas emissions by 79% by 2030. The main changes introduced to achieve reduced emission targets are:

- Phase-down of the HFCs available on the market (see blue line in Figure 2): It limits the total amount of HFCs that can be sold in the EU from 2015 and phasing them down by 79% of 2014 sales in 2030.
- Prohibitions of placing on the market products and equipment containing or relying on F-gases
- Prohibitions on use of F-gases where technically feasible low GWP alternatives are available,
- Containment by leak tests, certification, servicing and recovery of the gases at the end of the equipment's life and labelling.

The milestones of this F-gas Regulation are summarized on a timeline in
Figure 3, where HFC bans in equipments (i.e. HFC ban in domestic refrigeration) means the bans on placing on the market of that HFC equipment (i.e. ban on placing on the market of domestic refrigeration containing HFCs).

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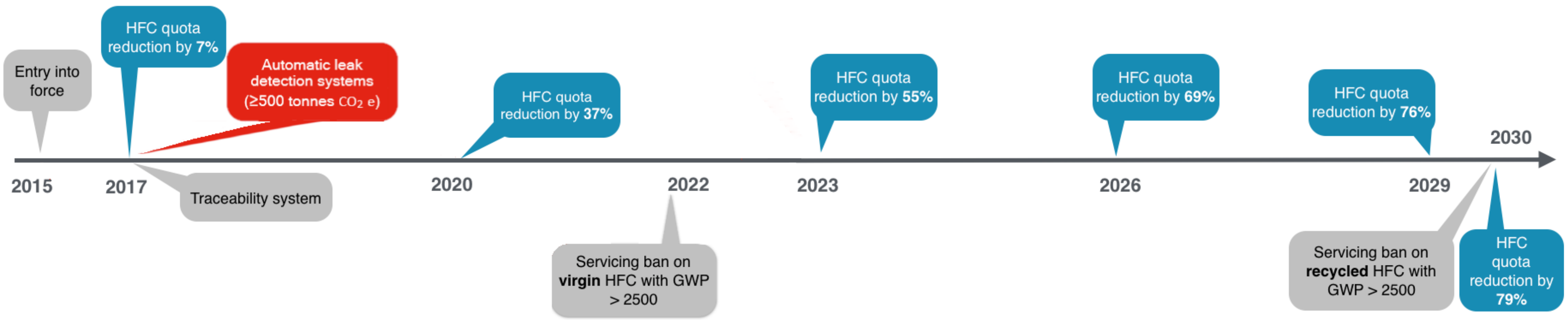


Figure 3. Provisions, bans, quotas and phase-down process for the Regulation (EU) 517/2014

2.1 Main obligations of operators of equipment insulated with SF_6

An "operator" is the natural or legal person who uses (i.e. exploits) the equipment which may or may not be the owner of that equipment. Under the Refulation (EU) No 517/2014 operators are legally responsible for preventing GHG emissions by acting on the following steps.

2.1.1 Labelling

All switchgear containing SF_6 shall not be placed on the market unless the SF_6 is identified with a label. The label shall indicate the following information:

- A reference that the switchgear contains F-Gases,
- The accepted industry designation for the F-Gas concerned or, if no such designation is available, the chemical name,
- The quantity expressed in weight and in CO_2 equivalent of F-Gas contained in the switchgear, and the global warming potential of the F-gas used.

2.1.2 Leak checking

Operators are required to have their equipment tested for leaks regularly by trained and certified service providers. To prevent emissions, any leakage must be repaired as quickly as possible. All electrical switchgear with SF_6 must frequently be checked. Automatic leak detection on larger equipment is required.
The frequency of the leak-checks depends on number of tonnes of CO_2 e (Table 1).

Table 1. Leak test frequencies under the current F-gas Regulations

SF_6 (tonnes of CO_2 e)*	No automatic leak detection	With automatic leak detection
150 - 500	Every 6 months	Every 12 months
500 or more	Every 3 months	Every 6 months
	***tonnes of CO_2 e = F gas Mass (in tonnes) × GWP of that F gas**	

2.1.3 Record keeping

Operators are required to keep records of the:

- Quantity and type of F-gases installed, added or recovered
- Identifications of the company or/and technician carrying on servicing
- Dates and results of leak tests of stationary systems containing the of 5 tons of CO_2 e F-gases or more.

2.1.4 Recovery of F-gases

Operators must arrange for the recovery, recycling, reclamation and/or destruction of the F-gases during any maintenance work or at the end of the equipment's life, by certificated technicians.

2.1.5 Other obligations

It is the operators' responsibility to ensure that the servicing, maintenance and any repairs of the F-gas equipment are provided by certified service providers. It is also the operator's responsibility that any new equipment is labelled as required by the EU F-gas regulation, indicating the type and the quantity of their content, also expressed in tonnes of CO_2 e.

2.2 Main obligations of service companies and technicians

Service companies and technicians must be certified to install, service, maintain and repair the equipments as well as to test for leakage and to recover/recycle/reclaim F-gases at the end of life of the equipment. Like the operators, the service companies and technicians are required to keep record of the quantity and type of F-gases installed, added or recovered, the details of the company serviced and the dates and the results of leakage checks, unless such data are kept in a central database.

2.3 Bans on placing on the market of products and equipment containing or relying on F-gases

One of the key changes Regulation (EU) 517/2014 introduced is the prohibition on HFC use in certain equipment and bans on placing on the market equipment containing HFCs in the market.

However, there are no bans related to the use of SF_6 in high voltage switchgear. Other F-Gas end use sectors are affected by a phase down in the quantity of HFCs to be placed on the EU market. This only applies to HFCs – it will have no impact on the SF_6 switchgear market.

2.4 Turkish National F-gas Regulation

In Turkey, the national F-gas Regulation, which entered into force on 4 January 2018, contains most of the provisions of Regulation (EC) 842/2006. The current national regulation was developed in the framework of the EU Project "Technical Assistance of the Usage of F-gases in Turkey and Harmonisation of Related Legislation" completed in 2014.

The national regulation is comprised of requirements for equipment operators, such as:

- Bans related with release of F-gases into the atmosphere, placing of products and equipment on the market and acceptance at disposal facilities without recovery;
- Requirements related with data entry at the central database of the MoEU;
- Requirements for labeling F-gas-containing products and equipment;
- Requirements for operators on leakage controls;

- Requirements for certification of those who work with F-gas-containing equipment (installation, maintenance and technical service, repair or decommissioning).

The national regulation will be updated with a new version in-line with Regulation (EU) 517/2014 in 2020, which will introduce, *inter alia*:

- HFC phase-down schedule
- calculation of country annual quotas and quota allocation to HFC importers, transfer of annual quotas between importers
- Principles and procedures regarding pre-shipment import licensing

3 Alternatives to SF_6 in electrical switchgear sector

3.1 General considerations

SF_6 was developed as insulating gas in electric switchgear equipment c.a. 50 years ago and so far, it has been effectively used globally because of its excellent electric arc quenching capability and high dielectric strength. Moreover, it is non-toxic and does not create any health risk to human beings though its decomposition products are considered as hazardous waste and must be properly handled. Leakage rates from equipment usually do not exceed 0.1% per year. It seems then to be an ideal insulating gas, but from environmental point of view it is not because it is a powerful greenhouse gas with GWP of 22 800 – the highest GWP value of all commonly used chemical substances. That is the reason why the scientific community and the major players on the switchgear equipment market started in the recent years to investigate the possibilities to move towards alternative technologies which would ensure similar electric arc quenching and insulation properties in switchgear equipment and in the same time would be less harmful for the environment.

Generally, in order to replace SF_6 any alternative technology is supposed to offer the following:

- resistance to high voltage
- arc quenching capability
- good heat exchange with surrounding environment
- possibility to work at very low temperatures
- compatibility with the materials used in switchgear equipment
- temperature and storage stability
- easy filling and emptying of the equipment
- equipment dimensions not exceeding those of SF_6 equipment
- very low GWP

The following chemicals have been studied so far as SF_6 replacements (usually in mixtures with dry atmospheric gases):

- $(CF_3)_2CFCN$ – Fluoronitrile supplied by 3M under a trade name of **Novec 4710™**, GWP = 2100
- $(CF_3)_2CF(O)CCF_3$ - Fluoroketone - supplied by 3M under a trade name **Novec 5110™**, GWP = 1
- CF_3I - **Trifluoroiodomethane** – supplied by several manufacturers, GWP = 0.4
- $CHF{=}CFCF_3$ (HFO-1,2,3,4ze) – supplied by Chemours (**Opteon™**) and Honeywell (**Solstice™**), GWP <1

Some manufacturers already offer the equipment that is based on such SF_6 replacements, the most promising solutions seem to be blends of Novec 4710™ or Novec 5110™ with N_2, CO_2 and O_2.
If the substantial properties of SF_6 and potential alternative substances mentioned above are compared it seems clear that they can be considered as SF_6 replacements see Figure 4 where dielectric breakdown voltage of SF_6, Novec 4710™ and Novec 5110™ is compared.

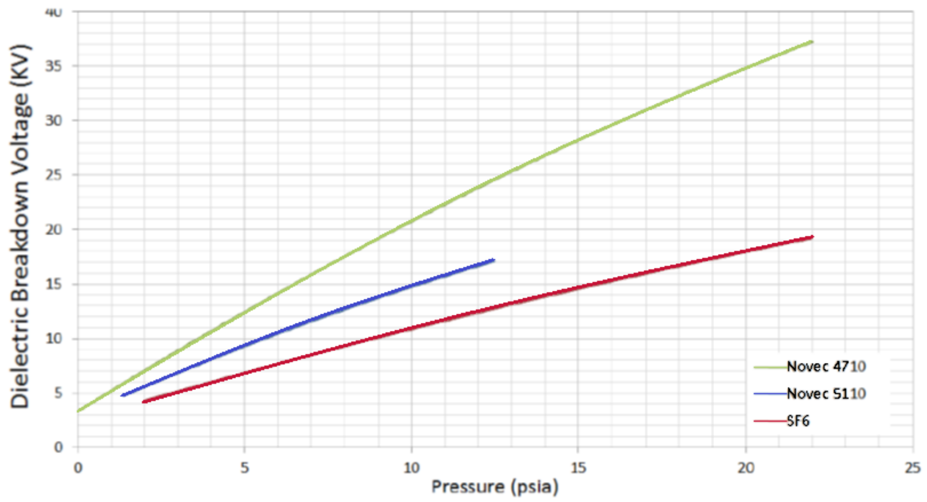


Figure 4. Comparison of dielectric breakdown voltage measured for SF_6 and alternative compounds

Switchgear equipment where just vacuum and "synthetic air" (dry mixture of 80% N_2 and 20% O_2) is used for arc-quenching and insulating purposes, respectively, has also been evaluated and this alternative technology is also commercially available. It is important to note that while replacement of SF_6 in medium voltage (MV) equipment is relatively easy, the major challenge is still to fully commercialize alternative technologies in high voltage (HV) GIS (>100 kV).

3.2 Description of the most promising alternative technologies

3.2.1 g3

An alternative technology utilizing a mixture of Novec 4710™ fluoronitrile (4-10%) and CO_2 (90-96%) was developed by GE under a trade name **g3** or **g³** (green gas for grid) and later GE has collaborated with Alstom in its commercialization. At -5°C dielectric strength for **g3** and SF_6 is the same and at -25°C it is ca. 90% of that of SF_6. Environmental benefits achieved from replacing SF_6 with **g3** in switchgear equipment are illustrated in Figure 5.

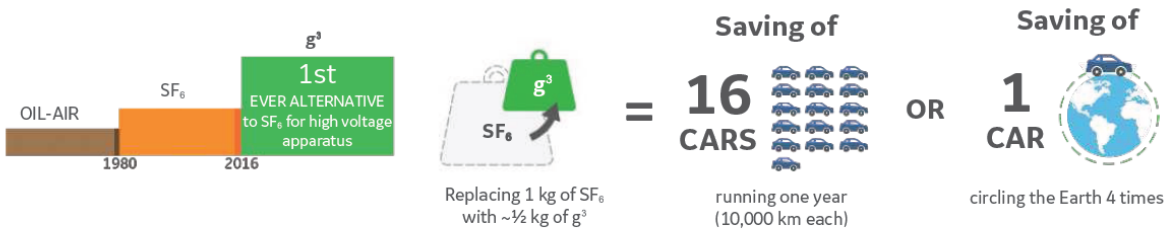
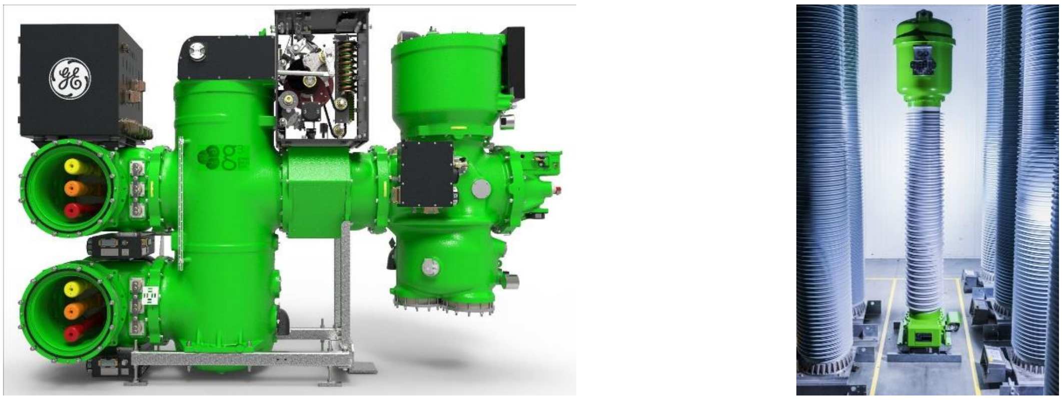


Figure 5. Environmental benefits of replacing SF_6 with **g3** in electric switchgear equipment

Although GWP of Novec 4710™ is much higher as compared to Novec 5110™ advantage of the former lies in much lower boiling point.
First commercial application of **g3** was replacing SF_6 in 420 kV GIL (Gas Insulated Lines) in Jebel Ali (UAE) where total length of transmission lines was as much as 73 km – see Figure 6 .

Figure 6. First commercial application of **g3** technology in 2009 – transmission lines in Jebel Ali (UAE)

Then, **g3** was successfully applied also in GIS and in transformers –see Figure 7 for examples.



(a) (b)

Figure 7. 145 kV GIS (a) and 245 kV transformer (b) constructed in g3 technology in Grimaud (France) and Frankfurt (Germany), respectively.

Substantial characteristics of 145 kV GIS shown in Figure 7 are presented in Table 2.

Table 2. Substantial characteristics of 145 kV GIS constructed in **g3** technology.

Item		Value			Unit
Rated Voltage		145			kV
Nominal Frequency		50 / 60			Hz
Rated Nominal current		up to 2500			A
Short duration pow frequency voltage		275	315		kV
BIL		650	750		kV
Short circuit	Ith	40			kA
	duration	3			s
Short circuit current peak		108			kA
Mechanical class for CB and		10,000 (M2)			Ops
Cap. Switching performance		C2 (LC/CC/BC)			
Pressure Design (lockout/Warning/Filling)		6	6.5	7	bar
		87	94	102	psi
Medium for insulation / interruption		6%vol g3			

3.2.2 AirPlus™

An alternative technology utilizing Novec 5110™ fluoroketone was developed by ABB under a trade name AirPlus™. The insulating gas is a proprietary mixture of Novec 5110™, CO_2 or N_2 and O_2. Such mixture has very low GWP (<1) and therefore the CO_2 equivalent emissions are reduced by 99.995% as compared to SF_6. A pilot substation with 8 170 kV GIS bays and 50 24kV GIS bays insulated with such gas mixture located at Oerlikon (Switzerland) was built in 2015, see Figure 8 and Figure 9.

Figure 8. A pilot substation in Oerlikon (Switzerland) where HV GIS 170 kV and MV 24 kV equipment that uses ABB proprietary gas insulating mixture containing Novec 5110^{TM} was installed.

Figure 9. Images of 170 kV HV GIS and 24 kV MV GIS equipment installed in pilot substation shown in Figure 8

Substantial characteristics of HV (GLK-14) and MV (ZX2) GIS installed in Oerlikon substation are presented in Table 3

Table 3. Substantial characteristics of HV (GLK-14) and MV (ZX2) GIS installed in Oerlikon substation.

	GLK-14	ZX2
Rated Voltage	170 kV	24 kV
Rated current	1250 A	2500 A
Rated frequency	50 Hz	50 Hz
Rated short-circuit current	40 kA	25 kA
Minimal functional pressure	700 kPa abs	120 kPa abs
Minimal operating temperature	+5°C	-15°C
Background gas	CO_2 and O_2	Tech. Air

In 2017 another pilot station that utilized the AirPlus^{TM} technology in MV switchgear equipment was installed in Stavanger (Norway) – see Figure 10 where both the old equipment and the new equipment that replaced it are shown for comparison.

(a)

(b)

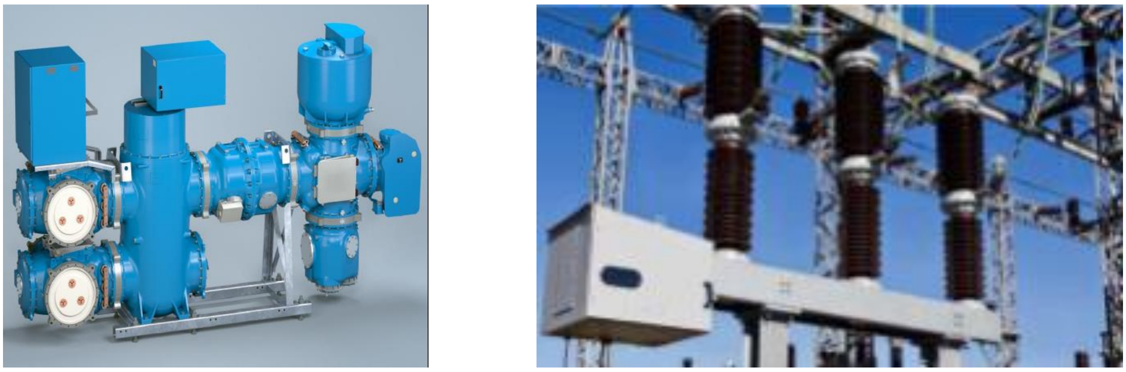
Figure 10. Old (a) and new (b) MV switchgear equipment installed in Stavanger (Norway). In new equipment the AirPlus^{TM} technology developed by ABB was used

3.2.3 Trifluoroiodomethane

Mixtures of trifluoroiodomethane with CO_2 or N_2 have been investigated as substitutes for SF_6 in electrical switchgear and it was concluded that this compound may be considered as insulating gas due to its relatively good dielectric strength (75-90% of SF_6). However, no commercial equipment utilizing such mixtures has yet been offered.

3.2.4 Clean Air and vacuum

A technology named Clean Air developed for GIL and GIS that was utilizing synthetic air for insulating and (for GIS) was combined with vacuum (in circuit breaker) was tested mainly by Siemens and Hitachi and some pilot plants utilizing GIS based on that technology have been built – see for such equipment and Table 4 for substantial parameters of 145 kV GIS developed by Siemens.



(a) (b)

Figure 11. 145 kV GIS developed by Siemens (left) and 72.5 kV live tank circuit – both utilizing Clean Air technology

Table 4. Substantial characteristics of 145 kV GIS utilizing Clean Air technology developed by Siemens.

Switchgear type	8VN1
Rated voltage	145 kV
Rated power-frequency	275 kV
Rated lightning impulse (1.2 / 50 μs)	650 kV
Rated normal current	3150 A
Rated short-circuit breaking current	40 kA
Rated short-time current (up to 3 s)	40 kA
Leakage rate per year	< 0.1 %
Driving mechanism of circuit-breaker	Spring
Rated operating sequence	O-CO-15s-CO
Interrupter technology	Vacuum
Insulation medium	Clean air
Bay width common pole drive	3'4"
Bay height, depth (typical)	10'6" x 18'
Bay weight (typical)	5 t
Ambient temperature range	-58 °F up to +122 °F
Installation	indoor / outdoor
First major inspection	> 25 years
Expected lifetime	> 50 years

The use of vacuum circuit breakers (see Figure 12) has a long history, but now it becomes to be more and more interesting for the industry due to the need of SF_6 replacement. Specifically, solid insulated switchgear (SIS) equipment is now offered, e.g. by Schneider, for low and medium or even high voltage systems. Combinations of solid and air insulation have also been investigated.

Figure 12. Vacuum circuit breaker

3.2.5 HFO-1,2,3,4ze

The use of HFO-1,2,3,4ze as foam blowing agent is already proven, but only few literature reviews mention the possibility of applying this compound as insulating gas in electrical switchgear equipment. However, due to its low boiling point (-30ºC), very low GWP (<1), low toxicity and potentially good dielectric strength it may be considered as future SF_6 replacement, but only as insulating gas and not in circuit breakers because it is mildly flammable.

4 Conclusions and Recommendations for Turkey

It can be concluded from information presented in 3.2 that technologies which are alternative to SF_6 in electrical switchgear equipment are commercially available for all range of voltages and their worldwide application will significantly diminish use and emissions of SF_6 and thus will help in combating global warming. Specifically, Clean Air, AirPlus^{TM} and **g3** technologies seem to be the most promising. Since the experience in practical use of these technologies is not yet mature it is not clear which of them will become the major replacement to SF_6. E.g. investigations on decomposition products from Novec 4710^{TM} and Novec 5110^{TM} that may be formed in switchgear equipment utilizing AirPlus^{TM} and **g3** technologies are still ongoing. Nevertheless, it is recommended that switchgear equipment operators in Turkey consider selection of any of the commercially available technologies alternative to SF_6 when installing new equipment.

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