

NUMERICAL SIMULATION OF PRESSURE RISING WITH INTERNAL ARC FAULT FOR A MEDIUM VOLTAGE METAL CLAD SWITCHGEAR

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ABSTRACT

This work aims to develop an analysing technology to predict the pressure characteristics for medium voltage metal clad switchgear in case of an internal arc fault. The numerical simulation method for the switchgear has been developed having the following features. (1) It enables to consider the influence of the flow of exhaust gases by applying simplified *Computational Fluid Dynamics* (CFD) method. This method is able to predict the time-dependent pressure distribution inside the switchgear in a short time. (2) For calculation of the arc energy, electric field of arc is acquired through experiments. The validity of the developed analyzing technology has been checked with experimental results.

1. INTRODUCTION

When an internal arc fault occurs in a switchgear, the pressure increases due to the energy input from the arc. In the worst case, the leaked hot gas from switchgear may cause a serious accident that would injure worker. A pressurized hot gas filled in the switchgear should be safely relieved through the pressure relief devices, such as rupture discs or flap. It is important to analyse the characteristics of the pressure increase and the pressure relief performance in case of an internal arc fault in the switchgear.

Some calculation methods to explain the pressure characteristics have been reported before [1]-[2]. The simplest method to predict the average pressure increase is to an average pressure value in switchgear. The average pressure is calculated with the internal volume of switchgear and arc energy, and it is assumed that the properties of hot gases are equivalent to the ideal gas (the first method). Recently, a method to predict the local pressure, temperature and

velocity of gases by applying a commercial three-dimensional CFD program has been developed (the second method).

Although the first method is simple, the influence of the exhaust gas through the pressure relief devices has not taken into consideration, while in the second method, the influence has taken into consideration. The second method however has rather long computation time. The calculation speed and analysing accuracy are needed for the design of a switchgear.

In this work, a numerical thermo fluid model has been developed for a medium voltage metal clad switchgear with pressure relief devices. In this model, an explicit method is applied, and calculation cost is reduced compared with the conventional model.

2. CALCULATION METHOD

In order to acquire the pressure characteristic inside a switchgear when an internal arc fault occurs, it is necessary to predict the arc power and the performance of exhaust pressure the switchgear.

In order to predict the arc energy, the circuit shall be analysed considering the voltage and impedance of the systems, the fault current, and the generating arc voltage. Especially, the calculation of the arc voltage is important. The arc voltage is influenced by an electrode gap distance and the electrode fall voltage which is decided by the electrode materials and the arc current. Therefore, it is necessary to acquire the arc performance data by basic experiments and to correlate with the data in mathematical expression.

The hydrodynamic equation should be solved to predict the increase and the exhaust pressure performance.

On occurrence of the arc fault, the temperature of gas would become high and due to the ionization and dissociation, the physical properties of gas, i.e. the density and specific heat, etc. might be changed.

2.1 The arc models

The arc voltage V_{arc} is given as a total voltages generated in two regions as shown below:

$$V_{arc} = E_{arc}(I_{arc})L_{arc} + V_{con} \quad (1)$$

whre $E_{arc}(I_{arc})$ represents electric field of arc,

L_{arc} arc length, V_{con} electrode fall voltage.

The electrode fall voltage V_{con} is determined by the material used for the electrode. For copper material currently used as a conductor of a switchgear, it has been reported that electrode fall voltage is 16.5V in the air [3]. The electric field of arc depends on the arc current. It is important to formulate the relation of the arc electric field with current in order to calculate the arc voltage in equation (1).

The electric field depending on the arc current was measured in air with the experimental equipment shown in Fig. 1. The electrode gap length is variable in the range between 2 mm and 20 mm, and the arc current is changed from 1 kA to 10 kA.

The relations between the arc voltage and current in each gap length are shown in Fig. 2. It turns out that the arc voltages and currents are in linear relation as shown in Fig. 2. Furthermore, the arc electric field is computed by eliminating the electrode fall voltage from the arc voltage, being divided by the arc length. The result is shown in Fig. 3. The arc electric field E_{arc} [V/mm] and the arc current I_{arc} [kA] are in linear relation, which can be represented approximately the following expression.

$$E_{arc}(I_{arc}) = 0.174I_{arc} \quad (2)$$

2.2 Simplified CFD method

In the general CFD method, a fine divided mesh of space needs to be made in consideration for the viscosity of the gas for computing the shear stress near the surface of a wall, and the pressure loss near the flaps. The calculation cost would become expensive in case of analysing the very high phenomenon of the flow velocity such as

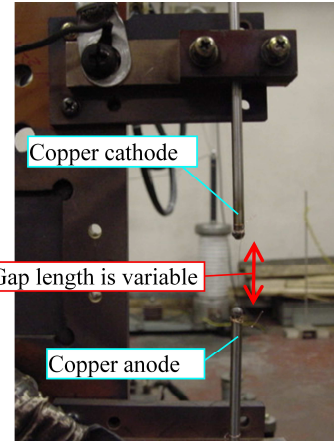


Fig.1. Experimental of set up for electric field of arc

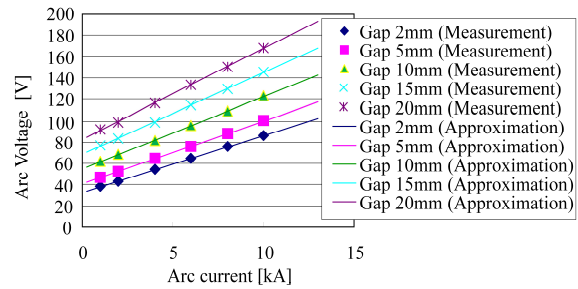


Fig.2. Relationship between arc voltage and arc current with changing gap length in air

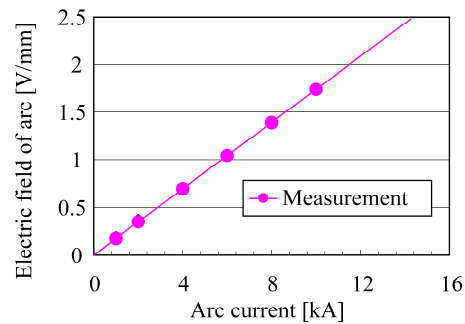


Fig.3. Relationship between the electric field of arc and arc current in air

the internal arc fault for a switchgear which is relatively a big analysis model.

The Simplified CFD Method has been developed which neglect the gas viscosity. When the internal arc fault occurs for a switchgear, the power of acting on the inside case of a switchgear has great influence of the pressure which increased with the arc more than the shear stress by viscosity.

Furthermore, even if the viscosity is not taken into consideration, the flow of the gas from an exhaust hole becomes analyzable by expression about the relation between the exhaust hole area, the angle of the flaps, the pressure loss near the flaps, and a gas velocity.

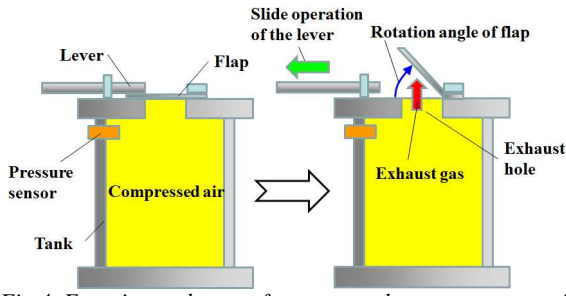


Fig.4. Experimental set up for pressure loss measurement in the vicinity of flaps

As an advantage, since the viscosity is not taken into consideration, a model can be divided in a comparatively large mesh, and calculation load can be lowered.

When the viscosity is not taken into consideration, the Euler equation is used for fluid calculation as shown in equations:

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \text{grad})\mathbf{u} = -\frac{1}{\rho} \text{grad}p \quad (3)$$

where \mathbf{u} represents the gas velocity [m/s], ρ the mass density of the gas [kg/m³], p the pressure [Pa], t a time [s]. The discretization method is the finite volume method.

2.3 The relation between the pressure loss and the gas velocity

To find out the relation between the pressure loss near the flaps and the gas velocity of exhaust holes in the method, the exhaust pressure experiment was carried out using the tank which has a flap shown in Fig. 4. Several conditions of the exhaust pressure experiment are shown in Table 1. Parameters based on the area of the exhaust hole and the maximum rotating angle of the flap, the process of the pressure decrease in the tank has been measured with pressure sensors in case of the flap operation. Also, the pressure waveform has been analysed and the average rate of flow from the exhaust hole during a certain period of time by the pressure depletion per time unit and the area of the exhaust hole has been calculated.

The relationship between the pressure losses ΔP around the flap and the calculated average gas velocity u is shown in Figure 5. Although it is non-linear relation, the calculation can be made using the rotating angle of the flap θ , and the area of the exhaust hole S_{hole} .

Table 1. Experimental conditions for pressure loss in the vicinity of flaps

Item	Condition
Exhaust hole size	0.0025 m ²
	0.0049 m ²
	0.01 m ²
Maximum rotation angle of flap	30 deg
	60 deg
	90 deg
Charging pressure to the tank	100 kPaG
	175 kPaG
	200 kPaG
Capacity of tank	0.0213 m ³

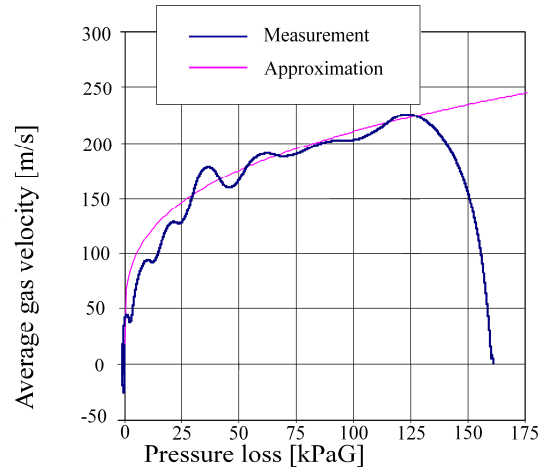


Fig.5. Relationship between pressure loss around flap and average gas velocity of exhaust hole

Table 2. Simulation conditions

Item	Condition
Voltage of circuit	11 kV
Fault current	18 kA
Frequency of circuit	50 Hz
Failure mode	Three-phase short-circuit
Gap length BUS conductors	50 mm
Capacity of the switchgear	0.447 m ³
Exhaust hole size	0.0763 m ²
Working pressure of flaps	60 kPaG

3. SIMULATION OF PRESSURE RISING WITH INTERNAL ARC FAULT

Pressure analysis for the switchgear using the developed method has been conducted. The conditions for the analysis are shown in Table 2. Figure 6 shows the results of the arc power analysis. The maximum arc power appears at the beginning of fault as the DC component

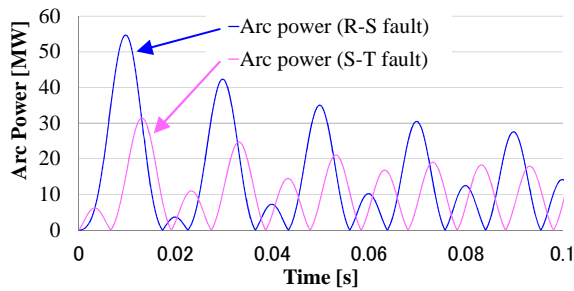


Fig.6. Calculation result of arc power wave form with three-phase fault condition

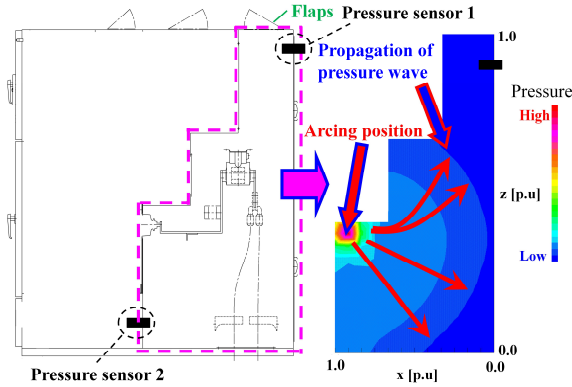


Fig.7. Calculation result of pressure distribution inside a modelled switchgear

superimpose on the AC and the power damps with time.

The internal pressure increase of the switchgear using calculated arc power has been carried out. Figure 7 shows the pressure distribution in the switchgear right after the arc generation, which demonstrates the pressure wave spreading around the arcing point. Furthermore, two pressure sensors to experiment and obtain the pressure waveform at those locations as shown in Figure 8 has been installed in the switchgear. The comparison of the results of the test and analysis are shown in Figure 8. The good agreement is observed between the experiment and analysis of the performance of pressure rise and pressure release after the flap operation. This ensures the validity of the analyzing method.

4. CONCLUSION

The numerical simulation method has been developed based on the experimental results. It enables to calculate arc power that would be generated on the occasion of an internal arc accident. In addition, the simulation for the pressure losses around the flap enables a simplified calculation for the pressure rise and for the pressure release performance in the switchgear. Although this method neglects the fluid viscosity which permits to use a rough divided mesh dimension for

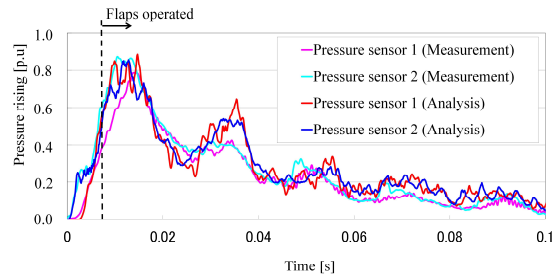


Fig.8. Calculation and experimental pressure wave form in the switchgear

calculation, the arc characteristics in a switchgear could be predicted accurately. The pressure properties at the internal arc accident in a switchgear can be calculated in a short time, the developed method would be useful to design the switchgears. Using the developed technique the next development is being planned for better performance of the switchgears

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