Three-Dimensional Analysis with a Two-Dimensional Source for Dielectric Characteristic in High Voltage Gas Circuit Breaker

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***Abstract*—This paper represents 3-D analysis for the dielectric characteristic in high voltage gas circuit breaker under condition in which the temperature of dielectric gas is reached up to several thousand degrees. For estimation of the dielectric strength in a circuit breaker, 3-D analysis must be performed because of non-symmetric region. Directly to apply the design of the dielectric for circuit breaker the 3-D analysis, however, has difficulties due to not only much computational time but also intricate modeling required to analyze in comparison with a 2-D analysis. To reduce the computational time and modeling, the novel technique is proposed for the 3-D analysis with a 2-D source acquired through the 2-D axisymmetric analysis. As a result, the computational time is saved up to 70% compared with the fully 3-D analysis. This technique is applied for 145kV gas circuit breaker in order to verify the accuracy and analysis results are in good agreement with experimental results.**

***Index Terms*—Dielectric breakdown, sulfur hexafluoride, circuit breaker, arc discharges.**

I. Introduction

To extinguish the arc plasma the dielectric gas is compressed to a high pressure by moving a piston and strongly flowed to the arc through the insulated nozzle. The intense axial flow is thus formed around the arc and flowed to the exhaust of the nozzle. This gas came through the exhaust has temperatures of a few thousand degrees and has a very low dielectric strength due to the low density and existence of free electrons.

After the arc is extinguished at a current-zero, the transient recovery voltage (TRV, up to several hundreds of kV) is applied to the circuit breaker and the possibility of its breakdown becomes high because of the hot gas having low dielectric strength [1]. In order to remove in advance of the possibility of dielectric breakdown due to thermal gas, it is imperative to verify the design parameter associated with the thermal dielectric characteristics by evaluating dielectric strength of circuit breaker [2].

To estimate dielectric strength in a circuit breaker, 3-D analysis must be performed because of non-symmetric region such as shields, insulators and enclosure. The 3-D analysis, however, has difficulties to perform in a circuit breaker on account of efforts for 3-D modeling and computational time in comparison with a 2-D analysis.

In this study to reduce the computational time and modeling, the calculation of arc plasma required the most computational time is firstly conducted by 2-D axisymmetric analysis. These 2-D results, such as pressure, temperature and velocity are used as inputted source for 3-D analysis. Finally the 3-D analysis for dielectric strength is calculated for entire domain except the arc plasma.

The proposed technique is then applied to a 145kV gas circuit breaker and analysis results for dielectric breakdown are in good agreement with experimental results.

II. Evaluation of Dielectric characteristic

A. The predicted algorithm of dielectric characteristic for gas circuit breaker

For TRV after current-zero the possibility of dielectric breakdown is calculated through the evaluation of dielectric strength for gas circuit breaker.

The breakdown can occur when the ratio of electric field E_{trv} to breakdown electric field E_{crit} is greater than value of 1 for applied TRV. E_{crit} as a function of pressure and temperature is obtained by analyzing for thermal fluid dynamics [3][4].

B. Calculation of the dielectric characteristic

Fig. 1 shows the entire computational domain. The geometries in 2-D analysis for arc plasma have thoroughly axisymmetric figure, on the other hand 3-D analysis region includes non-symmetric geometries. The dielectric gas is SF_6 and the material of nozzle is the Teflon.

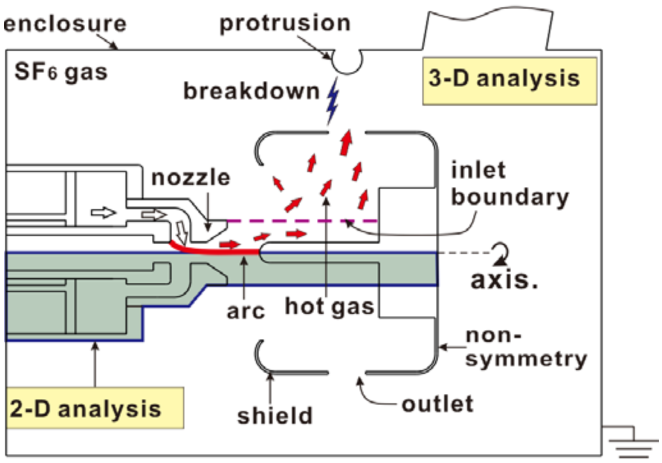

Fig. 1. Entire computational domain for 2-D and 3-D analysis in 145kV gas circuit breaker

To simulate arc plasma the arc source, radiation heat transfer, and nozzle ablation have to be calculated. The source term is defined by ohmic heating, which is included to energy conservation equation. The electric field can be obtained by solving current continuity equation.

The radiation heat transfer, which is must be considered due to the high temperature of arc plasma, is calculated by adopting discrete ordinates method in the present study. The radiation heat transfer from arc plasma causes the ablation at the nozzle surface with incident radiation. The ablation is a significant simulation factor which affects physical properties of arc plasma. In this work, multi-species technique based on the ablation-controlled arc model is taken into account.

The pressure value *P(t)* from 2-D analysis, which is as shown in Fig. 2, is used as the inlet source of 3-D analysis together with temperature *T(t)*, velocity *v(t)*, and density values *ρ(t)*.

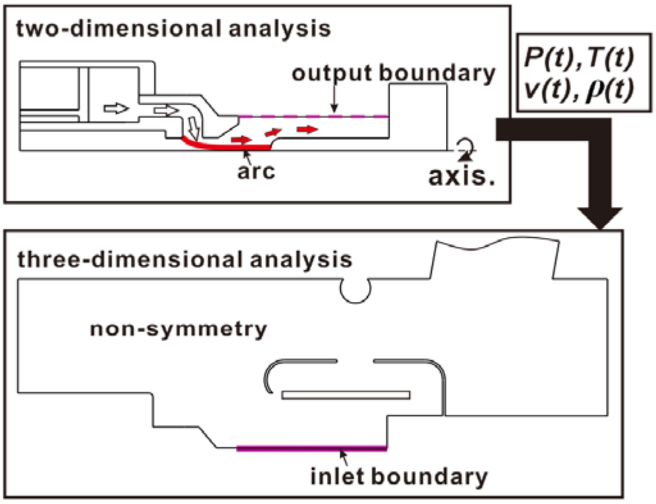

Fig. 2. Output values of 2-D analysis and boundary condition in 3-D analysis model

The pressure inlet value required to calculate 3-D model has to be considered static pressure p_s and dynamic pressure p_d which consists of density ρ and velocity v.

$$p_{inlet} = p_s + p_d = p_s + \frac{1}{2}\rho|\vec{v}|^2 . \qquad (1)$$

In this study, except the nozzle area, entire computational domain is assumed to be subsonic flows, Mach number of flow speed is less than value of 1.

III. Results and Discussion

In order to validate the proposed method in this study, the experiment and the evaluation of the dielectric strength are performed on the 145kV gas circuit breaker. As a test results, there is a soot due to the dielectric breakdown between shields and grounded enclosure as shown in Fig. 3.

The analysis results for dynamic characteristic of high temperature gas above 2,000 K and contours of the value of E_{trv}/E_{crit} are shown in Fig. 4 and Fig. 5 respectively.

The high temperature gas above 2,000K is reached the protrusion at the enclosure from the outlet. The above value of 1, which presents a high probability of breakdown, is also found at the outlet as shown in Fig. 5. Thus it can be predictable that this region has a very weak dielectric ability and found to be in good agreement with the experimental results.

Computational time is reduced to 21 hours in comparison with 72 hours in fully 3-D analysis.

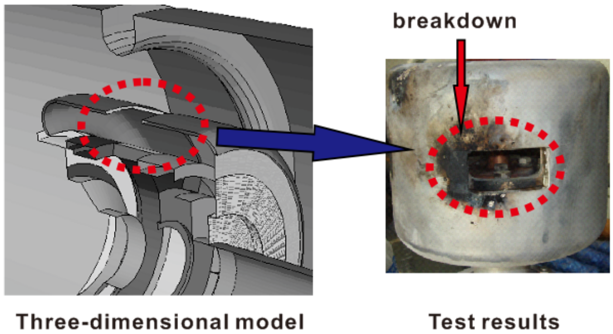

Fig. 3. Analysis model for 3-D and test results

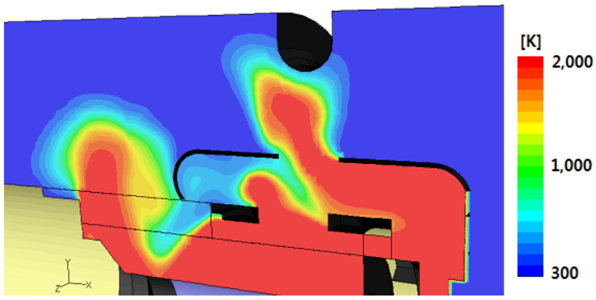

Fig. 4. High temperature distribution after current-zero

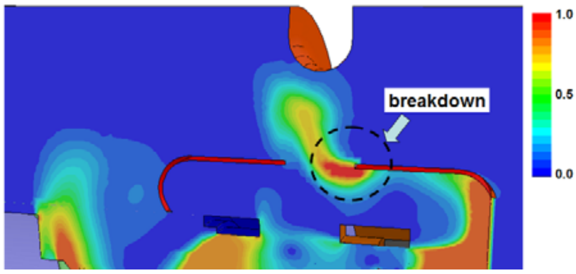

Fig. 5. Contour of the value of E_{trv}/E_{crit}

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