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

20/11/2019

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Publication MATPOST 2019

OAI: oai:www.see.asso.fr:94135:94541

DOI:

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Abstract

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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 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 switchgear is 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 behaviour in comparison with SF6. II. SWITCH-FUSE COMBINATIONS A. Main principle There are many 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 for a switch-fuse combination according IEC 62271-105 [2]. 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, independently of the type of fault (single-phase, bi-phase or three-phase). At this level of fault current the fuses have to 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) 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]. This switch-fuse 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 a) Switch in ambient air The architectures shown in figure 2 are equivalent to 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 need to be tested according IEC 62271-105 [2]. This switch-fuse TABLE I. 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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 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 and the power dissipation of other functional units enclosed in the same tank. All of them 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 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 package (e.g. determination of sand thermal conductivity and fuse tube 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 image of a FEM model for a 76 – 442 fuse size. A global accuracy of + 10 % (3D model vs. test) has been achieved for the temperature (ºC) and power losses (W) for the different fuse size studied. Fig. 2. Air insulated switch-fuse combination (metal-enclosed type) with the switch in ambient air Fig. 4. Hybrid switch-fuse combination (small volume) Fig. 3. Hybrid switch- fuse combination (big volume) Fig. 6. Gas Insulated switch-fuse combinations (horizontal – lateral) Fig. 5. Gas Insulated switch-fuse combinations (horizontal – bottom) Fig. 7. Critical points monitored Fig. 8. FEM analysis on 76 – 442 fuse size B. Fuses enclosed in high volumes–immersed in ambient air Figure 9 shows an example of 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 fuse rated current due to the ventilation restrictions, for the different fuse sizes analyzed is less than 10%. The impact of other functional units has not been considered. FEM analysis has not been carried out in this configuration 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 10. Comparison has been made on 86 – 537 fuse size to get the same temperature rise at the upper contact (see figure 11). The reduction in term of rated current to get 65K at the upper contact was around 35% regarding the rated current in air. This could be the situation of fuses installed as per figure 4 without considering any other heat sources. 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 Prel = 0 bar. There is no exchange between the air inside the tank and the ambient air. The reduction, in term of fuse rated current, for the different cases studied, 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, itself, 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 global accuracy of + 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 IV. STANDARD TRENDS IMPACT A. New temperature-rise limits scenario in IEC 60282-1 (from 65K to 75K) 1) Impact for fuses in ambient air Figure 15 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. In general, fuse elements would experience a temperature increase of less than 60ºC (5 times - for 76-442) at the hottest point. This temperature increase would be not more than 30ºC (2.5 times – for 76 – 442) outside of the fuse tube and around the striker zone. The potential rated current increase (up to 16% Fig. 9. Comparison of temperature rise and power (fuse size 50 – 442) Fig. 10. Fuse canister equipped with a 86 – 537 fuse size inside Fig. 11. Temperature rise / Power comparison for a fuse between air and canister environment Fig. 14. Influence of a canister inside a tank for a 86 – 537 fuse size Fig. 12. Temperature map inside the tank Fig. 13. Velocity map of the gas flow inside the tank depending on the fuse size) would be not enough to move the fuse rating a single step forward inside the R10 series 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 either enough to protect a higher power distribution transformer (within the R10 series). Temperature 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. 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. B. New temperature-rise limits in IEC 62271-1 (65K to 75K) 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 more likely the average temperature of the gas inside the tank, and hence would eventually affect the temperature-rise of the fuses. Experiences with two different type of switch-fuse arrangements show that: • Differences around 6-7 K and 2–4 K in the upper /lower gas temperature 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 Physical parameters as volumetric expansion, viscosity, but also, density, specific heat and thermal conductivity are influencing the thermal behavior. Based on 3D models calibrated, and detailed in clause III.D, the following alternative natural gases have been considered (Air, O2, N2, CO2). In practice, for steady-state temperature on sealed tank, the thermal conductivity
is the most influencing parameter, then results with air could cover any other gas or mixture detailed before. Figure 17 shows the impact of using SF6 instead of air for some critical points. Other molecules, as the ones cited in [5], are mostly used highly mixed with some of the natural gases detailed above (e.g. CO2).

As a consequence, the mixtures made with these molecules show a higher thermal conductivity than SF6 but lower than air. 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, for fuses equipped with organic materials and/or 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 increase the stress on the different product (switchgear, fuses) and/or materials (insulations), so specific design changes to mitigate them are strongly recommended. REFERENCES Standards

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