HOW TO CONTROL THE IMPACT OF THE SEVERE ENVIRONMENTS SURROUNDING MEDIUM VOLTAGE SWITCHGEAR

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ABSTRACT

This paper presents an ecosystem which aims at continuing the initiative of sustainable developments. This approach become more and more integrated in the regulation framework of the energy markets as the directives 2009/125/EC and 2014/25/EU. This ecosystem deals with increase the lifetime expectancies of medium voltage switchgear and controlgear exposed to special and severe service conditions. The association of sensors and algorithms enable to anticipate any early ageing. However a strong product design is still required, with a complete functional analysis anticipating the constraints met during the product lifecycle [1]. All of this allows a better expected lifespan coupled with a minimized environmental footprint.

INTRODUCTION

The Figure 1 shows how an ecosystem aiming the sustainable development, contributes to increase lifetime expectancies of MV switchgear and controlgear installed in severe atmospheric conditions.

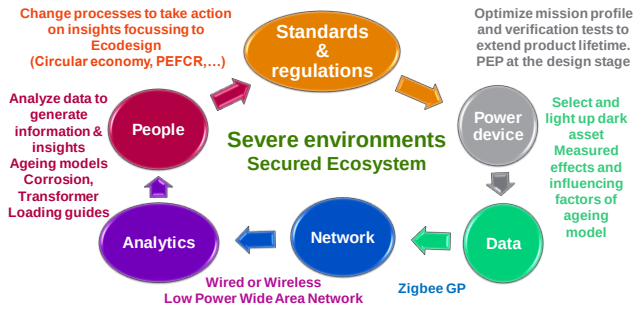

Figure 1: Ecosystem applied to MV Switchgear.

As all influencing parameters to the ageing of the MV switchgear can't be covered, only the temperature, the relative humidity, the pollutants as sulfur dioxide and chloride deposit will be taken into account. Those aimed by the indexes of atmospheric pollution, will be reminded to identify where the protection for operator is.

STANDARDIZATION FRAMEWORK

The IEC standard specifying the atmospheric service conditions of electrical distribution MV switchgear is the IEC 62271-1 standard. When it is made a reference to the conditions of pollution in which switchgear may be installed, this standard makes a reference to the specifications IEC/TS 60815-1 and IEC/TS 62271-304 which are respectively for outdoor switchgear and indoor switchgear. This last specification aiming at classifying switchgear according to degrees of severities of service conditions does not reproduce an ageing but provide an assessment of the electric insulation impacted by the condensation and the pollution. Follow-up studies are necessary to define robust tests trying to realize a fast ageing such as specified by the ISO/IEC directives part 2 2016: « The stability, reliability or lifetime of a product shall not be specified if no test method is known which can verify the claim in a reasonably short time ».

ATMOSPHERIC CONDITIONS

To extend the lifespan of medium voltage switchgear for which the electric insulation and operating parts are exposed to the atmospheric conditions, it is recommended that the operating area respects the normal service conditions as defined by the IEC 62271-1 standard, for all outdoor services conditions, even severe.

According to a NETA's report [10], the top five switchgear failure causes on distribution apparatus, from direct or indirect origins are as follows:

- Loose connections (Insurance carrier 25% of cases)
- Electrical insulation breakdown
- Water penetration from various origins
- Breaker raking
- Faulty ground fault protection

A right design of electrical switchgear which is installed according to the manufacturer recommendation completed to an accurate monitoring would contribute to solve the top 5 issues highlighted by the NETA.

Temperatures

The normal maximal temperatures mentioned in the standards of switchgear are 35 °C average over 24 hours, otherwise 40 °C.
Certain conditions can contribute to exceed these values. For example when the switchgear is installed in housing and in presence of a oil immersed power transformer, it is always necessary to consider an ambient temperature increased by twice the temperature rise class of the housing [3][4], and in the absence of test the values of the table of the standard IEC 60076-7: 2005 §8.3.2 can be retained. An enclosure of prefabricated substation or a not thermal isolated building exposed to sun radiation can be at the origin of a premature ageing of the switchgear

or the transformer [2]. The annex D of the IEC 62271-202: 2014 standard dealing with HV/LV prefabricated substations gives several examples of transformer loads inside housings following the limits of transformer temperature rise as defined by IEC 60076-7 and IEC 60076-11 standards. As it will be presented in the chapter "Solution" it becomes possible to generalize the support to facility management dealing with MV electrical distribution and condition based maintenance, even to modernize an existing installation [8].

Humidity

According to the IEC 62271-1 standard, for the indoor switchgear, under normal service conditions, the maximal relative humidity and water vapour pressure does not exceed respectively 95% and 2.2 kPa average over 24 hours, then 90% and 1.8 kPa average over a month. For a site it would be more relevant to specify the water vapour pressure, due to the effect of the temperature to the relative humidity being in opposition of phase as shows it the Figure 2. An example of a temperate climate according to the IEC 60721-2-1 standard gives the following values as yearly average Temp=23 °C, Rh=76% and Wvp=2.2 kPa. These values can be met as indoor service condition inside a substation, which are not normal due to the water vapour pressure value. Figure 2 shows for one month 3 samples of climates: temperate, arid and tropical.

Also according to IEC 62271-1, the ambient air is not significantly polluted by dust, smoke, corrosive and/or flammable gases, vapours or salt. Condensation can be expected where sudden temperature changes occur in periods of high humidity. Condensation may be prevented by special design of the building or housing, by suitable ventilation and heating of the station or by the use of dehumidifying equipment.

Condensation and pollution

The two main factors at the origin of accelerated degradation are the condensation and the pollutions against which it is necessary to protect the switchgear. When it is not workable it is recommended to refer to classified switchgear as defined by the specification IEC/TS 62271-304. This specification does not integrate a severity of pollution into its testing procedure. So one of the goals of this paper is to describe the atmospheres for which medium voltage switchgear could be exposed. This should help to select and light up dark asset as showed in the ecosystem Figure 1, trying to better control the ageing models and the processes, creating value for customers, users and we all as citizen.

The specification IEC/TS 62271-304 classifies devices through a testing procedure of cycles of wet heat while being energized at rated voltage, followed by an electrical assessment. The most realistic nominal constraint would be to introduce a minimum of conductivity through the water or through the adjuvant to reproduce constraints met in the environments considered as special or even severe. For that the specification IEC/TS 60815-1 "Selection and dimensioning of high-voltage insulators intended for use in polluted conditions" can help to define this need, as well as the documents to which it makes a reference.

That's why the best way of proceeding before specifying special services conditions, would be to measure the deposits on the targeted site for a project according to the IEC/TS 60815-1 to master the impact on the electric insulation. The measurement of the environmental and atmospheric parameters affecting the corrosivity has to be made according to the ISO 9225 standard.

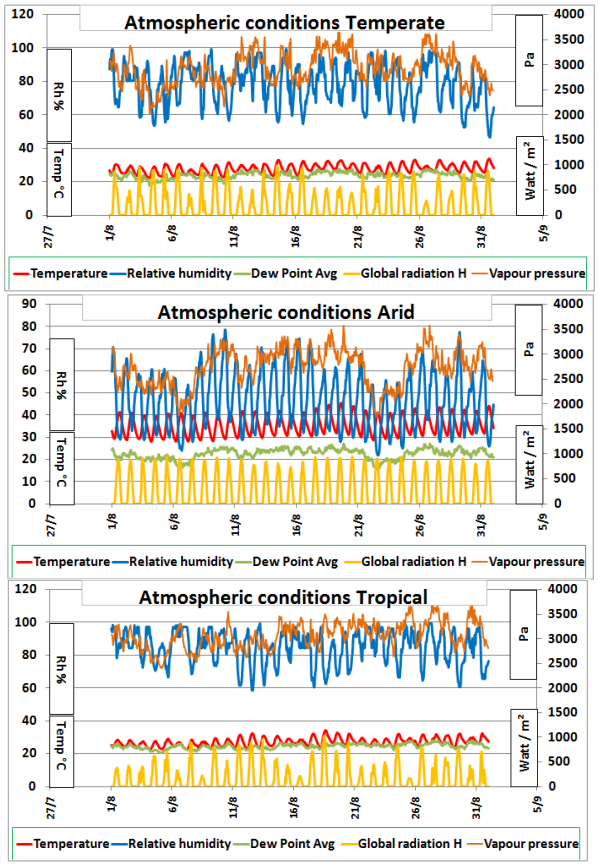

Figure 2: Examples: Temperate, Arid and Tropical.

Condensation

The condensation met in the HV/LV substation, results from a change of state of the vapour contained in the air in the contacts of the cold surfaces in environments with strong humidity. When the dew point is very close to the ambient temperature as shows Figure 2, every time the relative humidity exceeds 95 %, the cold surfaces with higher thermal capacity condense. This phenomenon can be met in HV/LV substation having openings towards the outside near the MV switchgear or inside of switching

unit without transformer. When such a phenomenon occurs and when it is not eradicated by ventilation or an adapted heating, the condensed water stay inside the substation and the internal humidity remains high.

Pollution

Numerous classifications of severities of pollution exist. The Figure 3 gives the results of an exercise trying to cross the concentrations of major environmental pollutants according to the requirements of the normative organizations IEC and ISO compared with the European directive on the air quality.

Pollutant	ISO 9223 (µg/m³) / y	Health EU directives 2011/850/EU		IEC 60721-3-3		ISO 9223
		(µg/m³) /y	(µg/m³) /h	Ref value (µg/m³) (Max < 30min a day)	Class	Area
SO_2	2 – 15			10		rural
	5 – 100	20		100 max	3C1L 3C1	urban
	50 – 400		350	300 1000 max	3C2	Industrial
NO_2	2 – 25			100 max	3C1L	rural
	20 – 150	40			3C1	urban
	151 – 1000		200	1000 max	3C2	urban
O_3	≤ 10			10 max	3C1L 3C1	
	10 < X < 90		180	50 100 max	3C2	
Particles $PM_{2.5}$		25 -> 18				
Particles PM_{10}	10 – 25					rural
	30 – 70	40	50			urban
						industrial

Figure 3: Concentration of atmospheric pollutants

However the salinity of the atmosphere mainly caused by proximity of a coastal zone or a zone subjected to de-icing salts should be considered as well as some precautions to avoid any pollution of electric room.

The data of the standard IEC 60721-2-5 "Environmental conditions appearing in nature: dust, without, salt mist" must be cross-checked with experimental data to be able to give models more accurate of chloride instead (Cl^-) of salt deposits (NaCl). It also depends on the height of the exposed element above the ground, its orientation and on the wind speed. This standard gives as constituents of salinity from sea water, 55.4% of chloride Cl^-, 30.4% of sodium Na, 7.7% of sulfate completed by other constituents. The Figure 4 represents the chloride deposits following experimental measurements according to the distance to the sea [5] [6]. It also is to consider that the speed of deposit is generally lower in the sheltered and ventilated operating area as met in HV/LV substations but the speeds of corrosions are superior, compared to those of an element exposed outside, being less washed by rainwater.

The criterion of wash is considered in the civil work European standard such as the EN 1993-1-4:2006/A1:2015 annex A, dealing with the durability of structural stainless and steels. The distance from the sea is even the first criterion in the process of optimization of maintenance by NATO in Canada in their aircraft wash program in front of the concentration of sulfur dioxide [6]. Works assessing the chloride deposits from coastal or de-icing salts with respectively regard to a distance of sea or highways are available. This depends on the rules and process of the de-icing, however we can note similar values at the coastal distance until 500 m from the source.

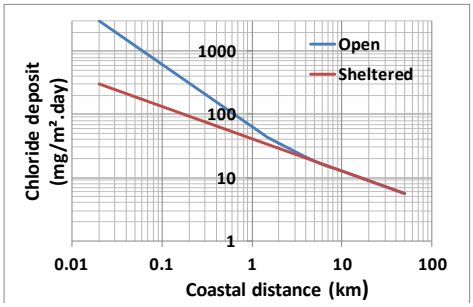

Figure 4: Cl^- deposit = f (coastal distance)

Atmospheric corrosion

The corrosion is one of phenomena which can affect metallic structures or mechanisms of medium voltage switchgear and for which the factors of degradation are common to the ageing of the electric insulations, the latter having the voltage for additional severity. The Figure 5 shows how ISO 9223 and ISO 9224 standards can help to assess an atmospheric corrosion on carbon steel further the examples of the Figure 2 with a coastal distance of 1km and one case at 40m [7] exposed to the washing by rain. When the model has been crossed with experimental results from 1 to 20 years, the average of deviation was 74% on 40 tests and became 50% when 2 extremes values have been removed. The evaluations of corrosions rate according to ISO 9223 and ISO 9224 are reliable enough if the atmospheric severities are known, but improvable. Indeed these standards do not consider the rain which is a main factor to cross the model with outdoor experimental results and on the contrary the results of experiment do not take the sheltered area not exposed to the rain [13]. According to the ISO 9223 Time of wetness (TOW) is the time that the temperature exceeds 0 °C and the relative humidity is over 80%.

	Corrosion	Chloride 40 m from source		Chloride 1000 m from source			
	µm 20y	Coastal	De-icing				
	IEC SO²	3C1L < X < 3C1	3C1L < X < 3C1	3C1	3C2	3C3	TOW h/y
Climate	Temperate	3141	2553	742	1034	3269	3778
	Arid	1483	1205	386	552	1823	407
	Tropical	2211	1797	500	688	2125	5023
	ISO 9224	CX	CX	C4-C5	C5	CX	

Figure 5: Corrosion of carbon steel after 20 years

When the TOW value is over 2500h/y, the condition corresponds to outdoor atmospheres in temperate and

tropical climates or to ventilated housings in humid conditions or unventilated housing in temperate climates, as defined by the ISO 9223 standard.

Conductivity

The conductivity is a measurable and controllable criterion in case of test. The IEC/TS 60815-1 shows the relation at 20 °C between the salinity and the conductivity, the Figure 6 expresses the opposite facilitating the definition of the conductivity for a given concentration.

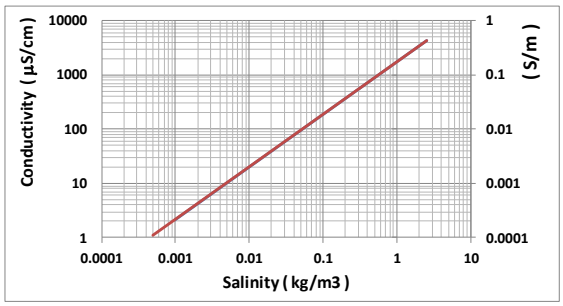

Figure 6: Salinity and conductivity

The standard IEC 60507 enables to assess various levels of conductivity at 20 °C according to volume or layer conductivities as showed Figure 7. This should help to define a conductivity severity within the specification to IEC/TS 62271-304.

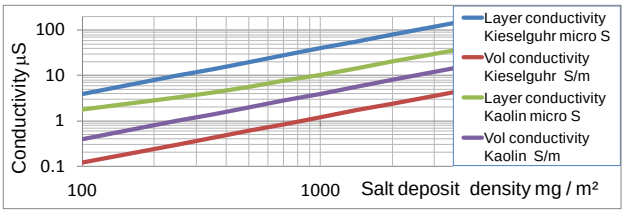

Figure 7: Conductivity / Salt deposit

In fact the specification to classify the MV switchgear and controlgear when facing to special service conditions is perfectible as far as the influencing criteria are understood and mastered avoiding any technical overbid targeting an optimized eco-design. In the presented ecosystem Figure 1, the climatic mission profiles for which MV switchgear and controlgear is the first step. The previous description could help to better specify the conditions for which the MV switchgear is intended to be exposed or to better specify the recommendation for their installation to avoid any early ageing.

SOLUTION

The main factor influencing the ageing is the temperature then the humidity especially when there are pollutants. These factors are variable and can easily be known. The salinity depends on the geographical situation and can be also assumed before the erection. However it will be necessary to protect the MV switchgear because the temperature and the humidity will increase strongly the ageing.

Data

Sensor of temperature and relative humidity

The sensor showed Figure 8 enables to measure the ambient temperatures of the MV or LV electrical installations. It could also be used for the microclimates of compartments integrating parts for which a permanent monitoring would allow to anticipate any maintenance phase even if this one was the object of an optimization plan [8]. This sensor is equipped with a battery for his power supply and communicates his information of temperature, relative humidity and battery voltage according to the Zigbee protocol Greenpower (ZGP) in compliance with the IEEE 802.15.4, for a lifespan and the mission profile adapted for the application of utilities or industrial. The whole information exchanges presented in the ecosystem of the Figure 1 has to be exchanged according to the standard dealing with cyber security [12].

Figure 8: Thermal and relative humidity sensor

This technology of low energy consuming communication allowed achieving not to use a battery when a measure of temperature is necessary on an active electrical part carrying current. It is what was made for the self powered thermal sensor showed Figure 9 [9]. It has been separately tested up to 5500 A in addition of the EMC tests, and for the dielectric withstand of the switchgear up to 50 kV for the short duration power-frequency voltage test and 125 kV for the impulse test. This sensor of small size 30mm*30mm is designed and tested according to the safety standard IEC 61010-1 “Safety requirements for electrical equipment for measurement, control, and laboratory use”, as well as the American national deviation UL 61010.

Figure 9: Self powered thermal sensor

Analytics

The ecosystem must be loop closed and the secure data put at the disposal of the Zigbee concentrator ❶

outcomes from the various sensors ❷ as those presented above, must be analyzed by a controller ❸ or through a platform before to join the cloud, see Figure 10. The algorithm is adapted if the temperature is measured on a connection, a circuit breaker, a busbar even a power transformer [10]. As any ecosystem a person is at the end of the chain even for machine learning systems to support the learning phases and optimize the processes.

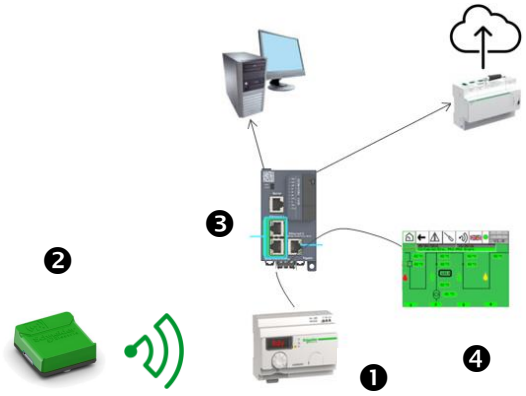

Figure 10: ZGP concentrator❶ + PLC❸ + HMI❹

Closed loop

In the era of the all-digital in these new energy markets Building Information Modeling (BIM) data are more and more required by regulatory frameworks. However the data of the products mainly the ratings will have to live with the electrical standardization framework dealt by the IEC product and installation standards as well as the data management, to deliver an optimized and secured lifespan. In this ecosystem, the man will remain the guarantee of these sustainable coherences and will insure the actions of adaptation of the normative or regulatory texts, to make them simple and applicable, facilitating the exchanges.

CONCLUSION

This paper drew up first a status of main climatic influencing factors of MV switchgear ageing as well as a standardization framework. The connectivity of these switchgear enables to watch if the conditions of installation and operation for which they were chosen and installed, correspond to the expectations of the users. This will help the condition based maintenance [8]. The man will have to keep the control of the process to make it more and more efficient and compliant with the new normative and regulatory frameworks. So a new ecosystem has been created.

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