Computational Investigation of SF_6 Hot-Gas Flow around Current Zero in UHV Gas Circuit Breakers

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Abstract — This paper presents the analysis scheme for the arc conductance before the current zero and the thermal recovery characteristics after it in the interruption of alternative currents. In order to calculate the arc conductance and the thermal recovery, the electro-magnetic calculation module and the arc model were combined using user defined function (UDF) of a computational fluid dynamics (CFD) code "FLUENT." The measured results of the arc conductance in 145kV gas circuit breakers (GCB) and the post-arc current data in the 245kV GCB were used to verify the proposed method in this paper. And also, by using the method, the arc conductance and the thermal recovery characteristics before and after the current zero were estimated according to the shapes of the interrupter and the results were utilized to predict the interruption capability of GCB.

I. INTRODUCTION

The simulations on the interruption mechanism of GCB in the 1990s were to analysis the cold gas flow with the moving boundary and to estimate the small current capability with a electric field calculation[1][2]. Entering the 2000s, as the calculation speed of computer was improved and the computational scheme was newly developed, the hot-gas (arc) analysis in GCB has been greatly activated. Especially, the arc model of Liverpool University has leaded the significant improvement in the simulation of arc in GCB using a CFD tool [3]. And also authors in [4] have provided newly the experimental criterion on the thermal recovery capability of GCB. This study started to improve the modeling of shape and the applicability to the real field and to estimate the flexibility of the criterion proposed in [4] in view of the numerical analysis.

In this study a CFD code "FLUENT" has been used and using the user defined function (UDF) the hot-gas flow analysis module has been combined it for the calculation of the arc conductivity and the thermal recovery characteristics. The analyzed results have been verified by comparing with the experimental results of 145kV and 245kV GCB. Finally, the calculated results have been used to determine the design parameters of an interrupter (of a specific GCB).

II. CALCULATION OF SF_6 HOT-GAS FLOW

An arc is inevitably formed between two contacts of GCB when an electric current is interrupted. The arc is assumed to be rotationally symmetric and the flow heated by it is turbulent [5]. Due to the high arcing current and strong radiation, the ablation occurs in the poly-tetra-fluo-ethylene (PTFE) nozzles and this result in the mixing of the SF_6 gas with the PTFE vapor. An additional equation to calculate the PTFE mass concentration in the mixture needs to be introduced together with overall mass, momentum, and energy conservation equations for the SF_6-PTFE gas mixture as shown below:

$$\frac{\partial(\rho\phi)}{\partial t} + \nabla \bullet (\rho\phi\vec{V}) - \nabla \bullet (\Gamma_\phi \nabla\phi) = S_\phi \tag{1}$$

where φ, Γ_φ, and S_φ are respectively the dependent variable, diffusion coefficient and source terms, which are listed in Table 1 for the mass, momentum, energy and PTFE mass concentration equations.

Table 1 MEANING OF VARIABLES FOR EQUATION (1).

Equation	φ	Γ_φ	S_φ
continuity	1	0	0
r-momentum	v	$\mu_l + \mu_t$	$-\partial P/\partial r - J_z B_\theta$ +viscous terms
z-momentum	w	$\mu_l + \mu_t$	$-\partial P/\partial z + J_r B_\theta$ +viscous terms
enthalpy	h	$(k_l+k_t)/c_p$	$\sigma E^2 - q + dP/dt$ +viscous terms
PTFE mass concentration	c_m	$\rho(D_l+D_t)$	0

ρ = *density*, v = radial velocity, w = axial velocity, h = enthalpy, c_p = specific heat at constant pressure, c_m = PTFE mass concentration, μ = viscosity, D = Diffusion coefficient, P = pressure, J = current density, B_θ= azimuthal component of the magnetic field, E = electric field, σ = electrical conductivity, q = radiation loss, subscript l and t present laminar and turbulent terms, respectively.

The mass fraction is defined as

$$c_m = \frac{n_{PTFE} M_{PTFE}}{n_{PTFE} M_{PTFE} + n_{SF_6} M_{SF_6}} \tag{2}$$

where n and M are respectively the molar number and molar mass.

Prandtl mixing length model was used for the consideration of turbulence flow and the semi-empirical radiation model [6] was employed. A current continuity equation is solved to obtain the electric field and the Ohmic heating which is equal to the electrical power dissipation. The shape of the arc column is determined by the solution of the energy equation. Lorentz force in both the axial and radial directions is operating in the momentum equations.

For the calculation of the arc conductance before current zero, Mayr arc model, which gives good results for low current phase arc, has been used [7].

$$\frac{1}{g}\frac{dg}{dt}=\frac{1}{\tau}\left(\frac{ui}{P}-1\right) \tag{3}$$

where g, u, i, τ, and P are respectively arc conductance, arc voltage, arc current, time constant, and cooling power.

Arc conductance and its rate of change from 4us to 3us before current zero by CFD simulation is used to extract the parameters for Mayr arc model for continuous prediction to current zero.

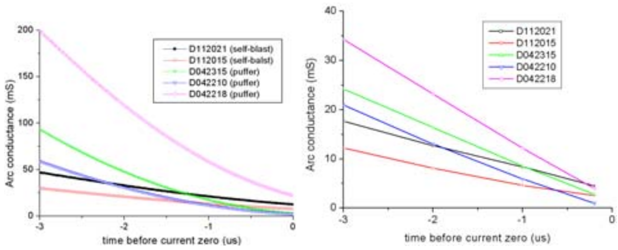
After current zero, the post-arc current flows owing to the conductivity of remained charges in the arc channel. Joule heating occurs due to the energy input into the arc channel by the current, while the energy loss arises by the surrounding cold gas and radiation. The success or failure of the thermal recovery is determined by the magnitude of the post-arc current, i.e. it should be investigated whether the magnitude decreases to zero within several microseconds after current zero.

In order to calculate the post-arc current, the electric field, magnetic field, and hot-gas flow analyses before current zero are firstly performed and the conditions between contacts at current zero should be obtained. These conditions are used as the initial conditions for the calculation of post-arc current after current zero. The resistance between contacts can be obtained from the calculated conductivity of the arc channel after current zero. When the RRRV (i.e. du/dt) is given, the change of the post-arc current according to time can be calculated as follows [8]:

$$I_{post-arc}=\frac{\left(du/dt\right)}{R}t \tag{4}$$

III. RESULTS AND DISCUSSIONS

The arc conductance for 145kV and 245kV GCB will be calculated and measured respectively.



(a) calculated arc conductance (b) measured arc conductance

Fig. 1. Calculated and measured arc conductance

Using the calculated and measured arc conductance, the validity of the criterion value at 200ns before current zero which has been proposed in [4] will be investigated numerically. Finally, with the estimation of thermal recovery capability, it will be reviewed that the earlier point of prediction time is available instead of 200ns before current zero.

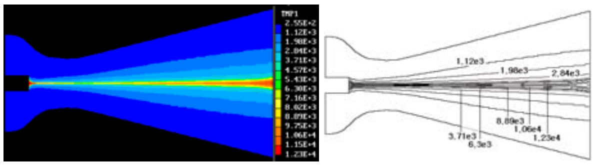


Fig. 2. Temperature distribution in an interrupter

As an example in Fig. 2, the temperature, pressure, velocity distribution, and so on will be calculated through the hot-gas flow analysis. Simultaneously, with the hot-gas flow analysis, the electric field will also be calculated with the arcing time as shown in Fig. 3.

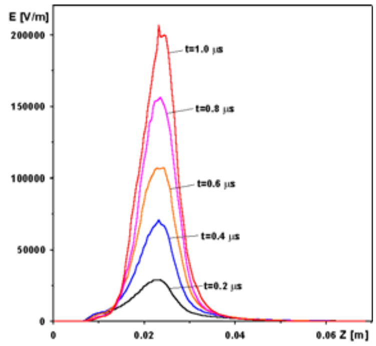
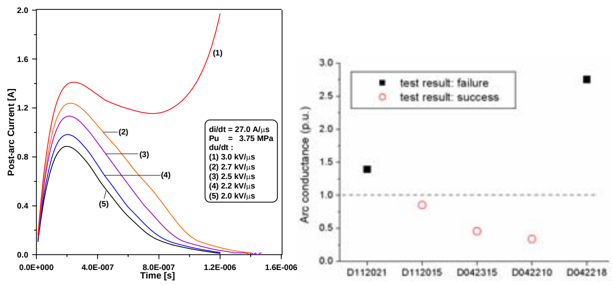


Fig. 3. Axial electric fields at various arcing times

For the various shape of interrupters, the thermal recovery which is predicted by the arc conductance at 200ns before current zero will be compared with that of the estimated by the calculated post-arc current as shown Fig. 4(a). The two predicted values will be verified by comparing with the test results (Fig. 4(b)).



(a) Post-arc current. (b) Arc Conductance.

Fig. 4. Estimation of thermal recovery capability

IV. REFERENCES

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