

# ELECTRIC FIELD OPTIMIZATION OF FLOATING ELECTRODE CONFIGURATION IN VACUUM INTERRUPTER

Hiroki Kojima<sup>1\*</sup>, Keiya Suzuki<sup>2</sup>, Katsumi Kato<sup>3</sup>, Hitoshi Okubo<sup>2</sup>

<sup>1</sup>EcoTopia Science Institute, Nagoya University, Nagoya, Japan

<sup>2</sup>Department of Electrical Engineering and Computer Science, Nagoya University, Nagoya, Japan

<sup>3</sup>Department of Electrical Engineering and Information Science,

Niihama National College of Technology, Niihama, Japan

\*Email: h-kojima@esi.nagoya-u.ac.jp

**Abstract:** We propose a new optimization technique for electrode configuration with floating potential. In addition, we applied this optimization technique to the edge of centre shield in VI with considering the arrangement of grounded tank. Consequently, the maximum electric field strength decreased to 70% of non-optimized shape. From the results, we have verified the effectiveness of the proposed automatic numerical optimization technique.

## 1. INTRODUCTION

For environment-friendly vacuum interrupter (VI), higher voltage operation and more compactness are required. The electric field optimization of electrode shape in order to suppress the maximum field strength was developed for improving the insulation performance. However, the shape optimization of a floating potential electrode, e.g. a centre shield of VI, has not yet been developed and required to be investigated. In this paper, we propose a new optimization technique for electrode configuration with floating potential. In addition, we applied this optimization technique to the edge configuration of centre shield in VI with considering the effect of grounded tank.

## 2. METHOD OF FIELD OPTIMIZATION

Our technique automatically obtains an optimized electrode shape, which has uniform field distribution by repeating modification of electrode shape based on the Charge Simulation Method (CSM) as a method of electric field computation of flowchart in Fig. 1. The floating potential value is automatically calculated by adding the condition that the sum of the charge in centre shield electrode equals to zero. The modification of electrode shape in each iteration is proportioned to the difference between the electric field at the contour point and the target electric field  $E_{\text{ref}}$ . Note that the identification of  $E_{\text{ref}}$  is one of important issues to obtain a reasonable result. Figure 2 is an example of the shape optimization of centre shield end in VI, where the average electric field in optimizing region ( $E_a$ ) and the electric field at the edge of optimizing region ( $E_b$ ) are selected as  $E_{\text{ref}}$ . By choosing  $E_b$  as  $E_{\text{ref}}$ , we could obtain the reasonable optimized result.

## 3. OPTIMIZATION OF CENTRE SHIELD EDGE

We applied this optimization technique to the end of centre shield in VI with considering the arrangement of grounded tank and the centre shield, i.e. length  $L_e$  and radius  $R_s$  of centre shield and radius of ground tank  $G_s$ . Table 1 shows the optimization results for the various  $G_s$ . As a result of the optimization, the floating potential

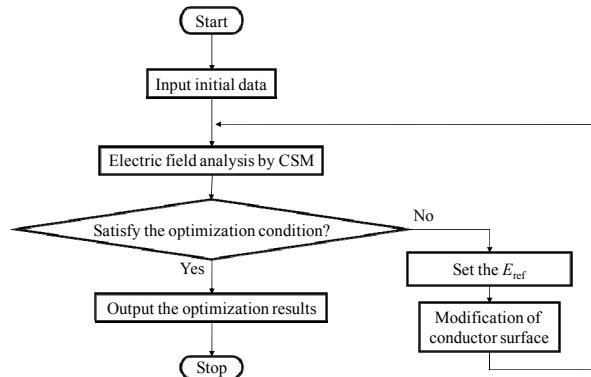


Figure 1: Flowchart of electric field optimization.

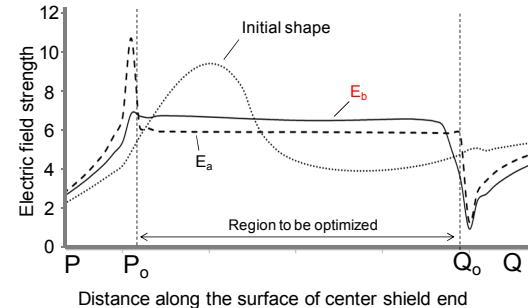


Figure 2: Electric field distribution at shield edge.

Table 1: Optimization Results for Parameter  $G_s$ .

| $G_s$                  | 33.5    |           | 53.5    |           | 73.5    |           |
|------------------------|---------|-----------|---------|-----------|---------|-----------|
|                        | Initial | Optimized | Initial | Optimized | Initial | Optimized |
| Maximum Field Strength | 11.5    | 7.6       | 9.9     | 7.2       | 9.3     | 7.0       |
| Floating Potential (%) | 12.7    | 12.6      | 27.3    | 27.6      | 32.2    | 32.8      |

of centre shield did not change so much, and the maximum electric field strength could be decreased to 70% or less of the initial condition.

## 4. CONCLUSION

We could verify the effectiveness of the proposed automatic numerical optimization technique for the improvement of the insulation performance in high voltage vacuum insulated equipment with floating potential electrode.

# Electric Field Optimization of Floating Electrode Configuration in Vacuum Interrupter

Hiroki Kojima

EcoTopia Science Institute

Nagoya University

Nagoya, Japan

h-kojima@esi.nagoya-u.ac.jp

Keiya Suzuki, Hitoshi Okubo

Department of Electrical Engineering and Computer Science

Nagoya University

Nagoya, Japan

Katsumi Kato

Department of Electrical Engineering and Information Science

Niihama National College of Technology

Niihama, Japan

**Abstract**—For environment-friendly vacuum interrupter (VI), higher voltage operation and more compactness are required. From this point of view, and to enhance the electrical insulation performance of VI, it is needed to introduce the field optimization techniques. In this paper, we propose a new optimization technique for electrode configuration with floating potential in VI. We applied this optimization technique to the edge configuration of center shield in VI with considering the arrangement of grounded tank. Consequently, the maximum electric field strength decreased to 70% of non-optimized shape. From the results, we verified the effectiveness of the proposed automatic numerical optimization technique for the improvement of the insulation performance in high voltage vacuum insulated equipment.

## I. INTRODUCTION

A development of environment-friendly vacuum insulated equipment like vacuum interrupter (VI) under high voltage operation is demanded [1-5]. For the development of sophisticated higher voltage VI, not only the research from fundamental physics is needed [6-8], but also the introduction of the numerical optimization technique based on the electric field computation is required.

The electric field optimization of electrode shape in order to suppress the maximum field strength was developed for improving the insulation performance [9,10]. However, the shape optimization of a floating potential electrode, e.g. a center shield of VI, has not yet been developed and required to be investigated [11].

In this paper, we propose a new optimization technique for electrode configuration with floating potential based on the Charge Simulation Method (CSM). We discuss the

identification of target electric field, which is one of the most important parameter for the optimization process, and then we can obtain a reasonable result. We apply this optimization technique to the edge of center shield in VI with considering the effect of grounded tank.

## II. VACUUM INTERRUPTER INSULATION DESIGN

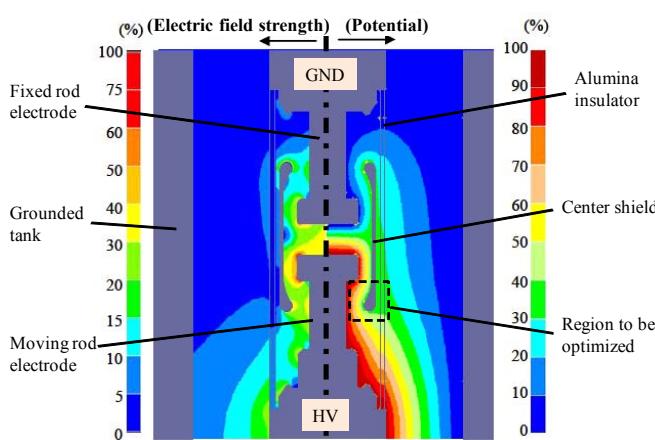
For the electrical insulation design of vacuum interrupter, we have to consider the insulation design components such as insulation between main contacts, insulation between main contactor and center shield electrodes, insulation along insulator surface, and outer insulation. Especially, the insulation between main contacts and center shield are important for determining the fundamental insulation performance of VI.

Figure 1 shows the potential and electric field distributions in the calculation model of VI. The calculation is carried out under the conditions of 100% potential to the moving rod electrode and grounded to the stationary rod electrode. The center shield electrode has a floating potential. The relative permittivity of alumina insulator is set to 9.0.

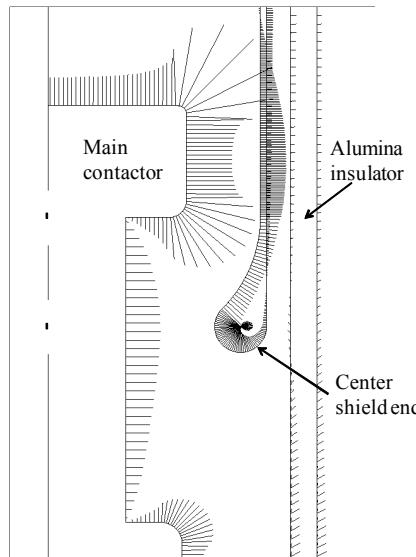
It is found from Fig. 1 that the maximum field strength is obtained at the edge of the main contacts, and the electric field strength of the center shield end is also intensified. Therefore, in this paper, we focus on the optimization of the shape of center shield end.

## III. METHOD OF FIELD OPTIMIZATION

Our technique automatically obtains an optimized electrode shape, which has uniform field distribution by repeating modification of electrode shape based on the CSM



(a) Electric field and electric potential distribution in HV VI.



(b) Distribution of electric field vector around center shield end.

Figure 1. Field calculation model and analysis result of vacuum interrupter.

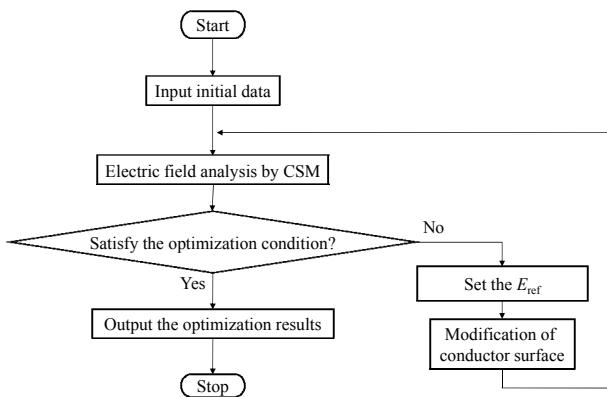


Figure 2. Flowchart of electric field optimization.

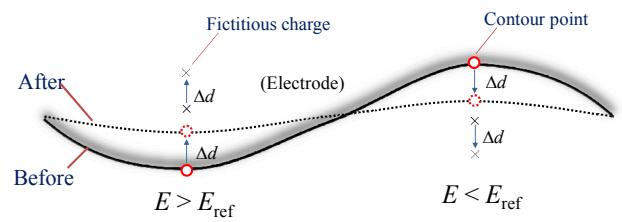
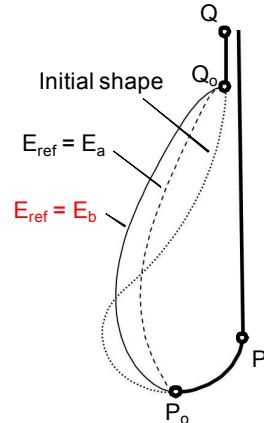
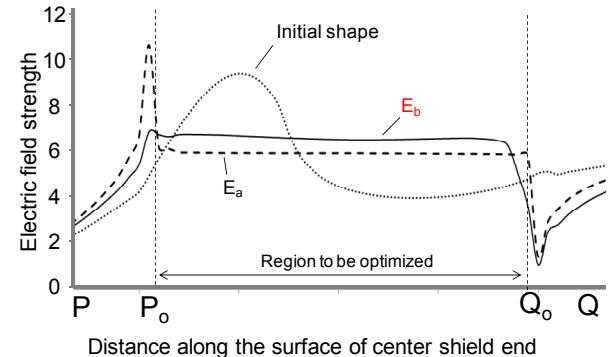


Figure 3. Optimization method of electrode surface.



(a) Optimized shape of center shield end



(b) Electric field distribution

Figure 4. Optimized shape of center shield end with floating potential and electric field distribution for different target electric field,  $E_a$  and  $E_b$ .

as a method of electric field computation as shown in flowchart of Fig. 2.

The floating potential value  $V_f$  is automatically calculated by adding the condition that the sum of the charge in center shield electrode equals to zero as follows:

$$\sum_{j=1}^n P(k, j)Q_j = V_k = V_f, \quad 1 \leq k \leq m \quad (1)$$

$$\sum_{j=1}^m Q_j = 0, \quad (2)$$

where  $P(k, j)$  is the potential coefficient between  $k$  th contour point and  $j$  th fictitious charge,  $Q_j$  is  $j$  th fictitious charge,  $V_k$  is

potential at  $k$  th contour point,  $n$  is the number of all fictitious charge and  $m$  is the number of fictitious charge in floating electrode.

We applied the following procedure for modifying conductor surface. At first, we set the target of the electric field  $E_{\text{ref}}$ . If an electric field of the contour point is larger than the target field  $E_{\text{ref}}$ , the contour point is moved to the inside of

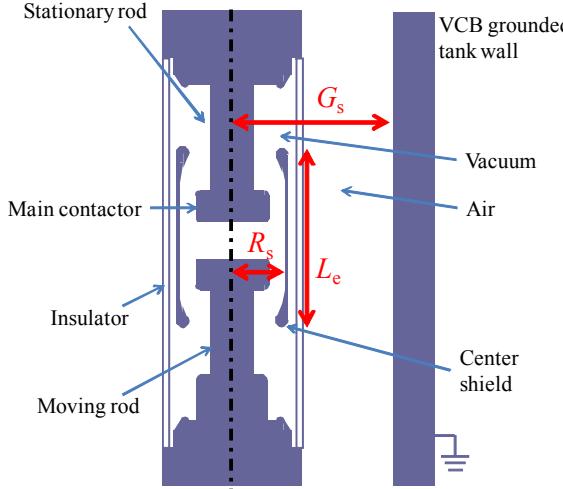


Figure 5. Definition of configuration parameters of center shield.

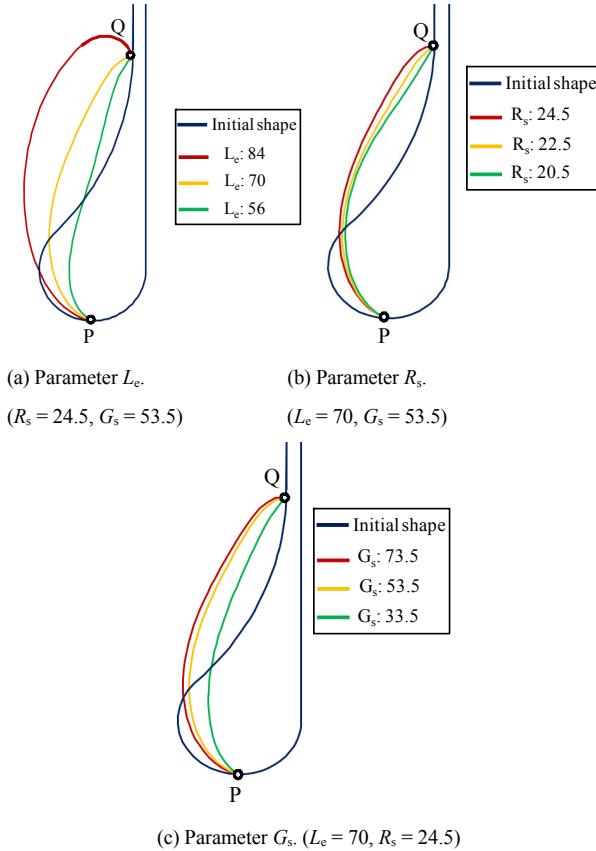


Figure 6. Optimized shapes of center shield end.

the electrode as shown in Fig. 3. The fictitious charge is also moved together. This modification generally decreases the electric field at the contour point. On the other hand, if an electric field of the contour point is smaller than the target field  $E_{\text{ref}}$ , the contour point is moved to the outside of the electrode. The modification distance  $\Delta d$  of electrode shape in each iteration is proportioned to the difference between the electric field  $E$  at the contour point and the target electric field  $E_{\text{ref}}$ , i.e.

$$\Delta d = K(E - E_{\text{ref}}) \quad (3)$$

where  $K$  is a proportional constant.

#### IV. OPTIMIZATION OF CENTER SHIELD EDGE IN VI

We applied this optimization technique to the end of center shield in VI. Note that the selection of  $E_{\text{ref}}$  is one of the

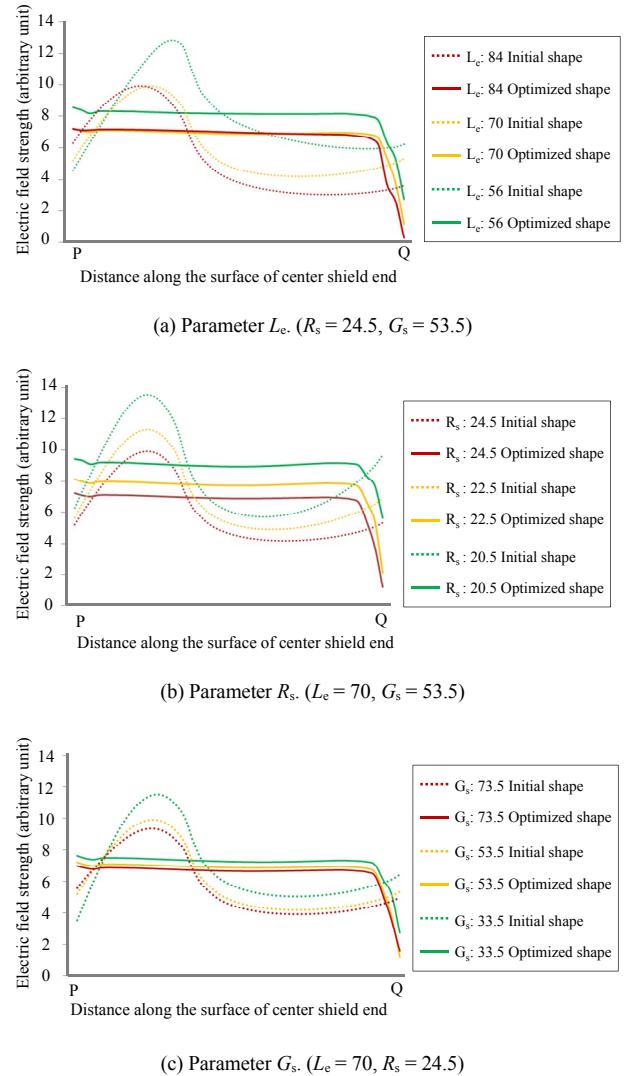


Figure 7. Electric field distribution along the surface of center shield end for initial and optimized electrode shape.

TABLE I. OPTIMIZATION RESULTS OF THE CENTER SHIELD END FOR DIFFERENT INITIAL CENTER SHIELD CONFIGURATION.

(a) Parameter  $L_e$ . ( $R_s = 24.5$ ,  $G_s = 53.5$ )

| $L_e$                  | 56      |           | 70      |           | 84      |           |
|------------------------|---------|-----------|---------|-----------|---------|-----------|
|                        | initial | optimized | initial | optimized | initial | optimized |
| Maximum field strength | 12.8    | 8.5       | 9.9     | 7.2       | 9.9     | 7.2       |
| Floating potential (%) | 28.2    | 27.8      | 27.3    | 27.6      | 27.1    | 28.1      |

(b) Parameter  $R_s$ . ( $L_e = 70$ ,  $G_s = 53.5$ )

| $R_s$                  | 20.5    |           | 22.5    |           | 24.5    |           |
|------------------------|---------|-----------|---------|-----------|---------|-----------|
|                        | initial | optimized | initial | optimized | initial | optimized |
| Maximum field strength | 13.5    | 9.5       | 11.3    | 8.2       | 9.9     | 7.2       |
| Floating potential (%) | 34.7    | 34.5      | 30.6    | 30.9      | 27.3    | 27.6      |

(c) Parameter  $G_s$ . ( $L_e = 70$ ,  $R_s = 24.5$ )

| $G_s$                  | 33.5    |           | 53.5    |           | 73.5    |           |
|------------------------|---------|-----------|---------|-----------|---------|-----------|
|                        | initial | optimized | initial | optimized | initial | optimized |
| Maximum field strength | 11.5    | 7.6       | 9.9     | 7.2       | 9.3     | 7.0       |
| Floating potential (%) | 12.7    | 12.6      | 27.3    | 27.6      | 32.2    | 32.8      |

important issues to obtain a reasonable result. Figure 4 is an example of the shape optimization of center shield end in VI. In Fig. 4 as  $E_{ref}$ , the average electric field in optimizing region ( $E_a$ ) and the electric field at the edge of optimizing region ( $E_b$ ) are identified. In the case of choosing  $E_a$  as  $E_{ref}$ , at the outside of optimized region, much higher electric field than optimized electric field exists. On the other hand, by choosing  $E_b$  as  $E_{ref}$ , we could obtain the reasonable optimized shape. From now on, we use  $E_b$  as  $E_{ref}$  in electric field and shape optimization process of Fig. 2.

We applied this optimization technique to the end of center shield in VI with considering the arrangement of grounded tank and the center shield. We carried out the optimization for different length  $L_e$  and radius  $R_s$  of center shield and radius of grounded tank  $G_s$  shown in Fig. 5.

Figures 6 and 7 and Table I show the optimization results for the various center shield configurations. Figures 6(a)-(c) are the optimized shapes of center shield end for the variation of  $L_e$ ,  $R_s$ ,  $G_s$ , respectively, and Figs. 7(a)-(c) show the electric field distributions for each case. Table I is the maximum electric field strength and the floating potential of center shield

in initial and optimized shield end shape for the variation of  $L_e$ ,  $R_s$  and  $G_s$ .

As shown in Fig. 7 and Table I, the initial distribution of electric field and the initial floating potential of the center shield strongly depends upon the parameter  $L_e$ ,  $R_s$ , and  $G_s$ . Nevertheless, for all the variation of  $L_e$ ,  $R_s$  and  $G_s$ , we could obtain the optimization results by using proposed automatic optimization technique. As a result of the optimization, the floating potential of center shield did not change so much, and the maximum electric field strength could be decreased to 70% or less of the initial condition.

## V. CONCLUSION

In this paper, we proposed a new technique for the optimization of electrode configuration with floating potential. We applied this optimization technique to the edge of center shield in VI for various arrangement parameters of center shield and outer grounded tank. Consequently, the maximum electric field strength decreased to 70% of non-optimized shape in our calculation sample. From the results, we could verify the effectiveness of the proposed automatic numerical optimization technique for the improvement of the insulation performance in high voltage vacuum insulated equipment with floating potential electrode.

## REFERENCES

- [1] L.T. Falkingham, "Fifty years of vacuum interrupter development in the UK," 20th Intl. Symp. Discharges and Electr. Insulation in Vacuum, pp. 1–8, 2002.
- [2] H. Fink, and R. Renz, "Future trends in vacuum technology applications," 20th Intl. Symp. Discharges and Electr. Insulation in Vacuum, pp. 25–29, 2002.
- [3] D. Liu, J. Wang, Z. Wang, and P. Gu, "Study on development of 110kV vacuum circuit breaker in China," 20th Intl. Symp. Discharges and Electr. Insulation in Vacuum, pp. 13–17, 2002.
- [4] T. Betz and D. Koenig, "Influence of grading capacitors on the breaking capability of two vacuum circuit-breakers in series," 18th Intl. Symp. Discharges and Electr. Insulation in Vacuum, pp. 679–683, 1998.
- [5] Y. Matsui, et al., "Development and technology of high voltage VCBs; brief history and state of art," 22nd Intl. Symp. Discharges and Electr. Insulation in Vacuum, pp. 253–256, 2006.
- [6] T. Yasuoka, T. Kato, K. Kato, and H. Okubo, "Electrode conditioning mechanism based on prebreakdown current under non-uniform electric field in vacuum," 23rd Intl. Symp. Discharges and Electr. Insulation in Vacuum, pp. 13–16, 2008.
- [7] T. Yasuoka, K. Kato, and H. Okubo, "Electrode conditioning characteristics based on discharge current in vacuum," 15th Intl. Symp. High Voltage Eng., p. 137, 2007.
- [8] S. Kobayashi, M. Kawada, Y. Yamano, and Y. Saito, "Investigation of pulse current occurrence observed for spark conditioning process of ultra high vacuum gap," 23rd Int. Symp. Discharges and Electr. Insulation in Vacuum, pp. 39–42, 2008.
- [9] K. Kato, M. Hikita, N. Hayakawa, Y. Kito, and H. Okubo, "Development of personal-computer-based high efficient technique for electric field optimization," Eur. Trans. Electr. Power, vol. 5, pp. 401–407, 1995.
- [10] K. Kato, S. Kaneko, S. Okabe, and H. Okubo, "Optimization technique for electrical insulation design of vacuum interrupters," IEEE Trans. Dielectrics and Electr. Insulation, vol. 15, pp. 1456–1463, 2008.
- [11] K. Suzuki, K. Kato, H. Kojima, and H. Okubo, "Automatic calculation of optimized electrode configuration in vacuum interrupter," 16th Intl. Symp. High Voltage Eng., B-15, 2009.