INTERNAL ARC SIMULATION IN MV/LV SUBSTATIONS

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ABSTRACT

Numerical simulation has been used for long on the internal arc issue. Computing and models improvements make possible to simulate switchgears and their surrounding, to study many parameters and geometries. As a complement to type tests, it allows to propose safer cubicles, substations, and installations.

INTRODUCTION

The internal arc fault is a short circuit that can occur in electrical equipment, after insulation loss or maintenance mistake. It is very rare but also very destructive because of the amount of energy at stake (up to 20 MJ over 1 second).

For many years, simulation models have been used to predict the consequences of an arc fault, and especially the pressure causing the blast effect. It is helpful to design switchgears that can withstand severe arc faults, as they are tested in accordance with IEC 62271-200.

Nowadays, the evolution of models and computation capabilities allows performing simulations on the geometry of the electrical equipment and also its surrounding. After having described the model used and its comparative results with the test on a standalone switchgear, the author proposes a simulation plan of a switchgear fitted in an electrical room. The simulation tests the influence of many parameters as buffer volume, room volume, ventilation section. It shows the interest of this kind of simulation in predicting consequences of the fault on the final installation, or on substations tested in accordance with IEC 62271-202.

SIMULATION MODELS

Electrical aspects

Electrical parameters of the fault (short circuit current, arc voltage) will determine the power involved in the arc, and then transmitted to the fluid, that will generate heating and overpressure. Therefore these parameters have to be predicted in a correct way.

Line currents $I_i$ are detailed for a three-phases fault, which is the most severe and also the most typical fault. They can be easily modeled (1) [1] knowing the max rated short circuit current $I_{cc}$, also called “performance” of the electrical equipment in arc test.

\[
l_i(t) = \sqrt{3} I_{cc} \left[ \sin(\alpha t + \phi) - \sin(\phi) e^{-At} \right] \quad (1)
\]

The phase to ground voltage $V_i$ is modeled, instead of modeling directly the arc voltage (Fig. 1). It is taken as a constant value, positive if the associated line current is positive, negative if not [2]. The arc being essentially resistive, phase shift between current and voltage can be neglected.

![Fig. 1 – Line currents and phase to ground voltage for a three-phases 20 kA fault](image)

The arc power can be written as follows (2). The model can finally be compared to the test to ensure that the energy is taken into account in a correct way. It can be noticed on Fig. 2 the transient shape of the power during 100 ms, that is essential to describe overpressure at the beginning of the fault.

\[
P_{\text{arc}}(t) = \sum_{\text{phases}} V_i(t) I_i(t) \quad (2)
\]

![Fig. 2– Arc Power versus time for a three-phases 20 kA fault](image)
CFD software and energy model

As the goal is to obtain the behaviour of the fluid around the arc, we get advantage of using a generic CFD software. Some extra components have been developed inside it to describe energetic exchanges involved during the arc fault.

The energy amount transmitted from the arc to the fluid is first being considered as the arc energy, by the mean of a source term $S_h$ in the energy equation (3).

$$\frac{\partial}{\partial t} (\rho E) + \nabla \cdot (\rho \mathbf{v} E) = \nabla \cdot (k_{eff} \nabla T) + \tau_{rad} \mathbf{v} + S_h \quad (3)$$

A net emission model [3] is included to describe the energy that is lost in the domain depending on the temperature of the fluid. It modifies the source term $S_h$ in (3). This method avoids introducing any ratio from the arc energy to the fluid energy.

Finally, vaporization of materials around the arc is being taken into account since it has a significant impact on the pressure rise and also on the convective effect. A source term $S_m$ is added in continuity equation, depending on the radiated power and the position.

TEST AND SIMULATION ON STANDALONE MV SWITCHGEAR

Test set up

A test has been first performed with a standalone compact switchgear, in accordance with IEC 62271-200. The ring main unit is represented in Fig. 3. The fault was created in the sealed switch compartment, by the mean of a thin wire linking the phases. The fault was maintained over 1 second with a 20 kA short-circuit current. Pressure levels were recorded with fast transducers, in the sealed switch compartment, and in the volume under it.

Simulation

The simulation has been carried out with a simplified geometry, and the energetic parameters set in agreement with the test. The fault can be divided in three main phases, put in evidence by the simulation.

First phase is the pressure rise in the sealed switch compartment. As the volume is hermetic, energy and mass supply raise the pressure level up to 2 bars in only 40 ms.

Second phase begins as the bursting disc of the sealed compartment opens. The overpressure in the sealed compartment releases downward and creates a very transient shock wave followed by a decompression lasting 100 ms. Pressure is also increasing in the other compartments of the ring main unit.

Third phase starting from 200 ms is the thermal phase: no more pressure effects are observable. The hot gases are expelling from the compartment under fault in a quasi static way.

Comparative

Pressure levels recorded in test are compared to the simulation results, in the sealed compartment and under it. As it can be seen on Fig. 5, pressure histories are in good accordance both for pressure rise and decompression phase.

Fig. 4 - Pressure map (Pa) under the switch compartment

Fig. 5 – Pressure versus time given by test and simulation
MULTI PARAMETER SIMULATION ON MV/LV SUBSTATION

It is essential to manage the safety of various designs of prefabricated substations and electrical rooms. Testing so various and numerous configurations would require too many tests. Therefore, it is highly useful to take advantage of the simulation to vary several parameters linked to the surrounding of the equipment, and to test their influence on the pressure inside and outside.

Set up

The same ring main unit as the one tested before is considered installed on a buffer volume, fitted in a surrounding that can stand for a substation or an electrical room (Fig. 6). The room has a variable volume $V_{room}$. It is vented to the exterior through a $S_{vent}$ section, and communicates with the buffer volume through the section $S_{decomp}$.

Simulations were run at a 16kA or 14kA short-circuit performance. Variable parameters are reminded on Fig. 6 and specified in Tab. 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Standard value</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{cc}$ (kA)</td>
<td>14</td>
<td>16</td>
<td>-</td>
</tr>
<tr>
<td>$V_{room}$ (m$^3$)</td>
<td>15</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>$S_{decomp}$ (mm$^2$)</td>
<td>150 x 150</td>
<td>200 x 200</td>
<td>300 x 300</td>
</tr>
<tr>
<td>$S_{vent}$ (mm$^2$)</td>
<td>300 x 300</td>
<td>600 x 600</td>
<td>1000 x 1000</td>
</tr>
</tbody>
</table>

Tab. 1 – Values of parameters in the simulation plan

Results

Pressure ranges are very different depending on the location of interest. On Fig. 7, pressure map is shown at the entrance of the room, between 0 and 50 mbar. Pressure histories are detailed on each of the three locations (A), (B), (C) reminded on Fig. 7.

![Fig. 7 – Pressure map (Pa) at the entrance of the room](image)

**Pressure in switch compartment (A)**

The pressure in tank follows the same pressure rise as it has been explained in the previous part, as long as the disc did not burst. It is not affected by the parameters we chose.

**Pressure in buffer volume (B)**

The buffer volume is standing just under the bursting disc of the breaker compartment. The shock wave due to the opening first causes a non homogeneous pressure in the buffer volume, in the same way as it can be seen on Fig. 4. Further in the decompression time, the pressure history at a middle point (Fig. 8) is representative of the mean pressure in the buffer volume. The section $S_{decomp}$ from the buffer to the room is the critical parameter. Its variation (increased or divided by two) changes the pressure of 35% around the 0.48 bars mean value.

From 150 ms, the vent section $S_{vent}$ starts raising the pressure inside the buffer volume if it is too small (300x300)! The other parameters do not have a high influence on the buffer volume.

![Fig. 8 – Pressure versus time in buffer volume](image)
Pressure in room (C)

The pressure in room is the combination of all intermediate effects of parameters. It is taken at a one meter high point in front of the apparatus. The critical parameter is by far the vent section to the outside $S_{\text{vent}}$. The pressure is limited to 25 mbar with a classic 600x600 venting, but it is still increasing up to 100 mbar after 300 ms with a 300x300 venting.

The room volume changes the peak time, but it is not as influential as it could be expected on the peak value: the 50 m$^3$ room gives a small advantage with 20 mbar versus 25 mbar for 20 m$^3$.

Flow rates to the room

It is our interest to look at the mass flow rate (Fig. 10) and volume flow rate (Fig. 11) at the exhaust of the apparatus to the room.

The $S_{\text{decomp}}$ section is naturally still the influential parameter. However, note that it increases or decreases the mass expelled out of the apparatus, but does not decreases the volume of the fluid expelled.

CONCLUSION

Numerical simulation is very helpful for internal arc issue in electrical equipments compliant with IEC 62271-200 and -202. There are so many differences in final installation of the equipment, that simulation is precious as a complement to the type tests, giving the influence of parameters or specific geometries. There are so many challenges in downsizing the equipments and the substations, and customizing the geometries, that simulation is helpful to design new products. Such simulation techniques are also pushed forward to propose safer electrical equipments.

REFERENCES

