NUMERICAL APPROACH TO PRESSURE RISE DUE TO SHORT-CIRCUIT FAULT ARC IN THE METAL-CLAD SWITCHGEARS

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ABSTRACT

This paper presents the CFD calculation results of the pressure rise due to the High Energy Arcing Faults (HEAFs) in the cable compartment of the metal-clad switchgears. The calculations were carried out considering the propagation of the hot gases from the cable compartment to the outside and the came-off of the compartment roof panel that was observed in the arc tests. The calculated pressure development was in good agreement with the measured one.

1. INTRODUCTION

High Energy Arcing Faults (HEAFs) can be caused by the failure within electrical installations due to either a defect or an exceptional service condition or maloperation [1]. The HEAFs lead to the pressure rise in the installations and then the spouting of hot gases from the installations. As a result, the successive fire incident may occur inside and/or outside the installations.

In Japan, the Tohoku District-off the Pacific Ocean Earthquake attacked the Onagawa Nuclear Power Station of Tohoku Electric Power Co., Inc. on March 11, 2011 and the successive fire incident due to the HEAFs occurred in the electrical cabinet. In order to grasp the pressure rise in the non-arc proof electrical cabinets due to HEAFs and understand the critical condition for the successive fire occurrence in the cabinets, a series of 3-phase internal arc tests with 6.9 kV switchgears were executed [2]. In the tests, the arc current I_{arc} was around 20 kA, the arcing duration t_{arc} was 0.1 s – 2 s, and the electric arc energy W_{arc} was 3 MJ – 45 MJ.

In this contribution, the pressure rise due to the HEAF in the switchgear was calculated using a CFD (Computational Fluid Dynamics) method. The calculated pressure rise was compared with the measured one. The propagation of the hot gases in the switchgear was also investigated.

2. CALCULATION METHOD AND CONDITIONS

In the 3-D calculations, a CFD program (CFD-ACE+) was applied to solve the full set of basic hydrodynamic equations (i.e., conservation equations of mass, momentum and energy). Those conservation equations in terms of partial differential equations were solved at each location in the switchgear iteratively, while the energy input was set locally. The general form of the conservation equations can be written as:

$$\frac{\partial}{\partial t}(\rho\,\phi) + \nabla\cdot(\rho\,\underline{v}\,\phi) = \nabla\cdot(\Gamma\,\nabla\phi) + S \tag{1}$$

where ϕ represents the conserved variables under consideration, ρ the gas density, $\underline{v}$ the gas velocity, Γ the transport coefficient of ϕ and S the source term for ϕ [3].

Fig. 1 shows the schematic arrangement of the switchgear used in the tests. The switchgear has two cable compartments (CCs), a bus compartment (BC) and two circuit-breaker compartments (CBCs). The compartments are separated by the metal plates. For the ventilation in the switchgear, the metal plates of the rear wall as well as the metal plates between the CC

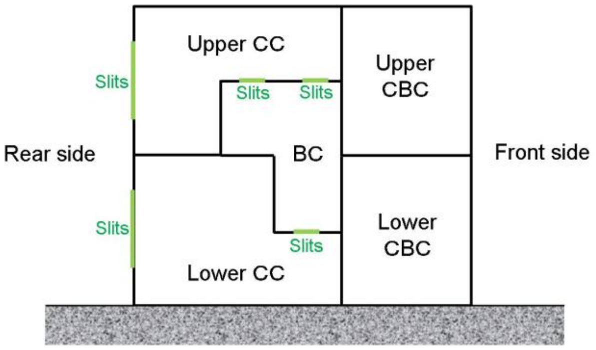


Fig. 1 Lateral view of the compartments in the switchgear.

CC: Cable compartment, BC: Bus compartment,
CBC: Circuit-breaker compartment

and BC have some rectangular slits. Fig. 2 shows the sketch of the upper CC considered in the calculations. The volume of the CC was 1.31 m^3. In order to simplify the calculations, the pressure and the temperature of the outside of the upper CC were 0.1 MPa and 293 K, respectively. As the arc was ignited in the upper CC, the energy input W_{input} was applied locally in the CC. W_{input} was given as k_p times W_{arc}. k_p is a fraction of the W_{arc} leading to the pressure rise. The pressure rise in the CC was measured at point 1 in the test. The gas inside was air with an initial pressure and temperature of 0.1 MPa and 293 K, respectively. I_{arc} was 21 kA, t_{arc} 0.1 s (100 ms), W_{arc} 3.1 MJ, the current frequency 50 Hz. k_p was taken as 0.53 [4]. The metal plate with the slits was simply considered as a medium of gas flow resistance and of heat resistance/capacitance in the same way as in [5]. The walls of the CC were assumed to be adiabatic, because the arcing duration was short (0.1 s), and the CC was embedded in ambient air, which was a good heat-insulating medium.

During the test, four tightening bolts of the roof panel of the upper CC broke owing to the pressure rise in the CC and the roof panel came off. In the calculations, it was assumed that a part of the roof panel (0.064 m^2) opened when the pressure rise reached about 16 kPa, which was estimated using the lower yield stress (340 N/mm^2) and the cross-sectional area (14.2 mm^2) of the bolt, and the area of the roof panel (1.2 m^2).

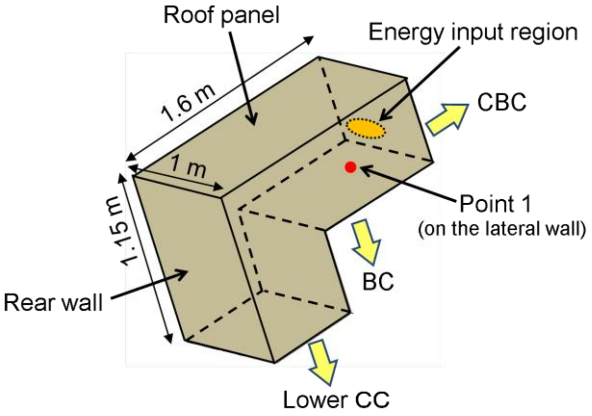


Fig. 2 Geometrical arrangement considered in the calculations (upper CC).

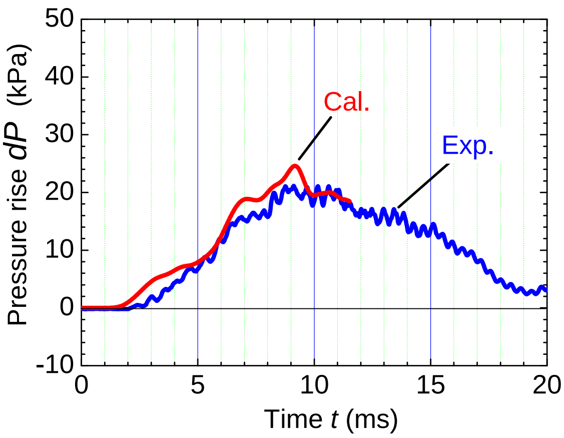
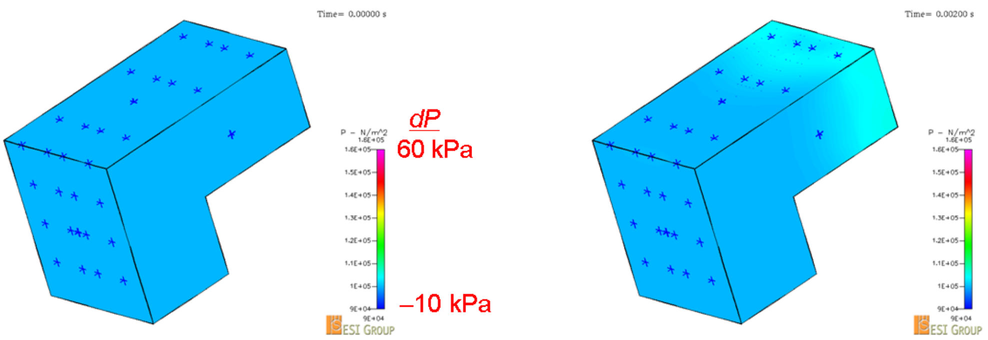


Fig. 3 Calculation and experimental pressure developments at point 1 in the upper CC.

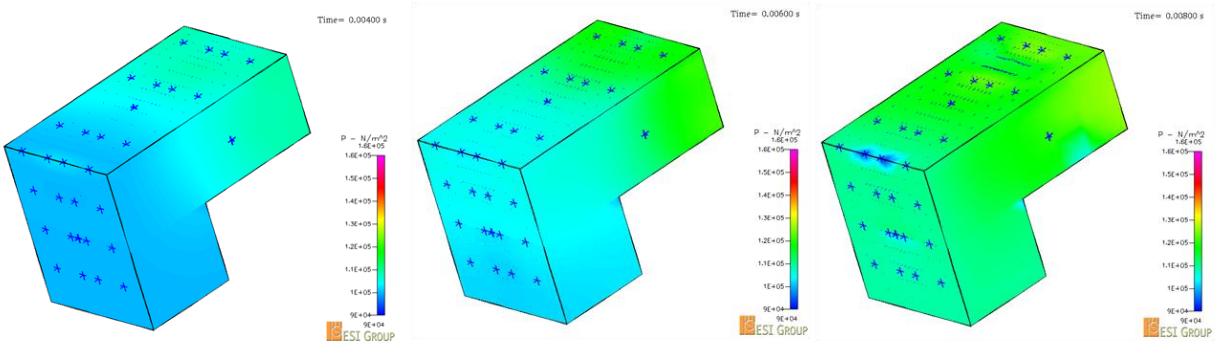
3. RESULTS

Fig. 3 shows the calculated and measured pressure developments of point 1 in the CC. The measured pressure rise *dP* increased and reached the maximum value of about 20 kPa at time *t* of around 10 ms, and *dP* showed a tendency to decrease although the arc continued to burn in the CC. As a first step, in this paper, the calculation was carried out until the measured *dP* reached the maximum value. The calculated pressure development was in good agreement with the measured one.



(a) t = 0 ms

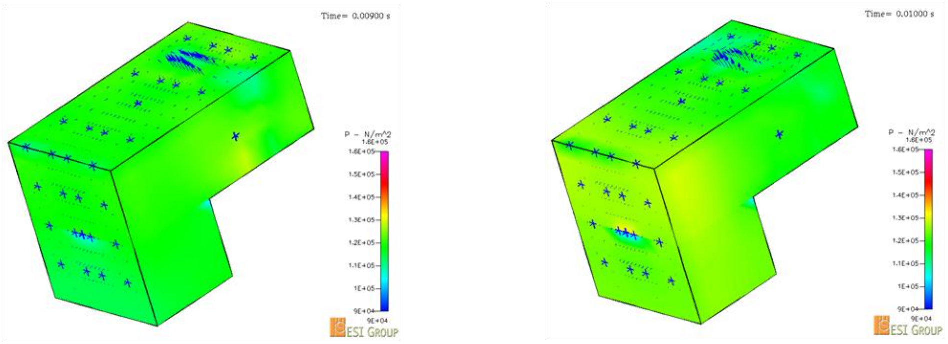
(b) t = 2 ms



(c) t = 4 ms

(d) t = 6 ms

(e) t = 8 ms



(f) t = 9 ms

(g) t = 10 ms

Fig. 4 Time dependence of 3-D pressure distribution in the upper CC.

Fig. 4 shows the 3-D pressure distribution in the CC. With time t, dP near the energy input region increased and the pressure wave propagated to another region, e.g. the rear of the CC. Also, the hot gases in the CC went out through the rectangular slits of the metal plates and through the opening of the roof panel as well after t of about 7.8 ms when dP of the roof panel reached about 16 kPa. It was considered that the release of the gases from the CC caused dP to decrease after time t of about 10 ms in spite of the arc continuing to burn in the CC.

4. CONCLUSION

This paper described the CFD calculation results regarding the pressure rise due to HEAFs in the metal-clad switchgears. The energy input took place locally in the upper cable compartment of the switchgear. The gas inside was air with an initial pressure of 0.1 MPa. The arc current I_{arc} was 21 kA, the t_{arc} 0.1 s (100 ms), W_{arc} 3.1 MJ. The calculations were carried out considering the propagation of the hot gases from the cable compartment to the outside and the came-off of the compartment roof panel that was observed in the test. As a result, the calculated and the measured pressure developments of the cable compartment were in good agreement. The pressure rise dP increased and reached the maximum value of about 20 kPa at time t of around 10 ms, and dP showed a tendency to decrease although the arc continued to burn in the cable compartment. It was considered that this was because the hot gases propagated from the arcing compartment to the outside of the switchgear.

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