Study on Measurement Error of Power Frequency Electric Field Intensity Caused by Change of Humidity on Surface Resistance of Field Intensity Meter Supports

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Abstract: This paper analyzes the different measurement results of field intensity meter in different environments, which confirms that humidity has a great influence on the support parameters of field intensity meter. In addition, by testing the actual electric field, the change of dielectric constant and resistance of field intensity meter and its support under different relative humidity conditions, and comparing the simulation results of COMSOL simulation software, it is concluded that the error of field intensity meter measurement results mainly comes from the influence of humidity on the surface resistance of field intensity meter support, and the relationship between the surface resistance of the support and humidity is obtained.

1. Introduction

Due to the importance attached to electromagnetic environment, environmental measurement will be conducted with field intensity meter before putting any kinds of electrical equipment into use, so the frequency of electric field measurement is very high. However, in some areas, there exists a big error between the measured value and the actual value due to the humidity. How to analyze and reduce the influence of humidity on field intensity meter has become a research focus.

References [1], [3] and [4] theoretically analyzed that humidity has no influence on the actual electric field from the angle of electric field calculation, and designed corresponding experiments to confirm it, and they concluded, through experiments, that humidity changes mainly affect the measurement results by influencing the field intensity meter and support. In reference [2], the support was improved based on the analysis of the influence of humidity on electric field measurement, and a prediction model for electric field measurement error was established by using neural network algorithm.

The above documents only verified the influence of humidity change on the measured electric field under different field intensity meter structures. In this paper, the influence of humidity on the actual parameters of field intensity meter components is tested and measured, and the influence of parameter change on actual electric field is simulated using software, which verifies that the insulation supports have a great influence on the actual electric field measurement under different humidity conditions.

2. Influence of Humidity on Power Frequency Electric Field Measurement

For the 50Hz power frequency electric field generated by a transmission line, the magnitude and direction of the electric field intensity at a certain point below the transmission line changes with time, but a point near a flat ground, the direction of the electric field is perpendicular to the ground, which
can be approximately regarded as a uniform electric field, so it can be analyzed by electrostatic field theory. In the analysis, the influence of humidity on line sag and other interfering objects is not considered, and only the influence of humidity on air, field intensity meters and insulation supports is studied.

3. Influence of humidity on actual electric field

The transmission line and the ground can be regarded as a parallel plate capacitor, with the amount of charge of the ground surface being 0 and that of the line being +q. The electric field intensity between the line and the ground can be calculated as \[ E = \frac{1}{2\varepsilon_0} \sigma \], where \( \sigma \) is the charge density on the line. The relative dielectric constant of dry air is \( \varepsilon_r = 1.0006 \). Macroscopically, polarization charges will appear in the dielectric medium in the electric field, which will affect the macroscopic electric field distribution. For air dielectric with a relative dielectric constant of \( \varepsilon_r \), the actual electric field \( E' = E/\varepsilon_r \), that is, if the dielectric constant of air changes with humidity, the actual electric field will also change. However, the dielectric constant of air that can be measured by experiment does not change much.

4. Influence of humidity on field intensity meter

In China, electric field environmental protection measurement for substations and lines before they are put into operation mainly uses parallel plate field intensity meter. Its structural diagram is shown in Figure 1. The field intensity meter is placed in a uniform field. Its measuring principle is to calculate the electric field intensity \( E' \) between the two plates and in the dielectric according to the current measured by the resistance circuit in series, and then measure the external electric field intensity according to the formula \( E' = E/\varepsilon_r \), where \( E \) is the measured electric field intensity and \( \varepsilon_r \) is the electric field intensity of the dielectric between the plates. The electric field distribution of a parallel plate field intensity meter in a uniform external electric field is shown in Figure 2.

It can be seen from the measurement principle that when the humidity changes, the dielectric constant between the plates will not change due to the waterproofness of the probe shell, so the electric field measurement results will not be affected. However, when the humidity is too high, a conductive channel may be formed between the two plates, resulting in a large current, which makes the final electric field measurement result relatively larger.

![Figure 1 Structure Diagram of Field Intensity Meter](image1)

![Figure 2 Field Intensity Meter in External Electric Field](image2)
5. Influence of humidity on insulation supports

Insulation supports only have dielectric properties in dry air, but reference [6] points out that the electrical conductivity of wood will increase sharply with the increase of water content [6], and it is found that in actual electric field measurement, the addition of insulation supports will greatly affect the measurement results. Therefore, when the air humidity is high, insulation supports have not only the dielectric property, but also the conductor property. When calculating the actual electric field, it needs to meet the basic laws of conductor and medium. An equivalent circuit can be made for it, as shown in Figure 3. When the electrical conductivity of the support (the lower parallel RC circuit) increases, the parameters of the air (upper) and the field intensity meter (middle) change little, so the voltage between the two plates of the field intensity meter increases and the measured electric field increases.

![Figure 3 Equivalent Circuit under Transmission Line](image)

As one of the important parameters of insulating materials, surface resistance can reflect the magnitude of the leakage current on the dielectric surface under a certain voltage. When considering the influence of humidity on electric field measurement, the surface resistance of the support is the most easily affected parameter by humidity, and during experimental measurement, the change of surface resistance can be reflected by measuring the bulk resistance of insulating materials.

6. Test Results

A constant temperature and humidity control box is used in the test to simulate the environment of humidity change. Since it is the content of water molecules that really affects the conductivity of the support, it is necessary to control the temperature to constantly change the relative humidity (the ratio of absolute humidity to the maximum absolute humidity at a certain temperature). The setting temperature of the test was 30°C, the relative humidity was adjusted from 40% to 90%, and the resistance change trend of three different materials was measured with a high resistance meter. The change of resistivity with relative humidity is shown in the table 1.

| Relative humidity (%) | PCTFE Resistivity ($\Omega / m$) | HDPE Resistivity ($\Omega / m$) | ABS Resistivity ($\Omega / m$) |
|-----------------------|-------------------------------|-------------------------------|-------------------------------|
| 45                    | $4.29 \times 10^8$            | $1.11 \times 10^8$            | $3.58 \times 10^6$            |
| 55                    | $7.07 \times 10^7$            | $1.01 \times 10^5$            | $2.07 \times 10^6$            |
| 65                    | $3.86 \times 10^7$            | $3.28 \times 10^3$            | $2.07 \times 10^3$            |
| 70                    | $3.54 \times 10^7$            | $9.33 \times 10^2$            | $1.38 \times 10^4$            |
| 75                    | $1.22 \times 10^7$            | $3.28 \times 10^2$            | $8.29 \times 10^4$            |
| 80                    | $8.36 \times 10^4$            | $1.21 \times 10^2$            | $9.33 \times 10^3$            |
| 85                    | $1.09 \times 10^4$            | $1.17 \times 10^2$            | $3.94 \times 10^3$            |
| 90                    | $5.78 \times 10^3$            | $1.01 \times 10^1$            | $1.83 \times 10^3$            |
It can be seen from the table 1 that the resistivity of the three materials decreases with the increase of air relative humidity, and the resistivity of material PCTFE decreases sharply at about 80% relative humidity. It can be seen from this that relative humidity has a great influence on insulation supports, so the influence of humidity on the insulation support must be considered in the measurement of actual electric field with a field intensity meter. In addition, the influence of humidity on the resistivity of different materials will be different. During the test, the change of resistivity of a hydrophobic material with the change of relative humidity was measured at the same time. Its resistance always exceeded the highest range of the high resistance meter with the change of humidity. Therefore, in practical use, an insulation support made of suitable material can choose for the field intensity meter to reduce the measurement error.

7. Simulation Results

In this paper, the simulation software COMSOL based on finite element method [5] was used to calculate the electric field distribution, and the influence of different resistivity supports on the electric field intensity between the two plates of field intensity meter was simulated.

The simulation model drawn by COMSOL is shown in Figure 4. The upper plane of the cylinder was connected with a voltage of 10,000V at 50Hz, the lower plane was grounded, and the middle was an equivalent model of field intensity meter and support. The dielectric material with a relative dielectric constant of 4 was filled between the upper and lower plates of the field intensity meter. The resistivity of the bracket material was changed by adding parametric scanning. The obtained variation curve of electric field intensity between the upper and lower plates of the field intensity meter is shown in Figure 5.

![Simulation Model of COMSOL Electric Field Measurement](image1)

![Curve of Variation of Field Intensity between Plates with Support Resistivity](image2)
field intensity, and the electric field intensity will increase with the decrease of the resistivity. Combined with the above test results, when the relative humidity of the air increases, the resistivity of the materials of supports will decrease, which will lead to the increase of the field intensity between the plates of field intensity meter, making the actually measured field intensity value relatively larger. Therefore, the influence of ambient humidity on electric field measurement can be reduced by selecting, based on the ambient humidity where the field intensity meter is located, materials that can maintain a certain resistivity under ambient humidity.

References
[1] Bin Zhai, Jian Ning, Jianhui Li, Yigang Ma, Wei Wang, Zhibin Zhao. Influence of environmental humidity on the measurement results of space electric field under the transmission line [J]. Southern Power System Technology, 2020, 14 (03):17-22.
[2] Yongqiang Deng, Jing Chen, Cong Zheng, Chunhua Peng. Optimization design of electric field measuring instrument holder based on finite element simulation and differential evolution algorithm [J]. Smart Power, 2020,48 (02):71-77.
[3] Bin Zhai, Lei Liu, Jian Ning, Jianhui Li, Yigang Ma, Wei Wang. Influence of ambient humidity on power frequency electric field intensity [J]. Power Equipment Management, 2019 (12):117-118+116.
[4] Tao Sun, Wangling He, Baoquan Wan, Chunming Pei, Jiangong Zhang, Junjia He. Influence of humidity on power frequency electric field measurements for high voltage transmission lines [J]. High Voltage Engineering, 2014, 40 (06):1710-1716.
[5] Guangzhou Zhang, Yinjun Zhu, Yemao Zhang, Yuchao Chen, Wenjun Zhou. Calculation methods and distribution characteristics of power frequency electric field of transmission lines [J]. High Voltage Engineering, 2011, 37 (10) :2581-2586.
[6] Youming Xu. Wood Science [M]. Beijing, China: China Forestry Press, 2006: 92-116.