Calculation of Thermal Characteristics in Disconnecting Switch by 3-D Coupled Technique

Y. H. Oh[1], K. D. Song[1], H. J. Kim[2], and W. H. Lim[2]
[1]Korea Electro-technology Research Institute and [2]Kwnag-Myung Electric Co. LTD.
Seoung-Joo Dong 28-1 Chang-Won, 641-120, S. Korea
yhoh@keri.re.kr

Abstract — This paper presents 3 dimensional coupled magneto-thermal-fluid technique considering contact resistance to calculate the temperature rise in disconnecting switch (DS). There is the contact resistance which is in the contacting parts besides the own resistance in DS. Therefore, the contact resistive loss has to be considered in the calculating the resistive loss with the eddy current loss. In this study, the harmonic eddy current loss and the resistive loss including contact resistive loss were calculated by using 3-D electromagnetic (EM) and the computational fluid dynamic (CFD) was employed to evaluate thermal-fluidic behavior. The calculated temperature was compared with measured one in order to verify the reliability of the analysis technique, and it showed good agreement.

I. INTRODUCTION

The heat source has to be calculated in order to predict the temperature rise distribution of the Disconnecting Switch (DS). There are generally two types of losses, the eddy current loss and resistive loss due to the resistive materials such as electric conductors. These losses are usually calculated in the electromagnetic (EM) field analysis and they are transferred to the thermal field analysis as a heat source [1].

In the thermal field analysis, the natural convection effect and the radiative heat transfer are considered to estimate the temperature rise distribution utilizing computational fluid dynamics (CFD) tool.

The contact resistance between electric conductors exists because the contacting surfaces are not completely contacted [2]. It is known that the contact resistance is associated with the bulk material electrical resistivity, surface roughness, the applied force and so on [3]. In the case of DS, the contact resistance has the portion of the tens percentage in the whole resistive loss. Therefore, it is imperative to calculate exactly the contact resistance for the temperature rise analysis.

Here, the resistive loss including the contact resistance and the eddy current loss have been calculated and results were provided for the input source of CFD. The CFD solver was adopted to solve the thermal-fluidic behavior. The proposed method was applied to predict the temperature rise of 29kV/2000A DS and the calculated results were compared with the measured one.

II. POWER LOSS OF DS WITH ELECTROMAGNETIC FIELD ANALYSIS

For quasi-stationary harmonic eddy current problems [5], the current distribution can be computed by:

$$\nabla \times \frac{1}{\mu} \nabla \times \mathbf{A} = \mathbf{J}_{total} = \mathbf{J}_s + \mathbf{J}_e = -\sigma \nabla \phi - j\omega\sigma \mathbf{A} \quad (1)$$

where $\mathbf{J}_{total}$ is the total current density, $\mathbf{J}_s$ the source current density, and $\mathbf{J}_e$ the eddy current density. In DS, the power loss is generated in the main conductor and enclosure tank. Using the current distribution from (1), the power loss density is calculated by:

$$P = \frac{J_{total}^2}{\sigma} \ (W/m^3). \quad (2)$$

where σ is the electric conductivity and a function of temperature.

III. CONTACT RESISTIVE LOSS

The resistance of a conductor is classified into the bulk resistance R_{Bulk} of the conductor itself and the contact resistance R_{CR}. The contact resistance existed between two electric conductors becomes

$$R_{CR} = R_{Total} - (R_{Bulk1} + R_{Bulk2}) \quad (3)$$

as shown in Fig. 1. In a bulk electrical junction, the electrical current lines become increasingly distorted as the contact interface is approached and the flow lines bundle together to pass through the separate contact spots (or "a-spots"). These constrictions of the electrical current by a-spots could generate melting the conductors.

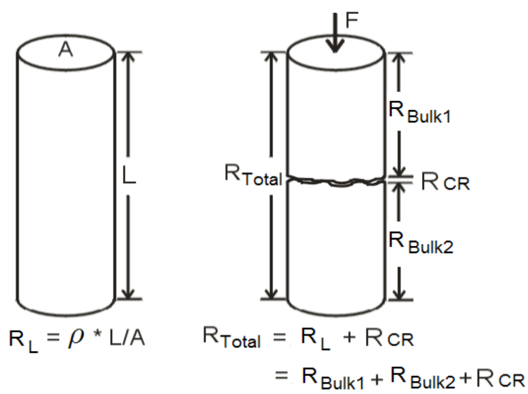


Fig. 1. Bulk resistance and contact resistance

Another method for calculating the contact resistance is the empirical formula as follows:

$$R_{CR} = P^{-0.4288} \cdot 10^{-8} \ \ (\Omega \cdot m^2) \quad (4)$$

where, P is the applied pressure to the conductors. The contact resistive loss is applied to (2) by modification for the electric conductivity of contacting parts at calculating the power loss.

IV. THERMAL-FLUIDIC ANALYSIS

The governing equations for the thermal-fluidic analysis can be expressed as the continuity, momentum, and energy equations. The main concern here is the steady state analysis of thermal-fluidic behavior, so the steady state basic governing equations are employed

For buoyancy calculations, a source term is added to the momentum equations as follows:

$$\mathbf{S}_{M,buoy} = (\rho - \rho_{ref})\mathbf{g} \qquad (5)$$

where $\mathbf{S}_{M,buoy}$ denotes the momentum source for buoyancy, ρ_{ref} the reference mass density and $\mathbf{g}$ the gravity vector. Here, we simplified (5) and adopted the Boussinesq model as follows:

$$\rho - \rho_{ref} = -\rho_{ref}\beta(T - T_{ref}) \qquad (6)$$

where β is the thermal expansivity and T_{ref} the buoyancy reference temperature.

V. NUMERICAL TEST

Numerical test model of a DS has the moving and fixed contacts, insulation gas, and spacer within enclosure tank as shown in Fig. 2. We tested 3 cases according to the insulation gas, where each case has the SF_6 gas, SF_6+N_2 gas, and dry air gas respectively. The regular specific voltage and current is 29kV/2000A.

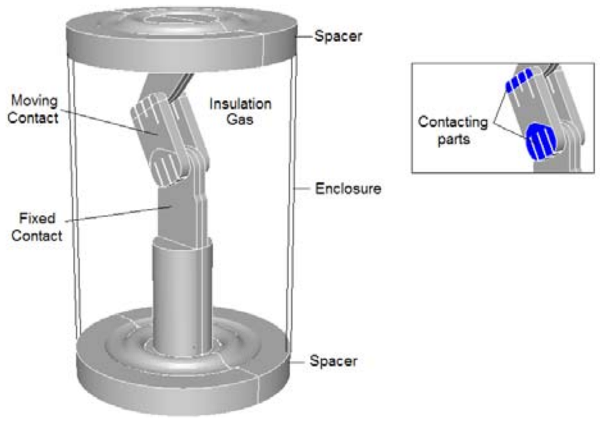


Fig. 2. 29kV/2000A DS model

The contact resistive loss and 3 dimensional EM field are planned to calculate. Here, we performed the thermal-fluidic analysis only by Joule heating. The resistance of main conductors and the contact resistance are measured, so that Joule heating was transferred to the thermal field analysis as a heat source. Table I shows that each resistances and heat source. Because of the symmetrical 3 dimensional shape, only a half of a real DS was used for calculation.

TABLE I
MEASURED RESISTANCE AND HEAT SOURCE

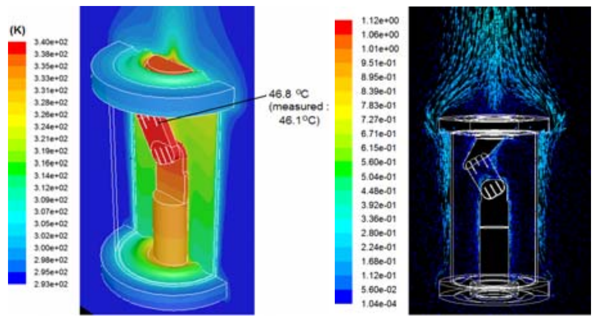
Part	Resistance (10^{-6} Ω)	Heat Source (10^4W/m^3)
Moving Contact	1.96	2.07
Fixed Contact	1.42	3.5
Contact Resistance at Moving Contact	10.0	33.3

Fig. 3 shows the temperature distributions and fluid flows in the case of SF_6 gas. The temperature rise on the moving contact agrees well with measured one.

Table II shows the temperature rise on the surface of moving contact according to the insulation gas. The temperature rise test and comparison with analysis according to the insulation gas will be performed.

TABLE II
MEASURED RESISTANCE AND HEAT SOURCE

Insulation gas	Temperature rise value (°C)
SF_6	46.8
SF_6+N_2	47.0
Dry Air	50.2



(a) (b)

Fig. 3. Temperature and velocity distribution for DS (a) Temperature distribution; (b) Velocity distribution

VI. REFERENCES

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