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Simulation of Electric Field Distribution in Intermediate Cold-Shrink Joints of 110kV Cables

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Abstract: With the development of the city, the city network cable rate gradually increased, power cables in the transmission and distribution network in the status of the rising, how to ensure the stable operation of the cable has become a growing concern of the subject. In order to ensure the safe and stable operation of the cable, in its design and manufacture before the need to understand its electric field distribution between the head, so as to better ensure the stable operation of the cable. This paper is based on ANSYS software to build the calculation model of the electric field of cable intermediate joints. Systematically on the cold shrink type intermediate joint for stress cone control occasions under the electric field numerical simulation. The specific simulation process includes geometric configuration, area division, mesh division, boundary assignment, driving calculation and solving the electric field poles. The results of the simulation show that the cold shrinkable cable joints have a good effect of electric field stress evacuation and a good effect on the improvement of the electric field.

1. Introduction

1.1 The significance of calculating electric field distribution in 110kV cable intermediate joints

Cable terminal in electric power, metallurgy, petrochemical, airports, railways, ports and civil construction and industry and other fields are widely used.[1-2] Therefore, this paper carries out the actual high-voltage cable testing, the choice of ANSYS software, constructed a middle joint electric field calculation model, systematic heat shrinkage, cold shrinkage type middle joints for stress tube control and stress cone control two occasions under the electric field numerical simulation. Which structure form is favourable to the improvement of electric field distribution can be analysed, and the conditions or parameters that need to be improved can also be determined.[3-4]

1.2 Research status of cable joints at home and abroad

Foreign cable accessories manufacturing companies such as the United States Tyco, the United States 3M, Switzerland, Nexans, France, Alcatel and Germany, F & G, etc. in the product design have used the electric field simulation technology, the domestic manufacturers have not yet been fully realised in this regard, the relevant universities and research institutes are the medium-voltage level of 10kV and 35kV cable joints as well as ultra-high-voltage level of cable joints the electric field distribution calculation as the focus of the research work is only a preliminary exploration of the high-voltage level of 110kV cable joints. The related universities and research institutes also focus on the electric field distribution calculation of medium-voltage grade 10kV and 35kV cable joints and ultra-high-voltage grade cable joints, while the research on high-voltage grade 110kV cable joints is only a preliminary exploration. The design, manufacture and application of AC cable joints in China are relatively mature, but the simulation research on the electric field distribution calculation of 110kV cable joints, including the optimisation of structural design, has not been carried out in depth and extensively.

1.3 Key points of the research

Determining whether the driving function relationship between voltage and electric field strength can match the actual situation of cable intermediate joints is a difficult task in electric field simulation. At the same time, the finite element numerical simulation of the electric field in ANSYS environment is carried out to plot the potential contour map of the electric field, and the meshing of the electrode components in this process is a key point depending on the accuracy of the simulation.

2. Finite element theoretical basis for electric field distribution in cable intermediate joints

2.1 Principles and basic ideas of electric field distribution calculation

There are various methods for numerical analysis of electric fields, such as finite difference method, finite element method and simulated charge method. Since the finite element method to solve the electromagnetic field in the multilayer medium is not subject to the limitations of the shape of the field boundary, and the boundary conditions of the second type, the third type and the interface of the different media separation can be automatically satisfied, without having to make a separate treatment, so it is more appropriate to use the finite element method to solve the electric field distribution. In this paper, the finite element method is used to calculate the electric field distribution in the middle joint.

The basic principle of the finite method is to divide the region of the solution into a number of small regions, these small regions become units or finite elements, in these small regions on the solution becomes relatively simple, only some algebraic operations, such as the application of linear interpolation in a small region to get the value of the unknown point, and then the sum of the results of the various small regions to get the solution of the whole region. For crosslinked intermediate joints intermediate joints, the distance between any two points in the radial direction of the field under study is much smaller than the wavelength of the industrial frequency electromagnetic wave in the medium.

So, the electric field in the region of the middle joint of the power cable is a slow-variable electric field or seemingly stable field, the distribution of the field is basically suitable for the distribution of electrostatic field law. In the conductive core outside the insulation layer and the air medium, the volume charge is zero (ignoring the medium polarisation effect), so the distribution of potential in the field to meet the Laplace equation. Electromagnetic field calculation problem, that is, the problem of solving the Laplace equation. And solving Laplace's partial differential equation can be transformed into a system of algebraic equations by the finite element method, and then combined with boundary conditions to solve. In solving the boundary value problem, finite element and finite difference methods are used, which are practically the same and are based on the variational principle and tangential interpolation. The partial differential equations are expressed in terms of differences and transformed into algebraic equations and based on this the boundary conditions are substituted to solve the unique solution of Laplace's equation which is called the boundary value problem and it is transformed into a set of multivariate algebraic equations and it is solved to get the desired parameters.

2.2 Application of Laplace partial differential equations to the electric field of cable intermediate joints

The cable is cylindrical, the conductor can be viewed as a shaft that generates a continuous charge, and its metal shield can be viewed as a circular closed electrode plate, which together form a cylindrical electric field. The cable can be regarded as an axially symmetric electric field in electromagnetic field analysis, in which the insulating medium has no free charge, i.e., ρ = 0. The cylindrical coordinate system is selected, and the boundary of the field is a hybrid boundary, i.e., it consists of chi-square natural boundary conditions and the first type of boundary conditions together. Based on the Laplace equation of classical electromagnetism:

$$\nabla^2\varphi = (1/r)\partial(r\partial\varphi/\partial r)/\partial r + \partial^2\varphi/\partial z^2 = 0 \quad (1)$$

When depicting the contour, it is necessary to obtain the spatial function corresponding to the contour. Interpolation is generally used to find an approximate solution to the function.

Set the need for linear interpolation method to draw the potential of Φ1 isobologram, if (Φ1-Φi) × (Φ1-Φj) <0 means that Φ1 value between Φi and Φj value, and then you can use linear interpolation formula to find out the potential is equal to Φ1 value of the spatial coordinates. Let the coordinates of node i for xi and yi, node j coordinates for xj and yj, potential for Φ1 value of the interpolation point to be sought for the spatial coordinates are x and y, then the above linear interpolation formula can be synthesised as:

$$T=(\Phi_i-\Phi_1)/(\Phi_i-\Phi_j) \quad (2)$$

$$x=(1-T)\,x_i + Tx_j \quad (3)$$

$$y=(1-T)\,y_i + Ty_j \quad (4)$$

So the interpolation point connection, you can draw the potential of Φ1 isobars. Similarly, you can find the equilibrium of the electric field to be sought.

Since the design of a cable accessory device requires the need to know the distribution of its electric field strength, we need to calculate the electric field strength in the relevant field.

The potential Φ1 respectively on x and y for the derivatives, you can get the electric field strength along the x-axis direction and the y-axis direction of the electric field strength component values, respectively, Ex and Ey, and then find the Ex and Ey, take its arithmetic mean, that is:

$$Ex=(\Sigma Exi)/n(i=0,\ldots,1) \quad (5)$$

$$Ey=(\Sigma Eyi)/n(i=0,\ldots,1) \quad (6)$$

If we agree that Ex and Ey are equal, then E = 1.414Ex = 1.414Ey.

2.3 Finite element solution of electric field in ANSYS

The electric field solving functionality of ANSYS does not contradict the Laplace equation; it is the solution of the Laplace operator in the generalised domain, solidified in a module for electromagnetic analysis, with the principle of generality. Electric field analysis involves many engineering problems, so the applicability of meshing and the determination of boundary conditions are very important.[5]

ANSYS solves the electric field mainly by using the fact that the vector sum of the electric flux across the positive and negative interfaces of the passive confined space is zero [6], whereas the intermediate joints of the cable are considered as a kind of insulated ends wrapped by different media, and the current excited at each interface is the same, independently of the dimensions of the space. In a non-uniform medium, the electric field strength varies due to the geometry of the two interfaces and the different parameters of the medium. Engineering then uses the potential shift vector to replace the electric flux to describe the real process closer to the electric field. Since $D = \varepsilon\gamma E$, it follows that

$$D_1=D_2=\cdots=D_n \tag{7}$$

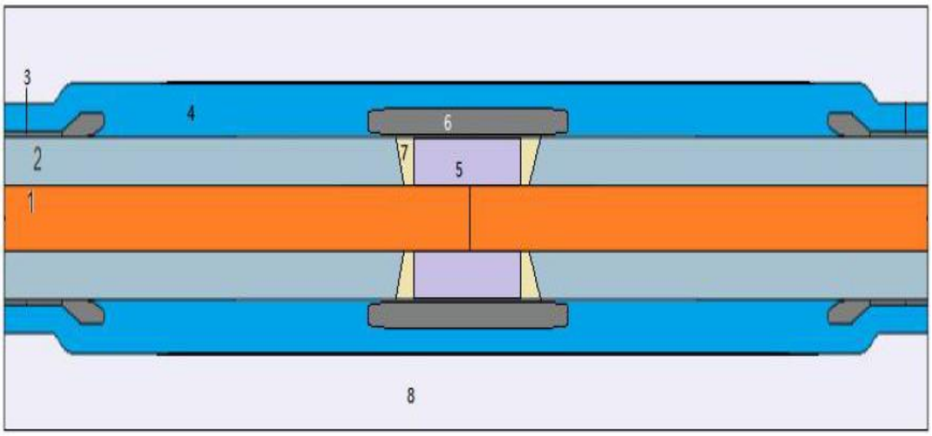
$$\varepsilon_{\gamma 1} E_1= \varepsilon_{\gamma 2} E_2 =\cdots=\varepsilon_{\gamma n} E_n \tag{8}$$

n is the number of dielectric layers. The geometrical parameters of the different layers and the insulating parameters of the material as well as the relative dielectric constant εγ will be involved in the calculation.

3. Simulation preparation based on ANSYS cable intermediate cold shrink joint electric field distribution calculation

3.1 Intermediate cable gland construction area division

In order to more importantly improve the degree of accuracy, it is necessary to divide the area guided by the objective reality, and this division is based on the principle of the same or similar function, and also at the same time to provide support for the subsequent mesh generation and boundary assignment, as shown in Figure 1 and Table 1 [7].



1- Metal conductor 2-Cable body insulation 3-Zero potential electrode 4-Silicone rubber insulation 5-Connection tube 6-Inner shield tube 7-Filler insulation 8-Air

Figure 1: Delineation of the core area of the cable intermediate joint stress cone control electric field

Table 1: Functionality of the division of the stress cone calculation area

region code	regional function	Voltage assignment/kV	εγ assign
1	High Voltage Drive	64	100
2	Cable insulation	calculate	2.5
3	Shield ground zero potential	0	--
4	Stress Cone Silicone Rubber	calculate	2.8

	Insulation		
5	metal connection tube	calculate	2.7
6	inner shielding tube	64	4.1
7	Insulation Genius Material	calculate	3.0
8	Air-insulated balloon domains	calculate	1.0

3.2 Grid division

After the computational model is built, the model is meshed. Firstly, the cell type of the infinite air region should be defined as a balloon region and the dielectric constant is 1. Different parts of the model and different types of regions do not necessarily have the same meshing method and accuracy. Here on the infinite air open area is selected is mapping mesh delineation method for its mesh division; cable model irregularity, so the other areas of free grid dissection is more appropriate. Take cold shrinkage as an example, see Figure 2 after the specific grid division guide.

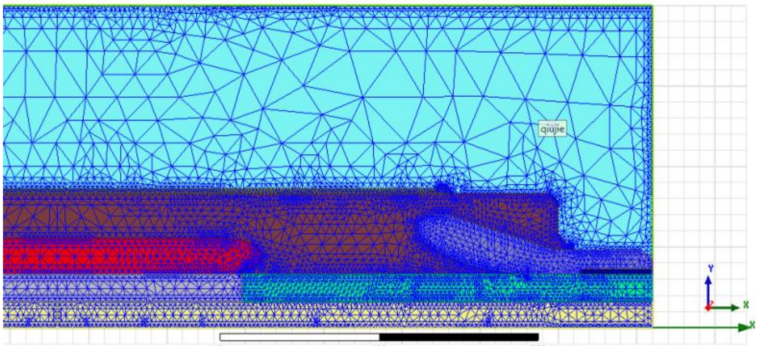


Figure 2: Schematic diagram of ANSYS mesh division guidance for cable intermediate joints

After the mesh division is completed, the potential can be applied according to the actual situation of the cable, 110kV voltage is applied to the line core, the inner shielding tube and the connecting tube under the inner shielding tube; 0kV voltage is applied to the copper shielding layer; 0kV voltage is applied to the upper boundary as the balloon boundary, which can be equated to an infinite air-open area. From the electric field distribution diagram in Figure 3, it can be seen that after disconnecting the stripped cable, there will be a very serious concentration of electric field, which is prone to breakdown and other accidents. Its simulation results also indicate that the cable intermediate joints without stress control measures, the electric field distortion is serious, more likely to be punctured, but also confirms the objective engineering of the cable joints without stress control when the natural joints run for a short period of time, so many in the prevention of the test is punctured.

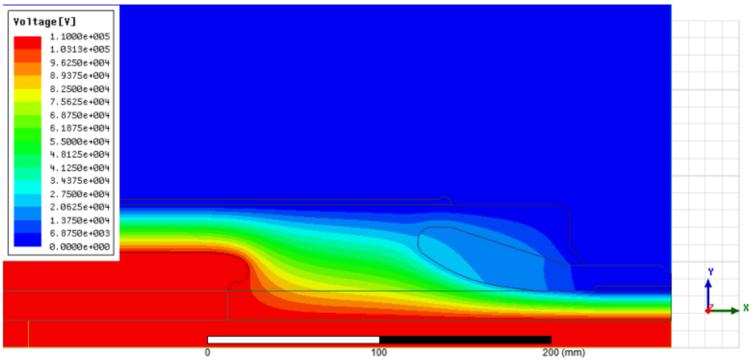


Figure 3: 110kv voltage cloud diagram

4. 4.110kV cable cold shrinkable intermediate joint type model

4.1 Effect of the radius of curvature of a cold shrinkage stress cone on the electric field

The radius of curvature of the inner surface of the shrinkage stress cone has an effect on the extreme value of the electric field because of its structure, and the radius of curvature is chosen to be 94 mm (Figure 4), 110 mm (Figure 5) and 118 mm (Figure 6) respectively. The simulation diagram of the electric field of the stress cone is as follows

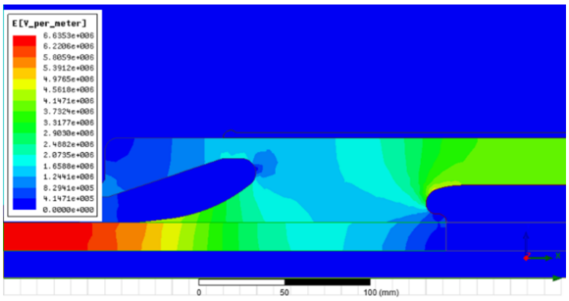


Figure 4: Simulation of the electric field for a curve radius of 94mm

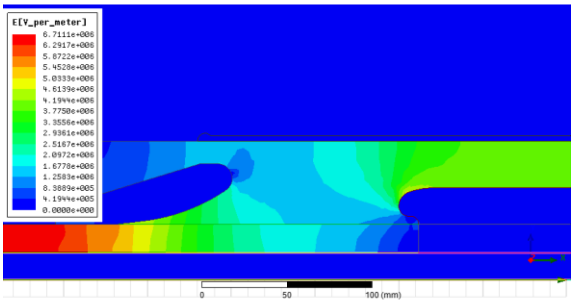


Figure 5: Simulation of the electric field for a curvature radius of 110mm

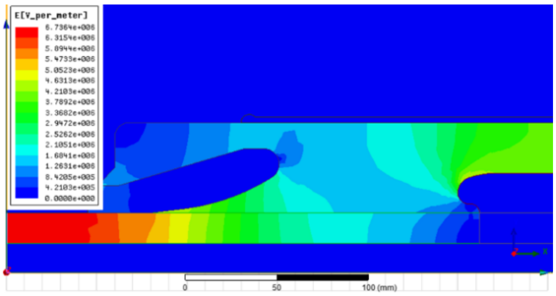


Figure 6: Simulation of the electric field for a curve radius of 118 mm

The effect of the radius of curvature of the inner surface of the stress cone of R=118mm (electric field pole value 6736V/mm) is better than the effect of R=110mm (electric field pole value 6711V/mm) and even better than the effect of R=94mm (electric field pole value 6635V/mm). The larger radius of curvature corresponds to the weakening of the sharpness of the electric field between the stress cone and the end of the inner shielding tube of the intermediate connector, which has an improved effect on the distribution of the electric field, but the large radius of curvature leads to the thickening of the waist of the conductive stress cone, which makes it difficult to expand the intermediate intermediate connector header body.

4.2 Position of the condensation stress cone for electric field effects

For a more intuitive view of the electric field poles and and stress concentration areas, the simulation of the effect of the change in the length of the stress tube on the electric field poles is Figure 7-10 as follows

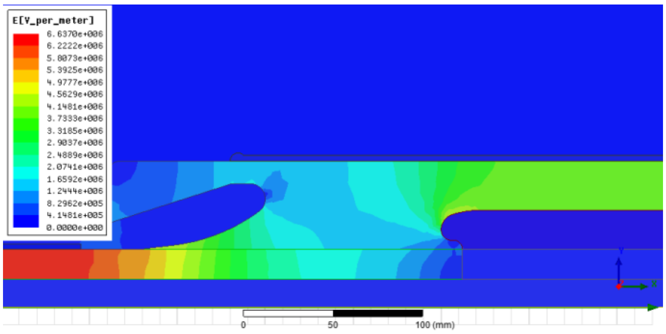


Figure 7: Original position of the stress cone

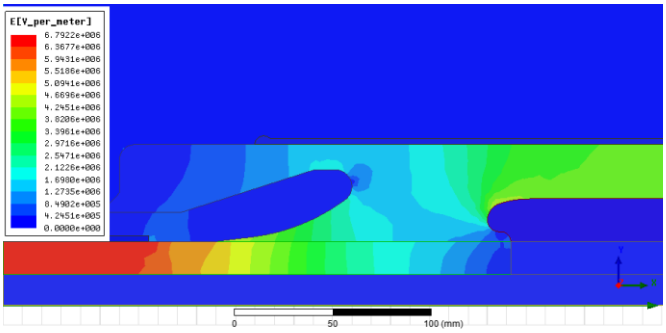


Figure 8: Stress cone moved forward 10 mm

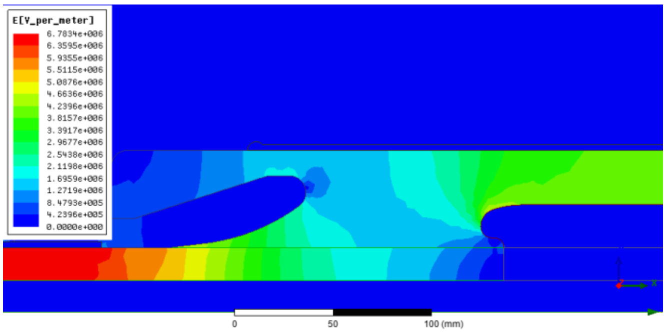


Figure 9: Stress cone moved forward 20 mm

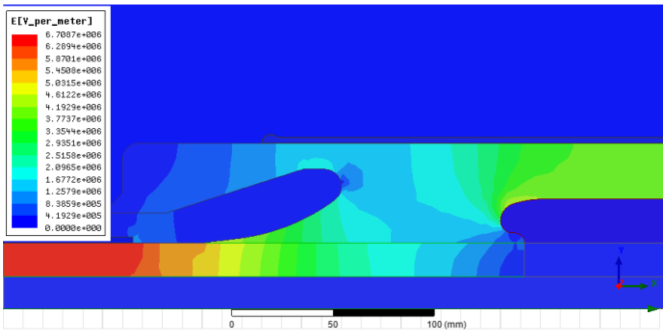


Figure 10: Stress cone moved forward 30 mm

It can be seen that the position of the stress cone moves forward and has an effect on the distortion of the electric field. In fact, the stress cone before and after the movement of the electric field on this end of the impact is not great, but on the other end of the impact is relatively large, may cause the middle of the cold shrinkage and the outer semi-conductor layer of the cable out. Therefore, when the actual installation of the stress cone should be placed in the appropriate position, otherwise it will lead to the damage of this part of the cable intermediate joint.

5. Conclusion

The electric field simulation work carried out in ANSYS environment: the results show that the improvement effect of the cold shrink stress cone on the electric field is better than that of the free intermediate joints without stress control; verification experiments are carried out through the cold shrink intermediate joints of cables in combination with the parameter conditions of the simulation results, and the results are confirmed by the simulation results; due to the reason of time and the issue of the degree of mastery of ANSYS, a lot of simulations on the intermediate joints of the cables have not yet been done, for example, the change of the thickness of the stress tubes, change of the mounting location of the stress tubes, change of the height of the cold shrink stress cones, and change of the angle of the flare mouths of the stress cones, and so on.

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