MITIGATE GAS COMBUSTION IN CASE OF INTERNAL ARC

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ABSTRACT

When an accidental arc occurs within a metal-enclosed Medium Voltage Switchgear, a significant volume of hot gases is produced, and evacuated out of the switchgear. Installations exist, where hot gases are expelled straight into the switching room. In such cases, they may ignite materials, or injured personals.

This paper presents measurements taken from real tests reproducing this case. Dedicated windows have been cut-out in the switchgear enclosure, so to see the phenomenon evolution inside, in addition to the gas flow within the room. Ultra-fast cameras, both in the visible and infra-red fields, have been used.

A detailed analysis of the gas flow is presented. Infra-red measurement is described and discussed. A combustion phenomenon, starting about 150ms after arc ignition, is especially shown, appearing to be key regarding safety. The impact of a new technology of absorber, mitigating this effect, is presented.

INTRODUCTION

Although new features are nowadays proposed to limit the probability of an internal arc event [1], this one is never zero. When gases are evacuated outside the switching room, through a duct, their characteristics are not a concern, as nobody is supposed to be present at the duct exhaust. The enclosure tightness is enough to ensure that gases do not impact significantly the switching room. This is proved by type-test as per the IEC 62271-200 [2].

More and more, switchgears evacuating gases inside the switching room are proposed [3]. This accounts for all applications where a gas duct could not be used. It has also the advantage of minimizing civil works and impact on neighbourhood.

For these installations, gases end up anyway in the switching room. The experience shows that cotton indicator ignition is the main failure cause of corresponding type tests. It is then of high interest to relate gases characteristics to indicators ignition, and to safety in general. What about gas composition, temperature, radiation, volume? What kind of risk these gases involve for operators, building, and other equipment in the room? Do absorber devices have other effects than on pressure?

Until now, only little information has been published about these questions. Attempts have been done to measure gases temperature using thermo-couple sensors [4]; but their reaction time for gases is some seconds: too long compared to the sudden rate of rise of an internal arcs, lasting less than 1s in all.

An estimation of gases temperature could be done using simulation tools. But depending on the model, the calculated temperature varies in a range of one to ten. Indeed, existing simulation tools are focusing mainly on pressure calculation, and their validation is done comparing calculated pressures with measured ones [5].

Furthermore, all models are considering air or SF6, or a mixture of both; species generated by raw material vaporization being ignored. This assumption is consistent with pressure calculation, but could not be valid to describe the gas flow after some time.

Tests dedicated to these questions are presented in this article. An ultra fast thermal camera, in the infra-red field, is used to measure gas radiations, in the hope to relate them to the temperature. A second ultra-fast camera is used in the visible field. In addition, standard pressure measurements have been recorded; they are partly published in [6].

INTERNAL ARC TESTS CONFIGURATION

The arc is initiated in the cable box of an air insulated metal-enclosed switchgear (figure 1). It is rated 12,5kA – 0,5s, three-phase.

Figure 1 : arc initiation (front view) and first window added along the rear face

This compartment has a single vent area, through a rear chimney, top side (figure 2). It is divided in two parts for structural purpose. The tested panel has 5 identical cells in order to reproduce an identical arcing fault, testing different absorbers installed at the chimney exhaust.

Five windows are made in the rear panel, so to film the event inside the compartment (figure 3). Cotton indicators are not used, as they would hid the switchgear.

Fig. 2 : Tested object, view from the rear.

A ceiling is installed 1 m above the switchgear for testing. A first test is done exhaust free (no absorber), right end cell figure 3.

The camera in the visible field records 2000 pictures/s. It focus cover the entire panel. The thermal camera focus is about one square meter above (and including) the gas exhaust, as per the red square figure 3. Both cameras are directed to the panel rear face, placed at about 7m from it.

Figure 3 : thermal camera, focused zone

The thermal camera record radiations in the bandwidth: [3,9; 4,1] µm. Filter is used so to adapt the expected radiation level to the sensor capability. One picture is taken every 2,5ms.

IMAGES FROM THE VIDEO IN THE VISIBLE FIELD

These images are given figure 4 and 5.

Figure 4 : view at arc ignition, at 81ms and 158 ms

At the arc ignition, the light is very intense and white. It appears only in the first (bottom) window. After 81ms, the situation is almost the same, although glowing particles can be seen above the exhaust. It is noticeable that at that time, pressure is back to zero everywhere. The first glowing particle is seen on the video at 42ms.

At 158ms, the situation has changed: still we can see glowing particles, but now the light of the background (coming from the two windows front side) is darker, orange colour. Even the highest window rear side is now of orange colour.

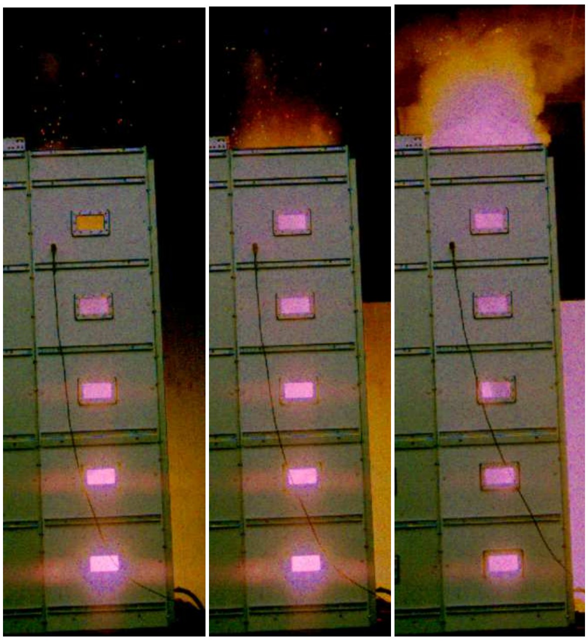

Figure 5 : view at 211ms, 251ms and 327 ms

After 211ms, light starts to be less intense through the bottom window. It continues to decline later. At 251ms, we can see flames starting to be expelled at the top.

The combustion phenomena

We explain these observations with the following assumptions:

- Hot air is transparent. The air being in the compartment prior to the arc, is expelled during the first 80 ms : the pressure stage. This cannot be seen in the visible field. Only glowing particles are detected.
- Material vaporization and ablation in the arc vicinity create new gases that replace the air. These gases are of orange colour.
- These gases are flammable. After about 150ms, they ignite in the arc region, generating flames that quickly occupy the full compartment volume.
- After 250ms, those flames are expelled out of the switchgear. Flames are yellow in the visible field, and generate also light, less intense than the arc light.

The back-flow phenomena at arc extinction

Figure 6 : view at 500ms and 520ms

When the arc extinguished, the 3 upper windows are black (figure 6). This shall be the consequence of the dust generated by the gas combustion. We can also observe that the maximum flames expansion, here at 520ms, is after the arc extinction: gases continue to burn, independently of the arc.

From the video, one can also clearly see a gas back-flow, starting at arc extinction. As the temperature suddenly drops within the switchgear, this one is depressed and the flame flow reverses.

IMAGES FROM THE VIDEO IN THE INFRA-RED FIELD

Unfortunately, the thermal video was not synchronized with the arc current. Thus, synchronization has been done thanks to the back-flow phenomena. It comes that the thermal video starts 173ms after the arc ignition.

It clearly shows the flames (see figure 7). The maximum radiated power, taken both at the gas exhaust and near the ceiling straight above, are reported figure 8.

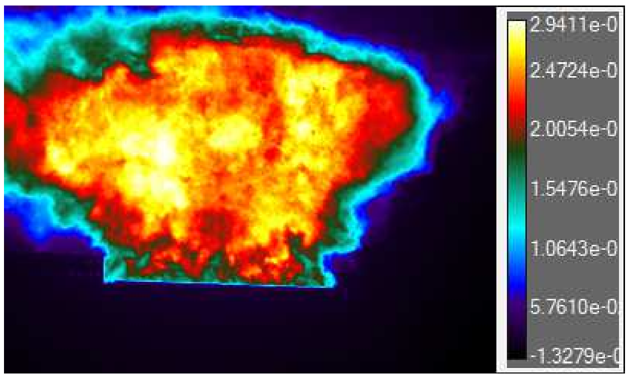

Figure 7 : radiated power recorded by thermal camera, 500ms after arc ignition (W/cm²/sr)

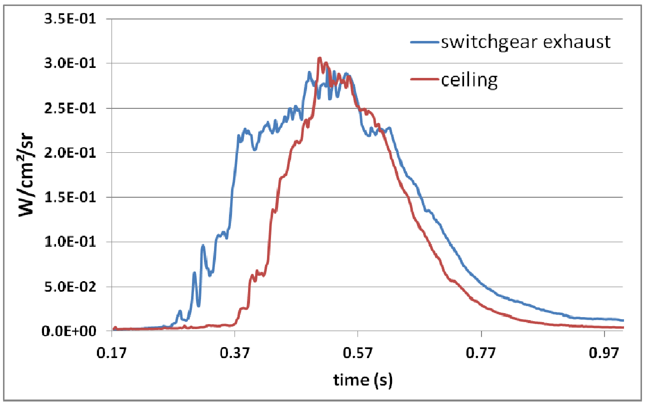

Figure 8 : radiated power (peak value) measured at the exhaust and near the ceiling

The maximum radiation is in the range of 0.3 W/cm²/sr. It is observed at both locations at 500ms, which is the time of the arc extinction. It corresponds to pure flames radiation.

ATTEMPT TO DERIVE GASES TEMPERATURE

Making the assumption that the gas expelled before 200ms is pure air, we try to derive its temperature from the measurement.

Net emission of hot air in the bandwith |3,9; 4,1] µm

In Figure 9, the net emission of pure air in the observed bandwidth is reported.

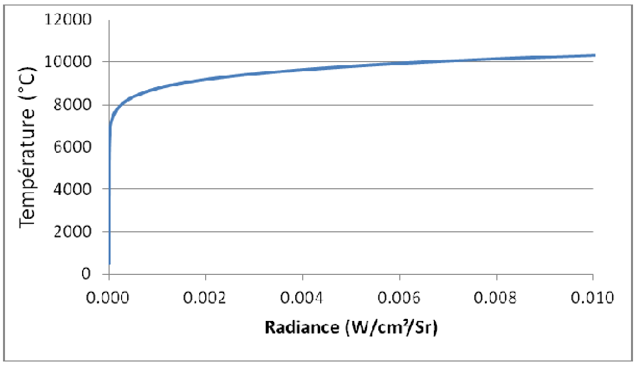

Figure 9 : air radiance in the bandwidth [3,9; 4,1] µm, zoom up to 12 kK

This cure has been derived using the methodology defined in [7].

Deriving air temperature

Focusing now at the very beginning of the thermal measurement, and comparing the mean exhaust value with the one derive from a surface aside the panel (not impacted by air flow), we can check that the exhausted air radiates about 0.001 W/cm²/sr (figure 10). This is the difference between the two curves.

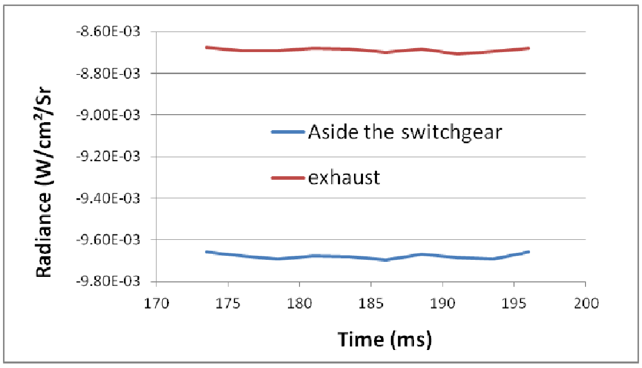

Figure 10: recorded radiance (mean value over a surface), above the exhaust and aside of the switchgear.

Looking now in figure 9, we read that the hot air could be almost at 9000°C. But as explained above, the gas composition at that time is certainly not pure air, but a mixture of different species vaporized by the arc. This evaluation should have been done before 80ms so to be sure that the expelled gas is essentially made of air, as shown figure 6.

Accuracy of the thermal measurement

Radiances reported figure 10 are negatives: this illustrate that the signal is too low. The signal treatment can not distinguish it from noise. In this end, this shows that one should have used a camera without filter in order to detect signals as low as 10^{-4} W/cm²/sr. Furthermore, one can see figure 9 that is would be anyway difficult to differentiate temperatures below 7000K in the observed bandwidth. This one could also be increased, so to have a higher signal level.

For safety assessment, the air temperature seems anyway not critical, as air is expelled only during the first 100 ms, other unknown gases being expelled later. They even are soon replaced by flames, which radiate several orders of magnitude above the air.

MITIGATION OF THE COMBUSTION PHENOMENA USING A METAL FOAM ABSORBER

The same shot is repeated installing a metal foam absorber in the exhaust. Absorber principle is described in [6].

On the visible field, we observe that flames do not cross the absorber during the event, staying inside the switchgear, except in a limited extent, after the arc extinction, during the back-flow stage. Figure 12 shows a comparison with the first test at 0.5s in the visible field.

Figure 13 shows a comparison of the maximum radiated power at the exhaust.

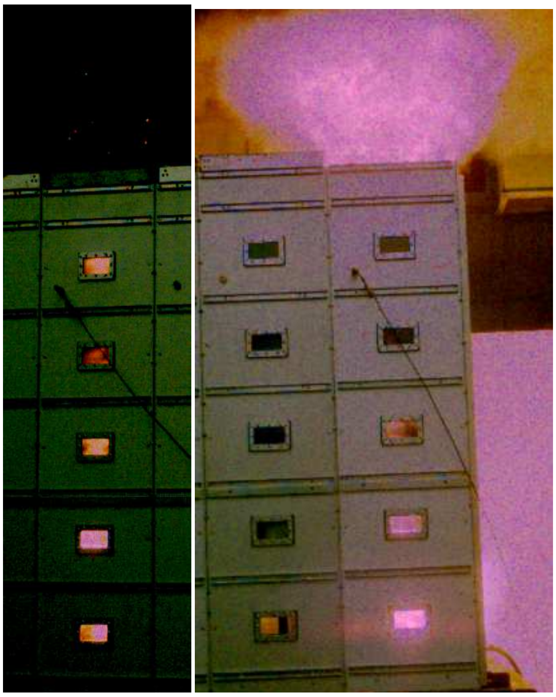

Figure 12 : w and w/o absorber in the visible field at 0.5s

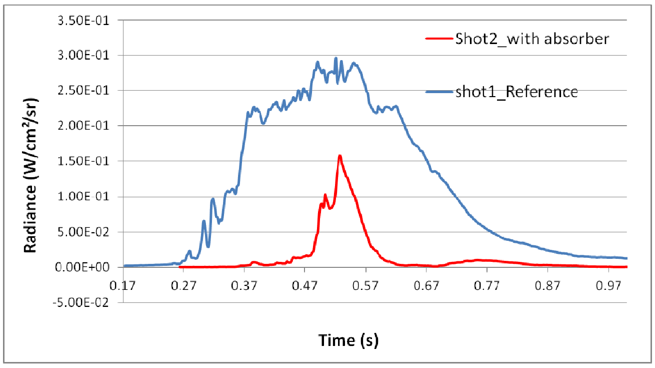

Figure 13 : radiance measured at the exhaust (peak value), w and w/o metal foam absorber

CONCLUSION

After the pressure stage, which lasts a few cycles, the air is progressively replaced in the compartment by gases coming from the material ablation and vaporization processes. Later on, in this case starting at about 150ms, these gases start to burn, flames reaching the switchgear exhaust at 200ms.

From the thermal measurement, it comes that those flames radiate about 300 times more compared to the hot air expelled during the first stage. The Flame stage appears then to be the critical one when addressing the risk of burning people, and the risk of igniting a fire in the room, when gases are expelled in the switching room. Studying this combustion phenomenon in depth appears to be the way ahead for internal arc assessment and modelling in this case.

The use of fast dedicated arc detection systems, clearing the arc in about 80ms as presented in [6], can avoid entirely the flame stage and then mitigate significantly these risks.

As well, metal foam absorber has demonstrated its capability to keep flames within the switchgear, for an arc duration up to 0,5s.

Ultra-fast thermal camera in the infra-red field appears to be a useful measurement technique, in order to assess flames propagation outside the switchgear. Hot air radiating several orders of magnitude less compared to flames, it is difficult to measure both stages with a single camera.

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