Influence of Pollution Degree and Humidity on the Discharge Characteristics of Porcelain Insulators in Fog Chamber Environment

ShaoTong Pei1, Zhe Zhang1, Jiashuo Liu1*, Yonglin Li1 and Yunpeng Liu1

1State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources, North China Electric Power University, Baoding 071003, China;

*Corresponding author’s e-mail: 1316048024@qq.com

Abstract. In order to study the influence of pollution degree and humidity on the discharge characteristics of porcelain insulators in a fog room environment, this paper uses Comsol Multiphysics software to simulate the electric field distribution of clean and dirty insulators in a 110kV transmission line with or without a fog room. The results show that the electric field around the clean insulator in the foggy room becomes larger at the high-voltage side and the low-voltage side becomes smaller than that in the non-fog room; and the electric field around the insulator in the fog room becomes larger as the contamination increases.

1. Introduction

Insulators play an important role in electrical insulation and mechanical connection in transmission and distribution lines. Their normal operation affects the safe operation of the power grid, and pollution flashover of insulators is an important factor that causes power outages[1-3]. And the polluted insulators in normal operation may flashover under adverse weather conditions, which may cause pollution flashover accidents. This accident ranks second only to lightning accidents, but its loss is 10 times that of lightning accidents[4-6]. In addition, Some scholars have found that the uneven distribution of insulator pollution has a great influence on the surface electric field distribution[3-8]. J.L. studied the distribution of electric field around FZSW-10/4 pillar composite insulators under different salt densities. It was concluded that the distribution characteristics of the electric field along the surface of the composite insulator umbrella skirt were almost the same under the conditions of different salt densities[9].Moreover, ANSYS was utilized to simulate the electric field and current density of glass insulators and porcelain insulators under different salt densities. The results appeared that the uneven distribution of pollution was beneficial to reduce the surface leakage current of the insulator string and increase the flashover voltage of the insulator[10-11].

From the above, many scholars have done a lot of research on the simulation of porcelain, glass and composite insulators with pollution, but little research on the simulation of polluted insulators with a fog chamber. For the insulator pollution experiment, the fog chamber is an indispensable part. Therefore, in order to correspond simulation and experiment more accurately, the influence of the fog chamber on the electric field distribution of the insulator surface cannot be ignored.

To sum up, in this paper, the simulation model of porcelain insulators will be built to analyze the electric field distribution of insulator with and without the fog chamber, respectively.
2. Simulation Model

Because the insulators have an axisymmetric structure, we selected a two-dimensional axisymmetric module while building a simulation model in COMSOL Multiphysics. When building the simulation model, we first draw in AutoCAD, then imported into COMSOL Multiphysics for simulation calculation. As far as we know, the medium in the model is not ideal. The conductivity of the conductor is limited and the medium is lossy (for example: polarization loss, magnetization loss or ohmic loss, etc.). For a conductive medium with a dielectric constant $\varepsilon$ in a time-harmonic electromagnetic field and considering ohmic loss, the ohmic loss appears in the dielectric equation as a negative imaginary number. Therefore, the relationship between the complex dielectric constant and the dielectric constant can be expressed as:

$$\varepsilon' = \varepsilon - \frac{j\sigma}{\omega}$$

(1)

Where: $\varepsilon'$ is the complex dielectric constant; $\varepsilon$ is the dielectric constant; $\sigma$ is the electrical conductivity; $\omega$ is the angular frequency.

The basic technical parameters of XWP2-120 are listed in Table 1. We substitute the complex dielectric constant for the dielectric constant. At this time, the potential and electric field around the simulated insulators are similar to the experiment results[12-13].

| Type       | Nominal Diameter ($D$/mm) | Structure Height ($H$/mm) | Creepage Distance ($L$/mm) | Breakdown Voltage ($U$/kV) |
|------------|--------------------------|---------------------------|---------------------------|---------------------------|
| XWP2-120   | 280                      | 120                       | 450                       | 120                       |

The main body of XWP2-120 is composed of steel leg, iron cap, cement and porcelain. The definition of material properties related to simulation is listed in Table 2. When the salt density specified in IEC60507 is 0.1mg/cm2, 0.2mg/cm2, and 0.4mg/cm2, the corresponding conductivity is 1.2S/m, 2.4S/m, 4.8S/m[14]. The thickness is taken as 1 mm[15]. When the thickness of the air layer around the insulator is $d>2.5D$ ($D$ is the nominal diameter of the insulator), the surface potential of the insulator can reach the maximum, and the electromagnetic field at the cutoff boundary can be ignored. In this paper, the thickness of the air layer is 3.5D. The size of the fog chamber in the simulation model is in line with reality. We apply 63.5kV power frequency AC voltage to the steel feet of the bottom insulator and set the iron cap of the top insulator to ground. After selecting the free triangle mesh for meshing, we perform calculations.

| Material     | Porcelain | Cement | Polluted Water Film | Air |
|--------------|-----------|--------|---------------------|-----|
| Relative dielectric constant | 6         | 8      | 81                  | 1   |
| Conductivity (S/m) | $2\times10^{15}$ | $2\times10^{16}$ | $1.2-4.8$ | $1\times10^{12}$ |

3. Simulation Results and Analysis

Under foggy and non-fog chamber, the electric field distribution of the insulator surface is different. Compared with the insulator string without foggy chamber, the one with foggy chamber has a higher surface electric field at the high voltage end and a lower value at the low voltage end. If the experiment is performed with a fog chamber at the voltage of 63.5kV, the results are significantly different from the actual. It is difficult to perform insulator pollution experiment under natural conditions. Therefore, the
fog chamber is essential for the experiment. We can conclude that whether in a fog room or a non-fog room, the electric field intensity of the surface of the clean insulator string has the same three-piece distribution trend near the high-voltage end. In addition, the values of the high-voltage end of the insulator string differ by 38.1%, 29.6%, and 20.5% from the first piece to the third piece, respectively. The average value is approximately 30%, and detailed field intensity values are listed in Table 3.

Table 3. Maximum field intensity near the high-voltage end.

| With or Without a Fog Chamber | Voltage/kV | Maximum first field intensity at high voltage side(kV/m) | Maximum second field intensity at high voltage side(kV/m) | Maximum third field intensity at high voltage side(kV/m) |
|------------------------------|-----------|--------------------------------------------------------|--------------------------------------------------------|--------------------------------------------------------|
| With                         | 63.5      | 647.9                                                  | 229.7                                                  | 132.8                                                  |
| Without                      | 63.5      | 469.2                                                  | 179.3                                                  | 110.2                                                  |
| With                         | 49        | 498.0                                                  | 178.8                                                  | 998                                                    |

In order to approximate the field intensity of the insulator with and without a fog chamber, the voltage of the fog chamber is divided by 1.3 to become 49kV. The electric field distribution on the surface of the insulator is extracted by the arc length of the insulator surface. At this time, the field intensity of the insulator string with the fog chamber at 49kV and the insulator string without the fog chamber at 63.5kV is close to the high-voltage end by 6.1%, 1.4%, and 10.4%, respectively.

4. Conclusion

- The surface electric field of the insulator string of the foggy chamber is larger at the high voltage end and smaller at the low voltage end, but the electric field distribution trends of the insulators near the high voltage end are consistent. Therefore, when the test is performed in a foggy room, the test voltage is appropriately reduced, and the discharge of the dirty insulator near the high-voltage end is closer to the actual field situation.

- It can be known from the simulation that with the increase of the pollution degree, the overall trend of the electric field distribution around the insulator string does not change, but the maximum value of the electric field becomes larger

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