Numerical Simulation Studies on the Influence of Metallurgical Contamination on the Electric Field of RTV Coating

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Abstract. The metallurgical industry in China has developed rapidly, which has caused an increasing amount of exhausted gas emission. After a long period of operation, a layer of metallurgical contamination is deposited on the surface of insulators near the metal work, which may have an effect on the distribution of electric field on the surface of insulator. The chemical test indicates that the metallurgical contamination layer contains particles of Fe3O4 with strong conductivity, which may become suspended potential conductor. In this paper, the influence of thickness of contamination layer and diameter, arrangement of conductive particles on the electric field are discussed by the simulation model.

1. Introduction
The contamination deposition on the insulator surface is more serious. The contamination on the insulator surface can reduce the insulation performance and increase the risk of contamination flashover with high conductivity and high dielectric constant. Currently, contamination flashover has become the most dangerous fault in the power system. The study on the distribution of electric field under the influence of contamination is essential for the research of contamination flashover [1-3]. The calculation of electric field distribution on composite insulators is helpful to the study of partial discharge occurs on the surface of composite insulators and relating surface aging problems and is also helpful for the insulation design, operation and maintenance of composite insulators [4]. The distribution of electric field of the insulator has become one of the research focuses for researchers around the world. Kontargyri V calculated the distribution of electric field of glass insulator string using finite element method and verified the result with the experiment [5]. In literature [6], the electric field and potential distribution under the effect of partial contamination and dry band were studied. However, current research mainly focuses on the influence of insulator structure and pollution distribution on the electric field distribution. The electric field distribution of insulator with water drop and dry band were simulated and analysed in literature [7]. The study of numerical and experimental results regarding the effects of pollution on the flashover performance of glass suspension-type insulators was presented in literature [8]. However, the study on the effect of metallurgical pollution layer and the suspended potential conductor on the distribution of electric field are relatively rare.

In this paper, the model of small ball array in the contamination layer is proposed to simplify the metallurgical contamination simulation. The geometric model is built on a finite element analysis.
software. The distortion of electric field under the influence of metallurgical contamination is calculated and analysed. Electric field and potential distribution of dry contamination layer are compared with that of wet contamination layer. The influence of thickness of contamination layer, diameter and arrangement of conductive particles on the electric field are discussed.

2. Modelling procedure

2.1. Geometric model

The geometric model was built utilizing finite element method. The simulation model was an RTV plate attached a layer of metallurgical contamination. The conductive particles were inlaid in the contamination layer in a uniform arrangement with 0.003m longitudinal gap and 0.0013m lateral gap. The outside of the contaminated RTV plate was air layer. The integral geometric model is shown as Figure 1. The geometric parameters of the model are shown in Table 1.

![Figure 1: The integral geometric model](image)

Table 1 The geometric parameters of the model

| Geometric entity       | Length (m) | Width (m) | Height (m) | Radius (m) |
|------------------------|------------|-----------|------------|------------|
| RTV                    | 0.02       | 0.01      | 0.002      | \          |
| Contamination          | 0.02       | 0.01      | 0.0005     | \          |
| Air                    | 0.2        | 0.2       | 0.2        | \          |
| Conductive Particles   | \          | \         | \          | 0.0002     |

2.2. Calculation setting

The surface of longitudinal end of RTV plate was applied with 1kV AC voltage. The other end was grounded.

The wavelength of 50Hz AC voltage is far greater than the length of RTV plate, the electric field can be regarded as stable at any one moment. Therefore, only steady state need to be considered. Frequency domain was used to calculate. The boundary conditions of the model are shown in Table 2.

Table 2 The boundary conditions of the model

| boundary conditions       | Surface of RTV longitudinal end 1 | Surface of RTV longitudinal end 2 | Surface of air layer | Surface of conductive particles |
|---------------------------|-----------------------------------|----------------------------------|----------------------|---------------------------------|
| setting                   | 1kV (50Hz)                        | grounded                         | grounded             | Suspended-potential              |
The electric field distribution of RTV specimen with dry and wet contaminated layer were comparatively studied. Supposing that the contamination layer was in ideal dry state, the conductivity of the contamination layer was low. The conduction current was so small that the influence on the electric field can be neglected. The electrostatic field was used to calculate the electric field of dry contamination layer. The material parameters of dry contamination layer model were set according to relative literatures as shown in Table 3.

| Geometric entity | Dielectric constant |
|------------------|---------------------|
| RTV plate        | 3                   |
| Contamination layer | 7               |
| Air layer        | 1                   |
| Conductive particles | 1e8           |

In actual circumstances, the air around the insulator has a certain humidity. The contamination layer can't be in absolute dry state absorbing moisture from the air. In order to make the difference more obvious and more convenient for comparative analysis, the wet contamination layer was defined to have fully absorbed water and in the saturated humid state. The wet contamination layer was highly conductive and had characteristics of resistance and capacitance. The current field was used to calculate the electric field of wet contamination layer considering the influence of conduction current and dielectric properties in contamination layer on electric field distribution. The material parameters of wet contamination layer model was set as Table 4.

| Geometric entity | Conductivity (S/m) | Dielectric constant |
|------------------|--------------------|---------------------|
| RTV plate        | 6e-15              | 7                   |
| Contamination layer | 0.1             | 20                  |
| Air layer        | 1e-14              | 1                   |
| Conductive particles | 1e7              | 1e8                 |

Finally, the number of longitudinal particles, the number of lateral particles, the thickness of contamination layer and the diameter of conductive particles were modified respectively on the basis of the wet layer model. The influence of the model parameters on the electric field distribution was studied.

3. Results and discussion

3.1. Difference between dry contamination layer and wet contamination layer
The influence of the conductivity of contamination layer on the electric field distribution was neglected in the model of dry contamination layer. The electric field distribution on the surface of contamination layer was determined by the capacitance distribution. The influence of dielectric characteristics and resistance characteristics of contamination layer on electric field distribution were both considered in the wet contamination model. The horizontal section of the contamination layer was taken as the subject of research. Cloud picture of electric potential distribution is shown as Figure 2. Cloud picture of electric field distribution is shown as Figure 3.
When the contamination layer is dry, the potential and electric field distribution is affected by the capacitance distribution of contamination layer. The equipotential line on the whole specimen is bent to the side of the grounding electrode. The electric field near the high voltage electrode side of the specimen is larger than that of the ground electrode. The electric field on the surface of conductive particles is distorted in the direction of applied electric field.

When the contamination layer is wet, the potential and electric field distribution is affected mainly by the conductivity distribution of contamination layer. Leakage current is uniformly distributed in contamination layer. Therefore, the equipotential lines are uniformly distributed and parallel to the electrode. The electric field on the surface of conductive particles is distorted in the direction of applied electric field.

The 3D line passed through the center of contamination layer along the direction of electric field. The electric field distribution on the path of dry and wet contamination layers with and without suspended potential particle were studied respectively. Variation of electric field along the longitudinal study path is shown in Figure 4. Change of electric field along the horizontal study path is shown in Figure 5.
Figure 5  Variation of electric field along the longitudinal study path

The blue line indicates the variation of electric field along the research path with the absence of conductive particles in contamination layer. The red line indicates the variation of electric field along the research path with the presence of conductive particles in contamination layer.

3.2. Influence of thickness of contamination layer

The distribution of electric field in contaminated layer of different thickness was calculated respectively. The influence of thickness of contamination layer on the distribution of electric field was studied. The geometric parameters and the arrangement of the particles are shown in Table 5. The variation curve of the electric field on the longitudinal path is shown in Figure 6.

Table 5 The geometric parameters and the arrangement of the particles

| Thickness of layer (mm) | Model a | Model b | Model c | Model d |
|-------------------------|---------|---------|---------|---------|
|                        | 0.4     | 0.5     | 0.6     | 0.7     |

Figure 6 The distribution of electric field with different thickness of contamination layer

The larger the thickness of contamination layer, the more uniform the distribution of conduction current is, the further the distance from the center of the layer to the specimen is. The result shows that the thickness of contamination layer has little influence on the overall electric field distribution. The maximum electric field distortion decreases with the increase of the thickness of layer.

3.3. Influence of diameter of conductive particle

The distribution of electric field in contamination layer with particles of different diameter was calculated respectively. The influence of diameter of conductive particles on the distribution of electric field was studied. The geometric parameters and the arrangement of the particles are shown in Table 6. The variation curve of the electric field on the longitudinal path is shown in Figure 7. The variation curve of the maximum distorted electric field is shown in Figure 8.

Table 6 The geometric parameters and the arrangement of the particles

| Particle diameter (mm) | Model a | Model b | Model c | Model d |
|------------------------|---------|---------|---------|---------|
|                        | 0.1     | 0.15    | 0.2     | 0.3     |
The result shows that when the diameter of the particle is 0.1mm, the electric field distortion of particle near the high voltage end is more serious, and the electric field distortion of other particles are relatively small. The maximum electric field distortion decreases with the increase of the diameter of conductive particle.

4. Conclusion
(1) The electric field distributes in exponential form along the longitudinal path in the dry contamination layer. The closer the particle is to the high voltage end, the larger the distorted electric field is. The electric field distortion ratio of different positions on longitudinal path is constant. The electric field distributes uniformly along the longitudinal path in the wet contamination layer. The electric field distortion ratio is 2.7 to 2.92. The electric field distortion ratio of the intermediate particle is larger. Distorted electric field and distortion ratio is larger than that of dry contamination layer.

(2) The larger the thickness of contamination layer, the more uniform the distribution of conduction current is. The thickness of contamination layer has little influence on the overall electric field distribution. The maximum electric field distortion decreases with the increase of the thickness of layer.

(3) The electric field distortion of particle near the high voltage end is more serious. The maximum electric field distortion decreases with the increase of the diameter of conductive particle.

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