Research on Ultra-high Frequency Receiving Characteristic of GIS Basin-type Insulator Grading Ring

WANG Zengbin1 ,GU Wenguo1 ,RAO Zhangquan1 ,LÜ Hong1 ,LI Xingwang1 ,WU Ji1 ,LI Liang 2

(1.Electric Power Research Institute of Guangdong Power Grid Co., Ltd., Guangzhou, Guangdong 5 1 0080,China;2. State Key Laboratory for Alternate Electrical Power System with Renewable Energy Sources, North China Electric Power University, Beijing 1 02206,China)

Abstract: With mass application of shielding ring basin-type insulator and constant miniaturization of equipment size, utilization of gas insulated metal-enclosed switchgear partial discharge ultra-high frequency sensor is greatly restricted and PD UHF detection is becoming difficult day by day. Aiming at above problems, regarding basin-type insulator grading ring as UHF aerial, relationship between loop aerial and factors such as PD apparent discharge magnitude, sensor position and grounding mode was tested. Meanwhile, frequency response characteristics of various UHF sensors were compared and analyzed. It was considered that GIS basin-type insulator grading ring was provided with good UHF receiving characteristic and was applicable for GIS PD test as UHF aerial.

Key words: gas insulated metal-enclosed switchgear; partial discharge; ultra-high frequency; grading ring; loop aerial

Application of GIS (gas-insulated metal-enclosed switchgear) is becoming more common in power system[1-2] and has more significant influence on safe operation of power grid. Thus, to monitor GIS operation status and prevent GIS equipment failure, GIS PD live detection as well as on-line monitoring became the research hot spot for key technology of improving GIS operation reliability[3-6].

Partial discharge within GIS generates delicate current on the machine shell, causing high frequency current impulse that flows through ground wire; partial discharge also causes abrupt gas pressure increase in passage, generating longitudinal wave or ultrasonic wave within GIS inner gas, as well as various sound waves on metal shell; partial discharge also causes SF_6 gas decomposition or emit light and heat. These physics and chemical variation characteristics can all be subject to partial discharge test[7-8]. Thus partial discharge test applies ultrasonic method, ultra-high frequency method (UHF), impulse current method, light test method and SF6 gas decomposition, applicable for GIS inner default detection. Viewing from the result of field application, UHF method is superior in sensitivity, and is convenient for practical operation and installation, thus, UHF is considered one of the most efficient method for GIS partial discharge detection.

In accordance with sensor installation method, PD UHF test can be divided into external sensor method and internal sensor method. External sensor method utilizes sensor outside GIS for partial discharge test, this requires access to PD UHF signal outside GIF, for GIS main body is basically at a perfectly enclosed status, sensor can only be placed outside

basin-type insulator. However, in consideration of safe grounding and aging protection, current GIS manufacturers generally add shielding ring outside basin-type insulator, reserving plug hole only, some manufacturers even seal the plug hole with metal. Therefore, testing method for GIS internal partial discharge with external sensor is getting more difficult and impractical to some GIS.

Another method is placing UHF sensor inside the GIS, this way not only the problem of installation position of external sensor can be solved, but also improves capability of anti-interference of the test system. However, there's no position left for internal sensor by the GIS design, handspike for installation must be added to GIS, causing extra potential risk to GIS operation; meanwhile, performance of UHF internal sensor is closely related to dimension and structure of the handspike, thus handspike dimension and structure must be ensured to guarantee sensing performance, yet it is hard to realize processing of handspike with appropriate dimension by reason of GIS miniaturization and large variation in dimension between different GIS equipment.

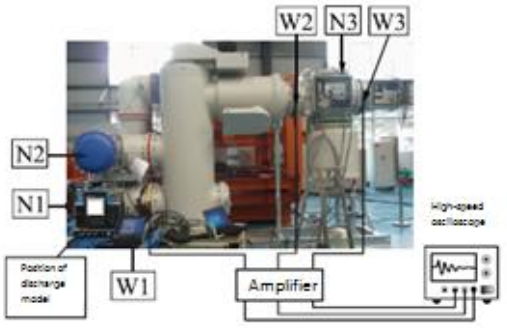
Due to obstacles mentioned, the major problem that restrains application of GIS PD UHF test is conducting partial discharge test within GIS.

To improve internal electric field distribution of basin-type insulator, some GIS manufacturers pours grading ring within basin-type insulator. With grading ring poured within basin-type insulator, partial electric field can be more even. Grading ring is generally designed to be arc shape or non-closed circle and with characteristics of UHF antenna, if applied as UHF sensor, the current problem of UHF sensor installation and layout will be solved. The University of Stuttgart conducted a joint study with ABB and RWE Energy Group on performances of loop sensor with three-phase combination GIS (175kV)[9]; Japanese company Toshiba jointly conducted performance test of loop sensor with Electric Power Cooperation and Waseda University, yet no research has been conducted comparing performances between the existing test sensor and grading ring UHF aerial, especially much space to be filled for domestic research in this field.

This article studied PD UHF test performance of basin-type insulator grading ring on 110kV GIS, compared test performances of basin-type insulator grading ring and existing internal and external UHF sensor, discussed merit and demerit as well as feasibility of applying grading ring as UHF sensor.

1. Test system

Test platform is designed on 110kV three-phase common box GIS. Diagram of test platform is shown on figure 1, test platform is consist of simulated partial discharge model, 110kV GIS substance, test sensor and test backstage.



N1, N2, N3 – internal sensor; W1, W2, W3 – external sensor

Figure 1 Structure diagram of UHF sensor virtual height test platform

Install partial discharge model inside GIS1 mother disconnector cabinet, installation method as shown on figure 2. Connect high voltage electrode of the model to V-phase conductor of insulated switch, connect ground terminal to GIS shell; discharge model applies needle-plate electrode structure, connect

needle end to high voltage and ground the plate electrode; all tests are conducted under circumstance of voltage imposed to V-phase.

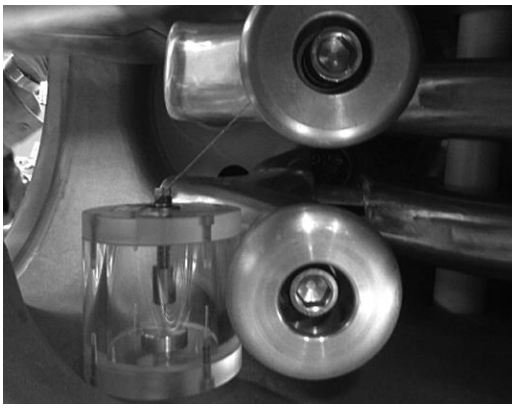


Figure 2 Installation schematic diagram for partial discharge model

Install external UHF sensor on breaker1 mother side basin-insulator and both sides of line disconnecting switch, by reason that installation position of internal sensor is restricted by GIS structure, internal sensor is installed in 1 mother disconnector cabinet, 2 mother disconnector cabinet and line disconnector cabinet. Measurement of virtual height applies UHF sensor test platform[10] developed by electric power research institute of Guangdong Power Grid Corporation on basis of gigahertz transverse electromagnetic (GTEM) cabinet, test result as shown on table 1.

Table 1 Average virtual height of different sensor

Sensor Number	Average virtual height/mm	Sensor Number	Average virtual height/mm
N1	17.04	$W3_S$	6.45
N2	16.93	$W1_b$	13.35
N3	16.91	$W2_b$	13.62
$W1_S$	6.32	$W3_b$	13.54
$W2_S$	6.51		

$W1_S$, $W2_S$, $W3_S$-UHF external sensor specially applied to basin-type insulator with grading ring structure; $W1_b$, $W2_b$, $W3_b$ is common UHF external sensor.

UHF external sensor $W1_S$, $W2_S$, $W3_S$ are characterized with small active test area yet strong energy detected within unit area. External sensor is covered on plug-hole of basin-type insulator during the test, plug-hole is 45mm in length and 20mm in width, as shown on figure 3.

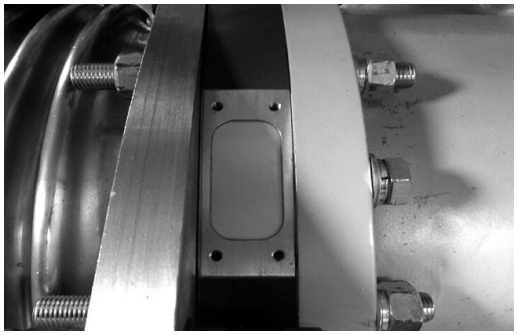


Figure 3 Plug-hole on basin-type insulator

Inner structure of GIS platform basin-type insulator is shown on figure 4, grading ring is poured outside conductor on every phase. Connect one end of the grading ring to signal cable, and the other end connected or suspended to the ground, measure respectively test performance of the aerial, as shown on figure 5.

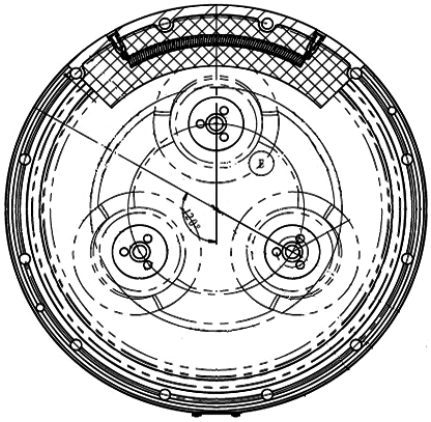


Figure 4 Basin-type insulator structure

Figure 5 Connection for loop aerial

Name loop aerial (grading ring) at W1, W2, W3 as $W1_c$, $W2_c$, $W3_c$. The signal will be amplified after tested by sensor and eventually recorded by oscilloscope. Oscilloscope applies type WAVERUNNER640Zi produced by Lecroy, with 4 GHz analog bandwidth and 40GS/s sampling rate.

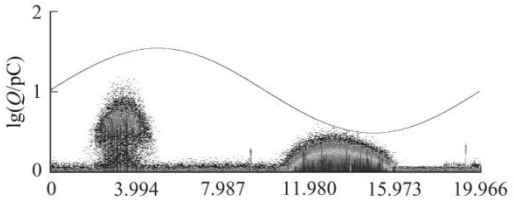
Gas-insulated transformer is applied to add voltage to GIS platform during the test, magnitude of partial discharge is tested with impulse current method using OMICRON MPD600 PD tester during the voltage adding process, test data is used as reference for comparative analysis.

UHF sensor test spectrogram accessible in this article is average value of 100 groups of test data gained after synchronous triggering.

2. Response characteristic test of loop aerials

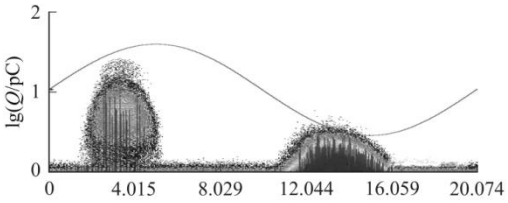
2.1 Response characteristic of loop aerials under different magnitude of partial discharge

Discharge patterns with apparent discharge magnitude at 10pC, 20pC, 30pC can be obtained by changing added voltage, as shown on figure 6. Discharge pattern is evidently featured with marginal discharge, magnitude of discharge increases as voltage rises, frequency of discharge gradually rises.



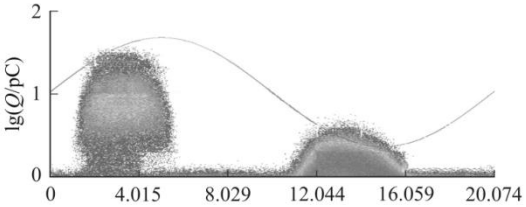
Time/ms

(a) 10pC



Time/ms

(b) 20pC



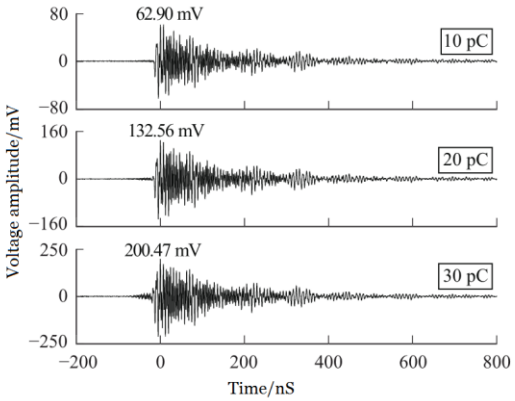
Time/ms

(c) 30pC

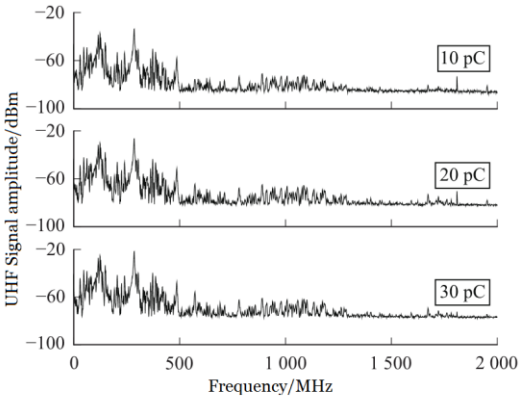
Figure 6 PD pattern under different apparent discharge magnitude measured with impulse current method

PD UHF signal measured by loop aerial $W1_c$ (one end of loop aerial is grounded) at 10pC, 20pC, 30pC apparent discharge is shown on figure 7.

The result shows that amplitude of time-domain signal measured by loop aerial increases along with apparent discharge rise, basically the two variables are related in linearity (as shown on figure 7(a));



(a) Spectrogram for time-domain response



(b) Spectrogram for frequency response

Figure 7 PD signal of loop aerial $W1_c$

Frequency response of loop aerial converges

below 500MHz or within range of 800MHz~1.25GHz, best frequency response appears under 500MHz (as shown on figure 7(b)). This is diverse from common UHF sensor, frequency response for common UHF sensor mainly converges between 300MHz~1.5GHz, high frequency response is relatively superior.

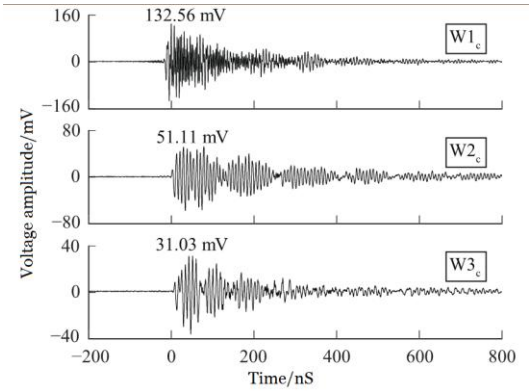
2.2 Influence of installation position to response characteristics of loop aerial

Imposed voltage causes partial discharge power source to generate 20pC apparent discharge magnitude, $W1_c$, $W2_c$, $W3_c$ (with one end of the loop aerial grounded) are used to measure PD UHF signal, the results are shown on figure 8.

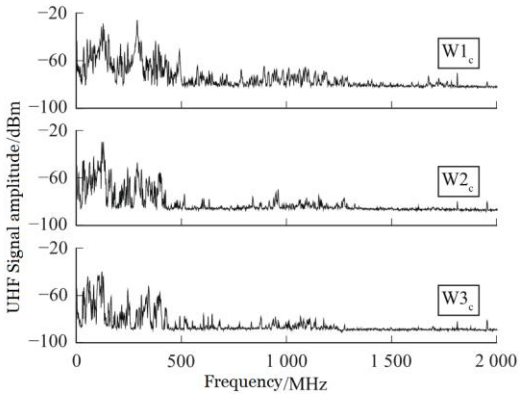
Along with distance expansion between loop aerial and partial discharge power supply, amplitude of UHF signal measured with loop aerial reduces evidently, wave shape appears tendency of oscillation, this is mainly caused by refraction and reflection of electromagnetic wave. As drawn from frequency response characteristics, signal near 500MHz is greatly weakened along with distance increase.

2.3 Influence of loop aerial grounding mode to response characteristics

Loop aerial is grounded at one end or with one end suspended to the ground, which will effect inductive potential on loop aerial, meanwhile change cut-off frequency of inductive electromagnetic wave thus impose influence on loop aerial response characteristics.



(a) Spectrogram for time domain response



(b) Spectrogram for frequency response

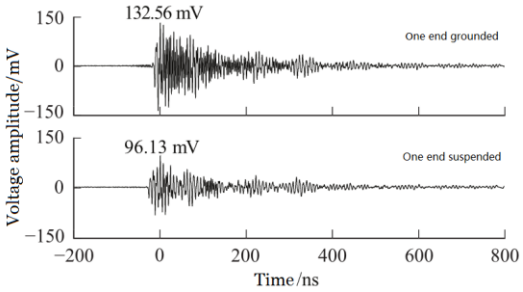
Figure 8 Partial discharge signal of loop aerial measured at different position at 20pC discharge magnitude

Imposed voltage causes 20pC apparent discharge generated by partial discharge power supply, test $W1_c$ response characteristics correspondingly under circumstance of loop aerial grounded at one end and suspended to the ground at one end, result as shown on figure 9.

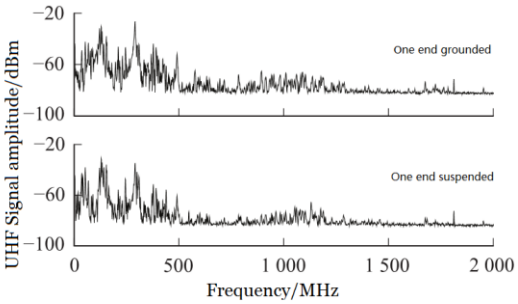
Amplitude of UHF signal when one end is grounded evidently surpasses the situation of one end suspended to the ground; signal spectrum of loop aerial under two different circumstances are basically coherent, discharge magnitude is mainly converged under 500MHz, yet scanty within range of 800MHz~1.25GHz.

3. Comparison of response characteristics of different UHF sensor

As shown from the above results, grading ring for basin-type insulator (loop aerial) has the characteristic of PD UHF reception. To compare differences in characteristics between loop aerial and the existing GIS PD UHF sensor, test reception characteristics at 20pC apparent discharge magnitude at different installation position of internal sensor, common UHF external sensor, UHF external sensor for plug hole structure and loop aerial. Test results are as shown on figure 10.

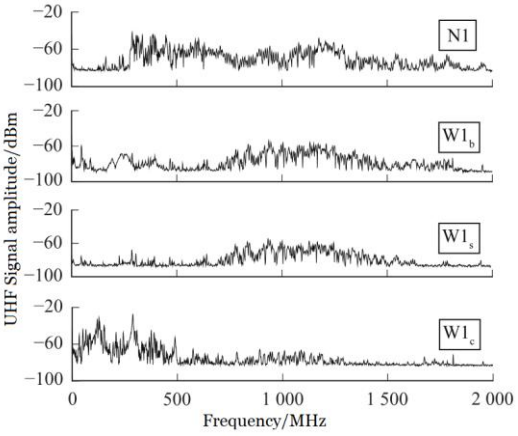


(a) Spectrogram for time-domain response

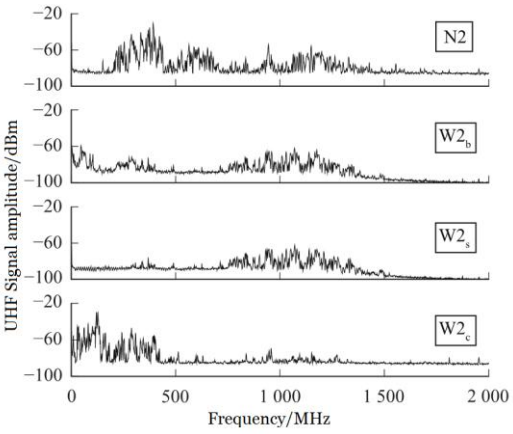


(b) Spectrogram for frequency response

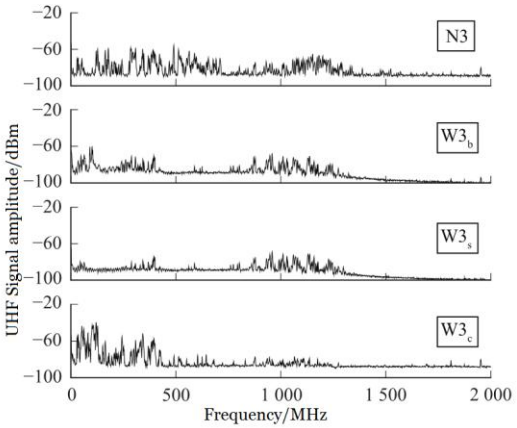
Figure 9 Influence of grounding mode of loop aerial to test performance



(a) Frequency spectrum measured at sensor 1



(b) Frequency spectrum measured at sensor 2



(c) Frequency spectrum measured at sensor 3

Figure 10 Curve of frequency response performance among sensors

The result shows that frequency response performance varies among four sensors, distribution of frequency response of internal sensor is relatively even within range of 300MHz~1.25GHz, range of response frequency converges towards 500MHz and 1.2GHz as the distance increases, two evident response peak emerges; response frequency spectrums are basically coherent between common UHF external sensor and external UHF sensor for plug hole structure, response frequency mainly converges between 800MHz and 1.5GHz, yet common UHF external sensor has better response performance around 250MHz, along with increase of distance between charging power supply and the two sensors, amplitude of frequency response reduces while frequency distribution basically stays the same; response frequency of loop aerial mainly converges below 500MHz, minor peak value appears between 800MHz~1.25GHz.

To compare response amplitude of various sensors, figure 11 shows maximum instantaneous power of different sensor at different position.

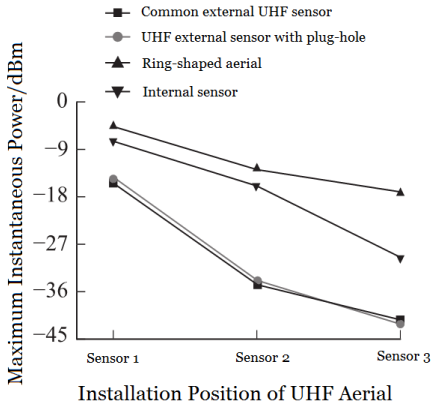


Figure 11 Frequency response performance curve of various sensors

As drawn from figure 11, amplitude detected on loop aerial greatly exceeds signal amplitude detected on the other three aerials; reduction of frequency response amplitude of loop aerial tends to be smaller along with distance increase between sensor and signal source, this is because response frequency of loop aerial is lower (as shown on figure 10), yet low frequency signal trafficability is better; frequency response amplitudes of common UHF external sensor and UHF external sensor for plug-hole structure are basically coherent, this is due to transmission of UHF signal is limited by plug hole, common UHF external sensor and UHF external sensor for plug hole structure has the same actual induction area, though average virtual height differs greatly between the two, response amplitudes during this test are still equal; response amplitude of internal sensor evidently exceeds amplitude of external sensor, yet lower than loop aerial.

4. Conclusion

This article studies feasibility of grading ring of basin-type insulator serving as UHF aerial in response to the difficulty of on-site application of GIS UHF sensor, tested relativity between reception performance of loop aerial (grading ring for basin-type insulator) and partial discharge apparent discharge magnitude, sensor position, grounding mode, compared frequency response performance of various UHF sensor. Following conclusions can be drawn from research results:

a) Grading ring for GIS basin-type insulator has characteristics of partial discharge UHF signal test, applicable for partial discharge test as UHF aerial;
b) Frequency response amplitude of loop aerial evidently exceeds that of internal sensor as well as existing external sensor at the same (or similar) position;
c) Response frequency of loop aerial mainly converges below 500MHz, minor peak value appears within range of 800MHz~1.25GHz, which differs from features of high frequency (800MHz~1.25GHz) range response characteristics of existing UHF sensor;
d) Time-domain response amplitude of loop aerial and apparent discharge magnitude is related in approximate linearity;
e) Response performance is distinctly superior when loop aerial is grounded at one end than one end suspended to the ground.

As drawn from conclusions above, grading ring of GIS basin-type insulator serving as UHF aerial for GIS inner partial discharge test is applicable, this technology is a potential solution to the challenge of test and installation of UHF sensor on GIS, especially GIS with shielding ring structure of basin type insulator. Moreover, due to low response frequency of loop aerial, it is more fragile to on-site UHF interference, therefore improvement of loop aerial on-site anti-interference will be the focus of following study.

Reference:

[3] JUDD M D,FARISH O,HAMPTON B F. Broadband Couplers for UHF Detection of Partial Discharge in Gas-insulated Substation[J]. IEEE Proc-sci. Meas. Technol.,1995, 1 42(3):237-243 .

[4] WANG Jiansheng, QIU Yuchang, WU Xianghua, et al. Frequency Response Characteristics of the UHF Sensors for Partial Discharge Detection in Gas[J]. Proceedings of the CSEE, 2000,20(8):42-45 .

[5] TANG Ju, WEI Gang, SUI Chaixin, et al. Research on the Dipole Antenna Sensor with Broadband for Partial Discharge Detection in Gas[J]. High Voltage Engineering,2004,30(3): 29-3 1 .

[6] DING Dengwei, GAO Wensheng, LIU Weidong. Analysis on the Typical Partial Discharge Using UHF Detection Method for GIS [J]. High Voltage Engineering,20 1 1 ,37 (3):706- 7 1 0.

[7] CHEN Chenyi, TAI Chengchi, SU Chingchau, et al. GIS Partial Discharge Examination and Classification from the Online, Measurement [C] // 2008 International Conference on Condition Monitoring and Diagnosis. Beijing:[s.n.],2008: 2 1-24.

[8] HAN Xiaolian, FENG Yunping, QIN Yuchuang, et a.l Partial Discharge and the Measurement in GIS[C] Conference Record of the 1 996 IEEE International Symposium on Electrical Insulation. Montreal, Quebec, Canada:[s.n.],1 996:1 6-1 9.

[9] NEUMANN C,KRAMPE B,FEGER R,et al. PD Measurements on GIS of Different Designs by Non-conventional UHF Sensors [C]// 2 1 ,Rue d'Artois,F-75008. Paris: [s.n.], 2000:1 5-305 .

[10] LI Xingwang, LU Qifu, TANG Zhiguo, et al. Study on Sensitivity of UHF Sensors for GIS Partial Discharge Detection [J]. High Voltage Engineering. 20 1 2,38(S):1-4