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Research on Electric Field Simulation of GTEM Cell Based on UHF Sensor Calibration

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Abstract. In this paper, the GTEM cell electric field using UHF sensor calibration is simulated by HFSS software. According to the simulation results, the field uniformity of the total electric field strength in the “1/3 area” of the GTEM cell can meet the requirements before being placed in the UHF sensor. However, the field uniformity of the total electric field strength has been greatly changed after the UHF sensor is placed. In addition, the maximum amplitude of the field strength change in the UHF sensor test area exceeds 10 dB compared to that before the UHF sensor is placed. It has a great influence on the calibration accuracy of UHF sensors. Through the simulation study of the electric field of GTEM cell, it provides a reference for further improving the calibration accuracy of UHF sensor.

1. Introduction

Partial discharge is an important means of insulation evaluation of power transformers, GIS and other equipment. With the deepening of power system state maintenance work, ultra-high frequency (UHF) detection technology has been widely used because of its high sensitivity, strong anti-interference ability and can be used for partial discharge identification. The performance of UHF sensor is directly related to whether partial discharge can be detected, which indirectly affects detection stability.

At present, the UHF sensor performance calibration method based on GTEM cell proposed by Judd et al. of the University of Strathclyde is widely used [1-2]. Many Chinese scholars have perfected the UHF sensor performance calibration method based on GTEM cell, and proposed a relatively complete test method [3-5]. However, using the GTEM cell as the field strength standard, and placing the measured UHF sensor in the cell will affect the GTEM electric field distribution, which will affect the accuracy of the UHF sensor calibration. Therefore, it is necessary to study the electric field distribution of the GTEM cell using UHF sensor calibration.

2. The UHF sensor calibration principle

The UHF sensor calibration platform of the GTEM cell consists of standard signal source, GTEM cell, UHF sensor, unipolar standard probe, high-speed digital oscilloscope, measurement and control computer, etc., as shown in Figure 1. Among them, the standard signal source inputs the voltage signal to the GTEM cell, forms an electric field in the GTEM cell, and the UHF sensor is located inside the GTEM cell.



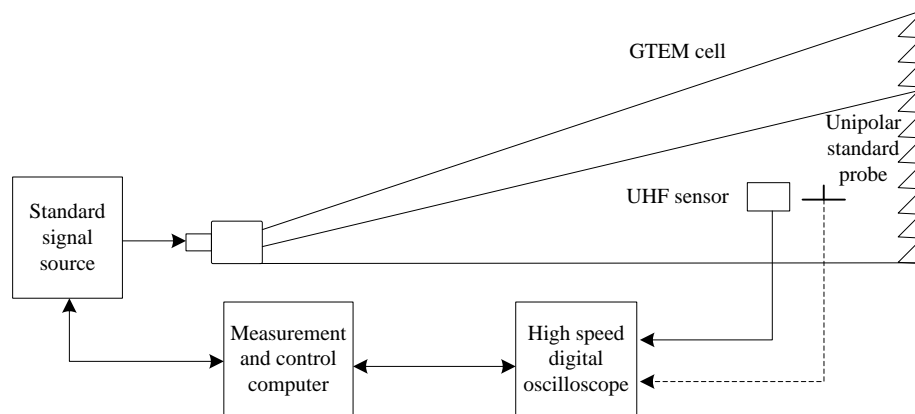


Figure 1. UHF sensor calibration principle in GTEM cell

In the traditional calculation of field strength in the GTEM cell[6], its internal field strength can be expressed as:

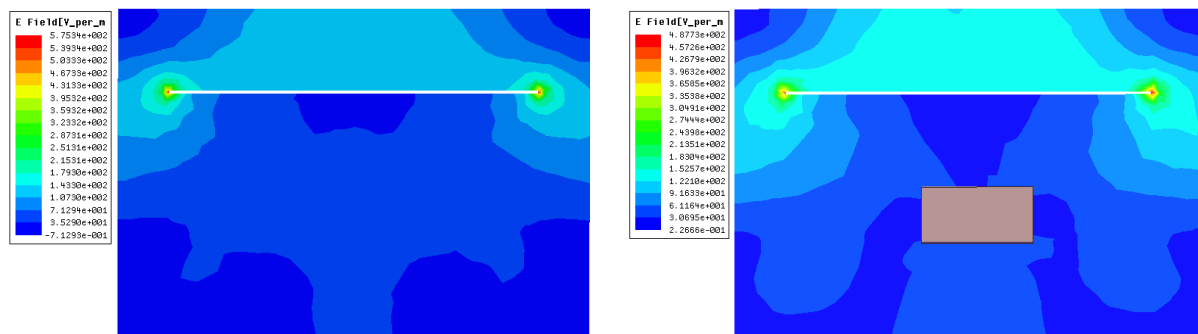
$$E = \frac{\sqrt{P_{in} Z_0}}{h} \quad (1)$$

In the Equation (1), P_{in} is the input power of the GTEM cell, Z_0 is the characteristic impedance of the GTEM cell, and h is the height of the core plate to the bottom plate of the GTEM cell.

However, because the GTEM cell core plate and the outer casing have a certain angle, the high-order mode wave is constantly changed by the cutoff frequency, and under certain conditions, the wave of a certain mode is excited. Therefore, the electromagnetic wave propagation law in the GTEM cell is very complicated, and the field strength calculated by the Equation (1) must have a certain error. Thus, consider using the finite element algorithm to calculate the internal field strength of the GTEM cell to get accurate results.

3. Electric field simulation analysis of GTEM cell

In this paper, the GTEM cell is modeled and simulated by HFSS software. When the input signal frequency of the GTEM cell is 1.5 GHz, the electric field distribution before and after the UHF sensor placed in the cell is compared and analyzed. The simulation results are shown in the Figure 2.



(a) Before placing the UHF sensor in the cell

(b) After placing the UHF sensor in the cell

Figure 2. Comparison of electric field distribution before and after placing UHF sensor

It can be seen from Figure 2. that before the UHF sensor is placed, the electric field distribution in the GTEM cell is relatively uniform, which basically conforms to the electric field diagram of the "open smile" in the uniform area of the cell. However, after the UHF sensor is placed, the electric field distribution is greatly changed, and the accuracy of UHF sensor calibration is inevitably affected.

Therefore, it is necessary to analyze the degree of change of the electric field distribution to study whether the GTEM cell field satisfies the electric field uniformity requirement.

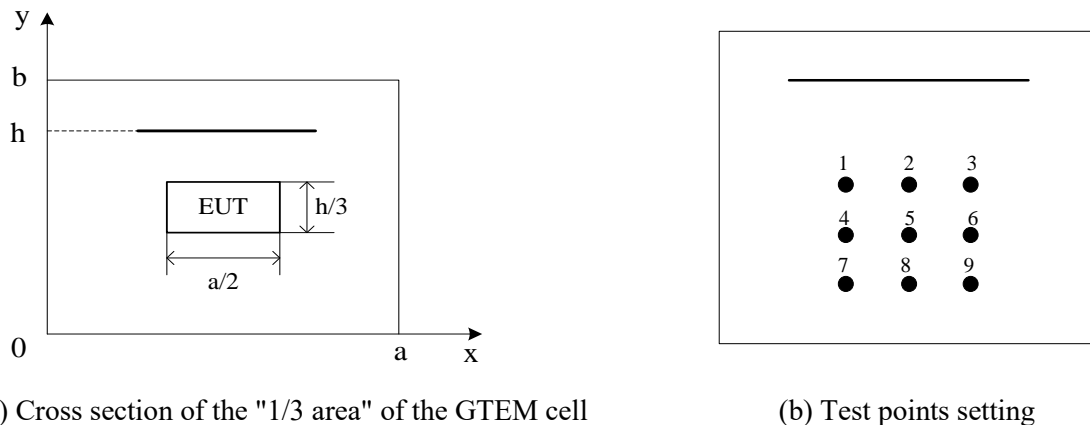
4. Analysis the electric field of GTEM cell before and after placing UHF sensor

4.1. Requirements of GTEM cell electric field uniformity

The GTEM cell is used as a test device for generating a standard TEM field, and the field distribution at the test area must be very uniform. In the GTEM cell, the uniform region is an imaginary plane perpendicular to the direction of electromagnetic field transmission and a region of 1/3 between the inner and outer conductors perpendicular to the cell bottom plate. This paper chooses to use the total field strength to verify that it meets the field uniformity requirements. At least 75% of the total field strength in the uniform region is within ± 3 dB tolerance[7].

$$\Delta E_{\max} = 20 \lg \frac{E_{\max}(f)}{E_{\min}(f)} < 6 \text{ dB} \quad (2)$$

Nine test points are evenly selected on the vertical section of the main test space in the GTEM cell, as shown in Figure 3.



(a) Cross section of the "1/3 area" of the GTEM cell

(b) Test points setting

Figure 3. GTEM cell "1/3 area" and test point settings

4.2. Field uniformity before placing UHF sensor

This paper selects the frequency range of 1.2GHz~1.8GHz and sweeps at intervals of 0.01GHz. The electric field strength of nine test points in GTEM cell was simulated and the simulation results are shown in Figure 4.

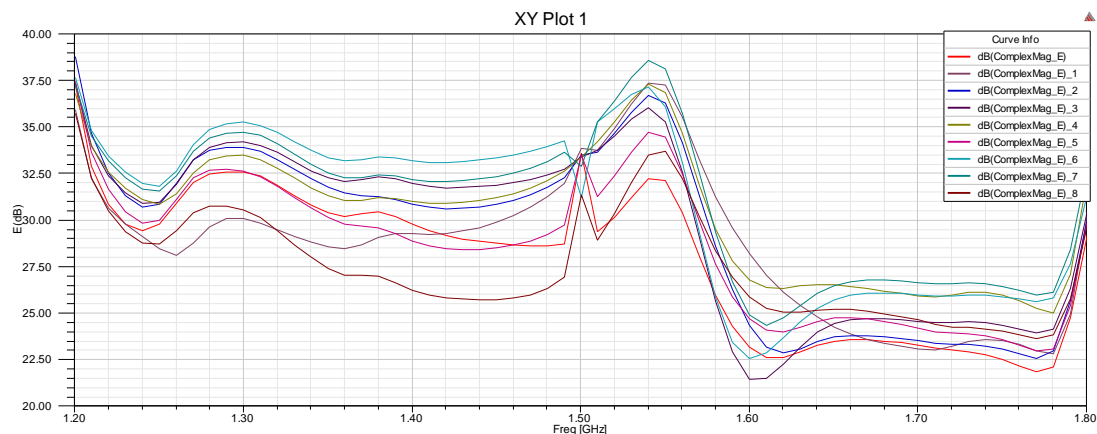


Figure 4. Field frequency domain characteristics before placing UHF sensor

It can be seen from Figure. 4 that before the UHF sensor is placed, the total field strength between the nine test points in the GTEM cell changes with frequency, and the trend of field strength is basically the same. Excluding the 2 test points with the largest deviation and retaining the remaining 7 test points. Through statistics, the maximum tolerance of the seven test points, in the frequency range of 1.2GHz ~ 1.8GHz all meet the requirements of equation (2), as shown in Figure 5. Therefore, the field uniformity of the GTEM cell before the UHF sensor is placed meets the test requirements.

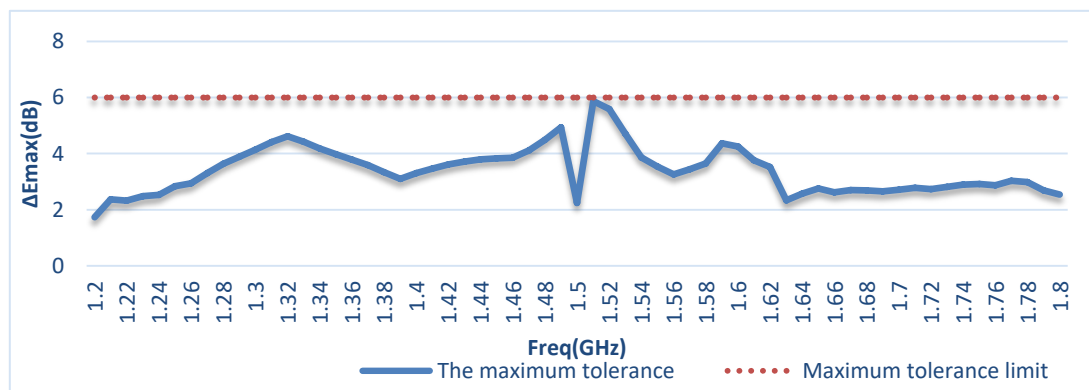


Figure 5. The maximum field tolerance before placing UHF sensor

4.3. Field uniformity after placing UHF sensor

Similarly, after placing an object of comparable size to the UHF sensor, the electric field strength of the eight test points in the GTEM cell (test point 5 cannot be measured inside the object) is simulated again, as shown in Figure 6. Then, eliminate the 2 test points with the largest deviation, retain the remaining 6 test points, and calculate the maximum tolerance, as shown in Figure 7.

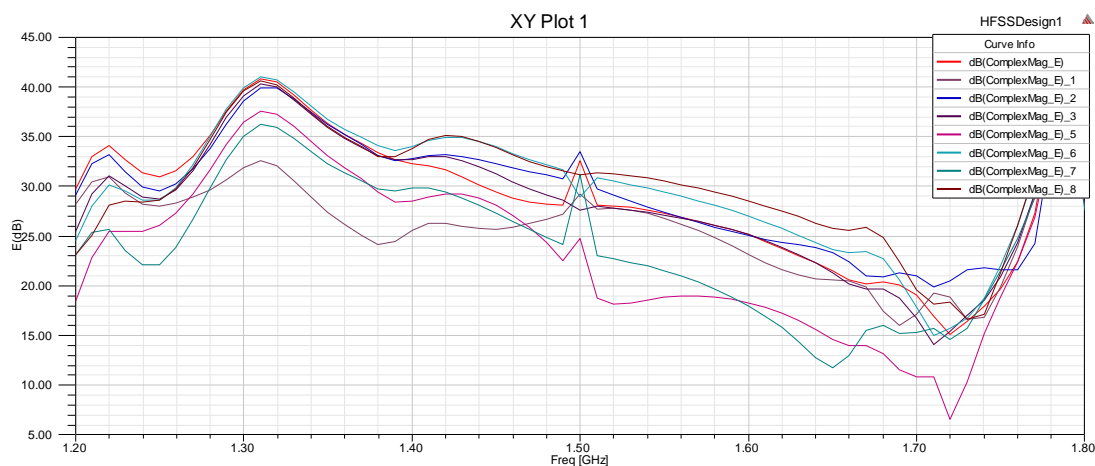


Figure 6. Field strength frequency domain characteristics after placing UHF sensor

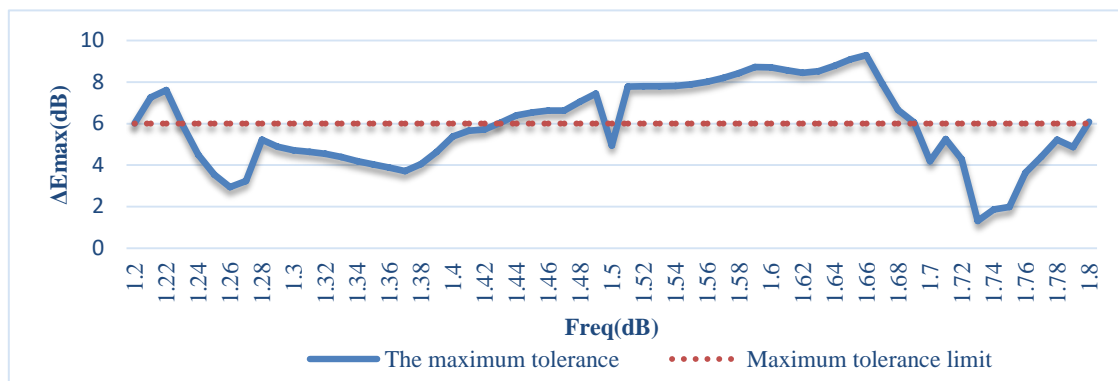


Figure 7. The maximum field tolerance after placing UHF sensor

It can be seen from Figure 6 that after the UHF sensor is placed, the total field strength of the eight test points in the GTEM cell changes with frequency, and the field strength change trend is basically the same, but there is a certain change compared with the field strength value before the UHF sensor is placed. The specific degree of change is shown in Figure 7. After eliminating the 2 test points with the largest deviation, there is still 49.2% of the frequency points with a maximum tolerance of more than 6dB. Therefore, the electric field uniformity of the GTEM cell does not meet the requirements after the UHF sensor is placed.

4.4. Field strength comparison of UHF sensor test area

When the UHF sensor is calibrated, the lower area of the UHF sensor is used to receive the electric field signal and can be used as a test area for the UHF sensor. The field strength variation of the test area has the most direct impact on UHF sensor calibration accuracy. Therefore, the field strengths of test point 7, test point 8, and test point 9 under UHF sensor are selected for comparison analysis. The field strength difference before and after the UHF sensor is shown in Figure 8.

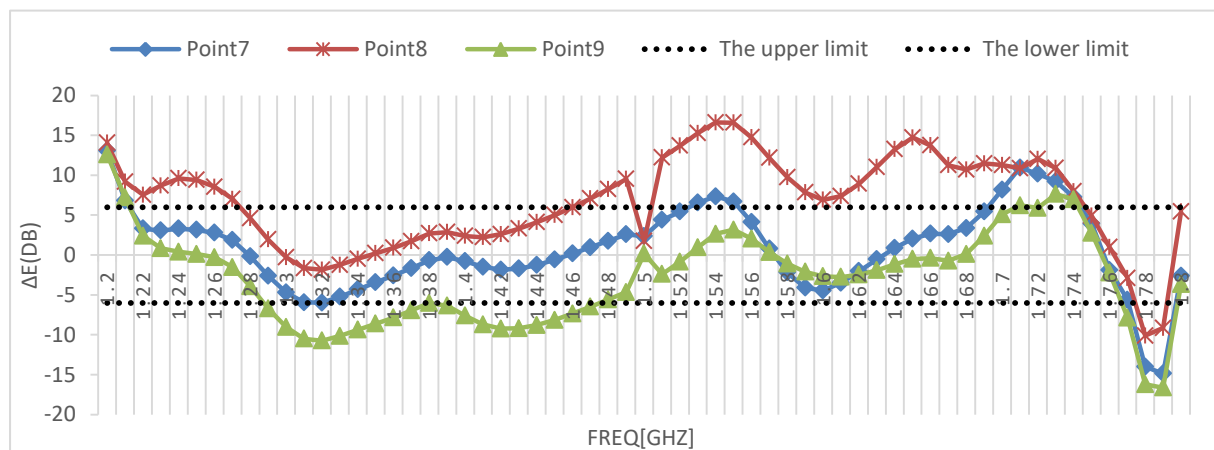


Figure 8. The difference curve of field strength before and after placing UHF sensor

It can be seen from Figure. 8 that after the UHF sensor is placed, the field strength underneath changes significantly. Taking test point 8 as an example, about 60.7% of the frequency point electric field intensity difference exceeds 6dB, and the maximum difference exceeds 10dB, which has a great influence on UHF sensor calibration accuracy.

5. Conclusion

By analyzing the electric field simulation of the GTEM cell for the UHF sensor calibration, the following conclusions can be drawn:

(1) Before the UHF sensor is placed in the "1/3 area" of the GTEM cell, the field uniformity of the total field strength satisfies the requirement of 6 dB. However, the field uniformity of the total field strength after the UHF sensor is placed cannot meet the requirement of 6 dB, but the maximum tolerance is basically within 10 dB.

(2) Compared with before the UHF sensor is placed, the maximum field strength variation of the UHF sensor test area exceeds 10 dB, which has a great influence on the UHF sensor calibration accuracy.

(3) When UHF sensor calibration is performed in a GTEM cell, the influence of the UHF sensor on the GTEM cell field distribution must be considered.

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