LIFE TIME ESTIMATION OF SF6 MV SWITCHGEAR ACCORDING TO ON-SITE CONDITIONS IN DNO'S DISTRIBUTION NETWORKS

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ABSTRACT

SF6 MV switchgear installed on the DNO's distribution network is subject to ageing and degradation, such as SF6 leakages. Manufacturers of SF6 MV switchgear have to demonstrate - according to IEC standards - that the absolute leakage rate does not exceed the permissible leakage rate, this in order to guarantee a life time of 20, 30 or 40 years. The Belgian DNOs however, raised concerns about the leakage rate, taking into account that the life time of the SF6 MV switchgear might decrease considerably when the switchgear is installed under on-site conditions. These conditions are mostly more severe than the reference condition (20°C) at which the tightness type test has been performed.

This paper presents a realistic approach to the behavior of SF6 MV metal-enclosed switchgear, taking into account the real service conditions of this electrical equipment installed in substations of distribution networks in Belgium.

INTRODUCTION

Three modes of ageing affect the lifetime of metal-enclosed SF6 MV switchgear used in real service conditions present in distribution networks substations:

- Corrosion of metal parts under the influence of humidity and heat;
- Degradation of the insulating parts under the influence of moisture, heat and dielectric stress;
- Tightness of the vessel containing the insulating and arc quenching gas, mainly influenced by ambient temperature, gas insulation temperature and consequent pressure.

Factors influencing the life of such equipment are the service conditions (temperature, humidity and ventilation), the design of the vessel containing the SF6 gas (gasket) and the applied maintenance.

The end of life is determined by:

- blocked mechanisms due to corrosion of metal or swelling of synthetic parts, disabling their manual or automatic operation
- tracking currents and partial discharges leading to dielectric breakdown between phases or between phase and earth
- loss of SF6 gas, the SF6 pressure reaching the minimum service pressure, possibly leading to an intrusion of air into the SF6 vessel which makes the MV switchgear dangerous to operate and to keep in service.

This study focuses on the influence of temperature on the SF6 leakage and the ability of the switchgear to be operated.

The Belgian DNOs field experience on some SF6 switchgear focussed their awareness on the risk that the SF6 pressure drops below the limit of the minimum service pressure before the end of the amortization time prescribed by the network regulator. In that case, the switchgear can no longer be operated under load conditions; also the insulation level is no longer guaranteed. Therefore, four years ago, DNOs Eandis Ores and Sibelga, collaborating closely, have imposed additional tightness test at temperatures approaching values as achieved in most of the substations installed on the MV distribution network.

GENERAL APPROACH

Followed method

The study aims to establish a predictive lifetime model for MV switchgear already installed in the distribution network as well as for new equipment, depending on climatic conditions in the substations.

The study comprises 4 stages:

- Determination of the temperature profiles encountered in a real network
- Determination of the model of gas leakage as a function of temperature and temperature variation
- Application of the identified profiles to measured leakages to obtain the daily and annual leakage rate, verification of the coherence of the models by simulation of the real temperature cycles in a climatic test bay, and deduction of the presumed lifetime of the different switchgear depending on the real service conditions.

Temperature profiles in network substations

A number of substations representing situations most often encountered in distribution systems were chosen in collaboration with the DNOs involved in this project. The distribution substations are located in Belgium in various types of premises and buildings. We can mainly distinguish, firstly, installations in premises included in buildings for general use, in basement or on ground floors, with exterior walls or not, secondly, installations in standalone premises made of metal, concrete or masonry, strongly or weakly exposed to climatic conditions, with dark or light roof following the requirements of the authorities, and thirdly,

underground installations located in premises under the sidewalk. For each case mentioned above, the room can be large or small and the ventilation can be strong or weak.
Temperature sensors were placed for a year in order to obtain curves of daily temperature of the room temperature in the substations in the vicinity of the switchgear. Several sensors were placed in each substation to monitor the accuracy of measurements.

After analysis of the measurements on daily and annual bases, all substations under study can be grouped and classified into three categories (Cat.) according to their temperature curve profiles:

- Cat.1: inside substations (basement of building, buried under a sidewalk or outdoor but not exposed to weather conditions. The temperature is rather constant throughout the days and the seasons.
- Cat.2: heavily exposed building (stand alone kiosk). High daily and seasonal variations of the temperature. This category is largely applied on the distribution network.
- Cat.3: half-exposed premises (outside cabins partially protected from weather elements, or semi-integrated in building with low thermal inertia and/or important ventilation).

Figure 1: Substation at Waterloo – Cat 2 - Small standalone premise (compact substation) made of concrete with metallic doors rather exposed to weather conditions, with dark a roof

The shape of the curve profiles are similar for a defined category. The average temperature level can differ depending on the special constructional properties and design of the substation. A typical daily summer and ~~a~~ winter profile are deduced for each category of the temperature curve profiles. In the same way, a typical annual profile is deduced for each category. The example given here is representative for a category 2 (heavily exposed building).

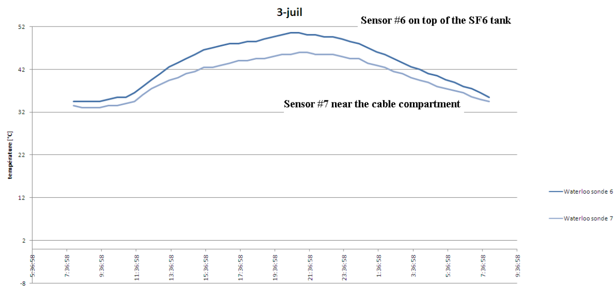

Figure 2: substation Waterloo – cat. 2 - Measured daily curve in summer period (3 July) with two sensors: sensor #6 on top of the SF6 vessel and sensor #7 near the cable compartment. The maximum T° is 50°C.

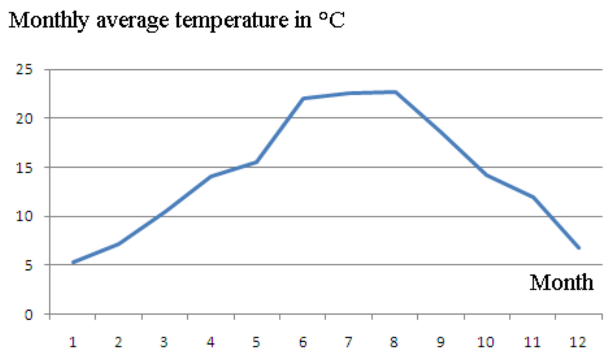

Figure 3: Annual profile of monthly average temperature for a substation of Cat. 2.

The same analysis is done for the 2 other categories.

Tightness of SF6 switchgear as a function of temperature

In order to ensure representative leakage rate values, a large number of different switchgear from different manufacturers were submitted to tightness tests for different constant temperatures (4 or 8 specimens for each type of switchgear).
All these switchgear are of the type "sealed pressure system". The expected operating lifetime specified by the manufacturers for all these switchgear with regard to tightness performances according to IEC 62271-1 is 30 years.
The tests are performed in accordance with the Qm test method of the IEC 60068-2-17 (tracer gas sealing test with internal pressurization), which is a method for measuring small leaks by accumulation.

The results of these tests are exponential curves giving the leakage rates in function of the temperature.

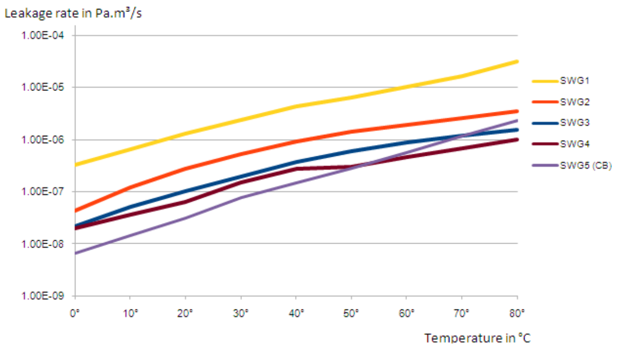

Figure 4: leakage rates of 5 different types of switchgear from 5 manufacturers as a function of the temperature in a semi-logarithmic graphic. For each type, most of the values are average values based on 4 to 8 specimens of the same type.

Those leakage rates are not directly representative for the expected lifetime at that constant temperature. The lifetime depends on the filling pressure as well as on the minimum service pressure.

Application of substation temperature profiles on SF6 switchgear

Temperatures are measured in the substation and not inside the SF6 vessel of the switchgear.
The temperature rise in the SF6 gas due to temperature rise of the main circuit should be taken into account, depending on the load.
According to the experience of the laboratory in temperature rise tests on many types of switchgear from different manufacturers, it is reasonable to consider a temperature rise of 40K at rated current (Ir) of the switchgear.
Since the ring current of distribution networks rarely exceeds 50% of the rated current of the switchgear (usually Ir = 630A), an additional temperature rise of 10K at the highest ambient temperature is taken into account.
The curve profiles are simplified to allow a simulation in the climatic test bay.

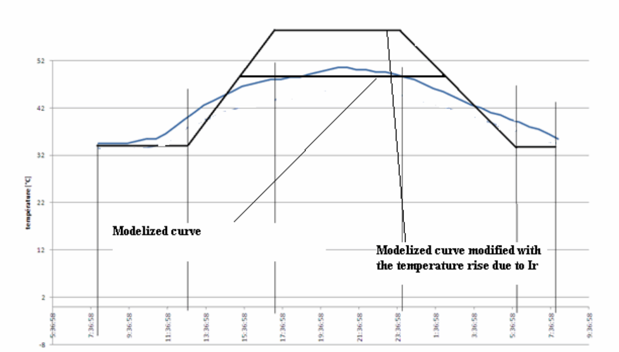

Figure 5: daily summer temperature model used to simulate the temperature curve for substation of the cat. 2

(see figure 2) taking the 10K temperature rise of the SF6 gas into account

The same exercise is done for the daily winter curves and for the annual curves for each substation category.

The impact of a rapid (daily) temperature variation on the leakage rate of the different switchgear is estimated by the comparison between a leakage measurement on a daily cycle and the corresponding calculation based on a combination of leakage rates at different constant temperatures. The conclusion of this comparison is that the error remains acceptable (being less than 10 %) if a constant value equal to the maximum temperature is considered for the temperature value during its rising time.

As it is not possible to perform a leakage equal to a full year period, the summer and winter daily profiles are superimposed on the annual curve profile and the leakage rate is determined by calculation.

For the switchgear 5 installed in a substation of the 2nd category, the calculation gives the following results:

Switchgear	expected lifetime
SWG 1	10 years
SWG 2	14 years
SWG 3	27 years
SWG 4	105 years
SWG 5 (CB)	189 years

Figure 6: calculated expected lifetime of 5 switchgear types installed in a substation of the 2nd category.

It should be noted that the expected lifetimes mentioned above are average values.
The switchgear installed in station of Cat.2 are subject to high daily and seasonal temperature variations. Hence the expected lifetime is the worst in comparison to both other categories. For this reason, the Cat.1 and 3 are not treated in detail in this paper.

Two of the 5 types of switchgear have an expected lifetime quite shorter than 30 years following the tightness test of the IEC 62271-1.

If the exponential inverse relation of the leakage rate as a function of the remaining pressure is considered, the average values become:

Switchgear	expected lifetime
SWG 1	26 years
SWG 2	17 years
SWG 3	62 years
SWG 4	127 years
SWG 5 (CB)	210 years

Figure 7: calculated expected lifetime of the same switchgear types for an exponential inverse relation between leakage rate and remaining pressure.

One can observe that this calculation mode, providing a more realistic approach towards the expected lifetime, has not the same impact on the "linear" lifetime value of all the switchgear because of the different volumes and pressures.

CONCLUSION

We succeeded in establishing a robust model to evaluate the expected or remaining lifetime of SF6 switchgear in real service conditions of distribution network substations installed in a region with moderate climate. This model can be applied on all possible switchgear of the type "sealed pressure system" containing SF6 after having measured its leakage rate for 3 constant temperatures.
The calculated lifetime based on the tightness test at an ambient temperature of 20°C, as required by the standard IEC 62271-1, is absolutely not representative of the actual lifetime in a distribution network substation. For most switchgear types, the calculated lifetime at a constant temperature of 20°C is much more than those 30 years, but the criteria on the leakage rate for routine tests have to be adjusted to higher lifetime values for network use.
Our calculation model demonstrates big differences on the expected lifetime of the considered switchgear. For some of the switchgear the expected lifetime is shorter than the amortization time as prescribed by the regulator.

MISCELLANEOUS

Acknowledgments

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