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PS2 Impact of Net Zero on the Lifetime Management of SF6 Filled Equipment

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Analysis of the SF6 Leakages Events with Respect to Recommendations for End-of-Life Management of the Substation Equipment

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SUMMARY

The decarbonization of the electric grid will be a great challenge in following decades. The whole process will be limited by production capacities of the equipment manufactures. It is expected that the Transmission System Operators (TSO) will be facing problems with optimization of the end-of-life management of the current SF6 substation. This paper describes the experiences of the SF6 leakages statistics during last a few years in Czech transmission network. All recorded events of SF6 leakages have been analysed and many parameters have been observed such as type of equipment, age of equipment, date of event, amount of leaked SF6 etc. Based on statistical data of the SF6 leakages for various types of substation equipment (circuit breakers, instrument transformers, gas insulated switchgear) the recommendations for the end-of-life management can be determined. These recommendations should take into account the global data of the equipment as well. The global data can represent number of installations and total amount of SF6 inside the equipment. All the mentioned methods above should decrease the risk of SF6 leakages during the long-term process of decarbonization of the electric grid.

KEYWORDS

SF6 Leakage, Equipment of Electrical Substations, End-of-life Management, Decarbonization

1 Introduction

In the last few decades, the gas sulphur hexafluoride (SF6) has been widely used in the HV equipment of the electric switchgear. Because of the negative properties of the SF6 in the field of environment every gas leakage from the electrical equipment must be recorded and evaluated (place of leakage, amount of leaked SF6 etc.). This duty is given by the F-gas regulation of the EU. The company CEPS, transmission system operator (TSO) in the Czech Republic, prepares every year the report of the SF6 leakage events which appear during the operation. With respect to the planned restrictions of the SF6 in the next decade (new F-gas regulation), the data from SF6 leakage events can be used for an optimization of the end-of-life management of the existing equipment.

2 SF6 map of installed equipment in the grid

The transmission system in the Czech Republic is operated at two voltage levels 400 and 220 kV. The equipment filled with SF6 is situated in 33 electrical substations (both voltage levels) – Fig. 1. There are 30 substations air insulated substations (AIS), where the SF6 gas is part of specific devices and only 3 substations at the voltage 400 kV are performed as the gas insulated switchgear (GIS).

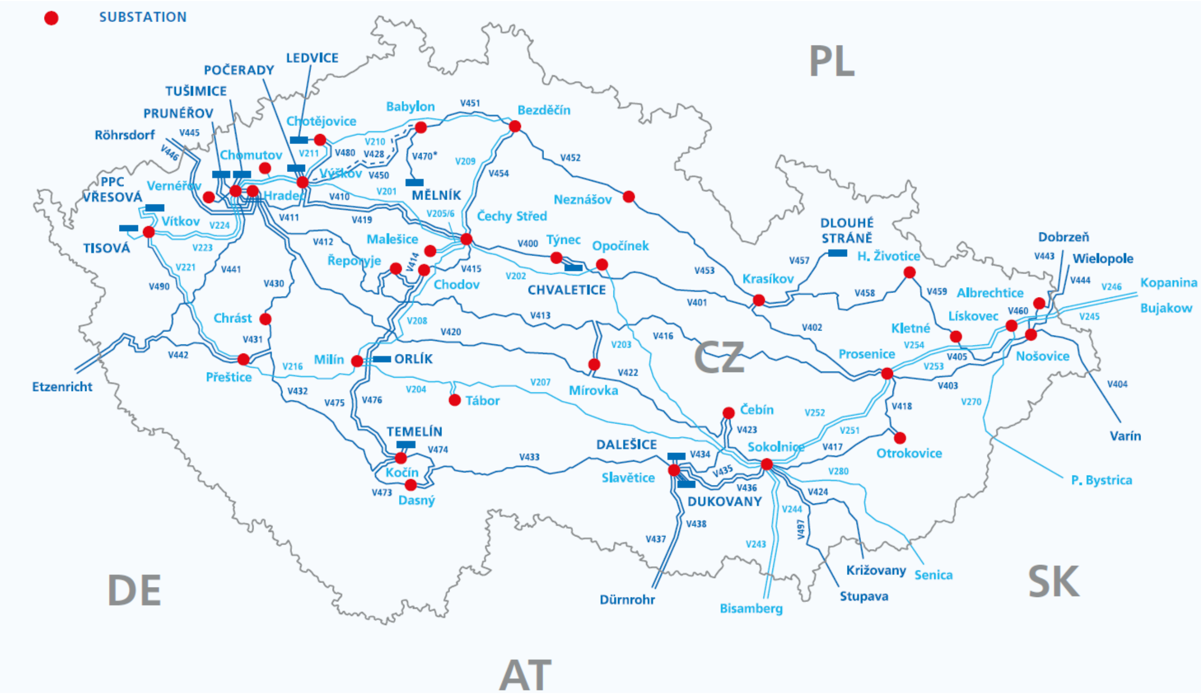

Figure 1: Map of the transmission system in the Czech Republic

For the further analyses the reliable database of the SF6 equipment must be made. As mentioned before, the SF6 is used in following applications:

- Circuit Breakers in AIS
- Instrument Transformers in AIS
- Gas compartments in GIS

For every type of AIS equipment, namely circuit breakers (CB), voltage transformers (VT), current transformers (CT) and combined transformers (VCT) the nominal value of SF6 mass is recorded. For every piece of installed equipment with SF6 the planned year of end-life is observed as well. The total amounts and numbers of installed equipment are shown in a Table I. The data about the SF6 in GIS is given in a Table II.

Table I – Installed base of SF6 equipment in AIS in 2022

Type of Equipment		Number of equipment (poles)	Total SF6 mass (kg)
Circuit Breakers		1 104	11 332
Instrument transformers	VT	271	5 845
	CT	267	6 971
	VCT	111	5 937
Total		1 753	30 085

Table II – Installed base of SF6 equipment in GIS in 2022

	Number of bays with CB	Number of bays without CB	Total SF6 mass (kg)
GIS 1	11	2	6 360
GIS 2	6	2	4 757
GIS 3	4	3	3 401
Total	21	7	14 518

3 Analyses of the SF6 leakage events

The circuit breakers and instrument transformers filled with SF6 in electrical substations are equipped with densimeters with switching contacts. Each of the gas compartments of the GIS is also observed by the densimeters with switching contacts. The setup of the alarm levels (1st and 2nd) is made by the manufacturer of HV equipment. On top of that, all installed densimeters are thermally compensated devices with the aim avoiding the false alarms of leakages as the consequences of rapid temperature changes. The functionality of the densimeters is checked in 5-year period. In following subsections, the SF6 leakages are more analysed. All these events were discovered via 1st alarm of densimeter switches.

Figure 2 – Densimeter installed on VT in AIS

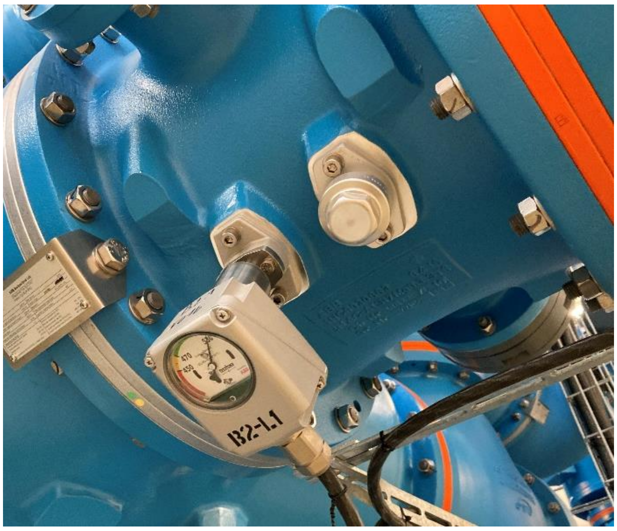

Figure 3 – Densimeter installed on GIS compartment

3.1 General statistics of SF6 leakages

In the Table III there is described a basic statistics of the SF6 leakages in Czech transmission grid during last 5 years. The data are shown separately for different HV equipment types filled with SF6. Then in the Table IV there are recorded values of SF6 refilled amount during those leakage events.

Table III – Basic statistics of SF6 leakage events

Year	Circuit breakers	Instrument transformers	GIS	Total
2018	3	8	0	11
2019	5	1	0	6
2020	7	2	0	9
2021	4	7	0	10
2022	7	4	0	11

For the specific type of equipment (index ST), the relative number of leakage events can be evaluated:

$$n_{\mathrm{ST}} = \frac{N_{\mathrm{ST}}}{K_{\mathrm{ST}}} \tag{1}$$

Where: n_{ST} … relative number of leakage events for specific type of equipment
N_{ST} … number of leakages of the specific type of equipment
K_{ST} … number of installed poles of specific type of equipment in the grid

Table IV – Refilled amount of SF6 during the leakage events with respect to the total installed SF6 mass during 5 years

Year	Circuit breakers (kg)	Instrument transformers (kg)	GIS (kg)	Total amount of refilled SF6 (kg)	Total installed mass of SF6 (kg)	Relative amount of refilled SF6 (%)
2018	1,95	15,2	0	17,15	~ 40 800	0,042
2019	7,62	2,12	0	9,74	~ 40 800	0,024
2020	7,69	6,4	0	14,09	~ 44 600	0,032
2021	6,65	4,5	0	11,15	~ 44 600	0,025
2022	9	7,04	0	16,04	~ 44 600	0,036

The amount of refilled SF6 strongly corresponds with the SF6 leaked to the atmosphere. The relative amount (described in last column of the Table IV) is related to the total installed amount of SF6 in a specific year. The standard IEC 62271 requires maximal permissible leakage lower than 0.5% per year for devices filled with SF6 (gas tightness requirement belongs to the type test set up). The rate of recorded amount of refilled SF6 after the leakage during last 5 years is stable and it is significantly lower than it the IEC 62271 standard requirement.

3.2 Age of the equipment

All the SF6 gas leakage events during last 5 years (47 in total) have been deeply analysed. First of all, the age of the equipment, on which the SF6 leakage appeared, has been investigated. Projected lifetime of installed equipment is usually 30 years. In Figure 4, the number of SF6 leakages with respect to the age of the equipment is demonstrated.

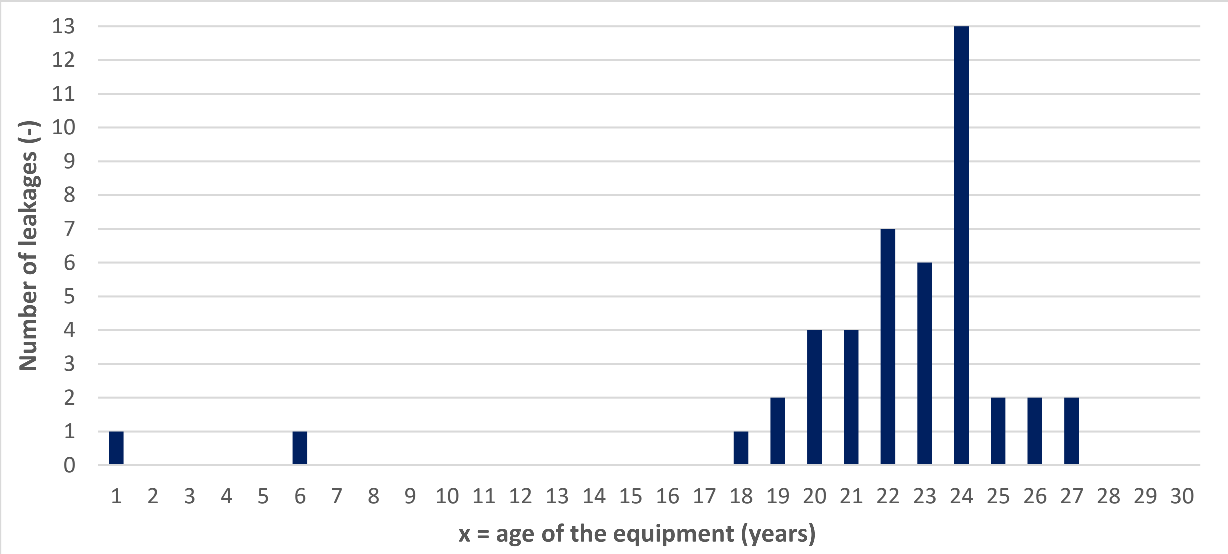

Figure 4 – Dependency of the leakage event frequency on the age of the equipment

The data in Figure 4 has clearly shown that the increase in the SF6 leakages is low until the equipment age become approximately 20 years. For the specific type of the equipment the mean value of the age can be calculated:

$$E_{\mathrm{ST}}(X) = \frac{1}{N_{\mathrm{ST}}} \sum_{N_{\mathrm{ST}}} x_i \quad (2)$$

Where: $E_{\mathrm{ST}}(X)$ …mean value of the age of the specific type of equipment

x_i … age of the equipment of *i*-th SF6 gas leakage

N_{ST} … number of leakages of the specific type of equipment

3.3 Seasonal effect of the SF6 leakage events

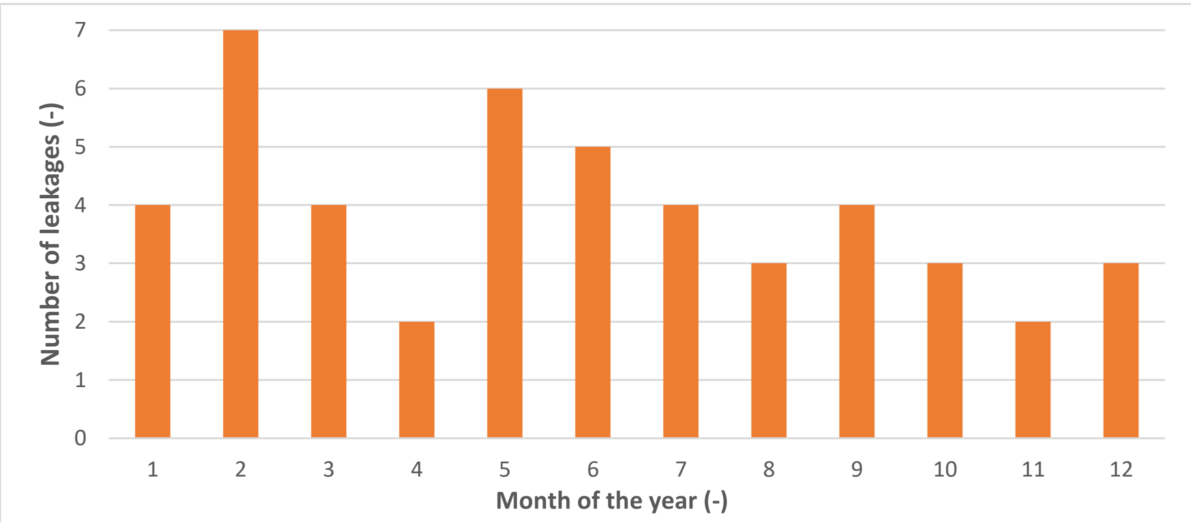

Figure 5 – Dependency of the leakage events frequency on the month of the year

The influence of the change of the climate conditions during the year on frequency of the SF6 leakages has been studied. In Figure 5, there are described all SF6 leakage events in last 5 years are divided into months of the year. The results have shown distribution of the leakage frequency during a year is quite uniform. Highest number of SF6 leakages appeared during the February - the coldest month of the year by temperature in Czech Republic. From global point of view, the statistics during last years didn't show a significant dependency between the number of leakage events and season of origin.

4 Recommendations for an end-of-life management

The projected lifetime of the HV equipment including the devices filled with SF6 in CEPS is 30 years. There are a lot of parameters and features those have influence on the end-of-life management such as:

- General reliability of the HV equipment
- Spare parts availability
- Results of the diagnostics performed during the routine maintenance

Considering those factors, the original lifetime of the HV equipment can be extended or shorten. SF6 leakage events belong to the general reliability of the HV equipment. Aiming to the reduction the SF6 leakage events to technical minimum, the statistical data and data from related analyses should be taken into account. Focusing on the SF6 leakage reduction, the end-of-life management can be handled via specific type approach, individual approach or via combination of both of them.

4.1 Specific Type approach

Considering the parameters described in chapter 3 such as relative number of leakage events for specific type of equipment n_{ST} and mean value of the age of the specific type of equipment $E_{ST}(X)$ the complex analysis and evaluation for all types AIS HV equipment (circuit breakers and instrument transformers) can be performed via following diagram – see figure 6:

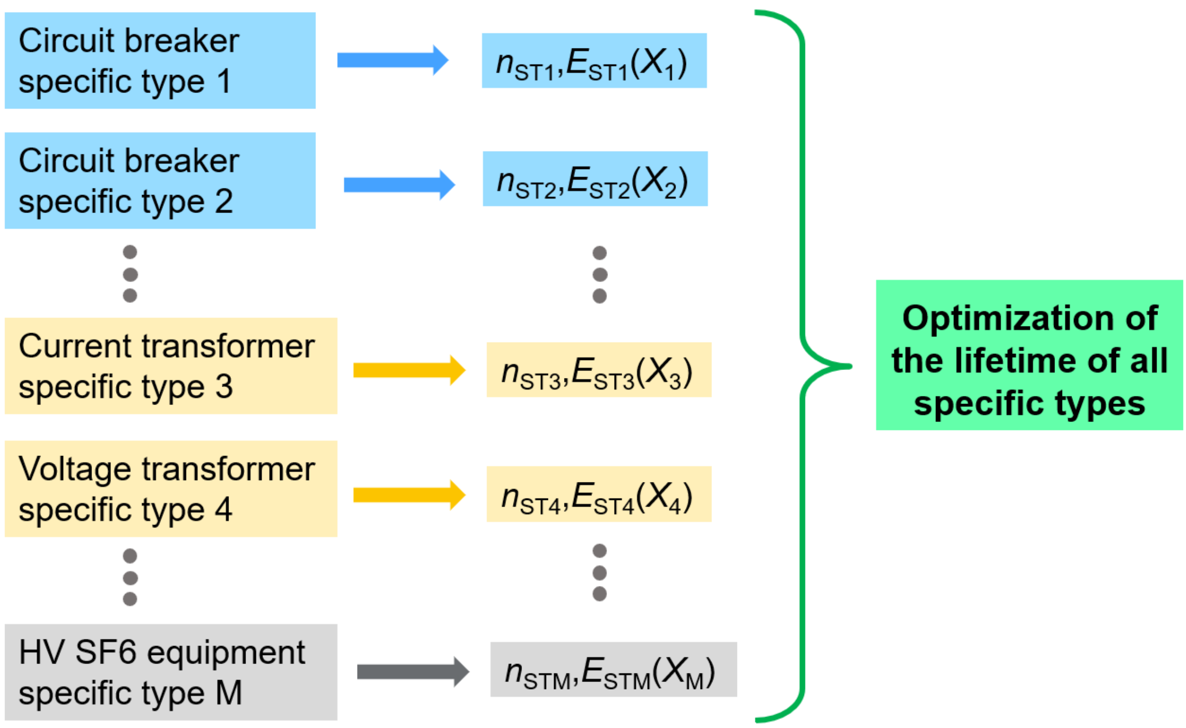

Figure 6 – Optimization of the lifetime of the HV equipment via SF6 leakage analysis

1. **Lifetime shortening** – in the case of high value of the relative number of leakage events the shortening of lifetime for the specific type of equipment should be considered. The new value of the lifetime should correspond with the calculated mean value of the age $E_{ST}(X)$ of the equipment with leakage events. In optimal way it should be smaller.

2. **Lifetime extension** – for the lowest values of the relative number of leakage events (sometimes is zero = no recorded SF6 leakage for the specific type of the equipment) the lifetime can be extended, if the other observed parameters and parts of the equipment are in a good condition.

Fig. 7 Different types of current transformers and circuit breakers in 420 kV AIS substation filled with SF6

4.2 Individual approach

Our experiences have shown that in some cases the specific type approach is not sufficient to reduce the SF6 leakages to the minimum. If the relative number of leakage events for the specific type is low, but there is problem with SF6 of one piece of equipment (for example one pole), the individual approach shall be applied. Especially, when the problematic piece of equipment shows the SF6 leakages repeatedly. In these cases, the complex evaluation (economical, technical…) is performed and two main possibilities as the solution are given:

1. **Repair of the equipment** – based on the cause of SF6 leakage, the specific parts of the equipment is repaired or replaced. Most often we record problems with gaskets, filling valves, material defects of the flanges.

2. **Exchange of the equipment** = lifetime shortening.

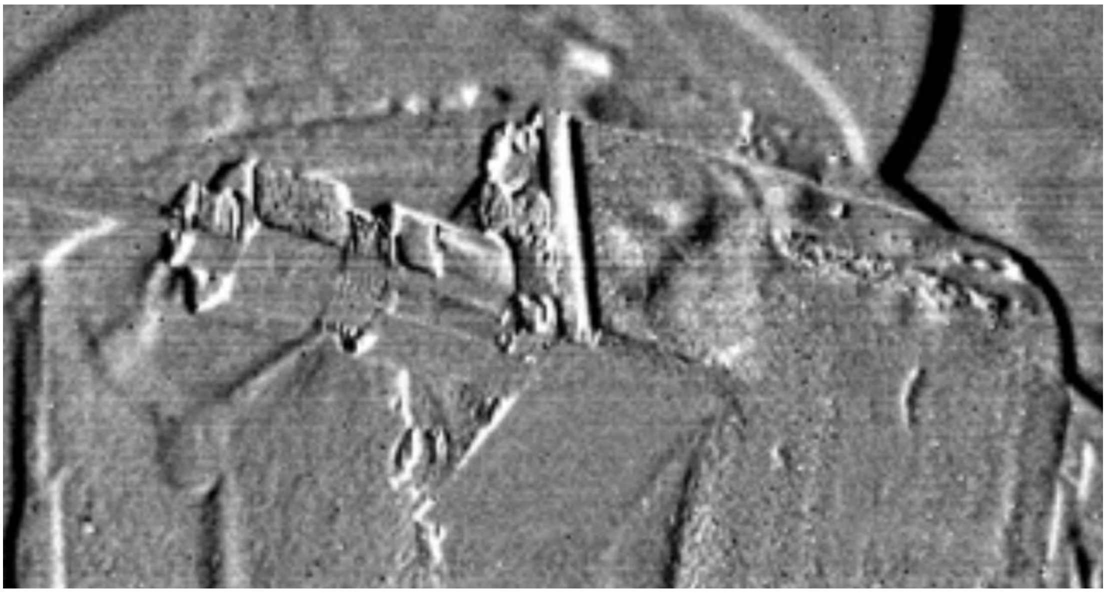

Fig. 8 Detected SF6 leakage on the 3-way valve recorded by SF6 camera

5 Conclusion

This article has described the analysis of the statistics of SF6 leakage events in Czech transmission grid during last 5 years. The presented data have shown that the leaked amount of SF6 is very low with respect to the installed amount of SF6 filled equipment – in relative quantity it is lower than 0,05%. On the GIS, there are no records of SF6 leakage events during last 5 years. Our GIS installations are quite young (the oldest one is 12 years in operation) and they are situated inside the buildings, where are stable temperature conditions. These facts help to keep the leakages at technical minimum. The further analyses of the SF6 leakage events of AIS HV equipment have been performed and the dependencies of the SF6 leakage events on several factors have been studied. Interesting data have been obtained from analyses of the relative number of leakage events and the mean age of the specific type of equipment. Obtained data can help to optimize the process of the end-of-life management with respect to the SF6 leakage minimization. Presented methods and analyses have shown the recommendations for setting up the preferences for the specific types of the equipment in the case of exchange towards the “non-SF6” solution.

6 Bibliography

[1] Internal CEPS database of SF6 leakage events

[2] EU F-gas regulation 514/2014

[3] IEC standard 62271 High-voltage switchgear and controlgear