

Effects of Insulation Structure on Electric Field Distribution of Valve-Side Outlet Device of Converter Transformer

Mengqing Huang^{1,*}, Yanbing Zhang², Lianguang Liu¹ and Jin Wang³

¹ North China Electrical Power University, Beijing, China

² State Grid DC Project Construction Branch Company, Xicheng District, Beijing, China

³ State Grid Running Branch Company, Xicheng District, Beijing, China

*Corresponding author e-mail: 18810930158@163.com

Abstract. The valve-side outlet device of the converter transformer is one of the key components of the converter transformer. The insulation structure design is the key technology for the design and manufacture of the outlet device. The insulation structure and electric field distribution of the outlet device have great influence on technical performance and safety. Based on the finite element method and ANSYS simulation software, under the AC and DC electric field distributions of the parts of the straight tube-shaped and allotype-shaped insulation structure were simulated, and the influence of the outlet device's operation characteristics and safety under AC and DC electric field was analyzed. The result shows that: 1 Under the AC voltage, the electric field distribution of the valve side outlet device depends on the relative permittivity of the material; the DC voltage depends on the resistivity of the material; 2 the insulation structure has a great influence on the electric field distribution of the outlet device.

1. Introduction

The insulation performance of the valve-side outlet device of the converter transformer affects the safe and stable operation[1]. The outlet device not only has to bear the effect of the AC voltage, but also the DC voltage connected to the valve side[2], so the electric field distribution of the outlet device is quite different from that of the ordinary power transformer. Presently, the valve-side outlet device of $\pm 800\text{kV}$ converter transformer is the key technology for the development of UHV converter transformer. Although in the construction of HVDC transmission project, the domestic production of converter transformer has been realized through the joint design of China and foreign countries and domestic independent manufacturing. However, as a key component of the voltage level of $\pm 600\text{kV}$ or above, the insulation manufacturing technology is still a foreign monopoly, so the outlet device still needs to be imported from abroad.

In order to design the outlet device of $\pm 800\text{kV}$ converter transformer independently, reduce the production and manufacturing cost of commutation, and decrease the technical gap with foreign manufacturers, domestic universities and transformer manufacturers have done some researches in the insulation structure and electric field distribution of $\pm 800\text{kV}$ commutation and output device. The electric field simulation model was established in references [4] to calculate the electric field distribution of the outlet device under AC or DC and polarity reversal voltages. References[10] studied the future



direction of the two mainstream structure outlet devices. Based on the finite element method and ANSYS simulation software, this paper compares the distribution of AC and DC electric field and its influence on the outlet devices of straight tube-shaped and allotype-shaped structures, in order to provide a basis for the design and manufacture of $\pm 800\text{kV}$ value-side outlet device of the converter transformer.

2. Structure of valve-side outlet device

The valve-side outlet device is consisted of oil-paper composite insulation, which is composed of transformer oil, corrugated grid, insulated elbow, cardboard cylinder, pressure equalizing tube and pressure equalizing ball. At present, the outlet devices produced abroad have two types of structures: straight tube-shaped and allotype-shaped. The main body of the former is an ordinary oil-paper sleeve, the capacitor core is directly immersed in the transformer oil, the bottom pressure-receiving ball is a metal electrode for spraying the corona-resistance paint, the multi-layer paper tube is surrounded by the raised seat, and the lead is made of a high-voltage external pressure. The value of the crepe paper technology; the latter is a dry sleeve of epoxy resin impregnated paper, the bottom of the sleeve is a conductive rod, connected to the coil through the lead wire, the oil pressure equalizing ball covers the pulp molded part, and the surrounding of the sleeve is used The profiled part and the paper tube have a multi-layered paper tube on the upper side of the raised seat, and the lead wire adopts the casing insulation technology and the multi-layered insulating member. Both structures are simplified to some extent before simulation calculations, as shown in (a) and (b) of Figure 1.

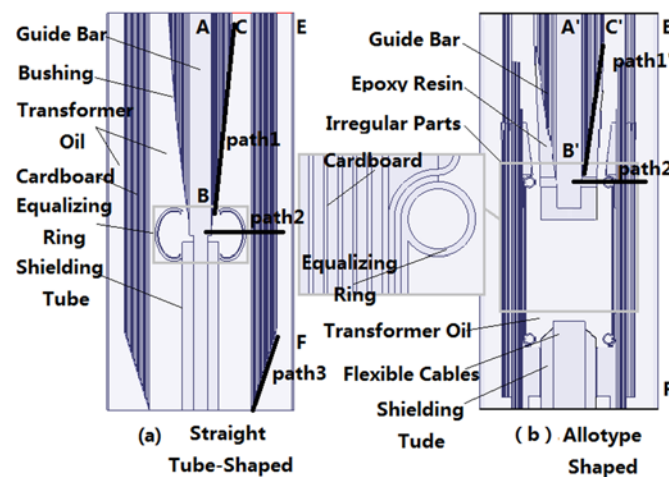


Figure 1. Two kinds of valve-side outlet device

Figure 1 The two outlet devices are multi-layer oil-paper insulation structure. The transformer oil provides basic insulation strength for the outlet device by filling and impregnation. The insulation cardboard cylinder and the struts and corrugated cardboard divide the oil gap into small gaps. The insulating barrier acts as a piezoelectric field and can hinder the formation of "small bridges" of impurities in the oil and improve the electrical strength of the outlet device. The difference in insulation structure between straight tube-shaped and allotype-shaped outlets is mainly reflected in the following three aspects:

1) The insulating partition of the straight tube-shaped outlet device is made of paperboard and corrugated cardboard. The cardboard and corrugated cardboard are arranged in a stepwise manner. The overall shape of the outlet device is similar to that of the straight tube; the allotype-shaped outlet insulating partition is made of the corner. Shaped parts made of materials such as rings and struts. The two outlet devices are named after the characteristics of the insulating characteristic.

2) The straight tube-shaped outlet device uses oil-impregnated cable paper as the inter-electrode insulating medium, and the double-thin aluminum foil is used as the pole plate. The plates are arranged step by step according to a certain regularity, and the tail end of the device is directly immersed in the

transformer oil; the guide rod of the allotype-shaped outlet device is packaged by Epoxy resin as the insulating medium, and the aluminum foil is arranged as a barrier according to a certain step rule. The device is isolated from the transformer oil.

3) The equalizing ball of the straight tube-shaped outlet device is tightly wrapped around the tail end of the sleeve; the equalizing ball of the profiled outlet device is covered by the pulp molded part, at the end of the sleeve and the exit of the paper tube are closely connected with the paper tubes of the raised seat.

3. Calculation model

3.1. Basic structure and material properties

Since the two-dimensional model of the two outlet devices in Figure 1 has axis symmetry, the simulation calculation model takes half of the model, then analyzes its possible effects[12]. Different measurement paths are taken for the two devices (the directions are from left to right).), as shown in Figure 1(a), path1 (along the end of the casing), path2 (through the equalizing ball from the guide to the outside of the baffle), path3 (the end of the baffle) and Figure 1(b) path1' (The end of the casing), path2' (through the molded part from the guide to the outside of the partition) is shown.

The insulation of the outlet device is composed of a variety of materials. The resistivity and relative permittivity of these materials are related to the electric field strength. To compare the effects of the two structures on the electric field distribution of the outlet device under AC or DC voltage, two types of outlets are assumed. The material properties and parameters of the device are the same. The parameters of the main materials of the outlet device at room temperature are shown in Table 1.

Table 1. Material parameter of value-side outlet device

materials	Relative permittivity	Conductivity(S/m)
air	1	1×10^{-20}
transformer oil	2.2	5×10^{-13}
epoxy resin	4.5	1×10^{-12}
aluminum	2000	3.5×10^7
copper	2000	5.7×10^7
cardboard	3.5	1×10^{-14}
corrugated cardboard	3	1×10^{-14}
equalizing ring	15.5	2×10^{-10}

3.2. Boundary conditions

The outlet device includes a plurality of portions such as a casing, a partition, a pressure equalizing ball, and a shielding tube, and a predetermined voltage is applied to the known boundary in the electric field calculation. The voltage boundary conditions that need to be applied in this paper are as followings:

1) The outerrmost capacitor core (C, C') of the casing and the outermost tank wall (EF, E'F') of the outlet device are set to zero potential, which is the first type of homogeneous boundary condition;

2) The guide rod of the bushing and the lead wire (AB, A'B') are the fluid guiding bodies, and the electrical conductivity is high, so the high voltage is directly applied to the whole, which conforms to the homogeneous boundary condition;

3)Other than the capacitance screen of the innermost layer and the outermost metal part of the capacitor core, remaining capacitance screen is set to a floating potential, and the potentials of the capacitor screens are equal and the size is unknown;

4) Computational model taked component is part of the device, and its upper and lower (AE, BF, A'E', B'F') are set to the second type of homogeneous boundary conditions to meet the characteristics of limited computer resources. In summary, the field boundary conditions are followings.

$$\begin{cases} \varphi_C = \varphi_{C'} = \varphi_{EF} = \varphi_{E'F'} = 0; \\ \varphi_{AB} = \varphi_{A'B'} = U; \\ \partial\varphi_{AE} / \partial n = \partial\varphi_{BF} / \partial n = 0; \\ \partial\varphi_{A'E'} / \partial n = \partial\varphi_{B'F'} / \partial n = 0. \end{cases} \quad (\text{formula 1})$$

Below formula: φ , U is the potential, $\partial\varphi / \partial n$ is the normal differential.

3.3. Voltage excitation

The outlet device is subjected to the impact of the AC and DC voltage shocking at the same time. between them, the rated AC voltage can take the design value of the valve side winding of the converter transformer; the DC voltage is considered to be greatly affected by the large number of harmonics of the converter due to the converter, so the rated DC voltage is the rated DC voltage of the converter. The safety margin of 1.15 times the design value.

Table 2. Voltage value of simulation calculation

parameter	voltage/kV
AC	909
DC	1254

4. Calculation and analysis of electric field distribution

4.1. Results and analysis under AC electric field

Figure 2 is a diagram showing the electric field distribution of the outlet device under the alternating field. Fig. 2(a) The electric field strength of the casing of the straight tube-shaped outlet device decreases along path1 and the maximum electric field strength appears in the first layer of the casing oil gap, the value is 27.83kV/mm, and the maximum field strength of path2 near the pressure equalization ball appears in the pressure equalization. In the spherical surface oil, the value is 14.58kV/mm, the tail end of the separator decreases along path3, and the maximum electric field strength appears in the oil near the second layer of cardboard, which is 0.37kV/mm; Figure 2(b) allotype-shaped outlet device cover The electric field strength decreases along path1', and the maximum value is 28.19kV/m. The maximum field strength of path2' near the equalizing ring appears in the oil of the pressure equalizing ring surface, which is 7.45kV/mm. (a) The field strength near the medium average pressure ball is larger than that of (b), but the field strength distribution in the casing is evenner than the latter.

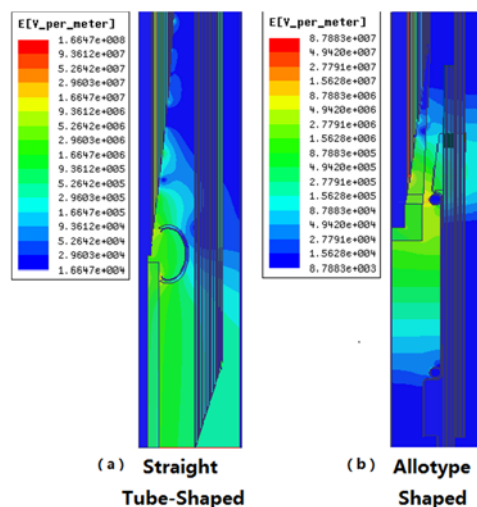
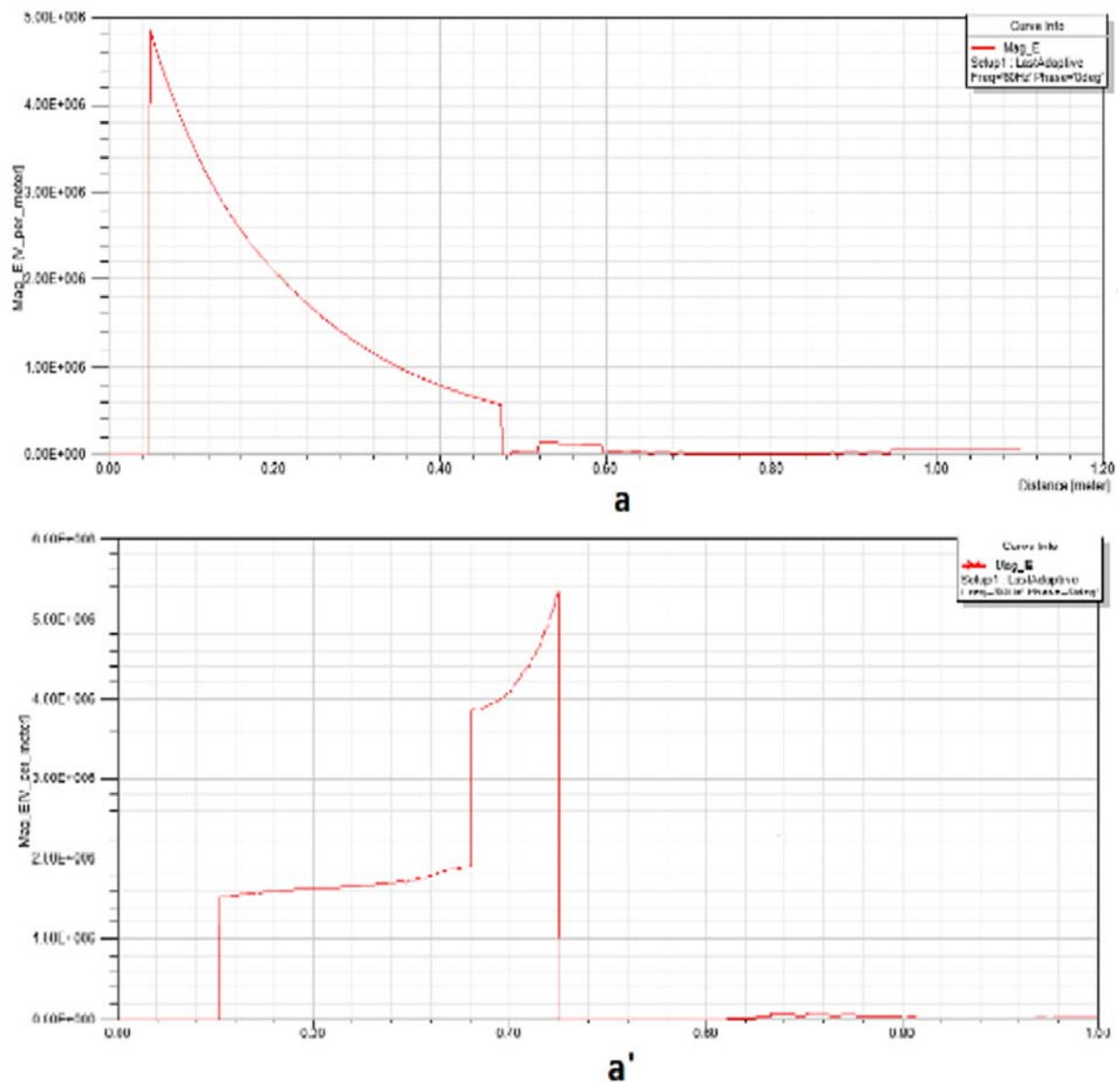


Figure 2. Cloud of electric field distribution under AC voltage

Figure 3 shows the electric field distribution curves of path2 and path2' in the AC field. Figure 3 (a) path2 guide rod - pressure equalizing ball - diaphragm in the transformer oil field strongest, Figure 3 (b) path2 (separator) field strength first decreased and then increased, and the oil field electric field strength ratio The electric field strength of the cardboard is large; as can be seen from Fig. 3(a'), the path2' guide-equalizing ball-separator has the largest and gradually increasing field strength in the transformer; the path2' (separator) field strength gradually decreases. And the electric field strength of the oil passage is larger than the electric field strength of the cardboard.



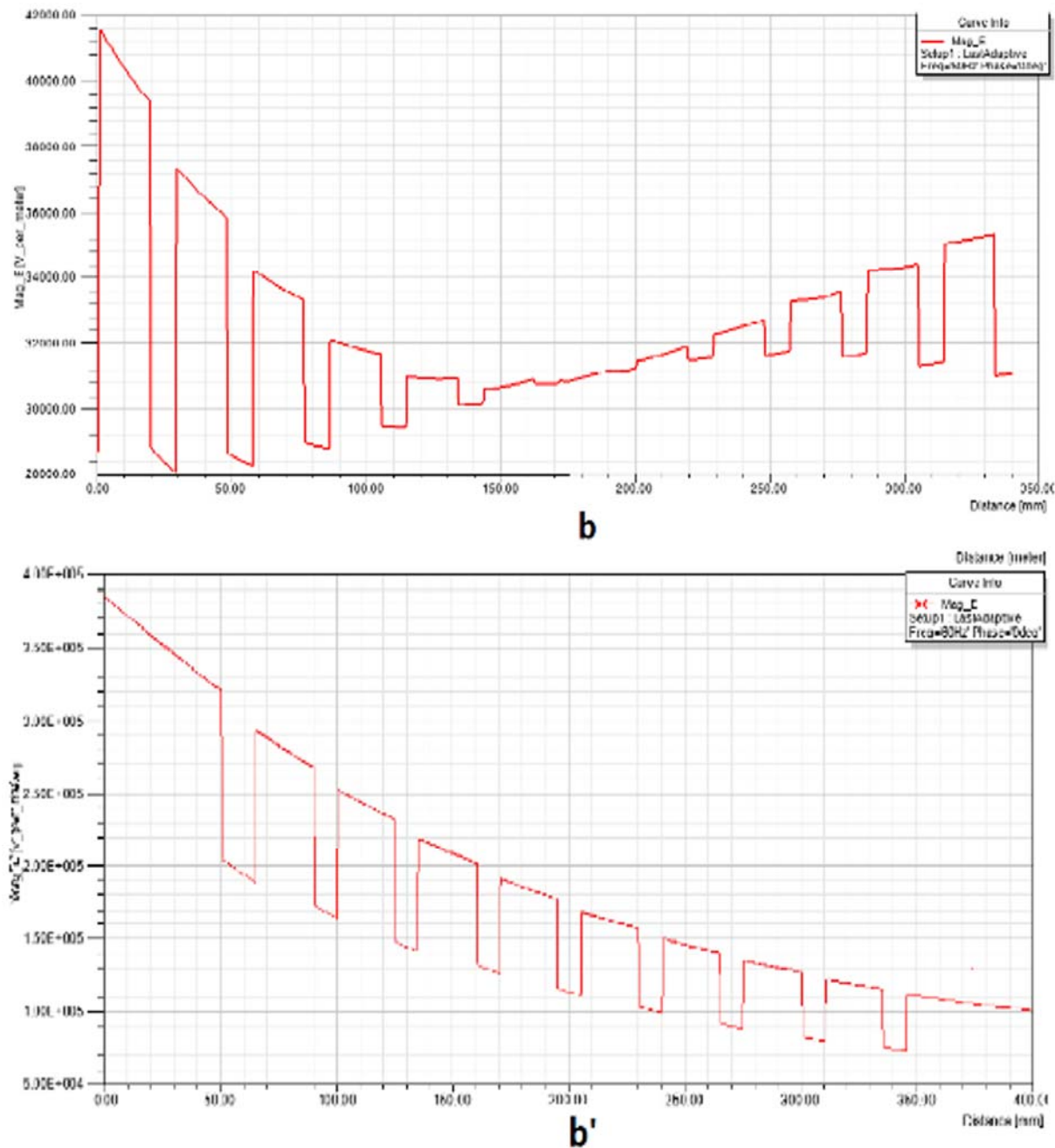


Figure 3. Electric field distribution of each path under AC voltage

It can be seen that under the AC voltage, the electric field distribution of the outlet device is mainly concentrated in the casing and is close to the guide rod portion. This is because in the AC field, the bound charge is generated on the surface of the medium, and the charge distribution directly determines the distribution of the electric field in the medium. Each medium is equivalent to a capacitor. The size of the capacitor is proportional to the relative dielectric constant. The capacitor is divided in series to make the material with a smaller dielectric constant smaller. Similarly, transformer oils with a relatively low dielectric constant will carry more pressure between the casing and the separator and in the separator than in other materials in path2 and path2'.

4.2. Results and analysis under DC electric field

Figure 4 shows the electric field distribution of the outlet device under the DC field. Fig. 4(a) The straight tube-shaped outlet device casing increases in electric field strength along path1 and has a maximum value at the outermost layer of the oil gap, which is 30.94 kV/mm. The maximum field strength of path2 near the equalization ball appears in the surface insulation of the equalizing ball. The maximum value is 12.76kV/mm, the path3 at the end of the separator is decreasing and the maximum electric field strength is 0.30kV/mm. It appears in the oil near the second layer of cardboard; Figure 4(b) The electric field strength path1' of the shaped outlet device casing is increasing, The maximum electric field strength appears in the first layer of the oil gap, the maximum value is 12.03kV/mm, and the maximum field strength of path2' near the equalizing ring appears in the surface insulation of the equalizing ring, and the maximum value is 6.39kV/mm. The electric field strength of the profiled outlet device in the vicinity of the casing and the equalizing ball is relatively small compared to the straight wire outlet device.

Figure 5 Electric field distribution of each path under the DC field. Figure 5 (a) path2 guide rod - pressure equalizing ball - partition in the transformer oil field strength maximum and gradually reduce; Figure 5 (b) path2 (separator) field strength is slowly reduced, and the oil field electric field strength The electric field strength of the paperboard is smaller than that of the paperboard; Figure 5 (a') path2' guide rod-pressure ball-separator has the largest and gradually increasing field strength in the transformer; Figure 5 (b') path2' (separator) oil channel The electric field strength is smaller than the electric field strength of the cardboard.

Under DC voltage, the electric field of the outlet device is still mainly concentrated in the casing, and the outermost layer is the largest. Under the DC voltage, the potential of the outlet device is distributed according to the resistivity of each material, and the high resistivity is high. Epoxy resin and paperboard have lower conductivity (higher resistivity), so both the path2 and path2' oil-paper insulation board and epoxy resin will have more partial pressure than other media.

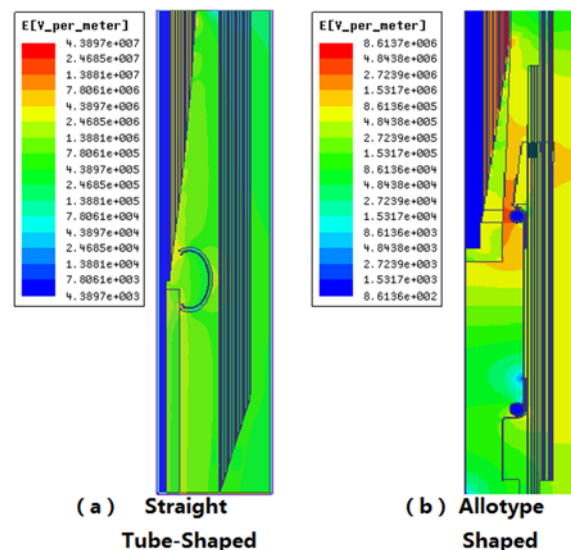


Figure 4. Cloud of electric field distribution under DC voltage

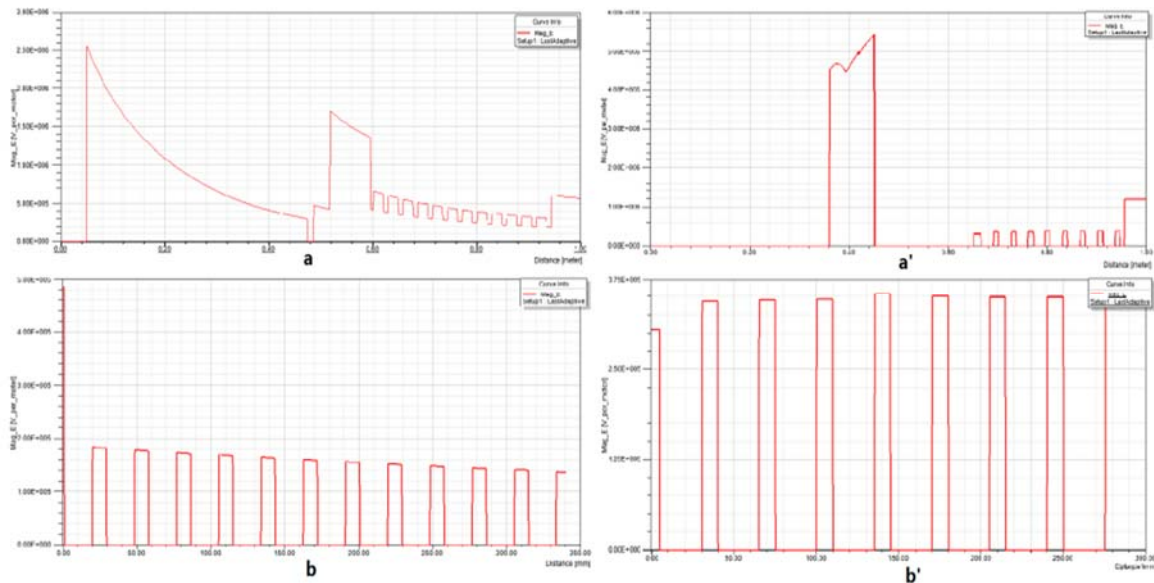


Figure 5. Electric field distribution of each path under DC voltage

5. Conclusion

Based on the finite element method and ANSYS software, the influence of the insulation structure on the electric field distribution of the valve-side outlet device of $\pm 800\text{kV}$ converter transformer under AC or DC voltage is calculated. The following conclusions are obtained:

(1) Under AC voltage, the electric field distribution of the two devices is mainly inversely proportional to the relative permittivity of the material, and the pressure in the transformer oil is relatively large; under DC voltage, the electric field distribution of the device is mainly proportional to the resistivity of the material. (Inversely proportional to conductivity), materials with high resistivity have more pressure.

(2) The casing type of the two devices is different, which has a certain influence on the electric field distribution at the end of the casing. The epoxy resin can relieve the voltage drastic changes to a certain extent, and must pay attention to the end discharge during the design. The equalization ball molding is more effective in equalizing the pressure equalization separately.

(3) In the insulation structure, the straight tube-shaped outlet device has a simple manufacturing processing and a convenient assembly compared to the allotype-shaped outlet device; in terms of electrical insulation, the allotype-shaped outlet device is more likely to meet the design requirements.

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