SGC switchgears compatible with real service conditions : Solutions that address on-site conditions

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ABSTRACT

MV switchgears in service are subjected to ageing and degradation, such as partial discharges, tracking, corrosion and leakages. The degradation and ageing of the MV switchgear is accelerated by the combination of humidity, temperature and dielectric stress. This ageing and degradation is insufficiently taking into account in the corresponding standards.

Furthermore switchgears, in particular when installed in secondary substations, are mostly subjected to more severe conditions than the normal service conditions as considered by IEC 62271-1 (common clauses). Standards covering adequate tests exist but are not mandatory in the common clauses according to IEC 62271-1 neither in the corresponding series 62271. The IEC 62271-304 (test under severe conditions) is well mentioned but without correspondence with the service conditions and focuses only on switchgears intended to be used in service conditions more severe with respect to condensation and pollution than the normal service conditions specified in IEC 62271-1. Additionally the test detailed in IEC 62271-304 has been designed primarily to investigate the behaviour of electrical insulation and not corrosion on equipments. The performance of mechanical components, such as mechanisms and interlocks is not mandatory.

When for gas insulated switchgears the ambient temperature goes beyond the limits according to the normal service conditions considered by IEC 62271-1, no adequate standards are available. For the MV switchgear subjected to on-site conditions not only the ambient outside temperature should be taking into account. More importantly, the ambient temperature inside the substation should be taken as reference. Manufacturers of SF_6 MV switchgear have to demonstrate 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. However, when the switchgear is installed under on-site conditions the life time of the SF_6 MV switchgear decreases considerably as conditions are more severe than the reference condition (20°C) at which the tightness type test has been performed. This papers reflects on on-site measurements and the direct influence on the expected lifetime of switchgears available on today's market.

The dielectric stress to which a component is exposed is determined by the design of the switchgear. The extent to which dielectric ageing occurs is determined by the environmental conditions and the proper material selection of the used insulating elements. The dielectric aspect of the MV switchgear in time can be verified by means of the level 2 ageing test according to IEC 62271-304. Furthermore, the requirement of the IEC 60587 for tracking current on insulation parts is be addressed. Although both tests provide a first indication of the dielectric ageing process, it does not fully cover the on-site conditions as the tests are performed on new specimens, disregarding their ageing after installation under real service conditions. Moreover it should be addressed that both tests are not mandatory.

In order to optimize the reliability and life span of the installations, it is advisable to map and monitor all addressed aspects. A solution is presented in this paper.

In addition to the quality of the MV switchgear, attention should be paid to the condition of the substation. Measures should be taken to prevent a moist cable cellar, rapid temperature fluctuations in the substation should be avoided and the ventilation should be tailored to the actual installation together with the positioning of the switchgear.

In summary, this paper aims to show which particularities should distinguish MV switchgear suited for real network conditions relative to the requirements considered in the standard. Additionally it points out that accidents or failures, no matter how rare, cannot be ruled out and adequate actions must be taken to protect operators and the general public. An adequate solution is presented for which the risk can be considered negligible in case of an internal arc. This applies both for the MV switchgear and its substation.

INTERNATIONAL STANDARD VERSUS ON-SITE CONDITIONS

The standard IEC 62271-1 defines the normal service conditions for which the assigned characteristics of the switchgear for indoor use are guaranteed. However no type test is foreseen to verify the compliancy of this switchgear with defined service condition.

Even the requirements for the severe climate conditions (level 2 ageing class) according to the IEC 62271-304 are not severe enough to demonstrate that the expected lifetime (30 years) of the equipment will be guaranteed under normal service conditions. A visual inspection on various switchgear after level 2 ageing class of the IEC 62271-304 (7 weeks of 5 days cycles) was performed and compared with switchgear submitted to real site conditions. One can conclude that the level 2 ageing class is equivalent with seven years under normal service conditions in not heated substations with transformer with an average relative humidity value between 70% and 80%. Failure of this level 2 test however shows that a switchgear design is not suitable for 30 years lifetime in normal service conditions according to IEC 62271-1, and certainly not for relative humidity level above 60%. To simulate 30-year aging under actual service conditions the conductivity of the water measured in the test room should be increased (> 100µS/cm), pulverization should be performed and its recommended to increase the duration of the test for some more weeks.

Different modes of ageing affect the lifetime of metal-enclosed SF_6 MV switchgear, used in real service conditions:

- Corrosion of metal parts under the influence of humidity and heat (**Figure 1**).

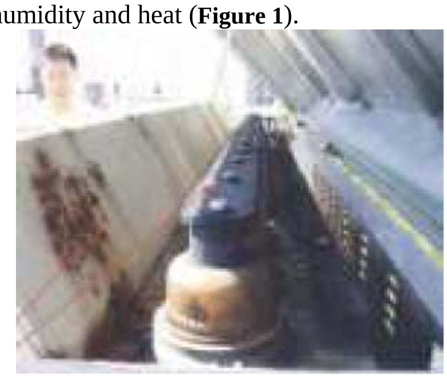

Figure 1: Corrosion on metallic part on a RMU

- Degradation of the insulating parts under the influence of moisture, heat and dielectric stress. Partial discharges and tracking currents leading to dielectric breakdown between phases or between phase and earth (**Figure 2**, **Figure 3**).

Figure 2: Degradation including tracking

Figure 3: Degradation due to corona effect

- Tightness of the SF_6 vessel containing the insulation gas mainly influenced by the ambient and insulation gas temperature.

TEMPERATURE PROFILES IN NETWORK SUBSTATIONS

<u>Classification based on temperature profiles</u>

Substations can be grouped and classified into three categories according to their temperature curve profiles:

- Category 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.
- Category 2: Heavily exposed building (stand alone kiosk). High daily and seasonal variations of the temperature.
- Category 3: Half-exposed premises, outside cabins partially protected from weather elements or semi-integrated in building with low thermal inertia and/or important ventilation.

The temperature profile in Figure 4 was obtained in a concrete substation according to Category 2. One sensor was placed on top of the SF6 vessel (red curve), a second sensor was placed near the cable compartment (blue curve). During this measuring period, an ambient air temperature outside the substation was registered between 19.8°C and 26.6°C. Inside the substation a maximum temperature, on top of the SF6 vessel, of 50°C was registered.

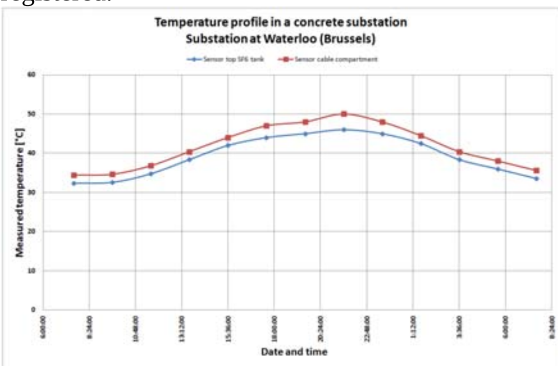

Figure 4: Measured daily curve in summer period

Application of substation temperature profiles on SF_6 switchgear

Temperatures displayed in Figure 4 are the ambient temperature in the substation and not inside the SF_6 vessel of the switchgear. The temperature rise in the SF_6 gas due to temperature rise of the main circuit should be taken into account, depending on the load. Based on our experience, it is reasonable to consider a temperature rise in the SF_6 vessel of 40K at rated current (Ir) of the switchgear. For distribution networks the ring current rarely exceeds 50% of the rated current of the switchgear, therefore an additional temperature rise of 15K at the highest ambient temperature should be taken into account.

The impact of a 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.

Tightness of SF_6 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 to 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 more than 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, given in Figure 5 and Table 1, are average values.

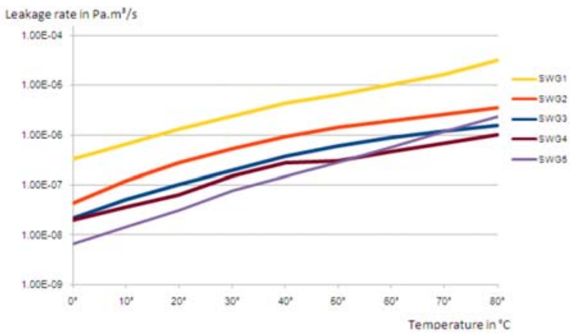

Figure 5: Measured leakage rate depending on the ambient temperature

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

Table 1: Calculated lifespan based on the measured leakage rate at 80°C

Life estimations based on tightness test according to on-site conditions

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. For most switchgear types, the calculated lifetime at a constant temperature of 20°C is much more than the required 30 years although when switchgears are tested in line with actual conditions most switchgears do not meet the expected 30-year lifespan.

In order to estimate a lifespan according to on-site conditions, additional tightness test a high temperature and extreme temperature (taking into account full load) should be performed.

Tightness type tests are performed on all SGC’s products at ambient temperature of 80°C whereby an expected life span greater than 100 years is obtained. This is achieved through thorough research and development.

MASTERING THE DIELECTRIC STRESS

The basic parameter that influences the ageing of electrical equipment is the local electric field. This is influenced by several factors related to the design of the switchgear such as the shape of both conductors, metal and insulating parts between which the electric field is applied; the quality of the insulation and in particular the insulation surface resistance subjected to local tangential fields and the resistance to tracking. Those two parameters are influenced by the quality of the insulating materials and by the degradation of their surfaces under the influence of the electric field as well as the pollutants present on the surface. These may be due to external pollution but also to internal pollution of the switchgear produced by partial discharges where the electric field is close to or above the limit of the dielectric strength of the air, taking into account its relative humidity. It should be noted that this limit can be reached for temperatures remaining above the ambient air’s dew point (i.e. without condensation). The degradation of the insulation surfaces itself increases the occurrence of tracking currents which amplify the degradation.

The combination of a poor design causing an excessively high local electrical field can be increased by a lower quality and degradation of the insulating components. Furthermore, it should be addressed that due to a lack of standardization dielectric type test on cable compartments can be made without cables or cables lugs. As a result of this shortcoming, the type test is not according to the real service conditions. All dielectric type tests performed by SGC are with connected cables, with maximum stated cross section, which guarantees that the design of the cable compartment is type tested in accordance with the real service condition and is compatible with all other cable configurations.

Figure 6: Degradation due to tracking after 12 years in service in normal service conditions

The tracking test according to IEC 60587 allows a good comparison between different insulation materials. Although it does not cover the on-site conditions as the tests are performed on new specimens, disregarding their ageing after installation under real service conditions. Moreover it should be addressed that the test is not mandatory.

In order to obtain an expected lifespan in accordance with real service conditions with regard to tracking and other forms of dielectric ageing the design of the switchgear should minimize local dielectric fields. Additionally tracking test 1A4,5 in according with IEC 60587 and level 2 ageing test in according with IEC 62271-304, taking into account the water conductivity > 100µS/cm, should be mandatory to verify the quality of the used material and assure the expected lifetime.

CONDITION OF THE SUBSTATION

Besides the selection of the proper MV switchgear attention should be paid to the inner climate of the substation. A poor inner climate of the substation will have a negative influence on the lifetime for the MV installation and should be avoided.

<u>Avoid rapid temperature fluctuations</u>

Before the thermal isolation of the substation, the inner temperature followed the outside temperature for about 60 %. These fast inside temperature changes caused condensation inside the MV installation. This due to the slow acclimation of the MV switchgear caused by the high mass of metal and isolators inside the installation.

After thermal isolating of the substation the temperature changes inside reduced significantly, less than 1 degree per 8 hours. In general this gives enough time for the inventory to acclimate.

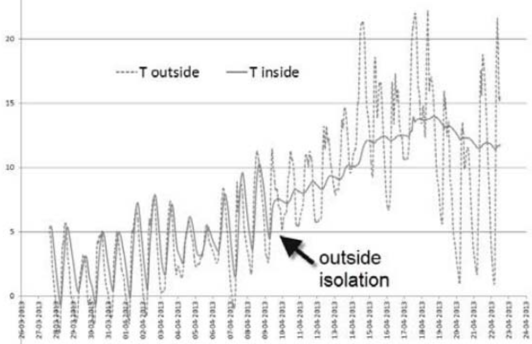

Figure 7: Minimizing the temperature fluctuations due to thermal isolation (Rc 0.3 up to 3W/Km)

<u>Minimize interaction between switchgear and cable cellar: usage of a floor and gland plates</u>

For substations which have no floor, and therefore have an MV switchgear that is in direct contact with the cold and moist cellar, condense will occur as the open cellar is much colder than the outside temperature. Additionally, ventilation is calculated to cool down the transformers at maximum load. The maximum temperature increase at the maximum load is 10 Kelvin. Due to the open cellar, the temperature inner climate is 10 degrees colder than outside. The air from the ventilation is many degrees warmer than the inner climate. The warm air inlet easily leads to condensation on the colder MV switchgear. Special care should be taken that the switchgear is not located in the direct airflow of the ventilation. Due to the holes in the gland plates and open spaces around the cables the inner climate in the MV-switchgear is dominated by the cellar.

In more than hundred substations analysis of the inner climate condition have been carried out. From this analysis the following three basic rules can be applied to improve the inner substation climate significantly.

- Every floor has to be air tight.
- Walls of substations without a MV-LV transformer require an Rc of at least 1 W/K.m
- MV switchgears should not be placed in front of or nearby vents.

It is necessary to avoid the low temperature and high humidity of the cellar from the surroundings of the MV switchgear to prevent condensation.

<u>Condition based maintence</u>

SGC has developed a remote substation interface (Figure 8) that allows to monitor both the substation as the MV switchgear and transformer (if applicable).

Based on an investigation of ageing phenomena and most frequent failures in MV switchgears three types of sensors are developed to register both temperature, humidity and effects of the partial discharge. An additional current sensor or tapping can be installed to verify the measurements as function of the load. In order to assure that the condition of the substation does not deteriorate over time, it is advised to install sensors both in the substation and the cable cellar (premature detection of moisture intrusion).

Furthermore, each individual switchgear can be equipped with sensors for registration of the humidity, temperature and effect of partial discharge with a sample rate of 1hour to detect any premature ageing.

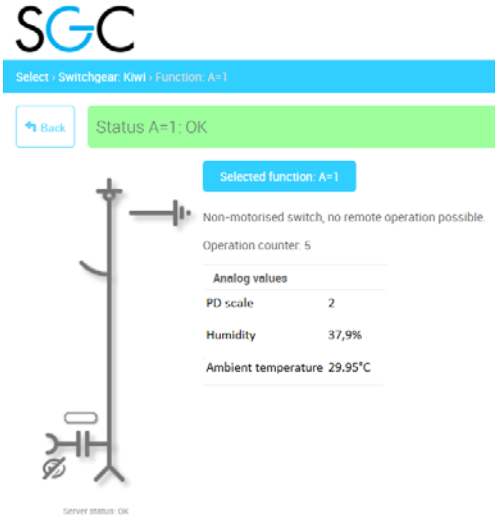

Figure 8: SGC's Remote substation monitor

Next to the instantaneous values that can be consulted, an algorithm was developed that integrates these measurements into condition assessment procedures resulting in condition based maintenance. Condition based maintenance aims at performing maintenance on equipment only if the condition implies urgency.

In addition to the registration of all capture information, this application also allows remote controlling of the switchgear.

PROTECTION OF OPERATORS AND THE GENERAL PUBLIC

Despite all precautions, an accident or failure cannot be ruled out. Therefore, the concept of internal arc class (IAC) is implemented to IEC 62271-200. No reference is made in this standard to the pressure applied on the building nor to the consequences that could have an indirect effect on persons. This is taken into account in IEC 61330 for prefabricated substations. No equivalent standard exists for substations inside buildings of general purpose. When the substation is located in a building: there is no way to make a full-scale test to investigate how the local conditions will affect the whole system behaviour. As a matter of fact, such a test cannot be considered because of non-repetitive surroundings.

On the field, two situations can occur. The designer can enforce his requirements to the architect of the new building for the design of the substation with a view to the equipment he wants to install. Most of the time, the building is already erected and there is only a limited impact on minor modifications as enlarging of the ventilation openings. This is also the case when a retrofit of MV switchgear is foreseen.

In such cases the most reliable option is to install a MV switchgear equipped with an arc eliminator, which diverts the electrical arc to metallic short circuit by means of fast-sensing and fast-closing devices. This technique avoids long reaction time before eliminating the arc.

SGC offers an particularly rapid arc eliminator system, the patented arc-killer, whereby a fast elimination of arc is obtained before having any external consequences (flames, hot gases, pressure) by diverting it to a metallic short circuit by means of fast sensing and fast-closing arc eliminator. In case of an AIS switchgear, the cubicle can be taken into service after occurrence of the internal arc due to the fast elimination. The fault must be removed and the cubicle should be cleaned prior to take back into service.

When a MV switchgear is equipped with an arc-killer, no pressure is applied onto the substation and maximum safety for both operator as general public is assured. Furthermore, network situation has to be re-established quickly.

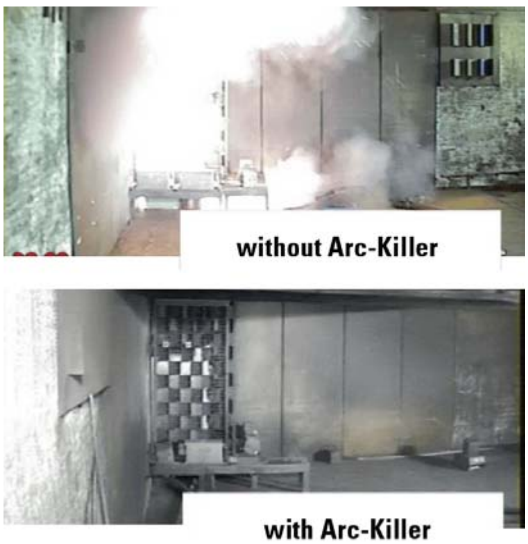

Figure 9: Maximum safety due to arc-killer

CONCLUSIONS

Factors influencing the lifetime of metal-enclosed SF_6 MV switchgear are the service conditions (temperature, humidity and ventilation), the design of the MV switchgear, the condition of the substation and the applied maintenance.

A successful level 2 ageing test according to IEC 62271-304 does not claim a lifetime of 30 years under all normal service conditions. Failure of this level 2 ageing test however shows that a switchgear design is not suitable for 30 years lifetime in normal service conditions. To simulate 30-year ageing under actual service conditions with regard to tracking and other forms of dielectric ageing the design of the switchgear should minimize local dielectric fields. Additionally tracking test 1A4,5 in according with IEC 60587 and level 2 ageing test according with IEC 62271-304 taking into account the water conductivity > 100µS/cm should be mandatory.

The calculated lifetime based on the tightness test at an ambient temperature of 20°C is absolutely not representative of the actual lifetime. In order to estimate a lifespan according to on-site conditions, additional tightness test a high temperature and extreme temperature should be performed.

Besides the selection of the proper MV switchgear attention should be paid to the inner climate of the substation. By means of the remote substation interface, condition based maintenance can be performed.

Despite all precautions, an accident or failure cannot be ruled out. When a MV switchgear is equipped with an arc-killer, no pressure is applied onto the substation and maximum safety for both operator as general public is assured. Furthermore, network situation has to be re-established quickly

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