Impact of the New Medium Voltage Switchgear trends on Medium Voltage fuses

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***Abstract* — This paper establishes a discussion, based on experimental results combined with Finite Element Analysis, about the impact of new MV Switchgear trends (higher temperature-rise limits and SF6 substitution) both on MV fuses and typical switch-fuse combinations. Additionally, a preliminary analysis is also presented about the eventual implementation of the new temperature rise limits by SC32A, on future editions of MV fuse standard.**

Keywords—Fuses, temperature-rise, switchgear, SF6 free, standardization

I. Introduction

Medium Voltage Current Limiting Fuses (fuses) are extensively used in combination with different types of Medium Voltage Switchgear (switches), in order enhance the breaking short-circuit capability of the switchgear.

At the IEC level, switches and fuses are covered by two different Technical Committees. MV switches are covered by TC 17 and particularly by SC17A and SC17C, while fuses are covered by TC 32 and particularly by SC 32A. TC 17A has published in 2017 the common rules for switchgear and controlgear (IEC 62271-1 Ed.2.0 [1]) allowing higher temperature rise limits for contacts, while these new limits are not considered by SC32A.

Additionally, and due to environmental reasons, GIS is being impacted by the progressive substitution of the SF6 as insulation and/or switching media, by alternative gases, having worse thermal characteristics in comparison with SF6.

II. Switch-fuse combinations

A. Main principle

There are several switch-fuse combinations concepts all around the world, but basically in all these concepts fuses and switches, or contactors, are coupled each one supplying a back-up protection for the other. The following table illustrate the duties expected to be delivered by each device, in a switch-fuse combination according IEC 62271-105 [2].

TABLE I. Duties in a switch-fuse combination

Performance	Switch-fuse combinations IEC 62271-105	
	Fuse IEC 60282-1	*Switch IEC 62271-103*
High Short-circuit faults and TRV's	☺	☹
Low current faults	☹	☺
Three-phase breaking	☹	☺
Cost-effective protection	☺	☺

Roughly speaking, if the fault current is high enough to cause the operation of the fuse(s) at times well below of the "fuse-initiated opening time" then the fault is cleared by the fuse(s) and the switch open the three-phases with no load and independently of the type of fault (single-phase, bi-phase or three-phase). At this level of current the fuses must deal with the breaking duties.

In contrast if the fault current is low enough to cause the operation of the fuse at times lower than the operation of the switch, tripped by the striker of the first fuse to operate, the breaking process is completed by the switch.

B. Main architectures

With the same operating principle detailed in clause II.A, we can find in the marketplace different concepts of switch-fuse combinations, each one affecting the fuse in a different way. All the architectures are ordered beginning from the older to the more recent ones

1) *Air insulated switch-fuse combination (non enclosed)*

Figure 1. Air insulated switch-fuse combination (non-enclosed type)

The older architecture shown if Figure 1 is the one where the fuses are submitted to a thermal condition similar than the ones stated in IEC 60282-1 [3], regarding the temperature rise arrangement. However, there are, even in this case, some differences that could challenge the fuse (three-phase arrangement, eventual heat sources coming from the switch) and that's why even in this case the rated continuous current of the switch-fuse combination need to be tested according IEC 62271-105 [2].

These switch-fuse combination architectures were normally installed on walls, in indoor substations, or pole mounted in overhead distributions.

In both cases heat sources coming from other switchgear are not common at all.

2) Air insulated switch-fuse combination (metal-enclosed)

a) Switch in ambient air

Figure 2. Air insulated switch-fuse combination (metal-enclosed type) with the switch in ambient air

The architecture shown in Figure 2 is equivalent to the Figure 1 but installed inside a metal sheet, totally enclosed, and with certain IP protection level (usually IP3X or higher), with no forced ventilation means. The installation inside a metal enclosure, provide in principle a higher level of safety for the people.

In this installation condition, the thermal restrictions imposed by the metal-enclosed switchgear on the switch-fuse combination impact the fuse thermal behavior and then a new rated continuous current of the switch-fuse combination, different from the one tested in clause 1) is mandatory. Heat sources coming from functional units coupled with the switch-fuse combination bay are quite usual. All the functional units are electrically linked through a busbar (not shown in the picture)

b) Switch in a gas different from the ambient

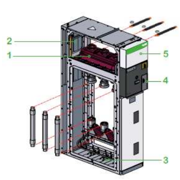

Figure 3. Hybrid switch-fuse combination (big volume)

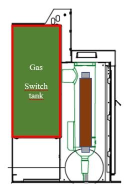

Figure 4. Hybrid switch-fuse combination (smal volume)

The architecture shown in Figure 3 is an evolution of the one shown in Figure 2 with the switch encapsulated in a closed tank, with a gas different from ambient air. The fuse can be installed rounded by the ambient air or in a closed canister as it is shown in Figure 4. In both cases, fuses are outside of the main switching tank. In these two arrangements the fuse thermal behavior is mainly influenced by the fuse itself and its environment, but the influence of the switch behavior is considered irrelevant. SF6 is used deeply in these type of architectures as an insulating and switching media for the switch. Similarly, to arrangement 2 a) different functional units can be coupled together, joining for an upper busbar or lower busbar, all of them contributing to the thermal behavior of the complete switchboard. In these cases, heat sources coming from other functional units could also contribute highly to the fuse thermal performance.

3) Gas insulated switch-fuse combination

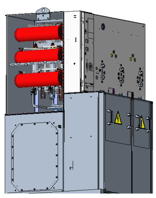

Figure 5. Gas Insulated switch-fuse combinations (horizontal – lateral)

Figure 6. Gas Insulated switch-fuse combinations (horizontal – bottom)

The architectures shown in Figure 5 and 6 are two different examples showing the most modern switch-fuse combination arrangements, where both the switch and the fuse-canister are enclosed inside the tank. The same single tank contains several functional units, usually different switches for incoming and outgoing.

Thermal behavior of the fuses is affected not only by the fuse-canister itself, but also by the position of the fuse-canister in the tank. The power dissipation of other functional units enclosed in the same tank, are contributing to increase the temperature of the gas inside the tank.

III. THERMAL & RATING IMPACT OF FUSES INSTALLED IN SWITCH-FUSE COMBINATIONS

As it has been shown in clause II, it can be found a quite different designs of switch-fuse combinations affecting differently the thermal behavior of the fuse and the rated current of the fuse inside the switch-fuse combination. So, as a first approach to understand how the switchgear evolutions are impacting fuses, a a comprehensive test plan together with 3D simulation has been developed. The different installation modes have been covered.

A. Fuses in ambient air

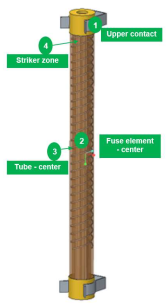

Figure 7. Critical points monitored

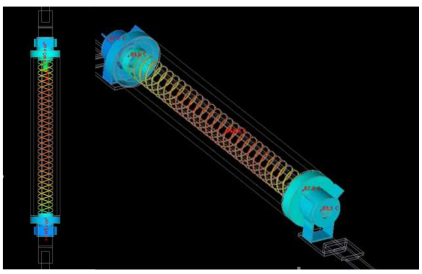

Figure 8. FEM analysis on 76 – 442 fuse size

A three-dimensional Finite Element model (3D FEM) has been built for three different fuse sizes. Maxwell 16.0 has been used for an AC electromagnetic modelling and Icepack 19 for Thermal modeling. For calibration of the model, temperature-rise tests have been also launched on fuses equipped with several thermocouples both inside and outside the fuses. The key physical parameters identified in [4] where studied and determined empirically, through several iteration with the 3D FEM packages (e.g. determination of sand thermal conductivity and fuse tube surface emissivity), data that are sometimes difficult to be found on technical data sheets.

Figure 7 shows the critical points considered and Figure 8 show an example of an image of a FEM analysis for a 76 – 442 fuse size. A global accuracy of $\pm$ 10 % (3D model vs. test) has been achieved for the temperature (ºC) and power losses (W) for the different fuse size studied.

B. Fuses enclosed in high volumes – immersed in ambient air

Figure 9 and Figure 10 shows the impact in the temperature of the critical points and power losses when a fuse is installed in a large enclosure as the one in figure 3. The **reduction in term of rated current** due to the ventilation restrictions imposed by the large enclosure (**less than 10%**). The impact of other functional units has not been considered. FEM analysis has not been carried out in this configuration.

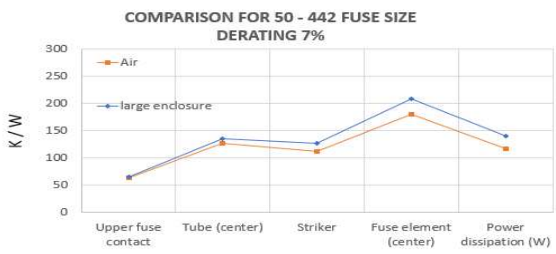

Figure 9. Comparison of temperature rise and power for a size 50 - 442

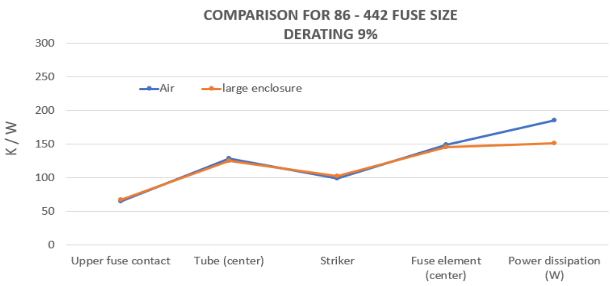

Figure 10. Comparison of temperature rise and power for a size 86 - 442

C. Fuses enclosed in small volumes - immersed in ambient air

A canister typically used in GIS switchgear has been analyzed. An empirical comparison has been made between the thermal situation of the fuses in ambient air and fuses installed inside the fuse canister as shown in figure 11. Comparison has been made on 86 – 537 fuse size to get the same temperature rise at the upper contact. T**he reduction in term of fuse rated current was around 35%** regarding the fuse rated current in air. This could be the situation of fuses installed as per figure 4 without considering any other heat sources.

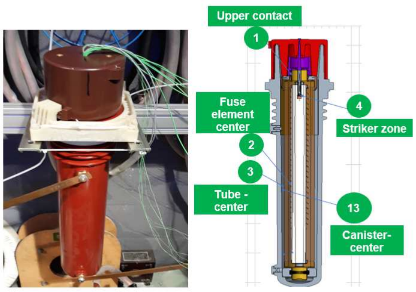

Figure 11. Fuse canister equipped with a 86 – 537 fuse size inside

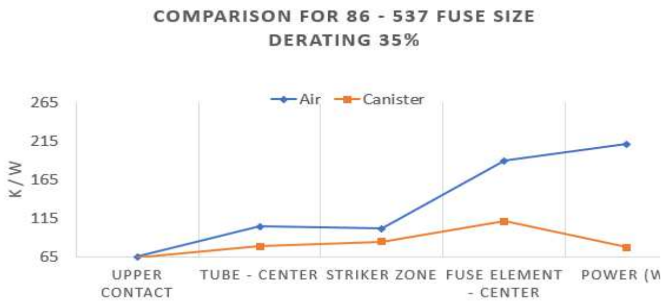

Figure 12. Influence of a canister inside a tank for a 86 – 537 fuse size

D. Fuses enclosed in a small volume - immersed in a gas different from ambient air

In this clause, architectures according figure 5 and figure 6 have been analyzed. In these architectures the canister is placed inside the stainless-steel tank. Then, not only the thermal characteristics/dimensions of the canister material are important but also the installation inside the tank, the gas around the canister and the thermal properties of the stainless-steel surface. For simplicity and environmental reasons, the results shown below correspond to tests performed on a sealed tank filled with air at relative pressure P_{rel} = 0 bar. There is no exchange between the air inside the tank and the ambient air.

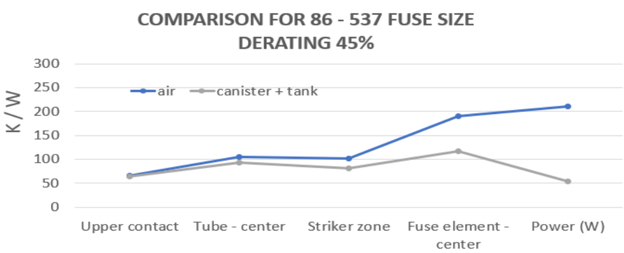

Figure 13. Influence of a canister inside a tank for a 86 – 537 fuse size

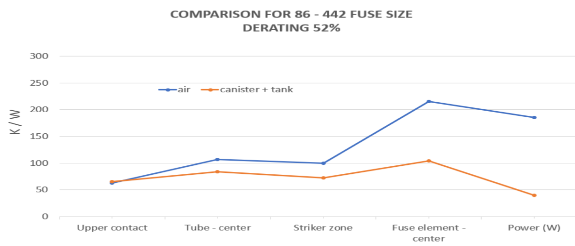

Figure 14. Influence of a canister inside a tank for a 86 – 442 fuse size

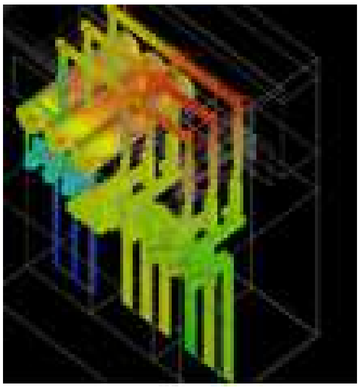

Figure 15. Temperature map inside the GIS tank

The reduction, in term of fuse rated current, was around 50% regarding the rated current of the same fuse in air. As it was shown in clause III.C, the derating imposed by a canister was around 35%. So, it means that an additional 10-15% of derating is imposed by the tank and the functional units inside.

3D simulation has been carried out in parallel to the test and a again a global accuracy of $\pm$ 10% has been achieved not only for the fuse critical points but also for the entire tank (switch contacts, gas temperature, …). This calibrated model will allow to investigate the temperature evolution for the new limits stated in IEC 62271-1:2017 and gases different from the air at ambient pressure as it will be shown in clause IV.B & C

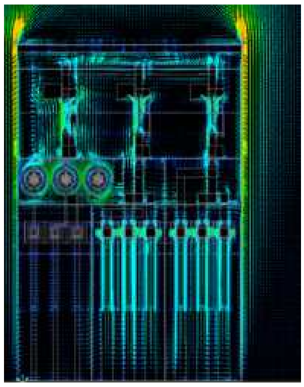

Figure 16. Velocity map of the gas flow inside the tank

IV. STANDARD TRENDS IMPACT

A. *New temperature-rise limits scenario in IEC 60282-1 (from 65 K to 75 K at the upper contact)*

1) *Impact for fuses in ambien air*

Figure 17 shows an example (FEM analysis for 76-442 size) with the evolution of the different critical points related to the change of the upper contact temperature. From the figure it has been noted that fuse elements would experience a temperature increase of less than 60ºC (5 times the upper contact increase) at the hottest point. This temperature increase would be not more than 30ºC (2,5 times) outside of the fuse tube and around the striker zone. Figure 18 show the current increase for different fuse sizes. This hypothetical increase would not be enough to increase the fuse rating on step forward into the R10 series.

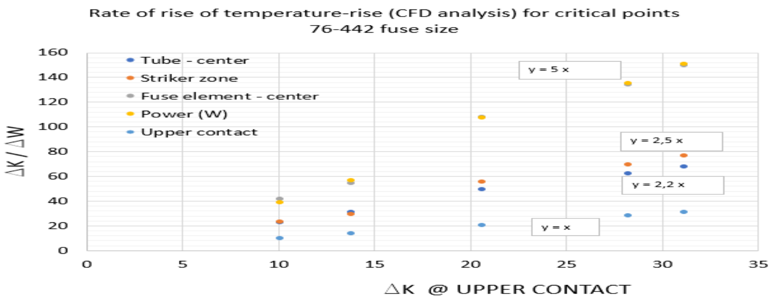

Figure 17. Rate of rise of temperature-rise as a function of upper contact temperature-rise

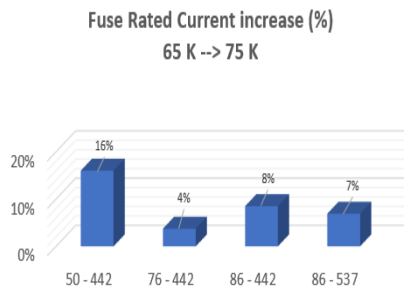

Figure 18. Rated current increase when passing from 65K to 75 K in the upper contact

2) *Impact for fuses enclosed in small volumes immersed in a gas different from ambient air*

The change in the temperature-rise limits would upgrade the current rating of the switch-fuse combinations of around 9-14 % for higher ratings. This will not be enough to protect a higher power distribution transformer (within the R10 series). Temperature

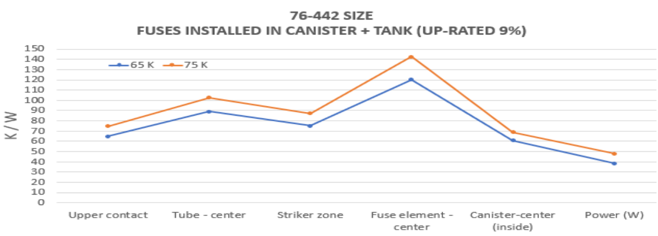

Figure 19. Impact in temperature rise for the critical points for 76 – 442 fuse size

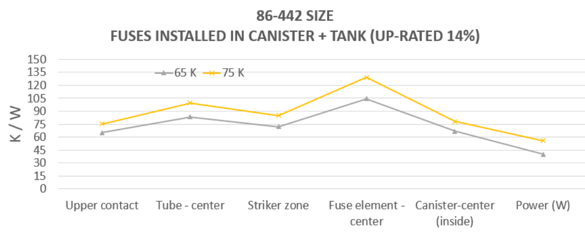

Figure 20. Impact in temperature rise for the critical points for 86 – 442 fuse size

increase for the critical points are quite homogeneous in all of them. **However, the canister will suffer also an increase of around 5 - 10 K at the hottest point of the canister**. This increase could be potentially dangerous, depending on the allowable limits of the material used for the canister, together with an ambient temperature of 40 ºC or higher and the existing design safety margins.

B. New temperature-rise limits in IEC 62271-1 (from 65K to 75K)

Among all the architectures detailed in clause II.B, the designs according figure 5 and 6, have been identified as the most onerous case for the fuse. The reason is mainly that, for the same switch design, the increase of the temperature rise limits will increase morel likely the average temperature of the gas inside the tank, and hence would eventually affect the temperature-rise of the fuses. Figure 19 shows that:

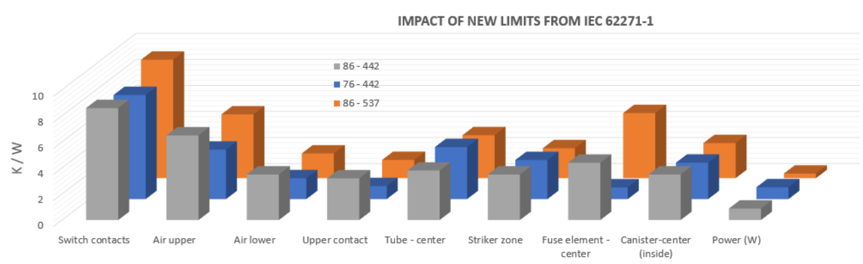

Figure 21. Impact in temperature rise for the critical points for different fuse size because of the change in the switch limits

- Differences around 6-7 K and 2–4 K in the upper /lower ambient have been recorded, respectively.

- Differences of no more than 3 K have been recorded as a temperature increase on the fuse contacts.

- Difference of around 3K at the fuse canister level

Special attention needs to be paid on switchgear contacts embedded in insulating materials where the difference will be roughly the same that for the contact itself (+10K)

C. SF6 substitution

The gas physical parameters as volumetric expansion, viscosity, but also and mainly molecular weight, density, specific heat and thermal conductivity are influencing the overall thermal behavior. Based on the 3D models calibrated and detailed in clause III.D, the following alternative natural gases have been considered inside the sealed tank in order to check the impact on critical points. In practice, for steady-state temperature on sealed tanks, the thermal conductivity is the most influencing parameter, and the results with air could mostly cover any other gas (O_2, N_2, CO_2). Figure 22 shows the physical properties of the different gases considered, normalized to the SF6 ones and figure 23 shows the comparison between SF6 and air obtained from the 3D model for different points inside the switchgear.

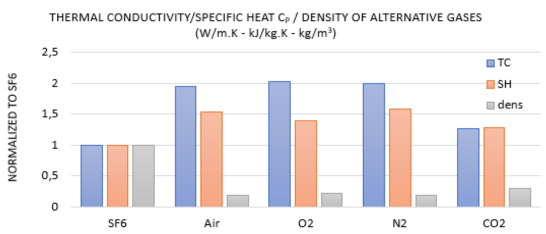

Figure 22. Physical properties mainly influencing thermal behaviour

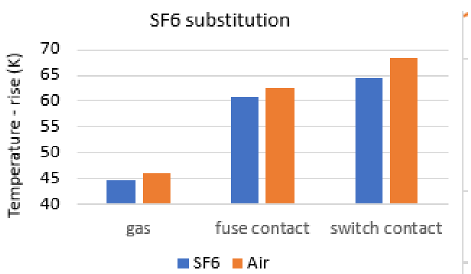

Figure 23. Gas impact on temperature rise

V. CONCLUSION

- The eventual change of the temperature limits currently considered in IEC 60282-1:2009+AMD1:2014 CSV will have no clear benefits for the fuses themselves. However, if fuses are equipped with organic materials and/or for fuses installed in canisters, the change could contribute to reduce the current safety limits and specific investigation on these materials could be needed.
- Depending on the safety margins considered for the different existing designs of fuses installed inside switchgears, the change of the temperature limits included in IEC 62271-1:2017 and/or the SF6 substitution could affect directly to the rated current of the fuse installed in the switchgear. So, additional tests will be needed, specifically for the higher fuse ratings.
- All the trends analyzed, contribute to the increase the stress on the different product (switchgear, fuses) and/or materials (insulations), so specific design changes to mitigate them are strongly recommended.

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