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Effect of Contamination on Electric Field Distribution of DC Voltage Divider

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Abstract

In order to research the influence of the contamination around the external insulating surface of DC voltage divider with different types in the electic field distribution by using the finite element method, a two dimensional axisymmetric model of the DC voltage divider in Longquan convertor station is built. Through the calculation comparison in electrostatic and quasi-electrostatic field, the relative dielectric constant of the dry, moist and the non-uniform mixed contamination layer is discussed under the condition of the material parameters is known in quasi-electrostatic field. Analysis shows that for dry contamination, the field type has no influence on the electric field distribution when the parameters of the materials are same. While for moist contamination, the relative dielectric constant in electrostatic field should be set according to the material resistivity in quasi-electrostatic field and the actual condition. The calculation of the non-uniform contamination prove that the materials parameters in electrostatic filed is reasonable.

Keywords*: DC voltage divsider, contamination, electrostatic field, quasi-electrostatic field*

1. Introduction

As one of the important device in DC converter station, the insulation design of DC voltage divider is extremely important. In case of bad weather, the insulation performance of DC voltage divider with serve contamination will significantly reduced, which will result in pollution flashover accident. During 2004 and 2009, pollution flashover accidents of DC voltage divider occurred in sequence in Jiangling, Tiansheng Qiao and Longquan converter station, and have caused serious consequences [1]. Therefore, the study of surface electric field distribution of DC voltage divider with contamination is very necessary.

Correspondingly, the study on surface electric field distribution of DC voltage divider with contamination at home and abroad up to now is rare. While many scholars had studied electric field distribution around polluted insulators, which had achieved fruitful results, and accumulated a lot of experience. The numerical computation methods of electric field distribution of AC polluted insulators has been relatively maturity, including finite difference method [2, 3], finite element method [4-6], charge simulation method [7] and boundary element method [8-10], while a lot of research on DC polluted insulators were based on measurement of potential distribution, experimental results had shown that potential distribution of DC polluted insulators depend on contamination composition and distribution [11]. Research on electric field distribution is extremely limited, and electric field distribution of DC insulators under uniformity and non-uniformity contamination was calculated in [12] and [13], the conclusion that existence of contamination on the insulators result in local extremums of electric field was proposed, while the influence of contamination on electric field distribution around polluted insulators and numerical simulation of contamination were rarely discussed [14-20].

In the case of moist contamination, there was leakage current in semiconductor contamination layer outside DC voltage divider, and the calculation of electric field distribution can not be simplified as an electrostatic problem. While according to the relation between electrostatic and quasi-electrostatic problem, it can be approximated by electrostatic field analysis method. A 2D axis-symmetric finite element model of DC voltage divider in consideration of uniformity contamination was built in the paper. By contrasting the calculation results of quasi-electrostatic and electrostatic field, parameters of contamination in electrostatic

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field were confirmed. Then, the influence of three different kinds of contamination on electric field distribution was discussed in the paper.

2. Research Method

As the major parameters of DC voltage divider and contamination in electrostatic field calculation were dielectric constant, leakage current in contamination layer can not be calculated. After introducing of conductivity in quasi-electrostatic field, its influence on electric field distribution is considered.

In quasi-electrostatic field, oulombian field $\boldsymbol{E_c}$ is much greater than induced electric field $\boldsymbol{E_i}$, which means that $\boldsymbol{E_i}$ can be neglected. The total electric field is irrotational, and satisfies:

$$\nabla \times E = \nabla \times (E_c + E_i) = \nabla \times E_c \approx 0 \tag{1}$$

Therefore, the differential forms of Maxwell's equations for quasi-electrostatic field are:

$$\begin{cases} \nabla \times E = 0 \\ \nabla \times H = J + \dfrac{\partial D}{\partial t} \\ \nabla \cdot D = \rho \\ \nabla \cdot B = 0 \end{cases} \tag{2}$$

Where, $\boldsymbol{E}$ is electric field intensity, $\boldsymbol{H}$ magnetic field intensity, $\boldsymbol{B}$ magnetic flux density, $\boldsymbol{J}$ electric current density, ρ electric density. The relationships between different parameters are:

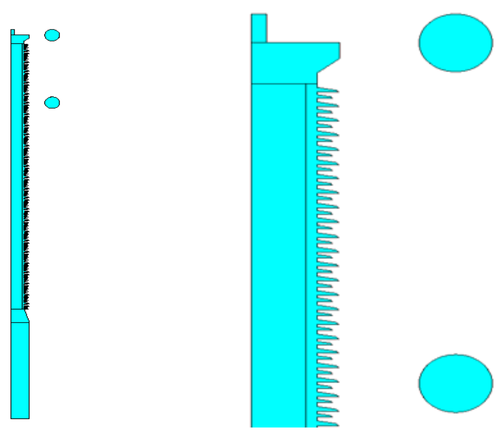
$$\begin{cases} D = \varepsilon E \\ B = \mu H \\ J = \sigma E \end{cases} \tag{3}$$

In which, ε is dielectric constant, μ permeability, σ conductivity. For isotropic medium, these parameters are scalar, corresponding to tensor for anisotropic medium.

Therefore, the electric field equations in quasi-electrostatic field are the same for electrostatic field, and making use of additional magnetic field equations, electric and magnetic field equations are decoupled.

3. Calculation Model

3.1. DC Voltage Divider



(a) Whole model (b) Local model

Figure 1. The Model of DC Voltage Divider

In this paper, a 2D axis-symmetric finite element model of DC voltage divider in Longquan converter station is introduced, as displayed in Figure 1. The main parameters of DC voltage divider are as follows. The total height of voltage divider is 5.060m, and the composite bushing consists of 93 big and 92 small insulator umbrella skirts, correspondingly diameters are 573mm and 533mm. The external diameter of grading ring is 1.340m, internal diameter 124mm, and the centre distance of two grading ring is 1.4m.

Due to the actual installation location, foundation of DC voltage divider is also built in the model, with its potential set to be zero in calculation.

3.2. Contamination Model

The uniformity contamination of DC voltage divider in finite element model is approximated by a thin layer on the surface of insulator umbrella skirts, whose thickness is 1mm, as displayed in Figure 2.

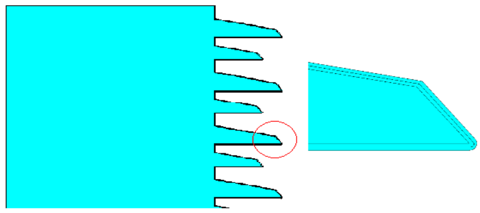


Figure 2. Contamination of the DC Voltage Divider

To ensure that contamination consists of at least two tier grids after discretization, contamination layer is partitioned to be two layers with same thickness. At the same time, the junctions of contamination layers are curved, so as to reduce the influence of model on the calculation results.

3.3. Parameters of Materials

In finite element analysis, potential distribution depends on relative dielectric constant of materials in electrostatic field, while in quasi-electrostatic field, it is codetermined by relative dielectric constant and resistivity. Making use of the previous research in [14], the parameters of materials in quasi-electrostatic field is shown in Table 1. The feature of different contamination is characterization by different parameter, and the thickness of contamination remains unchanged during calculation.

Table 1. Parameters of Materials in Quasi-electrostatic Field

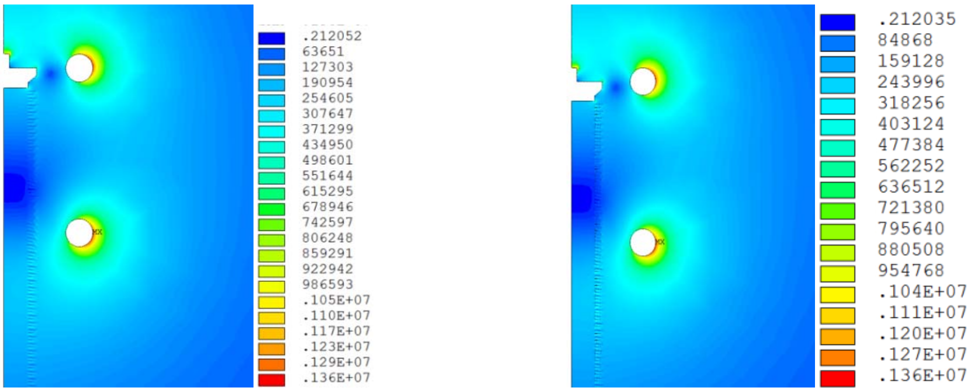
Material	Relative Permittivity	Resistivity
Air	1	10^{15}
Insulation	3.5	10^{12}
Dry contamination	2.8	10^{10}
Moist contamination	20	0.9754

4. Finite Element Analysis

In order to get the appropriate parameters that represent different contamination in electrostatic field, the potential and electric field distribution are compared with quasi-electrostatic field by finite element analysis method. Three different kinds of contamination, dry, moist and mixed are discussed in the paper.

4.1. Dry Contamination

For dry contamination, leakage current on the surface of DC voltage is so small that can be neglected because of its high resistivity. Therefore, the potential distribution still depends mostly on relative dielectric constant in quasi-electrostatic field. According to Table 1, relative dielectric of dry contamination is set to be 2.8 in electrostatic field. The electric field distribution results in quasi-electrostatic and electrostatic field are displayed in Figure 3.



(a) Electrostatic (b) Quasi-electrostatic

Figure 3. Electrical Field Distributions Results in Electrostatic Field and Quasi-electrostatic Field

The calculation results indicate that for dry contamination with a high resistivity, electric field distribution in quasi-electrostatic field is consistent with electrostatic field for same relative dielectric constant. The maximum electric field intensity are 13.6kV/cm, appears at the right surface of lower grading ring.

The electric field intensity results along the path on the surface of contamination in electrostatic and quasi-electrostatic field are displayed in Figure 4, which shows that electric field intensity in electrostatic field is slightly larger than quasi-electrostatic field.

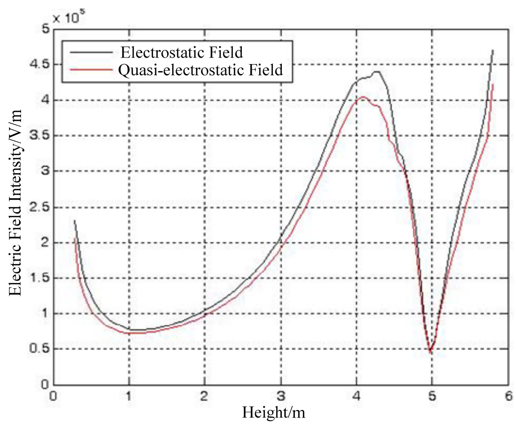
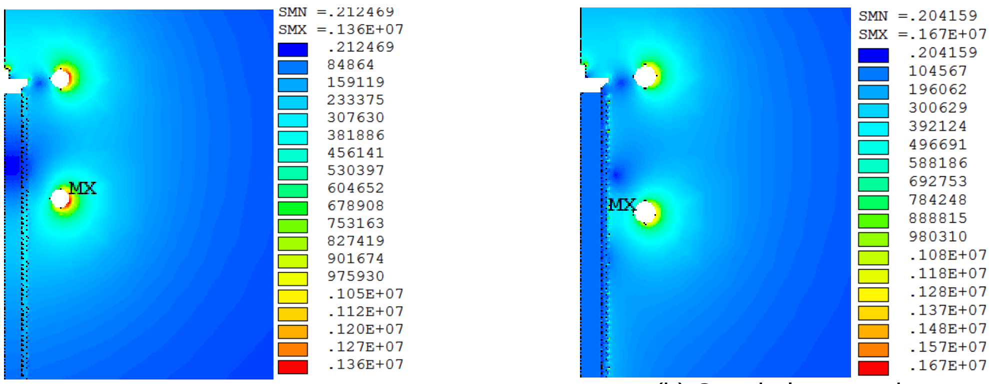


Figure 4. Electrical Field Distributions of the Contamination in Electrostatic Field and Quasi-electrostatic Field

The results of dry contamination indicate that high resistivity has little influence on electric field distribution in quasi-electrostatic field calculation, and the relative dielectric constant in electrostatic field should set to be 2.8, same as that in quasi-electrostatic field.

4.2. Moist Contamination

Moist contamination on the surface of DC voltage divider will form a semiconductor layer, which will lead to a substantial increase in leakage current. As the resistivity of moist contamination is very small in quasi-electrostatic field, its influence on the potential distribution can not be neglected. The electric field distribution results with the same relative dielectric constant in electrostatic and quasi-electrostatic field are shown in Figure 5.

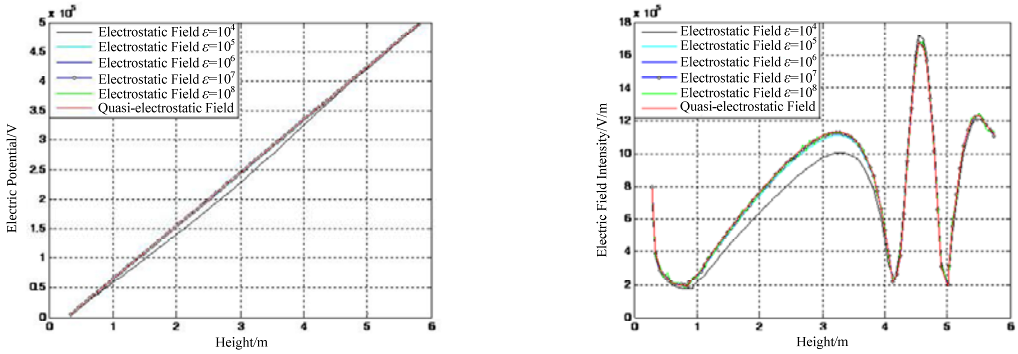


(a) Electrostatic (b) Quasi-electrostatic

Figure 5. Electrical Field Distributions Results in Electrostatic Field and Quasi-electrostatic Field

The results displayed in Figure 5 indicate that the same relative dielectric constant in quasi-electrostatic and electrostatic field lead to great diversity in electric field distribution. The maximum value of electric field intensity in quasi-electrostatic field is 16.7kV/cm, corresponding to 13.6kV/cm in electrostatic field, and the maximum values appear at different position.

In electrostatic field calculation, the relative dielectric constant of moist contamination is increased from 10^4 to 10^8 in sequence, the potential and electric field distribution curve of contamination compared with quasi-electrostatic field are displayed as Figure 6.



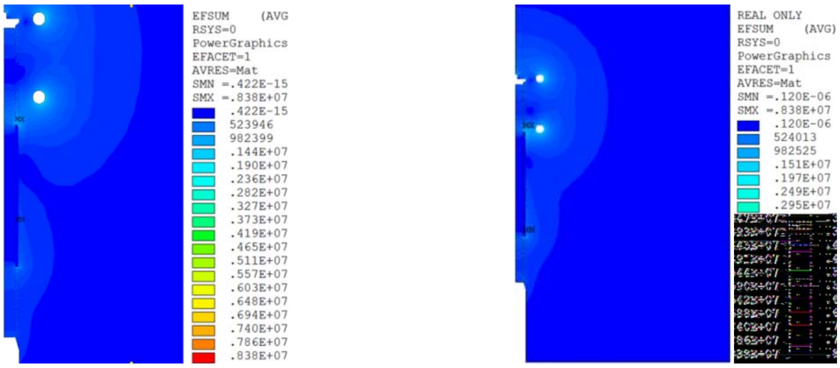
(a) Electric Potential (b) Electric Field

Figure 6. Electric Potential and Electric Field Distributions of Moist Contamination in Electrostatic Field and Quasi-electrostatic Field

The results show that when the relative dielectric constant of moist contamination is between 10^5 and 10^7, the potential and electric field distribution curves on the surface of moist contamination in electrostatic field are in good agreement with quasi-electrostatic field. The curve indicates that potential distribution is linear, and the potential distribution in electrostatic is smaller than that in quasi-electrostatic when relative dielectric constant is below 10^5. While if relative dielectric constant set to be 10^8 in electrostatic field, there will be oscillations in electric field distribution curve just as shown in Fig.6(b). Consequently, appropriate relative dielectric constant of moist contamination in electrostatic field should set to be 10^6.

4.3. Mixed Contamination

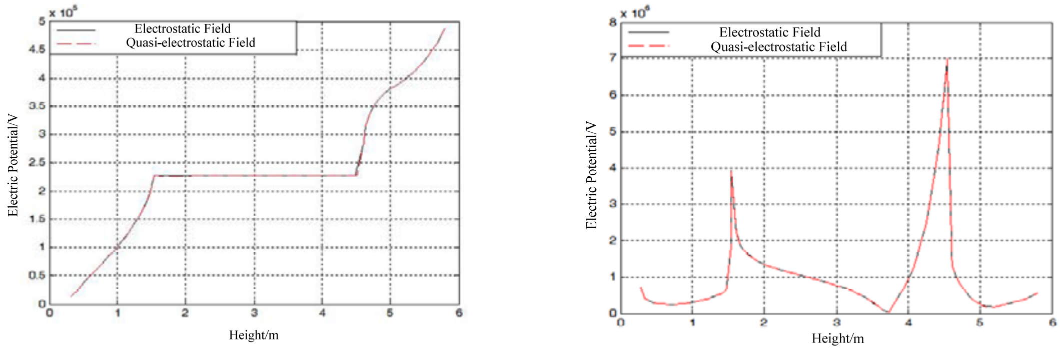
For mixed contamination discussed in the paper, the thickness remains 1.0mm, and the contamination is divided into three parts. Two ends of contamination are set to be dry contamination because of heating, the middle part is moist. The relative dielectric constants of dry and moist contamination are based on previous research in chapter 4.1 and 4.2. The electric field distributions in quasi-electrostatic and electrostatic field are displayed in Figure 7. The maximum electric field intensity appears at the junction of dry and moist contamination.



(a) Electrostatic (b) Quasi-electrostatic

Figure 7. Electrical Field Distributions in Electrostatic Field and Quasi-electrostatic Field

The potential and electric field distribution curves along the surface of mixed contamination are shown as Figure 8. The electrostatic calculation results are in good agreement with that in quasi-electrostatic field. The potential distribution curves indicate that for quasi-electrostatic field, as the resistivity of moist contamination is far less than dry contamination, the voltage drop in moist contamination almost equals to 0. While for electrostatic field, the same result can be obtained because of the huge diversity in relative dielectric constant. The electric field distribution curve shows that there will be distortions at the junction of dry and moist contamination.



(a) Electric Potential (b) Electric Field

Figure 8. Electric Potential and Electric Field Distributions of Mixed Contamination in Electrostatic Field and Quasi-electrostatic Field

The potential and electric field calculation results are also in good agreement for mixed contamination, which indicate that the parameters of dry and moist contamination obtained in the paper are valid and feasible.

5. Conclusion

Making use of 2D axis-symmetry finite element model of DC voltage, the influence of contamination on its surface electric field distribution is discussed in this paper. By comparing the electrostatic calculation results with quasi-electrostatic field, this paper studies the relative dielectric constant of dry, moist and mixed contamination in electrostatic field. The conclusions are as follows.

1) For dry contamination, because of its high resistivity, type of field has little influence on electric field distribution. The appropriate relative dielectric constant in electrostatic field is same as the value in quasi-electrostatic field.

2) For moist contamination, the appropriate relative dielectric constant in electrostatic is 10^6, which is much lager than quasi-electrostatic field.

3) For ideal mixed contamination discussed in the paper, the relative dielectric constant proposed is valid and feasible.

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