INFLUENCE OF ARC ENERGY ABSORBERS ON THE ENCLOSURE EFFECT IN CASE OF INTERNAL ARCING IN ELECTRICAL INSTALLATIONS

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ABSTRACT

Internal arcs in switchgear cause flows of hot gas between the faulty switchgear compartment and the switchgear room. Arc energy absorbers installed in between have two effects on pressure development in the room, pressure reduction by heat absorption and pressure rise by increased energy input due to flow resistance. This interaction is investigated for boundary conditions of a typical compact substation by varying the efficiency of heat absorption and the value of the effective absorber opening. It is demonstrated that for certain parameter combinations the absorber does not reduce overpressure.

1. INTRODUCTION

Internal arcs in electrical installations cause rapid increase of temperature and pressure in their surroundings and by that may endanger personnel, the electrical installation and even the installation (substation) building. A measure to control overpressure especially in substation buildings, is the installation of arc energy absorbers. In general such absorbers withdraw heat from the gas flow passing it and reduce the effective relief opening between switchgear and installation room. The last effect causes an increase of the amount of thermal energy escaping from the switchgear into the building and by this an increase of pressure (see section 3). This counteracts the heat absorption of absorbers. In this contribution the interaction of heat absorption and enhanced energy release in the building by the presence of an absorber is investigated for an example. The value of heat absorption, the effective opening of the absorber and the arc current are varied.

2. ARC ENERGY ABSORBERS

Most often energy absorbers consist of several layers of expanded metal. In case of internal arcing the hot gas escaping from the switchgear is cooled by absorbers. Apart from heat absorption absorbers are flow resistances, which retard the gas flow from the switchgear into the room and by this increase the thermal energy input in the room.

A further aspect of absorbers is the prevention or at least reduction of the emission of flames and of glowing metal particles from the faulty switchgear into the surroundings. However, with respect to overpressure the escape of flames and of glowing particles is not of importance so that only the first two effects will be considered here.

Calculating overpressure both effects have to be modelled separately. In general the absorbed energy is taken as heat sink; the flow resistance is modelled in a simple way by a reduction of the effective pressure relief opening in such a way that the resulting pressure development is equal to that with installed absorber. Further approaches have been investigated as well [1].

3. ENCLOSURE EFFECT

If an arc burns in a closed room, pressure rises with the amount of arc energy W (Fig. 1, left). However, if the same (relief) room is taken with the same energy input and the arc is burning in a switchgear cubicle with a pressure relief opening to the room (Fig. 1, right), the maximum pressure in the relief room is lower than in the first case. This has been found experimentally and is known as the “enclosure effect” [2].

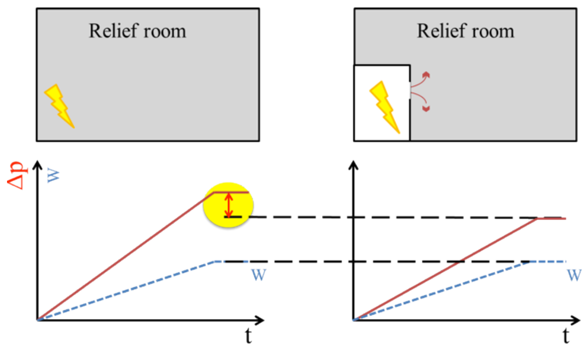

Fig. 1 Sketch to explain the enclosure effect

This phenomenon is explained by a change of the energy balance in the cubicle with gas density [3]. During the exhaust of gas from the cubicle, gas density decreases and temperature rises. Fewer and fewer gas particles are available to overtake thermal energy during continuous energy input and e.g. radiation becomes more important. In the timescale of interest, radiation absorbed from the walls does not contribute to pressure rise. As a consequence the change of the energy balance has to be considered calculating pressure development.

The enclosure effect is more pronounced the smaller the cubicle volume with the arc and the larger the opening to the relief room. This is true as long as the opening is not too large so that the enclosure must be taken as part of the relief room.

In an engineer-like approach the portion of electric arc energy causing overpressure W_{therm} is defined as the thermal transfer coefficient ("k_p-factor"); $k_p = W_{therm} / W_{elec}$ [3,4]. Taking this quantity as density dependent, good agreement between measurement and calculation has been found, if $k_p(\rho)$ is determined experimentally [3]. In Fig. 2 measurement results are provided. The pressure development is measured in a closed vessel varying the filling pressure i.e. the gas density by otherwise identical conditions and is compared with calculation results with the equation

$$\Delta p = \frac{\kappa - 1}{V} \cdot k_p \cdot P_{elec} \cdot \Delta t \, .$$

In this equation κ is the ratio of specific heat capacities, V the vessel volume and P_{elec} the electric power. By adapting the calculated pressure development to the measured one varying the value of the k_p-factor at different filling pressures, $k_p(\rho)$ has been determined.

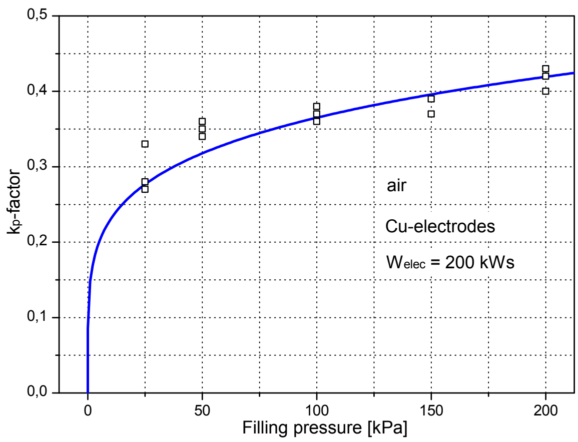

Fig. 2 Measurement results of the thermal transfer coefficient k_p (symbols) determined in a closed vessel changing the filling pressure (gas density)

While the overall gas density in the left case of Fig. 1 remains constant i.e. k_p = const., the gas density and by that k_p in the cubicle on the right hand side of Fig. 1 diminishes with energy input.

If the gas density reduction is retarded by the presence of a flow resistance (absorber), in average more gas particles are in the cubicle during arc duration and are able to overtake thermal energy. An increase of the maximum pressure in the relief room will result counteracting the heat absorption of absorbers.

4. SIMULATION RESULTS

Boundary conditions

The arrangement under investigation consists of a cubicle, representing the switchgear compartment with an arc fault (arc room; 0.512 m^3) with a quadratic opening of 0.04 m^2, located in a bigger cubicle with a volume of 27 m^3 (relief room). The investigations are performed for air as insulation gas at an initial pressure and temperature of 100 kPa and 300 K, respectively. The electrode distance is 17 cm. The three-phase current is varied between 10 and 20 kA (X/R = 13), the voltage is taken slightly current dependent and the arc duration is 200 ms. An absorber is inserted into the quadratic opening. Its effective opening is varied between 15 % and 100 % (100 % means opening without absorber). The absorber efficiency (referred to W_{therm}) is between 2 and 10 %. The simulations are performed with the Computational Fluid Dynamics tool CFD-ACE [5]. The density dependency of k_p is taken from experiments (Fig. 2).

Thermal energy input in the arc room

First of all the change of the thermal energy input in the arc room varying the effective opening of the absorber has been investigated. In principle heat absorption changes the pressure drop along the absorber and by that the flow velocity and the gas density in the arc room. This effect on the thermal energy in the arc room is neglected here. It has been shown to be negligible (see next section).

In Fig. 3 the mean k_p-value (averaged over arc duration, considering the gas density dependency of k_p) is shown depending on the effective opening of the absorber for different values of arc energy. The mean k_p-value is a measure of the thermal energy related to the electrical input energy. It depends on arc duration.

For the free burning arc in the relief room under consideration k_p is constant and equal to 0.37 (Fig. 2). At full size of the relief opening (i.e. without absorber) the mean k_p-value is smallest and the enclosure effect is largest due to the fast decrease of gas density at full opening. With absorber and decreasing effective opening, the mean k_p rises non-linearly but does not reach the value of the free burning arc. Due to growing pressure in the cubicle at rising arc energy, the gas density drops faster with the result that the mean k_p-value becomes smaller.

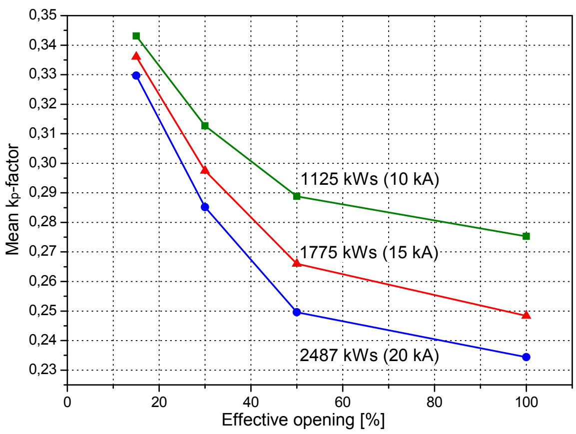

Fig. 3 Mean k_p-factor as a function of the effective absorber opening for different values of the electric energy

Effect of absorbers on pressure

From now on heat absorption is added to the investigations. The absorber efficiency is varied between 0 and 10 % in 2 % steps and the effective opening as before.

In Fig. 4 the spatially averaged pressure within the arc room at the time of arc extinction (t = 200 ms) is shown. It is a measure of the actual thermal energy within the arc room. The smaller the effective opening of the absorber the higher is the mean pressure in the arc room at the same electric energy input. Due to different flow conditions at changing opening area the provided pressure values at t = 200 ms are not necessarily the maximum averaged pressures in the arc room. At least for the smaller openings, pressure balance between arc and relief room is not reached at this time. Furthermore it is observed that the absorber efficiency practically does not influence the pressure behaviour within the arc room as already mentioned before.

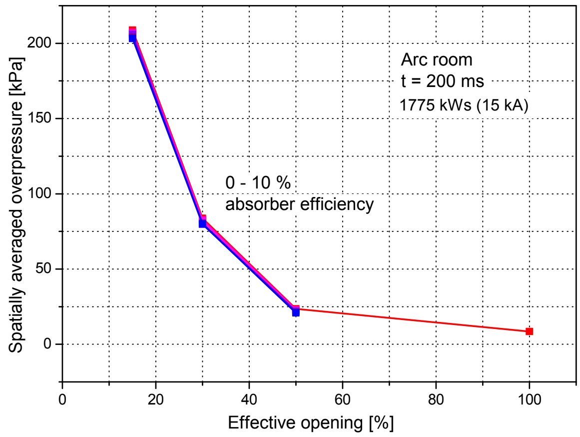

Fig. 4 Spatially averaged overpressure within the arc room at arc extinction (t = 200 ms) depending on the effective absorber opening

The spatially averaged pressure in the (closed) relief room at arc extinction (Fig. 5) behaves inversely to that in the arc room and depends on the absorber efficiency. Due to the smaller amount of hot gas escaping from the arc room at reduced effective opening, the mean pressure in the relief room is low at t = 200 ms. This value grows with increasing opening. However, because pressure equalization between arc and

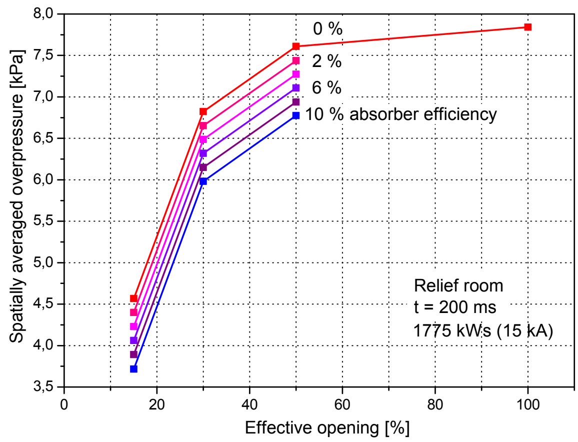

Fig. 5 Spatially averaged overpressure in the closed relief room at arc extinction (t = 200 ms) depending on the effective absorber opening

relief room still takes place, the maximum values in the closed relief room are not reached yet. In any case a remarkable influence of heat absorption on pressure is observed as well. The energy withdrawn by the absorber reduces the pressure in the relief room.

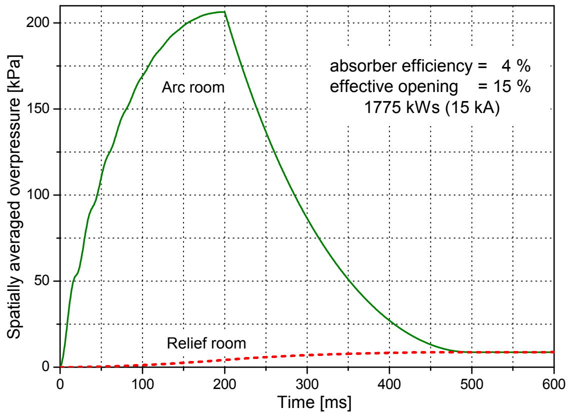

Fig. 6 Spatially averaged overpressure development within the arc room and the (closed) relief room

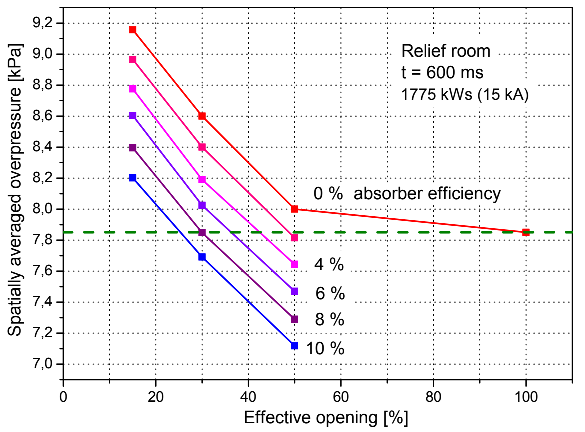

Fig. 7 Spatially averaged overpressure in the closed relief room 400 ms after arc extinction (t = 600 ms) i.e. after pressure equalization between arc and relief room for different values of the effective absorber opening and efficiency (the dashed line marks the maximum overpressure value without absorber)

400 ms after arc extinction pressure balance is reached between the arc and the (closed) relief room (Fig. 6). In Fig. 7 the final pressure values are provided depending on the effective absorber opening and its efficiency. In contrary to the situation at arc extinction (Fig. 5), now overpressure increases with decreasing effective opening. This is due to the enclosure effect. At small openings a larger part of the electric energy is converted to thermal energy (larger k_p-value).

For the given conditions the overpressure in the (closed) relief room will reach without absorber (effective opening 100 %) a value of 7.82 kPa. With absorber a pressure reduction will only be reached for effective opening / absorber efficiency combinations, which are provided in Fig. 6 below the dashed line.

For relief rooms with opening to the environment the situation is more complex. Due to this opening the pressure increase in the relief room is reduced. This effect is more pronounced, the smaller the opening between arc and relief room. In detail this effect together with heat absorption depends on the ratio of the openings and the volumes of the rooms.

5. CONCLUSION

Arc energy absorbers are a means to reduce overpressure due to internal arcing in relief rooms by heat absorption. If, however, absorbers reduce the effective size of the relief opening, the pressure decrease in the closed relief room is less pronounced or even overcompensated by the diminishment of the enclosure effect. As consequence it is recommended to avoid a reduction of the effective relief opening by either enlarging the relief opening with absorber or enlarging the size of the absorber in a distance of the opening. At typical values of heat absorption and effective opening of absorbers the influence of the effective opening i.e. the flow resistance on overpressure in the relief room is more pronounced.

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