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Numerical Simulation of Partial Arc along the Polluted insulation Surface under DC Voltage

***Abstract**. The development of an arc along the polluted surface depends to a great extent on the electric field of streamer at the arc head and the current densities in the wet polluted layer and arc. To investigate the parameters that vary depending on the arc length during the development of an arc, a simplified model of development arc along the polluted surface was established. Based on the numerical calculation of characteristic quantities of electric field and current density in the simplified model, the influencing factors on the development of arc were investigated.*

***Streszczenie.** W artykule opisano budowę uproszczonego modelu tworzenia się łuku elektrycznego przez zanieczyszczoną powierzchnię. Na podstawie analizy parametrów pola elektrycznego i gęstości prądu w modelu, określono i zbadano wpływ poziomu zanieczyszczeń powierzchni na rozwój łuku. (**Symulacja numeryczna łuku cząstkowego przez zanieczyszczoną powierzchnię izolacyjną przy napięciu stałym**)*

Keywords: partial arc; electric field; current density; numerical simulation
Słowa kluczowe: Łuk cząstkowy, pole, gęstość prądu, symulacja numeryczna.

1 Introduction

The prolongation of partial arc is the most important reason to form a pollution flashover; hence, it has been a constant research focus [1-3]. With the rapid development of computer technology in recent years, calculation using a computer to investigate the pollution flashover problem has become a new method [4], leading to the development of several algorithms [5-7]. At the same time, many researchers have calculated the simulation using the simulation software to investigate surface discharge. Junqi Chen [8] constructed a 3D model of an insulator to analyze the influence of conductive particle length and the non-uniform coefficient on the insulator surface. Yu Wang [9] investigated the parameter evolution of arc configuration, electric field strength, and dynamic temperature field of gliding arc plasma. Gang Yao [10] built a simplified model of insulation surface with water film and droplet, and calculated the influence of wet pollution to the surface field and potential through quasi-static harmonic analysis method. However, to date, there is no simulation research report on the distribution of electric field and current density with the development of arc.

In this paper, a simplified model of developing partial arc was built. In addition, the characteristic quantity variations of electric field and current density with the development of the arc were calculated. Based on the comparison of simulation calculation of the arc development parameters at different pollution degrees, the influence law of pollution degree to the development of partial arc was investigated, thereby deepening the understanding of discharge along the polluted surface.

2 Mathematical model

2.1 Basic assumptions

The partial arc belongs to thermal plasma. The thermodynamics condition, temperature distribution, and optical properties of the partial arc meet the assumptions as follows:

a) The partial arc is assumed to be in a local thermodynamic equilibrium.
b) The complex chemical reactions in the arc plasma are not considered.
c) The temperature distribution is uniform in the arc.
d) The arc plasma is steady and optically thin to radiation, and the reabsorption of radiation can be ignored compared with the total radiation.

2.2 Geometrical model and basic equations

Both column electrodes have diameter and height of 50 and 20 mm, respectively, and the anode-cathode distance is 50 mm. The distance of the electrode to the left and to the right boundaries is 25 mm. The thickness of the wet pollution layer is 0.2 mm.

Current density equation:

$$J = \sigma E \tag{1}$$

where: J – current density, σ– conductivity, and E – electric field strength.

With the development of arc, the arc radius and current meets the equation [11]:

$$r = \sqrt{\frac{I}{1.45\pi}} \tag{2}$$

where: r – arc radius, I – current.

2.3 Boundary conditions and model building

Voltage boundary condition:

$$\varphi = C \tag{3}$$

where: φ – applied voltage, c – constant.

Default boundary condition:

$$\frac{\partial \varphi}{\partial n} = 0 \tag{4}$$

where: n – normal vector.

Then we set the air physical parameters [12] and the material properties of polluted insulation surface; the conductivity and critical flashover voltage at different equivalent salt deposit density (ESDD) [13] as well.

Both the arc radius and current increase with the increment of arc length, meeting Equation (2). According to [14], with the development of arc, the arc current develops a corresponding relation to the discharge phenomenon. In this paper, we take the four typical data from the groups as examples to simulate the actual condition from the stage of the partial arc formed to the flashover, as shown in Table 1.

Table 1. Simulated values of arc length and current

Arc length [cm]	Current [A]	Radius [cm]
1	0.1	0.1482
2	0.15	0.1815
3	0.3	0.2566
4	0.6	0.3629

We take all the points at the arc path, then apply the temperature load [15]. The arc path is always a curve, so the spline curve is taken to simulate the arc path model.

3. Calculation results and analysis

When the pollution degrees of 0.03, 0.05, 0.1, and 0.2 mg/cm^2 are taken into the calculation model, the distribution of electric field, current density in the polluted layer, and arc with arc lengths 1, 2, 3, and 4 cm are obtained. To explain the problem in brief, the pollution degrees of 0.03 mg/cm^2 was taken as an example.

3.1 Electric field distribution

As shown in Fig.1, a, b, c and d are the electric distribution with arc length of 1, 2, 3 and 4 cm, respectively. With the development of arc, the electric field gradient at the arc head increases, whereas there is no obvious change in the electric field in the arc. With the increase of arc length from 1 cm to 4 cm, the maximal electric fields of the streamer at the arc head are approximately 7, 9, 11, and 22 kV/cm. The maximal electric field of the streamer at the arc head increases quickly with the increment of arc, and the electric field is close to the mean breakdown voltage of air at critical flashover. Therefore, the flashover cannot be attributed only to thermal ionization. It is caused by the rapid increment of the increment of thermal ionization and collision ionization.

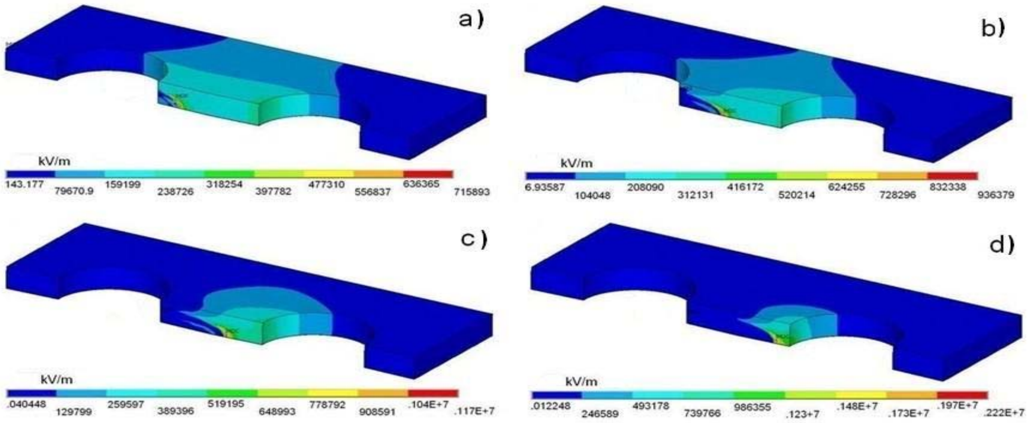

Fig.1. Variety of electric field distribution with arc length

The variation of maximal electric field of streamer at the arc head is different with different ESDD, as shown in Fig. 2. With the same arc length, the larger the pollution degree is, the smaller the maximal electric field of the streamer at the arc head. At the same pollution degree, the larger the arc length is, the larger the maximal electric field of streamer at the arc head. At small pollution degree, once the arc length exceeds the critical arc length, the maximal electric field of the streamer at the arc head is close to the air breakdown voltage, which indicates that the discharge is mainly electric breakdown at flashover time.

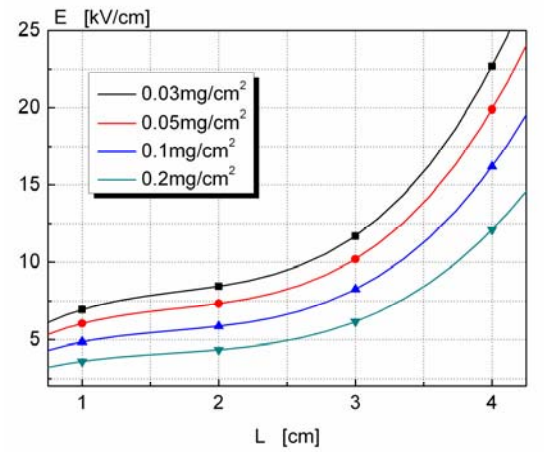

Fig.2. Variety of maximal electric field at streamer head of arc with the arc length

3.2 Current density distribution in pollution layer

As shown in Fig. 3, the relationship between the arc length and the current density in the pollution layer is presented. When the arc length is small, the space conductivity above the pollution layer is very low. In addition, almost all the current leak from the pollution layer. The distribution of current density in the pollution layer is uniform and has a wide range. With the prolongation of the arc, the electric field at the arc head becomes more concentrated, and the current density range in the pollution layer gradually decreases, whereas the current density increases.

The variation of the relationship between the arc length and the maximal current density in the pollution layer at different pollution degrees is given in Fig. 4. The maximal current density increases quickly with the increment of arc length. With the same arc length, the larger the pollution degree is, the larger the maximal current density in the pollution layer. The current increases with the development of the arc, so the current density at the position of the arc head in contact with the pollution layer increases. The larger the pollution degree is, the larger the conductivity in the pollution layer. The foregoing is in favor of the current leak in the pollution layer. Therefore, the current density is larger than that of the small pollution degree.

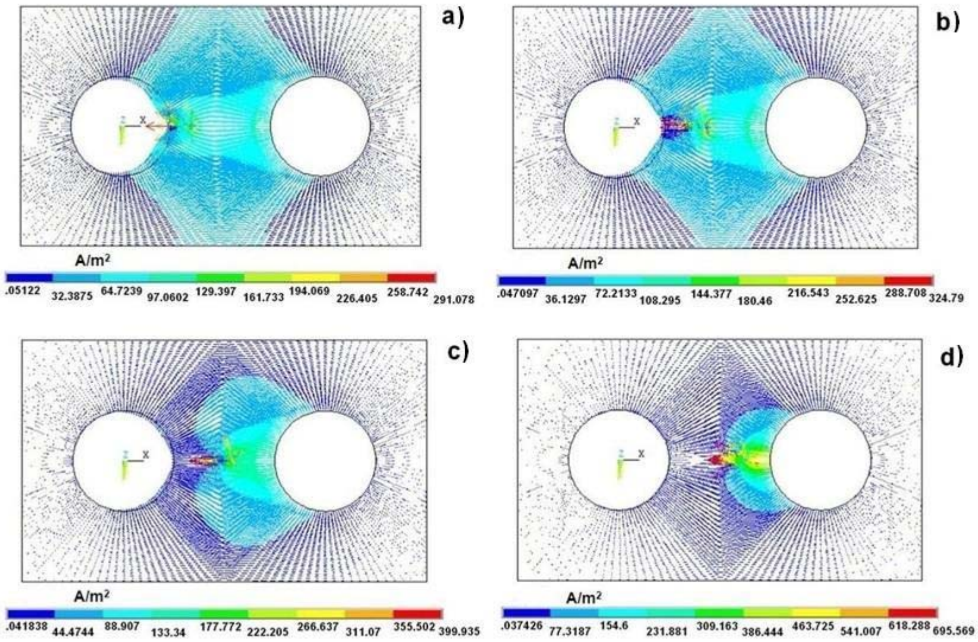

Fig.3. Variety of electric field distribution with the arc length

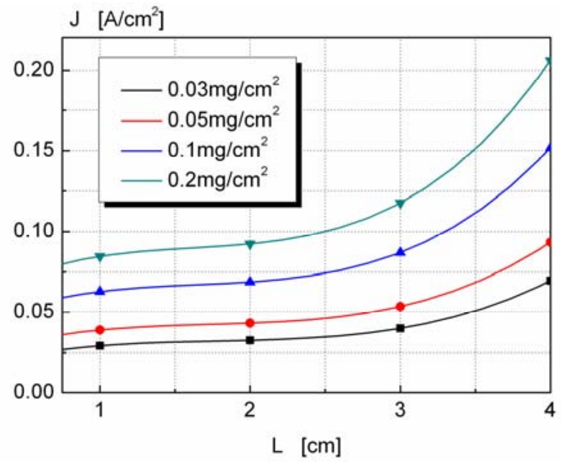

Fig.4. Variety of maximal current density in the pollution layer with the arc length

3.3 Current density distribution in the arc

As shown in Fig. 5, the variation of relationship between the arc length and the maximal current density in the arc is presented. With the prolongation of arc, both the arc radius and current are increase. The maximal current density in the arc does not increase all the time due to the effect of thermal buoyancy and ambient airflow. The position of the maximal current density is not immovable. When the arc length is less than 2 cm, the position of the maximal current density is at the arc root, but once the arc length exceeds 3 cm, the position of the maximal current density is at the middle of the arc.

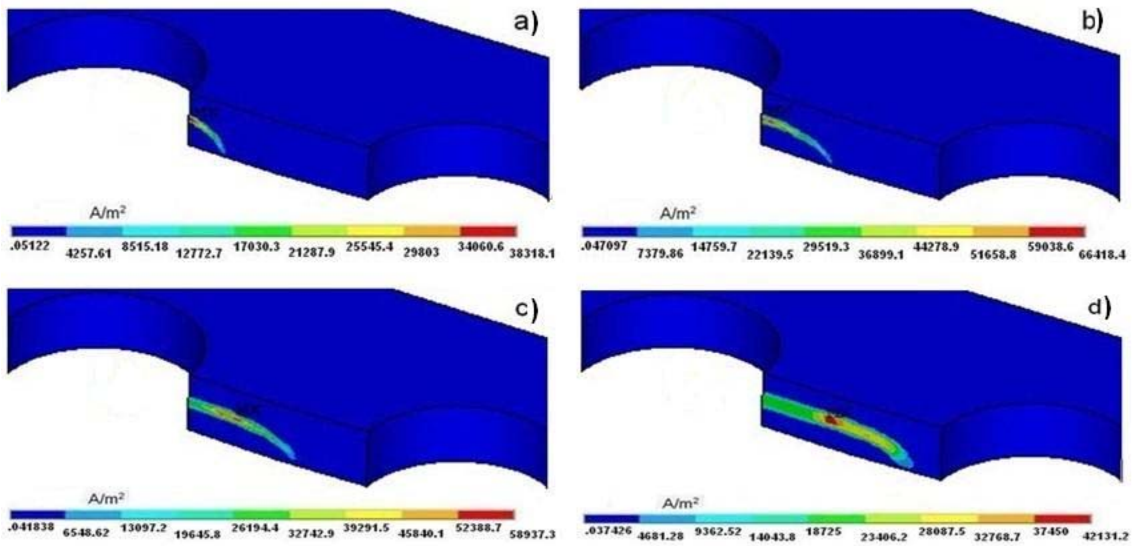

Fig.5. Variety of density distribution in the arc with the arc length

The variation of relationships between the arc length and the maximal current density in the arc at different pollution degrees is given in Fig. 6. The maximal current density in the arc is approximately 1.5 A/cm^2 to 6.7 A/cm^2, consistent with the measurement results in [16]. The maximal current densities at different pollution degrees are all initially increase, and then decrease. At the same arc length, the larger the pollution degree is, the larger the maximal current density becomes.

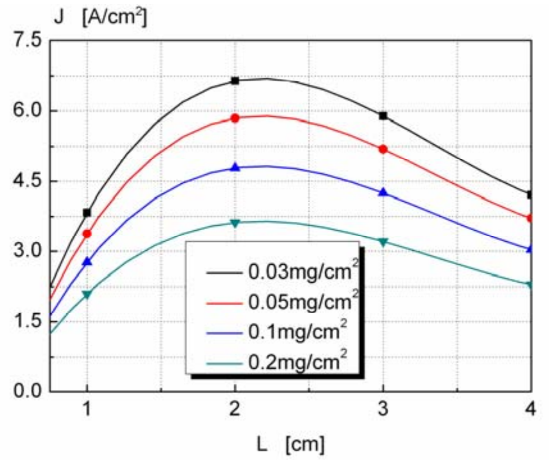

Fig.6. Variety of maximal current density in the arc with the arc length

4 Conclusions

This work focused on simulation calculation of the characteristic quantities of the electric field and current density in a simplified model of polluted insulator. The analysis of the calculation results are as follows:

(1) At the same arc length, the larger the pollution degree, the smaller the maximal electric field of streamer at the arc head. At the same pollution degree, the larger the arc length, the larger the maximal electric field of streamer at the arc head.

(2) When the arc length exceeds the critical arc length, the maximal electric field of the streamer at the arc head is close to the air breakdown voltage. The flashover is caused by the rapid increment of the increment of thermal ionization and collision ionization.

(3) With the prolongation of the arc, the current density range in the pollution layer decreases gradually, whereas the current density increases. At the same arc length, the larger the pollution degree, the larger the maximal current density in the pollution layer.

(4) The maximal current density in the arc does not constantly increase due to the effect of thermal buoyancy and ambient airflow. The position of the maximal current density is not immovable. With the development of the arc, the maximal current density in the arc is approximately 1.5 A/cm^2 to 6.7 A/cm^2.

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REFERENCES

[1] M. El-A. Slama, A. Beroual, H. Hadi, Analytical computation of discharge characteristic constants and critical parameters of flashover of polluted insulators, *IEEE Trans. Electr. Insul.*, (2010), No. 17, 1764-1771.

[2] R. T. Waters, A. Haddad, H. Griffiths, N. Harid, P. Sarkar, Partial-arc and spark models of the flashover of lightly polluted insulators, *IEEE Trans. Dielectr. Electr. Insul.*, 17 (2010), No. 2, 417-424.

[3] B. Subba Reddy, Udaya Kumar, Enhancement of surface flashover performance of high voltage ceramic disc insulators, *J. Mater. Eng. Perform.*, 20 (2011), No. 1, 24-30.

[4] R.Sundararajan, R. S. Gorur, Dynamic arc modeling of pollution flashover of insulators under dc voltage, *IEEE Trans. Electr. Insul.*, 28 (1993), No. 2, 209-218.

[5] I. F. Gonos, F. V. Topalis, I. A. Stathopolos, Genetic algorithm approach to the modeling of polluted insulators, *IEE Proc.-Gener. Transm. Distrib.*, 149 (2002), No. 3, 373-376.

[6] P. S. Ghosh, S. Chakravorti, N. Chatterjee, Estimation of time-to-flashover characteristics of contaminated electrolytic surfaces using neural network, *IEEE Trans. Dielectr. Electr. Insul.*, 2 (1995), No. 6, 1064-1074.

[7] M. T. Gencoglu, M. Uyar, Prediction of flashover voltage of insulators using least squares support vector machines, *Expert Syst. Appl.*, (2009), No. 36, 10789-10798.

[8] Chen J., Ding L., Numerical simulation of electric field distribution of insulator surface, *Insulators and Surge Arresters*, (2009), No. 6, 16-18.

[9] Wang Y., Li X., Yu L., Yan J., Numerical simulation study on characteristics of gliding arc discharge, *Acta Phys. Sin.*, 60 (2011), No. 3, 035203.

[10] Yao G., Wen X., Lan L., Electric field of wet contamination on dielectric surface and creeping discharge in needle-board electrodes, *High Voltage Engineering*, 36 (2010), No. 6, 1407-1414.

[11] N. Dhahbi-Megriche, A.Beroual, Flashover dynamic model of polluted insulators under ac voltage, *IEEE Trans. Dielectr. Electr. Insul.*, 7 (2000), No. 2, 283-289.

[12] Guo Z., Zhao W., Arc and thermal plasma, *Beijing：Science Press, China,* 1986, 55-60.

[13] Sima W., Guo F., Yang Q., Yuan T., Calculation of the arc velocity along the polluted surface of short glass plates considering the air effect, *Energies*, 2012, No. 5, 815-834.

[14] Guan Z., Insulator and the external insulation of power transmission equipment, *Beijing: Tsinghua University Press, China*, 2006, 351-352.

[15] Li S., Zhang R., Tan K., The study of electric arc propagating along a polluted dielectric surface under AC voltage, *Proceedings of the CSEE*, 11 (1991), No. 2, 1-7.

[16] Hubert P. Michel G. Drouet, Dynamic measurements of the current distribution in the foot of an arc propagating along the surface of an electrolyte, *IEEE Trans. Power Appar. Syst.*, 101 (1982), No. 3, 725-736.

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