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가스차단기 전류영점영역에서의 열유동특성에 관한 연구

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Thermal Flow Characteristics of Gas Circuit Breakers near Current Zero Period

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Abstract - Because the physics occurring during an interruption process is not well known, it is not easy to analyze the characteristics of a self-blast circuit breaker neither theoretically nor experimentally. Fortunately the available computational power and the numerical method improved recently make it possible to predict an interruption process as precisely and fast as possible. Therefore many researches using computational methods have been done for the interruption process of interrupters and applied to extend the information such as thermal and dielectric reignition. In this paper, we have simulated the interruption process of SF6 self-blast circuit breakers with the arc plasma during the fault interruption of a 10 kA current. The CFD program used here is coupled with the electromagnetic field analysis, the radiation model and the effects of turbulence. Through this work, we have get further information about the thermal performance as well as the behavior of the arc. The results have been compared with the measured arc voltage.

1. Introduction

Because the physics occurring during an interruption process is not well known, it is not easy to analyze the characteristics of a self-blast circuit breaker neither theoretically nor experimentally. The design and development procedures of circuit breakers are still largely based on trial and error through testing although the development costs go higher every year. Fortunately the available computational power and the numerical method improved recently make it possible to predict an interruption process as precisely and fast as possible. Of course, calculations cannot replace the tests because all the real processes arc not taken into account. But the knowledge of the arc behavior and the prediction of the thermal flow inside the chamber by numerical simulations are more useful than experiments due to the difficulties to obtain physical quantities and the reduction of the computational costs in recent years [1].

Because SF6 is an excellent gaseous dielectric medium, which has more than twice the dielectric strength of air, the most common type of circuit breakers for high voltage class has been SF6 puffer circuit breakers since SF6 was discovered in the 1950s [2]. But a powerful mechanism is required in order to get blowing-off force, which will blast the arc between the contacts during the switching process, through compressing the SF6 gas in the closed chamber. It is the best way to reduce the power required to the mechanism for increasing the reliability and compacting the size of the system. This reduction in mechanism energy can be realized using the arc energy itself to assist the blowing force in the interruption process. It is known that in order to achieve this reduction there are two main principles named self-blast, or autoexpansion by the arc energy itself and arc rotation by coils or magnets, though the various methods might be used in combination.

In this paper, in order to get further information into the interruption process of a self-blast circuit breaker, based on a combination of thermal expansion and the arc rotation principle, gas flow simulations with thermal arc plasma are performed during the whole switching process, high current period, pre-current zero period, and current zero period. Through the work, we will find out the effective cooling condition of the arc plasma during the fault interruption and investigate the thermal performance through the post arc current just after current zero. These results bring us the optimum design of an interrupter with much higher breaking performance.

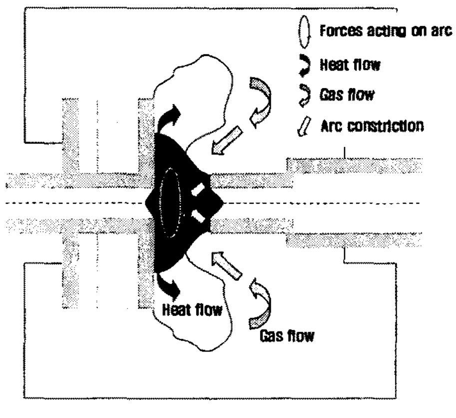

그림 1 Self-blast model circuit breaker

2. Description of the Interrupter

An SF6 self-blast model circuit breaker used here applies two arc quenching principles, thermal expansion and arc rotation, to its interrupter (figure 1). This type of circuit breaker uses a combination of rotary arc and pressure-rise inside the autoexpansion volume in order to extinguish the arc plasma between the contacts at an appropriate current zero. The two electrodes, moving contact and fixed contact, have a hole in their center in order to exhaust the residual gas during the interruption process. To rotate and guide the arc by the radial component and the axial component of the magnetic field respectively, the fixed contact contains coils.

3. Governing Equations

The governing equations of a turbulent arc and its surrounding flow in a cylindrical polar coordinate system can be written in conservative form, as the following time-averaged Navier-Stokes equations [3]:

$$\frac{\partial(\rho\phi)}{\partial t}+\frac{1}{r}\frac{\partial}{\partial r}\left[r\rho v\phi - r\Gamma_\phi\frac{\partial\phi}{\partial r}\right]+\frac{\partial}{\partial z}\left[\rho w\phi-\Gamma_\phi\frac{\partial\phi}{\partial z}\right]=S_\phi$$

$$S_w=-\frac{\partial p}{\partial z}+(j\times B)_z+\text{viscous terms}$$

$$S_v=-\frac{\partial p}{\partial r}+(j\times B)_r+\frac{\rho u^2}{r}-\frac{2(\mu+\mu_t)v}{r^2}+\text{other viscous terms}$$

$$S_u=-\frac{\rho vu}{r}+(j\times B)_\theta-\frac{(\mu+\mu_t)u}{r^2}-\frac{u}{r}\frac{\partial}{\partial r}(\mu+\mu_t)$$

$$S_h=\frac{dp}{dt}+\sigma E^2+\nabla\cdot q^R+\text{viscous dissipation terms}$$

The equations for calculating the electric field and the magnetic field are as follows [4]:

$$\frac{\partial}{\partial z}\left(\sigma\frac{\partial\phi}{\partial z}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(r\sigma\frac{\partial\phi}{\partial r}\right)=0$$

$$B_\theta=\frac{\mu_0\int_0 2\pi r' J_z dr'}{2\pi r}$$

$$\nabla^2 A_\theta=\begin{cases}-\mu J_z+\dfrac{A_\theta}{r^2}\\[2mm] \mu\sigma\dfrac{\partial A}{\partial t}+\dfrac{A_\theta}{r^2}\\[2mm] \dfrac{A_\theta}{r^2}\end{cases}$$

$$B=\nabla\times A=\frac{\partial A_\theta}{\partial r}+\frac{A_\theta}{r}$$

$$B_r=-\frac{1}{r}\frac{\partial}{\partial z}rA_\theta,\quad B_z=\frac{1}{r}\frac{\partial}{\partial r}rA_\theta$$

To calculate the governing equations with relevant boundary conditions, the commercial CFD code, which is customized to allow the inclusion of arc plasma modeling by Fortran subroutines, uses and interfaces with user coded subroutines for considering many physical models.

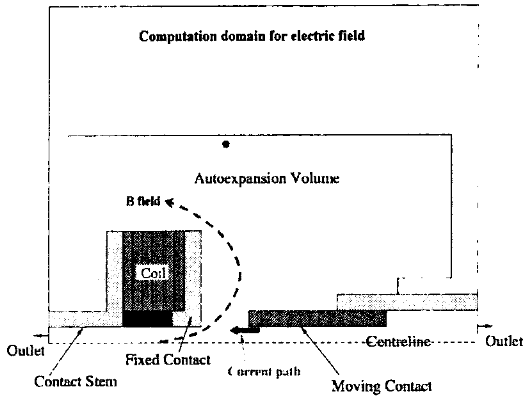

그림 2 Schematic diagram of model interrupter

4. Results and Discussion

A schematic cross-section through the interrupter axis is shown in Fig. 2. The filling pressure of the interrupter is taken to be 2 bar and the contact speed to be about 2.5 m/s as experiments. The domains for electrostatic potential and the magnetic vector potential are much larger than that required flow field for the stable calculation of the electromagnetic field. On the cathode, we set =0 V and the potential on the anode 5 V, which are changeable by user, in order to calculate the electric potential and the Ohmic heating term. The AC current has about a peak of 10 kA and the frequency is taken as 60 Hz [5].

We compared the arc voltage of chamber with experimental data in Fig 3. Through the first high current period the arc voltage is about above 100 V and in the second half cycle it is approximately above 200 V, which is reasonable values in comparison with experiments. Therefore it can be said that the methods and the approximations used in this study are applicable to the calculation of the interruption process of a self-blast circuit breaker.

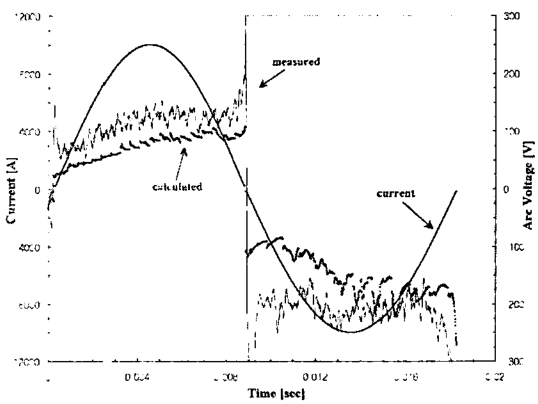

그림 3 Comparison of calculated arc voltage with measured one

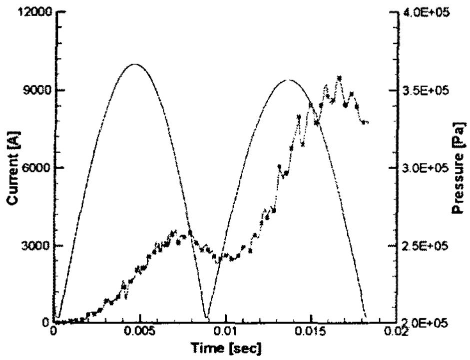

그림 4 Pressure-rise during switching process

The pressure is monitored inside the chamber close to the outer wall and at an axial position level with the initial position of the moving contact during the switching process, as a solid circle is shown in Fig. 2. As shown in Fig. 4, the maximum overpressure rise of chamber is about 0.15 MPa and this value is almost the same as the theoretical result of reference [6]. During high current period (about to 4 kA before the second current zero), the pressure continues to rise though the peak current passes. The peak pressure usually will never happen at the same time as the peak current occurs. The delay between the peak current and the peak pressure is due to the clogging by thick plasma with the peak of arc energy. It means that the arc energy used for increasing the pressure is penetrated as long as possible.

In case of a sufficient cooling of the post arc by the blowing-off force at this moment, the post arc current will be interrupted within a few microseconds, otherwise a thermal reignition will occur under the stress of the rate of rise of recovery voltage (RRRV) above the critical value. To investigate the thermal recovery capability of chamber, the post arc current is calculated as RRRVs change. As shown in Fig. 5, the thermal performance of the interrupter with chamber predicts the critical RRRV of about 1.5 kV/s. This value can be the criteria for designing this type of interrupter.

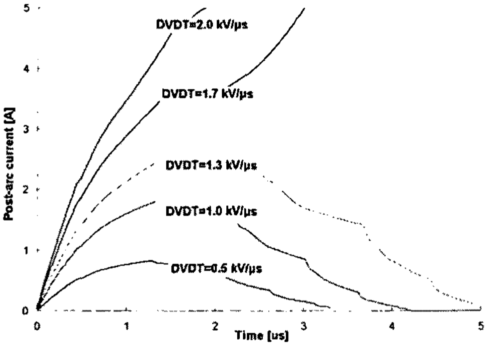

그림 5 Post arc current for different slopes of RRRV on chamber

In case of a sufficient cooling of the post arc by the blowing-off force at this moment, the post arc current will be interrupted within a few microseconds, otherwise a thermal reignition will occur under the stress of the rate of rise of recovery voltage (RRRV) above the critical value. To investigate the thermal recovery capability of chamber, the post arc current is calculated as RRRVs change. As shown in Fig. 5, the thermal performance of the interrupter with chamber predicts the critical RRRV of about 1.5 kV/s. This value can be the criteria for designing this type of interrupter.

5. Conclusions

The results are summarized as follows:

1) The maximum pressure-rise of chamber used to experiments is 0.15 MPa and it shows almost the same value as the existed theoretical result. And the calculated arc voltage of chamber M between the contacts is about above 100 V through the first high current period and 200 V in the second half cycle, which are reasonable values in comparison with experiments.
2) At pre-current zero period, the good designed chamber makes the arc plasma thin and the pressurized gas flow smoothly toward the outlets. And it is important part in the interruption capability that how high and how long the pressure rise continues. Therefore the pressure-rise and the ramp of the pressure to current zero should be a good criterion to decide the thermal performance of interrupters
3) Using the simulation tools, the critical rate of rise of recovery voltage (RRRV) can be determined. The thermal performance of this interrupter predicts the critical RRRV of about 1.5 kV/s.

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