Research on Verification Technology of Ultra High Frequency Partial Discharge Detecting Sensors

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Abstract. More and more substations introduce Ultra-High Frequency (UHF) Partial Discharge (PD) on-line monitoring system and live detection instrument. However, the sensors with low gain or SNR (Signal to Noise Ratio) can’t capture the PD signals from the complex background noise. So an objective and comprehensive performance evaluation method for UHF sensor is necessary. Taking advantage of the even electric-field distribution characters in GTEM cell, responsiveness of UHF sensor can be easily achieved. The calibrated steep pulse generator was injected into the GTEM cell, then the output signal of the sensor is connected to the oscilloscope for analysis, the ratio of the output to the input signal can reflect the response of the sensor. In this way the equivalent height was obtained. The evaluation method in this paper is simple, easy to operate, high degree of accuracy and with good repeatability.

Introduction

In recent years, with the in-depth study of partial discharge on-line monitoring and live detection, PD detection has been widely applied in UHV substations, and accumulated a large number of test data [1-2]. Currently, there are many kinds of UHF sensors. According to the technical principle, there are mainly equiangular spiral type and Archimedes type UHF sensors. According to the application object, there are ultra-high frequency partial discharge sensors for transformer and GIS. In accordance with the installation location there are built-in and external UHF sensors.

There is no uniform testing standard for UHF sensor verification methods, and there is no widely accepted performance testing method [3]. The existing verification method is generally setting the UHF sensor directly besides the fault of the transformer or GIS model for the efficiency evaluation, the evaluation index including the signal to noise ratio, sensitivity and gain. However, the difference of the model results in the difference of the test results varies much, resulting in not conducive to popularization and promotion. The United Kingdom DMS company using the method of injecting standard pulse signal into the GTEM chamber, and conducting Fourier decomposition of the receiving signal to obtain the equivalent height of the sensor under test [4-5]. But after the Fourier decomposition of the pulse signal, the UHF component is too small; the signal is particularly weak especially in band above 500MHz, thus resulting in output/input transfer function error become unacceptable, the accuracy and repeatability of the results cannot be guaranteed.

In this paper, a constant field strength sinusoidal signal is injected into the GTEM cell, and the scanning frequency is set from 300 MHz to 1500 MHz in this range, the response capability of the UHF sensor is checked, and the equivalent height value of the UHF sensor is mainly evaluated, and the test result is analyzed and evaluated. Because the difference of the equivalent height can reflect the sensitivity and gain characteristics of the UHF sensor, it can be used as an evaluation index of UHF sensor performance.
Calibration Technology of Ultra-High Frequency Sensor

Calibration Principle

The implementation principle of UHF sensor comes from the field of antenna, in the antenna field there exists a very important parameter called the effective height \( h_e \). The effective height of the antenna \( h_e \) (m) is a caliber-related parameters \([6]\). The effective height multiplied by the same polarization of the incident electric field \( E \) (V/m), in this way we get the induced voltage \( V \), that is

\[
V = h_e E
\]  

In the field of radio research at home and abroad, the study of equivalent height is relatively small, more research in antenna focus on coefficient \( AF \). According to the IEEE definition, the antenna coefficient is the ratio of the electric field strength of the incident electromagnetic wave in the antenna polarization direction and the voltage across the load of the antenna. The measure unit of antenna coefficient is \( 1/m \), antenna coefficient logarithmic form of the unit of measure \( \text{dB} / \text{m} \), electric field antenna coefficient can be described as equation (2).

\[
AF_{\text{electric field}} = \frac{|E_{\text{incident wave}}|}{|V_{\text{receiving}}|} \quad (1/m)
\]  

In the equation, the electric field \( AF \) is the electric field antenna coefficient; \( E \) is the measured electric field intensity (V/m); and \( V \) is the voltage amplitude (V) at the output of the measured sensor.

Compared the equivalent height \( h_e \) with the antenna coefficient \( AF \) it can be found the two parameter are reciprocal relationship. That is, we can using the method of measuring the antenna coefficient to measure the equivalent height, in fact, the two are intercommunity. According to the definition, it can be known that when the given electric field is constant, the greater the sensor output voltage amplitude is, the lower the sensitivity is. Therefore, we use the equivalent height as a main index of ultra-high frequency partial discharge detection sensor.

Test Equipment and Test Method

Test Equipment

The GTEM cell used for the UHF sensor test is a 4 meters long GTEM cell, as shown in Figure 1. The signal source used in the GTEM cell can stably produce the sweep frequency signal which frequency is adjustable from 1MHz to 3000MHz. The frequency range is 300MHz to 1500MHz, while the electric field strength in the range of 1V/m to 20V/m.

![Physical map of the GTEM cell.](image)

Figure 1. Physical map of the GTEM cell.

The calibration of the GTEM cell is required before the test. The calibration is divided into two
parts. One is to calibrate the homogeneous field in the GTEM cell, and the other is to calibrate the field strength to be generated. According to the test requirements, considering that the UHF sensor has a certain volume, assuming there is a 20 centimeter length and 20 centimeter width vertical plane at the measured position where the field strength of each point is uniformity, the receiving surface of the sensor to be test coincidence this vertical plane, ensuring that the electric field strength received by the UHF sensor is basically the same.

9 points were evenly spaced in the selected vertical plane for the uniformity measurement, as shown in Fig2.

![Figure 2. Location of field strength calibration in GTEM cell.](image)

And then use the field strength probe to measure the strength of each test point in turn, the system will automatically receive the signal according to the field strength of the probe to adjust the output until the test point field strength consistent with the set value.

After confirming the homogeneity of the receiving surface, it is possible to calibrate the field strength in the desired frequency range. Setting the electric field strength output at 20V/m, the allowing error is 0.5V/m, and the sweeping frequency range is about 300MHz to 1500MHz, while the step size is 1%. A field-frequency curve as shown in Table.1 can be obtained.

| frequency MHz | 300  | 600  | 900  | 1200 | 1500 |
|--------------|------|------|------|------|------|
| field intensity V/m | 20.01 | 20.05 | 19.99 | 20.13 | 20.12 |

Test Method

The UHF sensor under test is placed in the calibrated uniform electric field, the sensor output connect to the oscilloscope (bandwidth 6GHz, sampling rate 40Gs/s). Test wiring diagram is shown in Figure 3.

![Figure 3. Schematic diagram of detection.](image)

Set the scanning frequency range and sweep step size, and the output field strength before the test, by read the calibration file, the computer then control the amplitude of the output in accordance with the original set in turn, by recording the output of UHF sensor amplitude, according to equation (1) the equivalent height of the sensor can be calculated.
Test

Test of Equivalent Height

Take one ultra-high frequency sensor as an example for sweeping test, set the output field strength in GTEM cell at 20V / m and the scanning frequency from 300MHz to 1500MHz. According to equation (1) the equivalent height curve was calculated and shown in Figure 4.

![Figure 4. Equivalent height of UHF sensor under test.](image)

As can be seen from the curve, the frequency response characteristics of the sensor is not a smooth curve, on the contrary in some frequency range there exist a good response characteristics, and in some frequency range the response capability is poor.

To validate the results, the VSWR of the UHF sensor was measured using an Agilent network analyzer. The SWR curve of the sensor is shown in Fig5.

![Figure 5. Standing-wave ratio (SWR) of UHF sensor under test.](image)

Contrast the two curves it can be seen that a strong correlation between the two curves, for a more intuitive view of the result, the two curves was drawn in the same coordinate system, as shown in Figure 6.
As shown in figure 6, the red curve is the equivalent height of the measured sensor, while the black curve stands for the VSWR curve of measured sensor, the VSWR curve coordinates is in reverse order. We can see that the trend of two curves is almost the same. From the definition of standing wave ratio, the better the system impedance matching, the smaller the VSWR value is, the signal loss in the transmission process is also lower. Therefore, it can be seen from the figure where the VSWR is small, the signal response capability is strong as well as the output amplitude is large, in the opposite side, where the VSWR is large, the signal response capability is weak as well as the output amplitude is small. Therefore, the method proposed in this paper is consistent with the sensor characteristics itself, which indicating that the test method is accurate.

**Contrast with Other Test Methods**

The commonly used method for ultra-high frequency sensor performance evaluation is the pulse decomposition method, the pulse decomposition method and the sweep method is similar in the use of GTEM cell as signal transmission medium. The difference is that the pulse decomposition method will be placed on the top of the sensor in the GTEM outside the opening, while the sweep method is placed in the internal uniform electric field. Another difference is that the former is injected into the GTEM cell is a pulse signal, by using the frequency domain decomposition to obtain the equivalent height curve, the sweep method is in a way of injecting into constant electric field strength with frequency adjustable RF signal to obtain the equivalent height of different frequencies. In principle, the result of the sweep method is more accurate and intuitive.

In this paper, the sweep method and the pulse decomposition method of the test results are shown in Figure 7; it can be found that using the scanning method may be more accurately reflect the UHF sensor characteristics.
The smoother curve in Fig. 7. is the equivalent height curve measured by the pulse decomposition method, which corresponds to the right ordinate; and the more tortuous curve is the equivalent height curve obtained by the sweep method, corresponding to the left ordinate. Contrast the two curves can be found in the following differences (features):

(1) The change trend of the equivalent height measured by the two methods is the same. The response capability of the sensor is the strongest near 1000MHz, and the response ability is weak when below 500MHz and above 1400MHz. It is shown that both methods can find the frequency response characteristics of UHF sensors.

(2) The equivalent height value is not the same. The result of the sweep method is in the range of 9.2mm to 10.7mm, and the pulse decomposition method is between 8.1mm and 10mm. The result of the pulse decomposition method is the result of comparison with the standard probe, while the sweep method is the result of direct testing. The values are different but the test results are consistent.

(3) The sweep method can detect more performance details. For example, in the low-frequency band 400MHz and 540MHz there exists a peak value, if filtering out this band to suppress interference in the system, the whole detection sensitivity may be affected; in the band 1000MHz to 1400MHz the frequency response are stronger, thus it can take full advantage of this band to protect the sensor detection effect. Therefore, these details can be used to determine the system to meet the requirements of the field of anti-interference requirements and detection sensitivity in the field of band detection design.

Conclusion

This paper presents a calibration method for the response capability of UHF sensors based on the gigahertz transverse electromagnetic cell. The stability of the RF signal in the small room of the GTEM is studied. By analyzing the output of the UHF sensor, the sensor detection capability is calculated and the performance of the sensor is evaluated. The calibration data also confirm the test method proposed in this paper. The proposed method can be used to guide the testing of the UHF sensor detection performance, and the method is simple and reproducible, and can be used for reference in the verification of the UHF sensor for the PD detection of transformers or GIS.

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