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Global Warming Effect of Switchgear Using Sulphur Hexafluoride in Nuclear Power Plants

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ABSTRACT

As we are all aware that nuclear power plants are in vast majority made as part of the electric power grid system. Therefore, it is unavoidable that a switchyard plays a vital role as part of power plant operation and nuclear safety. Historically, to reduce size and increase reliability, the SF_6 – sulphur hexafluoride gas has been noted and widely used as the most successful medium for reliably breaking the electric current. Sulphur hexafluoride can be found in basically all high-voltage equipment such as circuit breakers, voltage and current transformers and gas insulated substations. SF_6 gas is the most potent greenhouse gas with 3,200 years of decay half-life in nature cycle and has 22,800-times more impact on global warming than CO_2. A typical switchyard element has around 5 kg - 15 kg and Gas Insulated Switchgear (GIS) bay up to 170 kg of this gas. That would mean 456 tons and 3,876 tons of equivalent CO_2 respectively, if a gas would completely escape to atmosphere. As all these devices cannot be made completely airtight, some gas still escapes its confined area. It has been estimated that a leakage itself would contribute the same amount of yearly impact on the environment as emissions from 3 up to 6 internal combustion engine cars would cause for each of such an element in high voltage switchyard that is above or at 110 kV. Nuclear power plant Krško (NEK) has 11 elements filled with SF_6 gas, which means that leakage itself equals to 38 cars making an average distance of 12,653 km per year.

Keywords: *Global warming, GWP, SF_6, CO_2, Circuit Breaker, F-gas, EU Regulation, Switchyard.*

1 INTRODUCTION

1.1 SF_6 in the environment

SF_6 gas has many nature-neutral properties:

- It is colourless, odourless, and without taste.
- It is not toxic or mutagenic, and it is chemically stable.
- It is not flammable and it is 4.7-times heavier than air, which poses a danger of suffocation in closed spaces or below ground level.
- It has the highest Global Warming Potential (GWP) of all listed gases in the 517/2014 regulation. (1.3)

The gas was first used in 1953 for electrical switching elements and for magnesium, semiconductor, and integrated circuits production. Therefore, SF_6 gas production has risen rapidly from basically zero in the year 1953 to 85,700 tons a year in 1995. As the gas has a relatively long lifespan of 3,200 years, it is relatively rapidly accumulating in Earth's atmosphere [1]. The greatest influence of SF_6 gas on the environment is its extraordinary high GWP, which has according to the latest studies been measured of being 22,800-times greater than CO_2 GWP [2].

The combination of high GWP and a long lifespan in the atmosphere has made the European Union (EU) take certain precautions and it has first limited the use of this gas in all sectors by issuing the 517/2014 F-gas regulation [3] (described in chapter 1.3). SF_6 is thus only allowed to be used in sectors where there is no alternative available.

There are several ways how SF_6 gas can reach the environment if we limit our scope to only using electrical equipment that is filled with it:

- Actual gas leakage of devices (designated on year-timescale);
- Gas being lost due to non-optimal handling during maintenance. Some gas is always lost in the environment;
- SF_6 being made in processes happening by nature.

Naturally, SF_6 gas is being made at a rate of 0.054 pptv (parts per trillion by volume) ± 0.009 pptv per year [1]. But presumably due to human activity, its yearly rate has increased to 10.5 pptv per year as can be seen on Figure 1, since the beginning of its commercial use. Its yearly release rate is also increasing by 0.3 pptv ± 0.004 pptv and the concentration of SF_6 in the atmosphere has increasingly been a target of concern as its long lifespan means its long term impact on future generations [4].

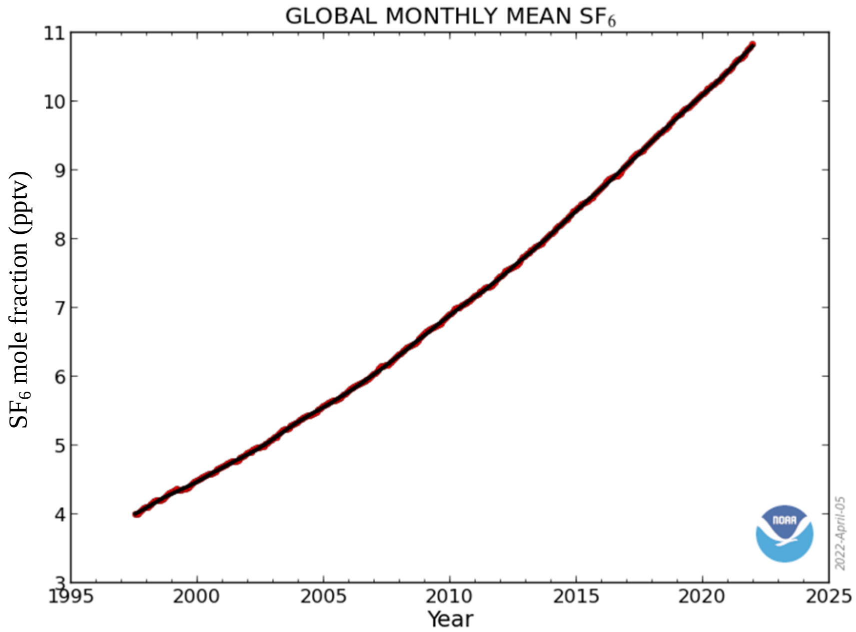

Figure 1: Historic SF_6 mole fraction in water, atmosphere, above ground, and in the troposphere [4]

A comparison can be made of how much emissions is contributed of Slovenia for year 2018 presented in Table 1. It can be seen that NEK switchyard contributes 0.15% to Electricity, gas and steam supply (SF_6 only) [5]. NEK switchyard contribution is presented in chapter 2.2.

Table 1: Comparison of CO2 equivalent emissions in relation to presented emission types

Emission type (for year 2018)	CO_2 equivalent	% of CO_2 emissions
Total CO_2 emissions of Slovenia	13,895,000 t	100%
Electricity, gas, and steam supply	5,193,047 t	37.4%
Electricity, gas, and steam supply (SF_6 only) *	15,800 t	0.11%
NEK Switchyard (average year)	24 t	0.00017% (0.15% of *)

1.2 SF_6 in electrical equipment

SF_6 gas has phenomenal insulation properties equivalent to oil itself and that is why it is (was) widely used in switching elements, mostly due to its ability of arc quenching. It has a unique ability to greatly increase thermal conductivity at 2,000 K by an order of magnitude due to the generation of chemically reactive ions displayed on Figure 2 therefore it ultimately protects contacts of switching element and increases their lifespan. Figure 2 left side also displays that SF_6 gas always returns to its original form after cooling down meaning the process of generating by-products is reversible apart from chemical reactions with impurities being present in gas. But due to high chemical reactiveness of newly created ions, a careful choice of materials composing the arching chamber and all components is mandatory. Less than 10 μs or basically all the starting quantity of SF_6 is recombined using those chemically reactive ions as building blocks. All that remains are some toxic by-products that were created by impurities such as moisture trapped in the SF_6 gas. Therefore, the use of protective gear is mandatory while handling arced SF_6 gas [6].

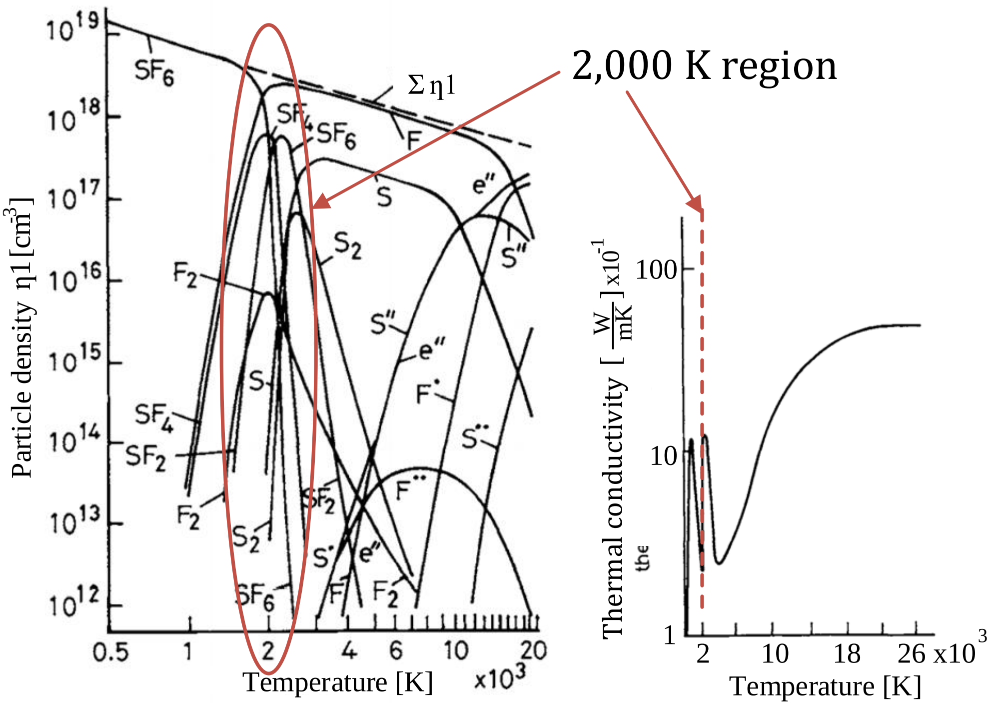

Figure 2: Particle density and thermal conductivity in relation to the temperature of SF_6 gas [6]

1.3 Regulatory requirements concerning the restrictive use of high GWP gas and gas mixtures

SF_6 as a fluorinated greenhouse gas was found to have a deleterious effect on the ozone layer contributing to the intensive global warming for years to come. In 1987, aiming for an overall greenhouse gas emissions reduction, an international treaty named the Montreal Protocol was signed by a total of 46 signatories, becoming effective in 1989. It was initially considered to provide for protecting the ozone layer of our atmosphere and it counts as a turning point in subsequent treaties and regulations that are taking action to protect our environment.

In recent years starting from 2014, constraints on the use of invasive gases and related leakage in our atmosphere were made by the 517/2014 regulation [3], especially concerning Air Conditioning (A/C) devices, which have seen extensive use of ozone depletion substances. This regulation tackles the problem of all f-gases (fluorinated gases) used in any of the devices and includes switchgear equipment and circuit breaker devices used in power distribution and transmission networks.

The new regulation is expected to be issued this year and it will most likely contain a prohibition against placing on the market switchyard elements that European Network of Transmission System Operators for Electricity (ENTSO-E) comments in the Position Paper Transition-times from SF_6 to alternative technologies for High Voltage (HV) and Extra High Voltage (EHV) applications published in October 2021. ENTSO-E took the decision that the Transmission System Operators (TSO) community will continue working on the development of SF_6 alternative technologies and substitutive gases for the existing fleet. ENTSO-E exhibits a strong influence on the TSO community, where ELES is participating, too, representing an important mediator and negotiator with the related EU bodies.

In the above Position Papers, ENTSO-E clearly delineates which restrictions are to be reasonably introduced and accepted and specifically comments on the timely follow-up process. In the Position Paper Transition-times from SF_6 to alternative technologies for HV and EHV applications, a roadmap of the transition course is presented, forecasting the introduction of alternative technological solutions, and banning the placing on the market of SF_6 filled equipment. The ENTSO-E community is expecting the new F-gas Regulation to be put in force by January 2023 as shown in Figure 29. The newly introduced restrictions should encompass voltage levels from 53 kV up to 400 kV and include all standard Air Insulated Switchgear (AIS) and GIS applications. Concerning the state of the market ENTSO-E estimated 80% of a standard application, others are considered special:

- For high switching capacity (switching of reactive power sources);
- For high reliability (generator switch, offshore applications);
- For higher operating temperature range, size limitations, weight limitations;
- Direct Current (DC) links.

One of the crucial conditions the EU will be taking for prohibiting placing on the market of SF_6 GIS presents the opportunity to have at least two alternative solutions from different manufacturers. Such an approach could facilitate the refurbishment and extension of the transmission system while keeping the supply quality. For the 400 kV voltage level, a 9-year transition time is planned to include three years equipment development phase. ENTSO-E is acting as an interlocutor, suggesting, and advising the EU Commission bodies to keep the planned dates, and not to shorten the transition times. It can be expected that EU Commission will keep this pace, but this decision is not legally binding.

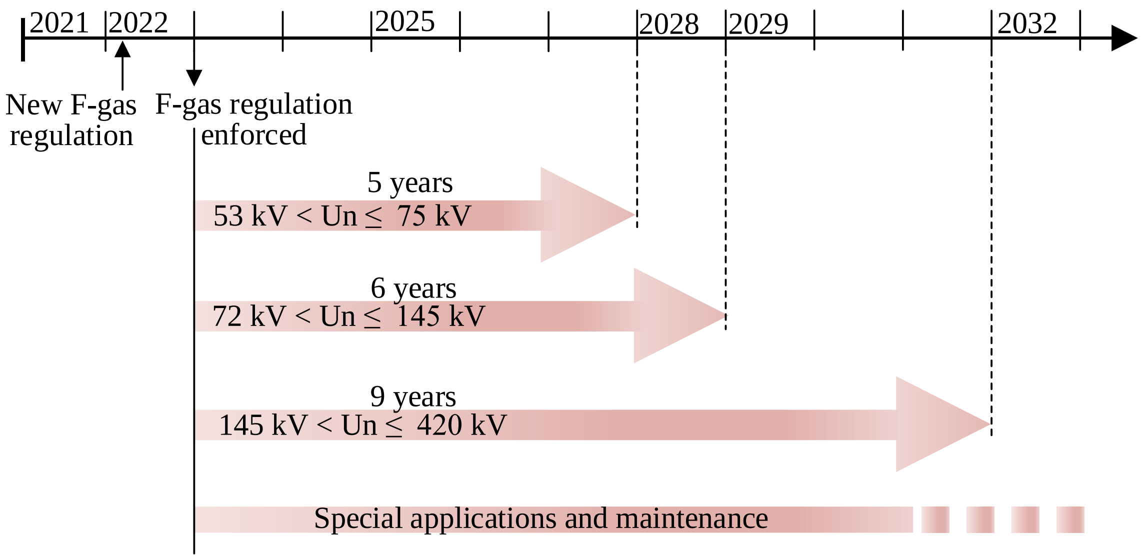

Figure 3: Estimated placing on market SF_6 switchgear equipment prohibition

2 SWITCHYARDS

The switchyard of the NEK plays an important role for the plant and provides necessary connections to power grid for electricity generation or electricity consumption in times of outage or emergency. NEK has three voltage levels at its switchyard: 400 kV, 110 kV and 21 kV. For the 400 kV switchyard NEK is responsible only for Transformer Bay 1 and 2.
400 kV switchyard consists of:

- Two busbars:
  - G I
  - G II
  - Its related bus coupler bay
- Transformer bays:
  - Transformer bay 1 (SYCAA01)
  - Transformer bay 2 (SYCAA02)
  - Transformer T411 and T412
- Overhead line bays:
  - Tumbri 1
  - Tumbri 2
  - Maribor
  - Beričevo 1
  - Beričevo 2

The 110 kV part of switchyard has gas insulated substation (GIS) of single bay which connects NEK and Krško Switchyards with oil-insulated cable for plant own consumption. A 110 kV line concludes with T3 transformer 110 kV to 6.3 kV main bus voltage for NEK as a backup power supply for plant own power consumption.

A 21 kV line is used as a power output of the plant and as normal power supply for power plant own consumption during normal operation. During normal operation the generator supplies:

- T1, T2 plant own consumption transformers 21 kV/6.3 kV;
- GT1, GT2 21 kV/400 kV main power output transformers.

2.1 SF_6 Elements in the switchyard

There are a lot of different elements in any switchyard and NEK is no exception. However, only Circuit Breakers (CB) and GIS devices are filled with SF_6 gas as quenching and insulating medium.

Elements filled with SF_6 are:

- Single Generator Load Break Switch (GLBS, model ABB model HEC 7C), an element that can separate plant generator from transformers T1, T2 GT1, and GT2;
- Single 110 kV GIS (model ABB EXK-0), supplying T3 for plant alternative own power supply;
- 9x 400 kV CB (all are model Alstom GL316), each with the ability to separate G I and G II busbars from any bays and one in bus coupler bay. Each of those CB have three phases, therefore, three separate elements represent one 400 kV CB. Strictly speaking for the output of power plant only 2 x 400 kV CB named SYCA01Q0 and SYCA02Q0, each for G I or G II busbar respectively. Those two CB are also in operation and maintenance domain of NEK.

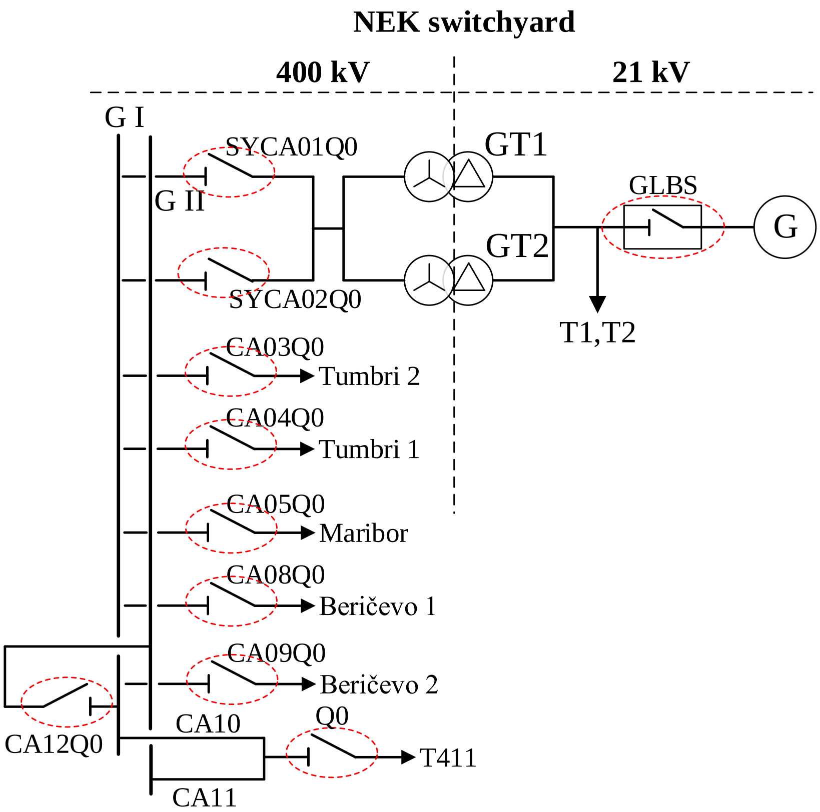

Figure 4: Simplified 400 kV NEK switchyard with marked SF_6 gas filled elements. In total there are 8 outgoing or incoming feeders and one bus coupler bay, each with SF_6 filled CB

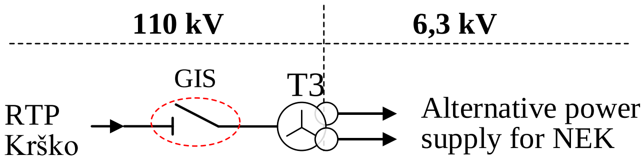

Figure 5: Simplified 110 kV part of NEK switchyard. GIS contains SF_6 gas and encompasses all elements normally found in the switchyard.

2.2 Amount of gas estimation and leakage in the switchyard

All these elements contain some SF_6 and each has its own leakage rate. Further information are listed in Table 2. To calculate CO_2, equivalent a factor 22.800 was used which is described in chapter 1.1. There are two types of leakage during lifetime of any SF_6 equipment:

- Leakage of seals and other structural materials. Standardized values are 0.1%, 0.5% and 1%.
- Gas released unavoidably during revitalization maintenance which occurs periodically when gas compartments need to be evacuated of gas and opened for CB contact check. It is always

mandatory for SF_6 gas to be reclaimed anytime the compartment is being emptied. The gas must not be released into atmosphere. It is estimated that at revitalization maintenance approximately 0.3% of gas is released into the atmosphere. The period for revitalization maintenance varies from product to product but it is normal to be 20 years apart.

Table 2: SF_6 gas weight comparison

Element filled with SF_6 in NEK switchyard	**SF_6 amount for all three phases**	**CO_2 equivalent**	**Rated leakage**	**CO_2 released per year**
GLBS, ABB HEC 7C	69.6 kg	~1,587,000 kg	≤ 0.5%	~8,000 kg
110 kV GIS, ABB EXK-0	91 kg	~2,175,000 kg	≤ 0.5%	~10,500 kg
400 kV CB, Alstom GL316	45 kg	~1,026,000 kg	≤ 0.5%	~5,100 kg
Total	205,6 kg	4,788,000 kg	≤ 0.5%	23,940 kg

3 LEAKAGE

To asses real leakage and compare it to rated leakage, a study in United Kingdom (UK) was taken into account [7], where an average leakage was found to be ~0.4% as it can be seen in Figure 6. Next observations can also be deduced using data in Figure 6:

- SF_6 inventory is getting bigger over the years.
- Yearly leakage is remaining roughly the same or its even dropping over the years.

As more devices filled with SF_6 should cause more leakage but that is not the case as new devices have been vastly improved and have less leakage in general also leakage rate for older devices was rated normally to 1% per year. Therefore using 0.5% to assess leakage rate is good conservative estimate on leakage rate.

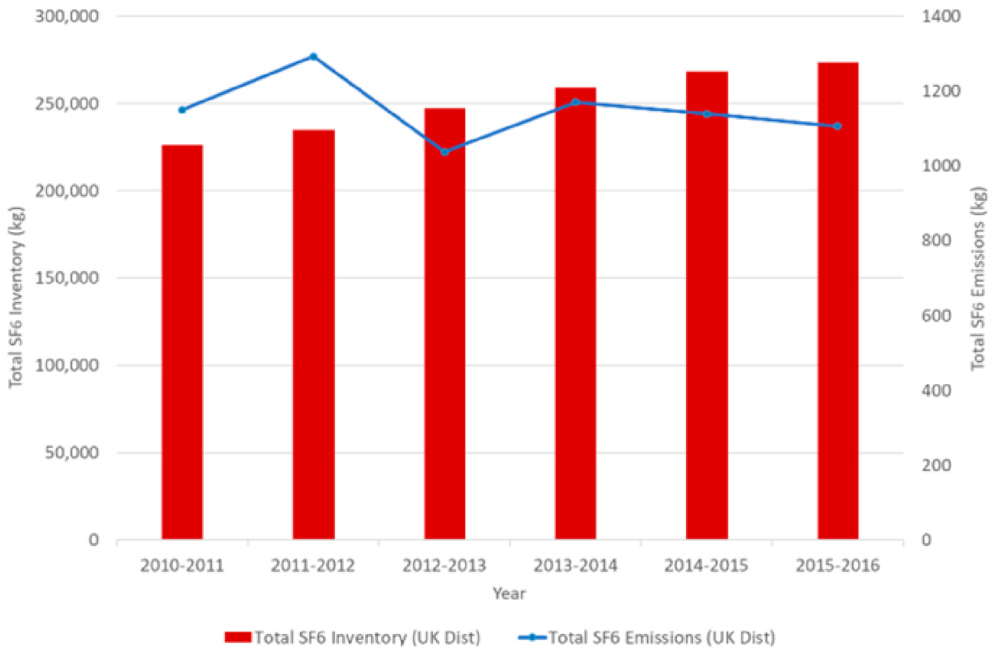

Figure 6: UK leakage of all SF_6 filled electrical equipment [7]

To put that into perspective a comparison with average car distance can be made. Firstly, an average car in Slovenia makes 12,653 km/year (in year 2021) and secondly, the average consumption of gasoline of a car generates 15.34 kg CO_2 per 100 km [8]. Using data from Table 2 a calculation (1) can be made to assess the distance one combustion engine car can make (or number of cars driving average yearly distance) to create the same environment impact as yearly leakage of evaluated SF_6 filled devices as presented in Table 3.

$$Distance\ traveled = \frac{Leakage}{Emmisions\ per\ kilometer} = \frac{10{,}500\,\frac{\text{kg}}{\text{year}}}{15.34\,\frac{\text{kg}}{100\text{ km}}} \approx 68{,}449\,\frac{\text{km}}{\text{year}} \quad (1)$$

Table 3: List of NEK elements with estimated environmental assessment impact

Element filled with SF_6 in NEK switchyard	**CO_2 released per year**	**Distance travelled[a]**	**Number of cars with average distance[b]**
110 kV GIS, ABB EXK-0	~10,500 kg	~68,500 km	6 cars
GLBS, ABB HEC 7C	~8,000 kg	~52,200 km	5 cars
400 kV CB, Alstom GL316	~5,100 kg	~33,200 km	3 cars

4 ALTERNATIVE SOLUTIONS

The leading manufacturers of non-SF_6 GIS who are active in our near market are Siemens Energy, General Electric (GE) and Hitachi Energy. GE accomplished an alternative, whose characteristics are like SF_6 using a gas mixture Fluorinated Gas Mixture (FGM) based on fluor-nitrile component. Hitachi got on in developing a technology based on fluor-ketone, but it was found that FGM brings substantial advantages in comparison with fluor-ketone based variants which led Hitachi to accept the same solution [9]. Siemens Energy directed its development towards the use of synthetic air as an insulation medium and implementing Vacuum Circuit Breaker (VCB) as compressed air does not enable the required arc-breaking capacity. More details are in continuation.

There are also few known suppliers, for instance, the Chinese Shenyang Huade High Technology, Meiden America, Mitsubishi Electric Power Products, Toshiba, and Meidensha. Some, like Toshiba and Meidensha, merged their development of non-SF_6 circuit breakers presenting in 2020 a 145 kV VCB [10].

It can be observed in general, that the manufacturers offer various suited technical non-SF_6 variants, meeting the state-of-the-art requirements and being commercially satisfactory for rated voltages not higher than 145 kV.

Based on references, there is only two major cooperation among companies, one is GE a leading company and the other leading company is Siemens Energy both being presented in Table 4. Within the GE the endeavours resulted in introducing FGM gas mixture replacing SF_6, Convention with Siemens Energy in the front decided to avoid all the fluorinated gases and are implementing gas-mixtures nitrogen/oxygen or CO_2/oxygen [11].

[a] Rounded to 100 km.
[b] To achieve the same environmental impact. Rounded up.

Table 4: Two groups developing non-SF_6 GIS variants

FGM technology	Vacuum and compressed air technology
GE [9]	**Siemens** [11]
GE	Siemens Energy
Hitachi Energy	Toshiba
	Mitsubishi Electric
	Nuventura
	Schneider Electric
	Iljin Electric
	Meidensha

Despite many world-recognized manufacturers deciding to develop and supply products using vacuum technology, there are doubts about whether it may suitably handle, meet the requirements and prevail at the voltage levels ≥ 400 kV. It is worth mentioning that this came by using a variety of alternative solutions. The diversity of alternative solutions developed by manufacturers combined with the high confidentiality requirements associated with strong competition in the market restricted the sharing of experience and considerably slowed down the process of deployment of alternative technologies.

Considering recent achievements, it may be concluded, that at least in midterm (up to 50 years from now) two technologies may prevail: the use of fluor-nitriles and vacuum. However, it should be emphasized, that in singular applications like in the case of generator switches (rated current 25 kA and 25,2 kV rated voltage [12]) due to the limited market and high-reliability demand, the SF_6 technology may not be banned. Besides, the vacuum technology is facing, at higher voltage levels (≥ 250 kV) a lower increment of the dielectric strength needed to withstand the Transient Recovery Voltage (TRV) in comparison with SF_6 gas [13].

By now in total there is 116 non-SF_6 GIS bays in different switchyards across Europe for voltage levels of 110 kV up to 145 kV already installed [14, p. 85]. With dominating but not exclusive countries Norway, Finland for Vacuum technology and Switzerland, Germany, and UK for FGM solution. In total ~11 t of SF_6 was omitted from use in Europe region by these newly installed GIS bays which is about 4.4% of UK total SF_6 inventory [15].

4.1 Fluorinated gas mixture solution

FGM solution offers use of already proven state of the art technology of gas circuit breaker where the same gas also acts as insulating and quenching medium while at the same time reduces GWP from 22,800 of SF_6 to below 1,000.

FGM is a mixture of carbon dioxide, oxygen and 3M™ Novec™ 4710 acting as insulating gas [16][17] which is also part of fluor-nitrile branch of chemicals. Its molecule is $(CF_3)_2CFCN$ or written differently C_3F_7CN. Gas exerts mild toxicity, however, as there is only small quantity of it needed in mixture (< 10%) it falls below the CLP toxicity criterion [18]. Laboratory tests have concluded its dielectric strength being twice higher than SF_6 while its GWP remains 2090 roughly 10-times less than SF_6 GWP. Dielectric strength of mixture is somewhat lower and it is a bit below SF_6 one at same pressure reaching ~160 kV/cm at 7 bars while SF_6 reaches ~200 kV/cm. GWP of mixture is also substantially lower as CO_2 and O_2 have one and zero GWP respectively in total FGM GWP sums up to ~470-times CO_2 equivalent. Novec™ 4710 also liquifies at temperature of –5°C and mixture needs to achieve lower temperature liquification at higher pressure of approximately 7 bars.

FGM is a mixture of:

- 4% - 10% Novec™ 4710,
- 5% - 6% oxygen,

- the rest is CO_2.

By thermal velocity of molecules the FGM mixture does not require any additional mixing device while being enclosed in the compartment [19][20]. Maximum capabilities of such non-SF_6 solution that can be found on the market, is 145 kV nominal voltage and 40 kA nominal breaking current.

4.2 Vacuum and compressed air solution

In contrast to fluorinated mixture an innovative approach to solve dependency to F-gas regulation is the solution where that a vacuum circuit breaker is used for the breaking medium, and the surrounding area is insulated by compressed air. That way a negligible GWP can be achieved while at same time completely omitting the use of any F-gas.

4.2.1 Compressed air

Compressed air is also considered as a gas mixture, but it is simply the same percentage mixture as it exists in our atmosphere with all impurities removed. Therefore, the mixture comprises of N_2 79.5% and O_2 20.5% [18, p. 77]. Compressed air is non-toxic nor mutagenic nor biologically active, and with GWP 0, where all molecules are two-atom, as such they do not absorb infrared light, which causes GWP, but rather ultraviolet light [21]. Compressed air as an insulation medium will always be excluded from any future f-gas regulations. Its biggest cons are that it is a very bad quenching medium, and its dielectric strength is medium at best; therefore, a vacuum circuit breaker (4.2.2) is needed to break the current. As dielectric strength is a bit higher than half of SF_6 the size of any device will inevitably be bigger or operating pressure will need to be higher.

4.2.2 Vacuum

Vacuum is essentially very thin air at very low pressure. At a certain point during lowering the pressure of atmosphere, air becomes so thin and molecules so far apart that their electrons stop conducting electricity and it becomes an insulator. Its dielectric strength reaches about 400 kV/cm, at an absolute pressure of 0.1 μbar. Vacuum circuit breaker uses magnetic force to quench arc of breaking current by forcing it outwards to electrodes' edge in the shortest time possible. Two types of vacuum circuit breaker exist and both operate by the same principle of magnetic forces as can be seen in Figure 7:

- The first one uses its own current to generate necessary magnetic force by using spiral electrode design, suitable for lower than 145 kV voltage levels.
- The second axial magnetic field electrode uses magnetic field in axial direction to exert the outward force on arc. Suitable for 145 kV voltage as it induces far less electromagnetic disturbances [22, p. 1].

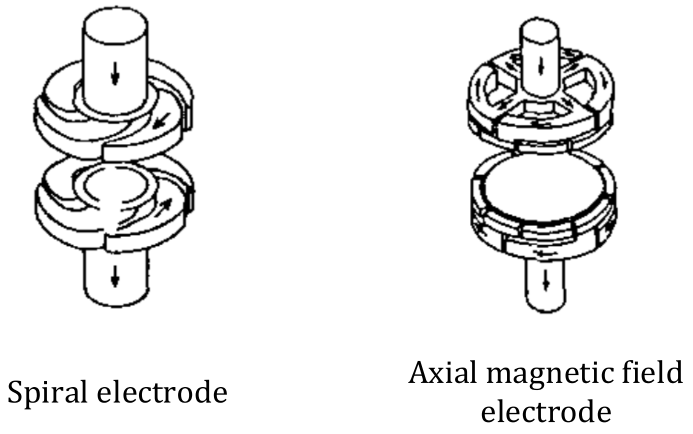

Figure 7: Two different types of vacuum circuit breaker electrodes. A spiral and axial magnetic field electrode. Arrows represent the path of current that exerts the magnetic field and consequently a force on arc.

Fine touch is needed to prevent local overheating of the electrodes as contact surface is flat and not rod shaped as in the gas breaking chamber. Therefore, certain technological aspects need to be addressed:

- Special contact surface is needed to be able to withstand extreme temperatures.
- The interior of contacts that needs to be an excellent conductor of heat and electricity.

The first 145 kV vacuum CB was developed and installed in 2002 [23]. Siemens has been installing 145 kV vacuum CBs since 2010 and by 2020 several thousands were been installed [24].

4.3 Comparison of SF_6 elements to non-SF_6 variant

Circuit breaker filled with SF_6 gas has reached a state-of-the-art level of technology, where only minor modifications are being made for voltages up to 400 kV and there is also ongoing development for higher voltage breaking capabilities. Such application took a lot of time to develop and since non-SF_6 variants have become available on market since roughly 2018, 2019 [14, p. 116], there is still a lot of development to be done to fully encompass all market needs for non-SF_6 variants. Figure 8 represents current market availability of non-SF_6 and SF_6 CB variants available. Similar conclusion can also be observed in a special EU report by the commission assessing the availability of alternatives to fluorinated greenhouse gases in switchgear and related equipment, including medium-voltage secondary switchgear [2].

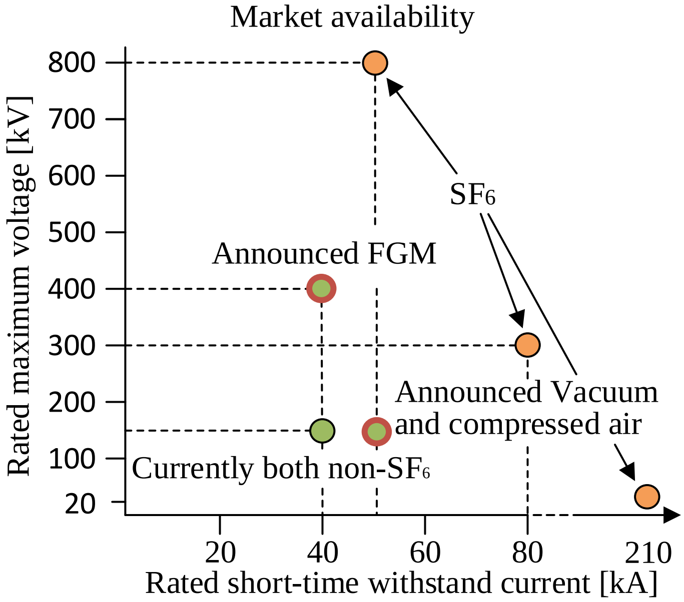

Figure 8: 2022 Market evaluation of SF_6 and non-SF_6 CB accessibility.

4.3.1 GLBS

As this element is considered to be used for special applications and is therefore used in small quantities worldwide, there is no non-SF_6 model available. There is also another obstacle that needs to be tackled to implement such technology, that is the high breaking current capability. As for now, only up to 40 kA peak interruption current is available on the market (Figure 8).

4.3.2 110 kV GIS

110 kV is the only high voltage level for which non-SF_6 CB variants that include live tank CB and GIS, can be found on the market, both of which can be found using technology of FGM and vacuum.

Siemens Energy has presented the vacuum CB and compressed air solution [25]:

- Live tank CB 3AV1 Blue
- GIS 8VN1 Blue

General Electric has presented FGM 145 kV solution [26]:

- Live tank CB GL 312g
- GIS F35g

Hitachi Energy has presented FGM 145 kV solutions [27]:

- Live tank CB EconiQ LTA
- GIS ELK-04 EconiQ

While all solutions offer comparable (same as SF_6 variant) electrical statistics, there are some differences in terms of maintenance, gas filling specifics, investment costs and different footprint size. As no live tank for 110 kV is used in NEK, no further comparison has been made. However, GIS comparison is presented in Table 5.

Table 5: Comparison overview of non-SF_6 and SF_6 GIS equipment

GIS variant	**8VN1 Blue**	**F35g**	**ELK-04 EconiQ**	**SF_6 in general**
Breaker type	Vacuum CB	Gas CB (FGM)	Gas CB (FGM)	Gas CB (SF_6)
Insulation medium	Compressed air	FGM	FGM	SF_6
Gas composition	20.5% - O_2 79.5% - N_2	6% - 7% - C_4F_7N 5% - 6% - O_2 The rest is CO_2	≤ 10% - C_4F_7N ≤ 11% - O_2 The rest is CO_2	100% - SF_6
Nominal gas pressure	7 bar - 7.5 bar	7.5 bar	6 bar - 8.8 bar	~ 7 bar - 7.5 bar
Rated maximum voltage	145 kV	145 kV	145 kV	145 kV
Rated maximum withstand current	40 kA[a]	40 kA	40 kA	40 kA
Footprint size	About 20% bigger than SF_6	Same footprint as SF_6	About 20% bigger than SF_6	/
Nominal number of 40 kA short circuit breaks	~ 30	~ 6	~ 20	~ 9
GWP	0	470	< 1,000	22,800
Leakage rate per year	< 0.1%	< 0.5%	< 0.1%	0.5%[b]
Gas weight in GIS	31 kg	31 kg	60 kg	~ 91 kg[c]
CO2 equivalent	0 kg[d]	14,570 kg	< 60,000 kg	GIS SF_6 ~2,100,000 kg
CO2 equivalent rated yearly leakage	0 kg	~73 kg	~60 kg	~10,500 kg
Lifespan	50 years	40 years	40 years	Can be extended up to 50 years

4.3.3 400 kV CB

400 kV non-SF_6 solutions are still in development although General Electric, Hitachi Energy and Siemens Energy have announced that better technology will be available in the coming years.

5 CONCLUSION

A simple calculation presented in chapter 3 estimates that using one SF_6 device in electrical grid has a potential to produce emissions equalling the yearly emissions of 3 to 6 internal combustion engine cars driving the average mileage. Also, NEK switchyard consists of 11 such elements:

- 1 x GIS which equivalents to six cars on the road continuously.
- 1 x GLBS which equivalents as five cars on the road continuously.
- 9 x 400 kV CB each equivalent to three cars on the road continuously and only three of such CBs are in NEK maintenance domain.

Summing all up all NEK switchyard elements equivalents to 38 cars continuously on the road every year as elements being operational. But if we take into account only part of the switchyard that is in maintenance domain of NEK a total elements count would equal to 20 cars.

Please take not that this is not the actual CO_2 that a life on Earth can have use for e.g., plants and trees but a gas SF_6 is being released that has much longer lifespan in the atmosphere of 3,200 years and

[a] 50 kA announced.
[b] Leakage rate was vastly improved in recent years.
[c] As SF_6 Gas roughly 4.7-times heavier than air.
[d] Gases N_2 in O_2 are two-atom molecules and they absorb UV light and not IR light that has GWP [21].

currently the highest known GWP is being released. However, as alternative technology is in its early stages, its reliability and accessibility need to be further proven. New technology is also not cheaper than state of the art SF_6 technology. It comes with an investment price tag that is 20% to 40% higher than SF_6 filled devices would be. In addition, a new EU regulation which is expected to be released in 2022, will most likely ban or severely limit the purchasing of new SF_6 filled devices by year of 2030 (Chapter 1.3), meaning that any company using such SF_6 filled devices should have a plan to purchase non-SF_6 electrical devices in years to come. According to currently available items on the market only NEK 110 kV GIS could be replaced for non-SF_6 variant (Chapter 4.3). As its installation dates to 2009 it is unlikely that NEK will invest into non-SF_6 variant of 110 kV GIS during its lifetime except if any new regulation disallows its further use.

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