

# Research of UHF External Sensor Performance Calibration Test

YAN Jiangbao<sup>1, 2, \*</sup>, TAN Xiangyu<sup>2</sup>, ZHANG Changsheng<sup>1</sup>, ZHOU Lei<sup>2,3</sup> and ZHANG Shaoquan<sup>2</sup>

<sup>1</sup>College of Information Engineering and Automation, Kunming University of Science and Technology, Kunming, 650500, China

<sup>2</sup>Yunnan Electric Power Research Institute, Kunming, 650217, China

<sup>3</sup>Department of Automation, North China Electric Power University, 071003, China

\*Email:120958764@qq.com

**Abstract:** UHF sensor is one of the most important parts of GIS equipment partial discharge detection system, and its performance directly affects the accuracy of fault diagnosis results. UHF sensor lacks uniform standard, performs equivalent height test and sensitivity test to calibrate its performance, and builds a UHF sensor performance calibration test platform based on GTEM cell for testing. This paper mainly tests the equivalent height of different types of UHF external sensors at different installation angles. With the UHF detection system, the sensitivity test and performance comparison of each sensor are used to select the better sensor.

## 1.Introduction

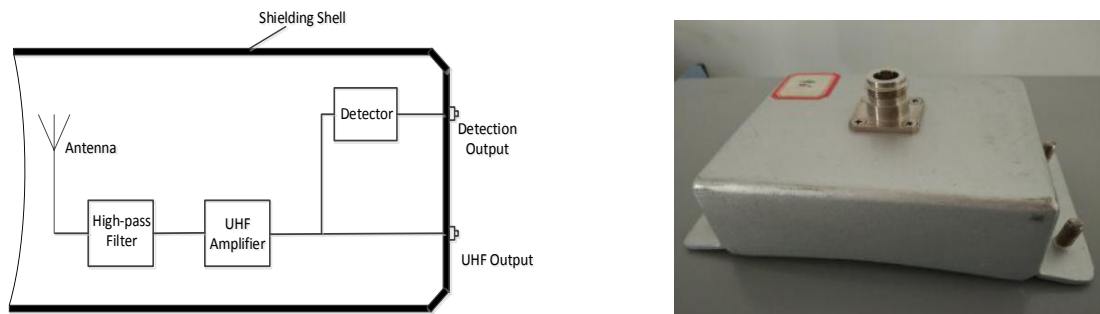
Gas Insulated Switchgear (GIS) has the advantages of miniaturization, high reliability, good safety, prevention of adverse impact to the outside, short installation period, convenient maintenance and long maintenance period. [1].As GIS is more and more widely used in power system, the accident rate in GIS increases. Therefore, it is necessary to carry out partial discharge test to detect the defects in GIS. At present, the main methods for detecting partial discharge of GIS include Ultra High Frequency (UHF) detection, pulse current method, TEV (Transient Earth Voltage) detection and ultrasonic testing[2].The UHF detection method can well shield the electromagnetic interference which is not easy to be identified, overcomes the shortcoming of low frequency and narrow frequency band of the traditional pulse current method, and is safe and reliable. It has been well used in Partial discharge detection of GIS, cable motor, combined electrical apparatus and transformer[3].

UHF sensor in the entire testing system is crucial, the performance of a direct impact on the entire testing system fault diagnosis accuracy, it is necessary UHF sensor performance calibration test.Based on the UHF detection platform of partial discharge in GTEM cell, the UHF external sensor is tested for its effective altitude and sensitivity, compared with the performance of different models to choose a better sensor.

## 2 UHF Sensor

UHF sensor by the antenna, UHF amplifier, detector, high-pass filter, the coupler and the shield shell composition, in addition to the antenna surface is epoxy board for receiving the discharge signal, everything else is the use of metal shielding material to prevent external signal interference [4].UHF sensor internal and physical structure shown in Figure 1:





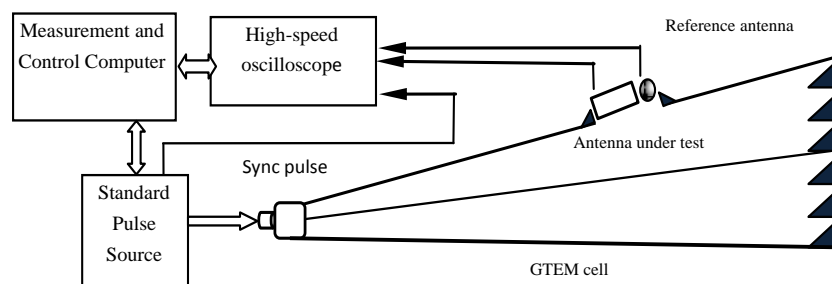
**Figure 1.** UHF sensor internal structure and physical map

In partial discharge UHF detection method, UHF sensor is divided into two types of built-in and external [5]. At present, most of GIS devices with high voltage level at home and abroad are equipped with built-in sensors pre-installed in production, which have high sensitivity and can well collect partial discharge signals generated in GIS devices. However, the introduction of built-in sensors is to a certain extent will change the internal structure of GIS equipment, may change the internal electric field distribution, causing breakdown. A large number of medium-voltage GIS equipment and GIS equipment which has been put into operation for a long time without installing built-in sensors, and external sensors are required to be installed on the inside of the GIS equipment for online monitoring [5].

The external sensor belongs to the antenna detection method and is installed on the pot insulator. The partial discharge condition is judged by detecting the electromagnetic wave signal transmitted from the insulating material. The external sensor is easy to use and disassembled and is widely used in the power system at present [6].

### 3 GTEM cell testing platform

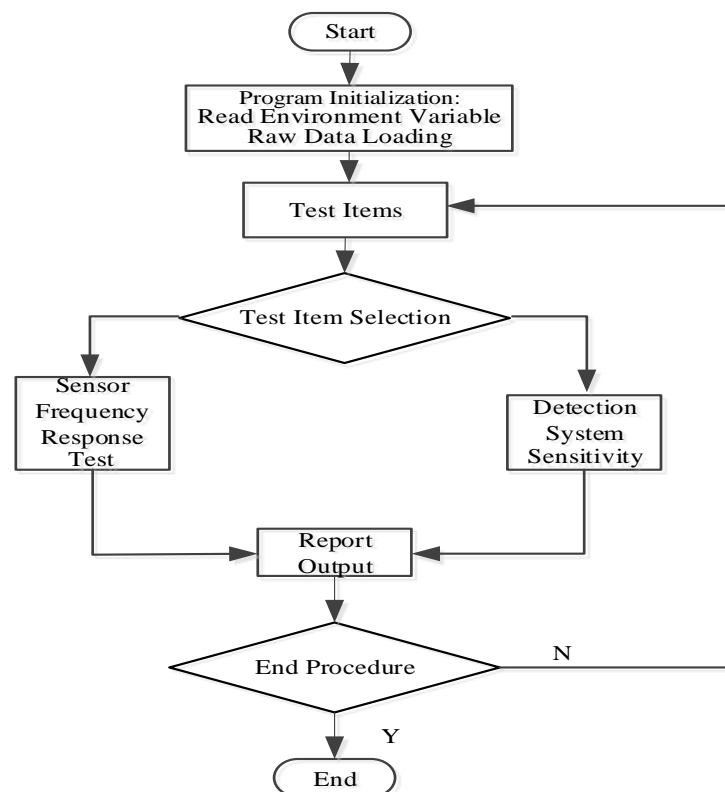
Due to the low available frequency range of traditional transverse electromagnetic (TEM) cells, which is only a few hundred megahertz, it can not effectively cover the working frequency band of UHF sensors, so the application has been limited [7]. Therefore, a Gigahertz transverse electromagnetic wave (GTEM) cell is proposed to transform the TEM cell into a semi-conical coaxial structure to prevent the reflection of indoor electromagnetic waves [8]. The size of the GTEM cell is  $4 \times 2 \times 2.5$  (L $\times$ W $\times$ H). The voltage standing wave ratio is  $<1.5$  in the 80M-2000MHz range and the input impedance is  $50\Omega$ . A test window was opened in the middle of the top of the GTEM cell and covered with a teflon cover. The sensor under test was placed on the cover to receive the signal. Window opening in the GTEM chamber near the terminal  $1/3$  of the area, where there is open space and the field strength distribution is more uniform [9]. The calibration signal is injected into the GTEM chamber through a standard calibration pulse source, and a pulsed electromagnetic field is established in the GTEM chamber. The UHF detection platform based on the GTEM cell is composed of a standard pulse voltage source, a measurement and control computer, a high-speed oscilloscope, a GTEM cell, a unipolar standard probe (reference sensor), and measurement and control analysis software, as shown in figure 2.



**Figure 2.** UHF detection system based on GTEM chamber test calibration platform

The test platform software (control/analysis) system mainly includes six parts: (1) Measurement project data management; (2) Through the serial port control signal source to generate periodic pulse calibration signal of a certain amplitude and repetition frequency; (3) Through the USB or Ethernet port control high-speed oscilloscope, the calibration signal, the reference sensor and the test sensor output signal synchronization acquisition and preservation; (4) According to the pulse time domain measurement data and reference method principle, the frequency response characteristics of the sensor under test are analyzed and calculated; (5) The control signal source scans the calibration signal amplitude, according to the signal to noise ratio (SNR) is greater than or equal to 3 principle to determine the sensitivity response of the detection system.; (6) The test data is reported output.

Specific software workflow shown in Figure 3.



**Figure 3.** System software work flow chart

The GTEM cell test platform built uses an external sensor and is installed on the top of the GTEM cell window. This approach minimizes the effect of the antenna under test on the field inside the GTEM cell, flexible and does not affect its operation, not only close to the actual installation of high-voltage equipment, but also measurement results more accurate.

#### 4 UHF external sensor equivalent height test

##### 4.1 Equivalent height

Judd M D et al proposed using the equivalent height of the frequency domain to define the coupling performance of the sensor [10]. A pulse voltage  $U_1$  is fed to the GTEM cell via a standard pulsed voltage source and a field strength  $E_1$  is generated inside the GTEM. The output voltage of the reference sensor and the sensor under test are respectively  $U_r$ ,  $U_s$ ; GTEM cell, reference sensor, the transfer function of the sensor under test are  $H_{cell}$ ,  $H_{ref}$ ,  $H_{sens}$  respectively, and the transfer characteristic of the measurement system is  $H_{sys}$ , The sensor's measurement output is respectively

$$\begin{cases} U_r = U_1 \cdot H_{cel} \cdot H_{ref} \cdot H_{sys} \\ U_s = U_1 \cdot H_{cel} \cdot H_{sens} \cdot H_{sys} \end{cases} \quad (1)$$

By subtracting Href and Hsens from the upper and lower expressions of equation (1), the expression of the transfer function of the sensor to be measured is expressed by the transfer function of the reference sensor.

$$H_{sens} = \frac{U_s}{U_r} H_{ref} \quad (2)$$

By formula (2), it can be known that when the reference transfer function Href, and the voltage response of the reference sensor and the tested sensor to the injected pulse signal are known, the transfer function Hsens of the tested sensor can be obtained.

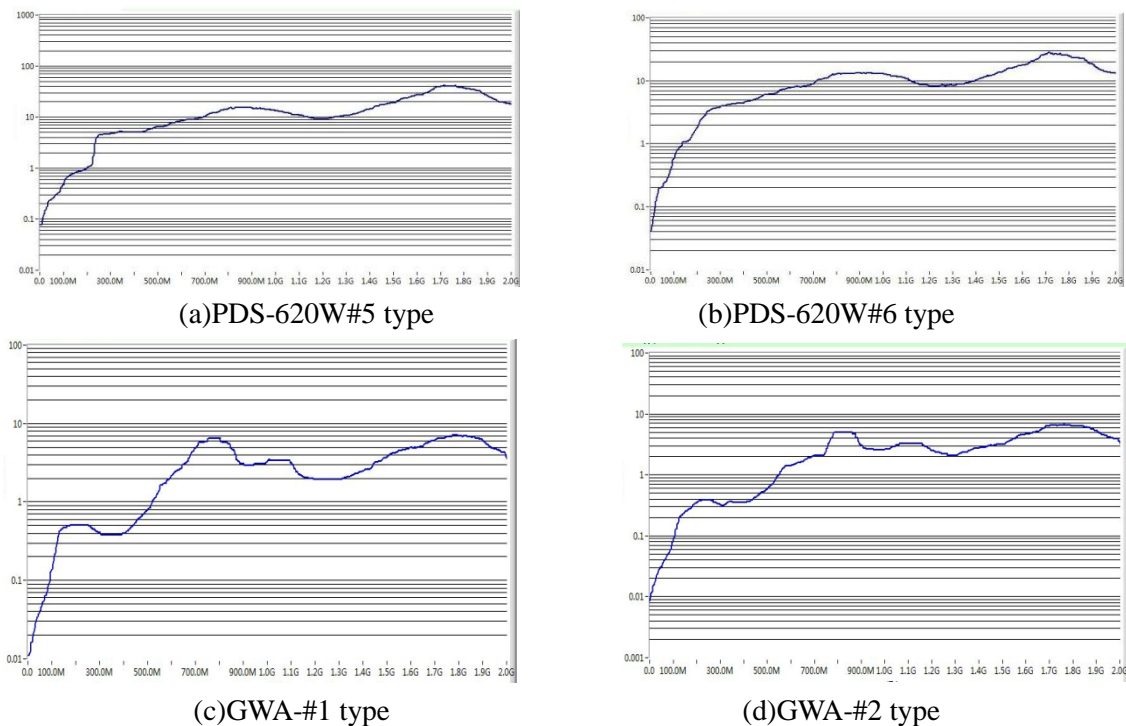
The test sensor is placed on the test window of the GTEM cell, that is, the antenna under test. The electric field at this position is  $E_0(f)$ , and the voltage signal output by the antenna is  $U_0(t)$ . It is converted into frequency domain signals  $E_0(f)$ ,  $U_0(f)$  after FFT transformation. The unit of electric field is V/mm, and the unit of voltage is V. According to the relationship between the incident electric field and the output voltage, the transfer function of the sensor to be measured is obtained:

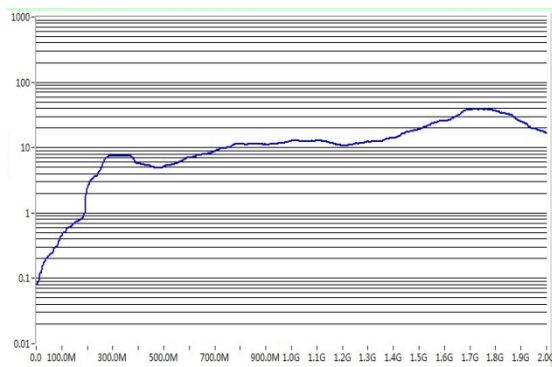
$$H_{sens}(f) = \frac{U_0(f)}{E_0(f)} \quad (3)$$

From Equation (3), the unit of Hsens(f) is mm, which is known as the effective height in the frequency domain. When  $E_0(f)$  is constant, the higher the output voltage  $U_0(f)$  of the sensor is, the stronger its coupling ability is, ie, the greater the equivalent height. It can be seen that the size of the equivalent height reflects the receiving capability of the sensor and is used to characterize the relevant performance of the sensor. In the test band of 0.3 ~ 1.5 GHz, the cumulative height of the equivalent height of each frequency point of the sensor is called the average equivalent height [11].

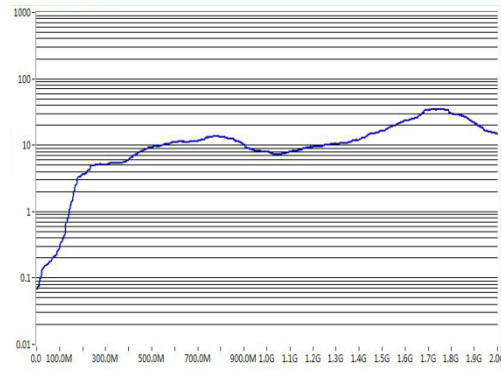
#### 4.2 Equivalent height test of different types of UHF external sensors

In this paper, six UHF external sensors from three vendors were tested from different models and different installation angles, including two models of PDS-620W, GWA, and SPM-2/GPD. The test result screenshot is shown in Figure 4, and the statistical data results are shown in Table 1.





(e)SPM-2/GPD #8 type



(f)SPM-2/GPD#9 type

**Figure 4.** different product types UHF external sensor frequency response curve**Table 1.** Equivalent height of different models of sensors

Model	Average equivalent height/mm
PDS-620W-#5	11.85
PDS-620W-#6	10.22
GWA-#1	3.14
GWA-#2	2.81
SPM-2/GPD #8	11.44
SPM-2/GPD#9	11.89

When the incident field intensity is the same, the higher the output signal of the GTEM cell antenna, the stronger the coupling performance of the sensor, ie, the greater the equivalent height. From the above results, it can be seen that there is a significant difference in the equivalent height of different types of sensors, and the average equivalent height of sensors in the same factory exhibits a certain degree of consistency. The average equivalent height of the GWA model sensor is obviously lower than that of the other two types of sensors by the above-mentioned frequency response curves of the sensor and the average equivalent height data. The average equivalent height difference between them is 3 to 5 times, which indicates that the GWA model sensor is relatively poor with the PDS-620W model and the SPM-2/GPD model.

#### 4.3 UHF external sensors with different mounting angles

Since the sensor is not ideally mounted to various fixtures during actual installation, UHF external sensors with different mounting angles are tested. The test result data is shown in Table 2.

**Table 2.** different mounting angle UHF external sensor equivalent height

Model	Average equivalent height/mm		
	0 °	90 °	180 °
PDS-620W-#5	11.85	1.66	11.57
PDS-620W-#6	10.22	3.9	10.82
GWA-#1	3.14	2.43	4.56
GWA-#2	2.81	3.02	2.61
SPM-2/GPD #8	11.44	1.54	10.22
SPM-2/GPD#9	11.89	3.7	12.61

The data in Table 2 shows that the equivalent heights of the sensors at different mounting angles

are different, indicating that different mounting angles have an impact on the detection performance of UHF external sensors. The effective height of the sensor is basically the same at  $0^\circ$  and  $180^\circ$ , and the effective height at  $90^\circ$  is obviously lower than  $0^\circ$  and  $180^\circ$  about 3 to 6 times. Among them, the performance of the GWA sensor is relatively poor compared to other models. The conclusion shows that the different mounting angles of UHF external sensors have a great influence on the acceptance performance (coupling performance) of the sensors.

### 5. Sensitivity testing

The UHF detection system measures the electric field strength of electromagnetic waves radiated by partial discharges. In order to unify the unit problem of the UHF detection system, the transient peak pulse electric field intensity is used to express the partial discharge UHF detection result. The sensitivity is defined as the peak value of the minimum pulsed electric field strength that the UHF detection system can recognize, that is, the field strength corresponding to the minimum output voltage that the detection system can detect. The smaller the field intensity peak that the UHF detection system can recognize, the better the sensitivity.

The field strengths corresponding to different output voltages are calibrated by standard sensors with known frequency response curves:

$$E_i(t) = IFFT[E_i(f)] = IFFT\left[\frac{U_o(f)}{H_{sens}(f)}\right] \quad (4)$$

The sensor under test is placed on the GTEM cell close to the top window of the upper 1/3 of the terminal, connected to the relevant measurement equipment, and a standard pulse signal is injected into the GTEM cell to adjust the output voltage of the signal source, until under test system detects no voltage signal. The  $E_i(t)$  value at this time is the minimum pulse field strength value, that is, the sensitivity of the system under test. The output voltage of the signal source is continuously increased until a certain value makes the signal received by the detection system reach the upper limit. At this time,  $E_i(t)$  is the maximum pulse field strength peak value, that is, the maximum measurable value of the detection system.

Through the above method, three different types of sensor sensitivity of the UHF detection system were tested. The test data is shown in Table 3:

**Table 3.** Sensitivity Test Data Sheet

Model	Minimum Injection Voltage U(V)	Minimum Injection Voltage Corresponding to the Peak Field Strength $\mu\text{V/m}$	Voltage Injection Upper Limit U(V)	Injection Upper Limit Voltage Corresponding to the Peak Field Strength $\mu\text{V/m}$
PDS-620W	5	0.0538	40	0.43
GWA	6	0.1038	10	0.208
SPM-2/GPD	6	0.0645	8	0.086

The peak value of the field strength corresponding to the minimum output voltage of the signal source of the PDS-620W type sensor detection system in the table is  $0.0538 \mu\text{V/m}$ , that is the sensitivity is  $0.0538 \mu\text{V/m}$ ; When the received signal of this detection system reaches the upper limit, the maximum output voltage of the signal source is 40V, and the corresponding peak field strength is  $0.43 \mu\text{V/m}$  maximum. The dynamic range of the detection system can be derived from the above minimum field strength peak and maximum field intensity peak. The smaller the sensitivity of the UHF sensor, the better the performance. Compared with the above three sets of data, the PDS-620W model sensor has the best sensitivity and can detect the maximum dynamic range of the system, so its performance is best. Based on the above test data, a better sensor can be selected and used in the actual system.



## 6. Conclusions

In this paper, UHF external sensors based on GTEM cell partial discharge UHF detection system are tested to test the performance. The test results show that the test data show that the coupling performance of UHF sensors of different types is significantly different. The greater the equivalent height, the better the coupling performance. Different installation angles also affect the acceptance performance (coupling performance) of the sensor to a certain extent; the smaller the UHF sensor sensitivity, the better the performance. Through the above performance tests, compare the test data of different sensors, better sensor can be selected according to the actual demand.

The evaluation platform can evaluate the internal and external sensor characteristics, system sensitivity, and partial discharge ultra-high frequency dynamic range characteristics. It can evaluate the overall performance of different manufacturers of different types of UHF detection instruments to solve quantitative calibration issues and comprehensive evaluation issues of the GIS partial discharge detection system, provide a good reference for establishing a complete and standardized test calibration system. UHF sensor performance test can be used to evaluate the performance of the entire UHF partial discharge detection system, improve the accuracy of GIS fault diagnosis results, and ensure the normal operation of the system.

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