Bezier Curve-based Shape Optimization of SF_6 Gas Circuit Breaker to Improve the Dielectric Withstanding Performance for both Medium and Maximum Arcing Time

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This paper presents the optimization to scheme to improve the interruption performance of a gas circuit breaker, which must do the interruption duty within specific arcing time for successful operation. The systematic process of design optimization was proposed by using the Bezier curve and sequential approximation technique for satisfying both medium and maximum arcing time. Depending on the specific arcing time, the position of moving parts is changed and the changed position directly affects the gas flow in the circuit breaker. Consequently, this flow change affects the temperature, pressure, density, and flow rate between electrodes and tank, which determines success or failure in the interrupting operation. To satisfy the design criteria for successful interruption, it is necessary to satisfy more than one arcing time at the same time. The diameter and the shape of the nozzle in the circuit breaker is a key part in securing the pressure rise resulting from the heated hot gas in the chamber. Thus, the nozzle shape design requires high expertise and proficiency. To solve this problem, we used the finite volume fluid in cell (FVFLIC) for flow analysis and the Bezier curve for fitting nozzle shape. The control points in the Bezier curve were selected as design variables and the optimization process was performed employing the sequential approximation technique. Based on the experimental results, the consistency of the optimization results was confirmed, and finally we will analyze the relationship between the fixed contact at each arcing time and the inflection point of the downstream of the nozzle.

Index Terms—**Bezier Curve, Gas circuit breaker, Optimization, Multiple Arcing Time, Sequential Approximation Technique**

I. INTRODUCTION

The role of gas circuit breaker (GCB) is to protect a power system by interrupting the fault current, generated by the ground fault or shot circuit. Recently, a self-blast GCB has been actively developed in which a heating chamber is connected in series with a compression chamber. The self-blast type GCB uses a high temperature and high pressure arc, generated between the contacts to secure the necessary pressure for interruption. The high temperature energy due to the arc is transferred to the nozzle wall through radiative heat transfer, which causes nozzle ablation. The ablation nozzle vapors flow back into the heating chamber and increase pressure and temperature. The high pressure gas in the heating chamber is injected between the electrodes at the time of current zero, and the hot gas existing in the gap is discharged into the outside. After the current zero, the transient recovery voltage (TRV) is applied between the electrodes, and the insulation ability is required to be successful [1]-[3]. The GCB must be successful at the minimum (MIN), medium (MED), and maximum (MAX) arcing time for each test. When the shape of arcing contact is changed, the flow and the electric field patterns are different at each arcing time. Therefore, it is necessary to have a shape that satisfies the performance at all the arcing times in design. Numerous variables directly affect the interrupting performance at the current zero.

In this paper, to satisfy the interrupting performances at each arcing time, we conducted an optimal process employing the geometric shape of the nozzle downstream as a design variable. In a conventional shape optimizing process, node points can be design points in the finite element procedure. In this process, irregular inflection points in the shape cause stagnation flow and adversely affect the interruption performance. To resolve this problem, we introduced the Bezier curves for nozzle downstream design, which leads to more smooth shape and improved interruption performance incorporating with the sequential approximation technique (SAT). The optimized model was successfully verified by using the test results. Additionally, we analyzed the relationship between the position of the fixed arc contact and the inflection point of the nozzle downstream in detail.

II. INTERRUPTION PERFORMANCE INDEX FOR BTF

Generally, the breakdown of GCB after large current interruption is classified as thermal breakdown and dielectric breakdown. When breaking a bus terminal fault (BTF) associated with dielectric breakdown, a high TRV is applied across the GCB after the current zero, and dielectric breakdown should not occur even at high TRV. To specify the insulation status, here, we used E/rho as an interrupting performance index which is the ratio of electric field intensity over mass density of gas. The two zone model based on the experimental index data was adopted to model the electrical arc [4]. In addition, we calculated the ablation mass per unit time by using the nozzle ablation model and then performed the flow analysis by using the finite volume fluid in cell (FVFLIC) technique [5]. Fig. 1 shows the interruption performance index calculated for the 145 kV and 40 kA at 60 Hz with peak current 56.7kA. The longer the arcing time, the lower the electric field strength. Finally, the E/rho becomes lower. It can be seen that E/rho below a certain level is successfully interruption at each arcing time. The calculation results of E/rho are used as the objective function at the simultaneous design for the MED and MAX arcing time.

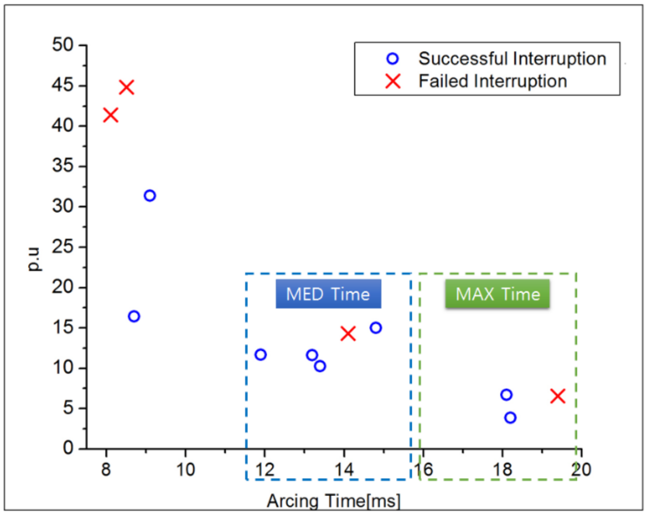

Fig. 1. Interruption performance index.

III. PROPOSED OPTIMIZATION TECHNIQUE USING BY THE SEQUENTIAL APPROXIMATION AND BEZIER CURVE

Thermal flow analysis of GCB requires a lot of time due to the complicated physical phenomena. The flow pattern differs from the GCBs due to the delicate shape change of the nozzle downstream. Electric field analysis is performed by finite element method(FEM). This analysis has time constraints for testing all of the shapes within the design variable range. Therefore, optimization process is essential and design parameter selection is significantly important. To solve this problem, we employed the Bezier curve with the advantages of flexibility and continuity to obtain a stable flow pattern [6-7]. The optimization process was performed with the control points that determine the shape of the Bezier curve as a design variable.

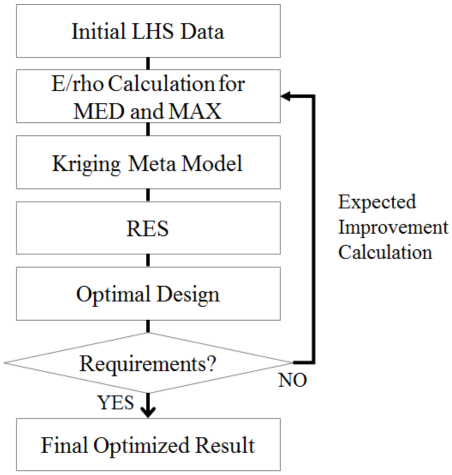

Fig. 2. Optimization procedure for simultaneous arcing time design.

The proposed optimizing process is shown in Fig. 2. We used the latin hypercube sampling (LHS) technique to identify trends within the design variable range. Each design variable performs the flow analysis set by the MED and MAX arcing time. The sum of the calculated E/rho for MED and MAX arcing time is set as an objective function. The Kriging meta model is composed using the current data set. This approximate model replaces the E/rho calculation solver. The restricted evolution strategy (RES) technique [8] is an optimization algorithm that obtains optimal design variable candidates. The flow and electric field analysis was performed on the obtained optimum design variables and the convergence was checked. When it is not converged, an optimal solution point is added automatically, and the Kriging model is reconstructed. This process is repeated until a convergence criterion is satisfied.

IV. RESULT AND DISCUSSION

Fig. 3 shows that the density distribution is dependent on the shape of the nozzle downstream. Fig. 3(A) shows that the probability of dielectric breakdown is higher than that of Fig. 3(B) because the density is lower at the front of the fixed arc contact. As a result of the analysis, the optimized model shows a performance improvement of about 20.8%. By using the Bezier curve, we found a smooth nozzle shape that can simultaneously improve the MED and MAX arcing time as shown in Fig. 3(B). Finally, we will also check the relationship between the position of the fixed arc contact point and the inflection point of the nozzle downstream shape in detail considering the optimal shape in the full paper.

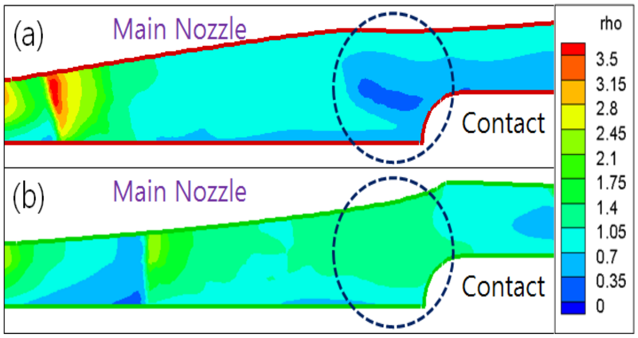

Fig. 3. Density distribution of the gap according to the shape of the nozzle downstream before and after optimization. (MAX arcing time)

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