THE COMPARISON OF SENSITIVITY BETWEEN THE UHF AND ULTRASONIC METHODS FOR PARTIAL DISCHARGE DETECTING IN GIS

Bibo Geng[1*], Chengrong li[1*], Bo Qi[1*], Le Yu[1*], Jinxin Gao[1*]
[1]High Voltage and EMC Beijing Area Major Laboratory, North China Electric Power University, Beijing, China
*Email: gengbibo@126.com

Abstract: In order to compare the sensitivity between the UHF and ultrasonic methods for partial discharge detecting in GIS, a 252kV GIS experimental platform was established. Five typical defect models are taken into consideration, including metal particle stuck on the insulator surface; free metal particle on the insulator surface; high voltage electrode defect; ground electrode defect and poor contact of high voltage electrode. Through the PD inception voltage and the PRPD (phase resolved partial discharge) spectrogram of UHF and ultrasonic signals, the sensitivity and feature of UHF and ultrasonic methods could be compared. The results indicate that: 1)Compared to the ultrasonic method, the UHF method could detect all five defects mentioned above with high sensitivity. 2) The ultrasonic method could only detect some models with high sensitivity.

1 INTRODUCTION

GAS Insulated Substation (GIS) has been widely used in the filed of high voltage transmission system attribute to its small volume and perfectly anti-interference performance. Some GIS have been used for 20~30 years. So it is essential to deal with insulation on-line monitoring to GIS to improve the reliability of power system [1]. Partial discharge activity is the most prominent indicator of insulation degradation in GIS [2]. Since the frequency band used to acquire the partial discharge signals is relatively low, the conventional measuring method (IEC60270) is not suitable for on-line partial discharge detection [3]. So in recent years, UHF and ultrasonic methods have been more and more used for PD on-line monitoring thanks to their principle advantage of minimal noise interference.

The principle on UHF method is to detect the high frequency electromagnetic waves emitted from PD source. And for ultrasonic method, the pressure waves generated in the event of PD will be captured. In the past, researchers focalize their work on the pattern recognition, PD source location, etc [4-7]. But For the field measurement engineers, the most often problem is whether UHF and ultrasonic method could detect different insulation defects in GIS with sufficient sensitivity and how to find a reliable means to use these two methods for more accurate PD on-line measurements. So a comparative study on the sensitivity between the UHF and ultrasonic method for partial discharge detection in GIS is necessary.

This paper is going to compare the sensitivity of UHF and Ultrasonic methods for partial discharge in GIS. A 252kV GIS experimental platform based on a real GIS equipment was established. And five typical partial discharge models in simulation of the common and hazardous discharge faults in GIS field operation were set in the experiment tank. The experiment results are supposed to be used as helpful references when the UHF and Ultrasonic methods are used for partial discharge detection in GIS.

2 EXPERIMENTAL SETUP

2.1 The experiment circuit

The experiment circuit is showed in figure 1. A 150kV experiment transformer is used to provide AC high voltage for the GIS. All the high voltage electrodes are covered with grading rings and grading shields to prevent corona. The data acquisition unit and PC are used to collect, record and analyse the data of UHF signals and acoustic emissions.

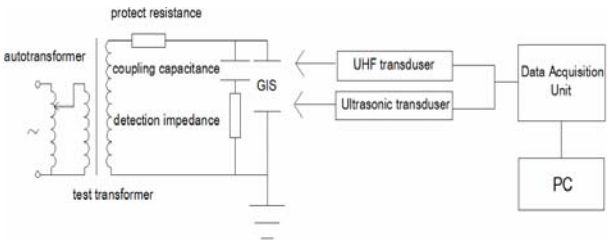


Figure 1: Schematic diagram of test platform

2.2 The experiment vessel

Figure 2 shows the L-shaped 252kV GIS which was constructed for the study. It contains a input high-voltage bushing and eight air chambers of various sizes. Every chamber is filled with 0.4MPa SF_6. The upper chamber is used as the experiment chamber, in which all test models are set up.

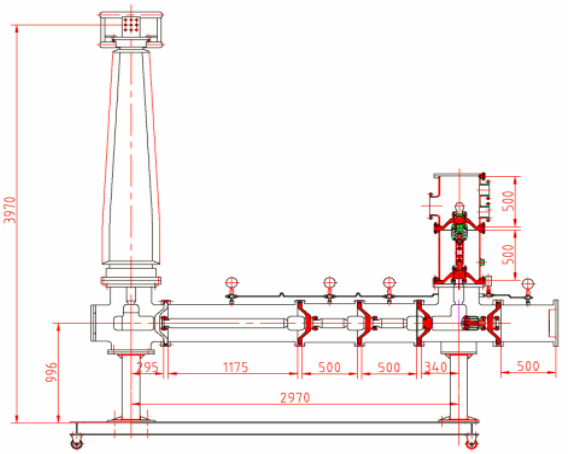


Figure 2: Structure of the 252kV GIS

2.3 Partial discharge detection device

The EFS1 UHF sensor and RPA1F preamplifier are used to detect the UHF signals. The detection band is from 300MHz to 2GHz. And the gain of the preamplifier is 40dB. The ultrasonic signals are detected by the AS75I Ultrasonic sensor and RPA1F preamplifier with the band range from 40kHz~800kHz, the gain of 40dB.

Taking the structure of GIS and detection sensitivity into consideration, the UHF sensor is fixed on the observation window of the test chamber. The ultrasonic sensor is fixed on the hand hole of the GIS. And some organic silicon is filled between the chamber and the ultrasonic sensor in order to improve the sensitivity of the ultrasonic detection. The location of these two sensors is shown in figure 3 and figure 4.

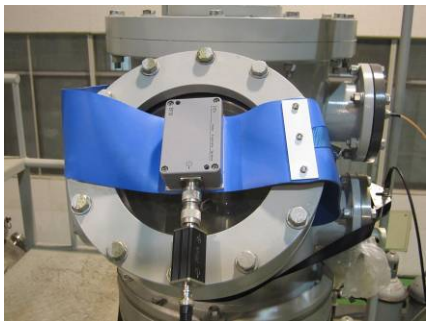


Figure 3: Location of the UHF sensor

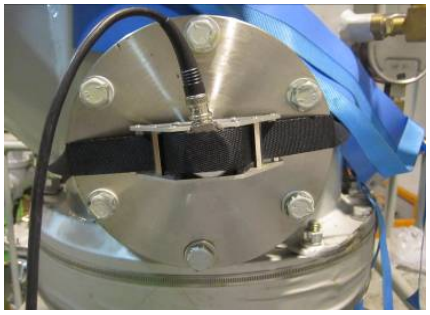


Figure 4: Location of the ultrasonic sensor

2.4 Defect models

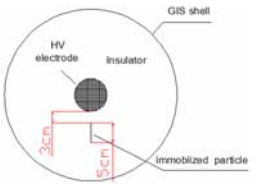
Metal particle stuck on the insulator surface: An aluminium wire of 5cm in length and 0.8mm in diameter is stuck on the insulator surface to simulate the often occurred fault in GIS that some fallout metal particles such as screws are immobilized on the insulator. The wire is set in parallel with the electric field line. The model is shown in figure 5(a) .

Free metal particle on the insulator surface: In order to simulate the often occurred fault in GIS that free metal particles fall on the insulator surface, 10 aluminium wires of 1cm in length and 0.8mm in diameter and 10 aluminium wires of 2cm in length and 0.8mm in diameter are set freely on the insulator surface closing to the GIS sheath. The model is shown in figure 5(b).

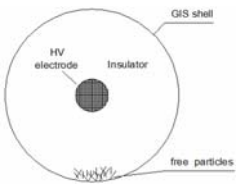
High voltage electrode defect: The triple junction in GIS where the metal electrode meets the solid insulator in SF_6 has a weak insulation and could initial surface flashovers. In order to simulate this fault, an aluminium wire of 2cm in length and 0.8mm in diameter is positioned in parallel with the electric field line, clinging to the high voltage electrode. The model is shown in figure 5(c).

Ground electrode defect: Protrusion on the sheath is one of the most frequently ground electrode faults in GIS. An aluminium wire of 2cm in length and 0.8mm in diameter is positioned in parallel with the electric field line, clinging to the metal sheath of GIS in order to simulate this fault. The model is shown in figure 5(d).

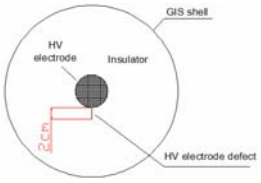
Poor contact of high voltage electrode: During the operation of GIS, some incidents such as switching operation or mechanical vibration can lead float conductor. To model this fault, high voltage electrode grading shield is made to insulate the high voltage electrode. The model is shown in figure 5(e).

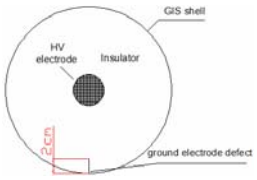


(a) Immobilized particle

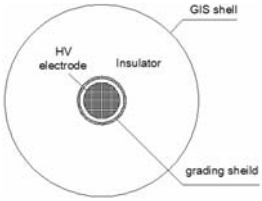


(b)Free particles





(c)HV electrode defect (d) Ground electrode defect



(e) Poor contact of high voltage electrode

Figure 5: The schematic diagram of defect models

3 EXPERIMENTAL METHOD AND DATA ANALYSIS

3.1 The experimental method

After the defect model is set up carefully, the experiment chamber is vacuumed and filled with 0.4MPa SF_6. After that, the applied voltage is raised slowly until stable partial discharge is detected. The inception discharge voltage detected by UHF sensor V_1 and the inception discharge voltage detected by ultrasonic sensor V_2 are recorded. Then the applied voltage is gradually raised. And the raising step is different among each model. The duration time of each specific voltage level is 5 minutes. The phase resolved partial discharge (PRPD) spectrogram of UHF signals and acoustic emissions are recorded to compare the sensitivity of these two PD detection methods.

3.2 The comparison of inception discharge voltage

The inception discharge voltage is defined as the applied voltage when the UHF sensor and ultrasonic sensor begin to detect stable discharge signals. The inception discharge voltage by UHF sensor (V_1) and by ultrasonic sensor (V_2) under five defect models as well as the comparison between them (V_2- V_1) are shown in table1.

Table 1: comparison of the discharge inception voltage under different fault models

PD Models	V_1(kV)	V_2(kV)	V_2- V_1(kV)
Metal particle stuck on the insulator surface	60.9	75.0	14.1
Free metal particle on the insulator surface	16.7	18.0	1.3
High voltage electrode defect	62.5	74.5	12.0
Ground electrode defect	60.4	63.0	2.6
Poor contact of high voltage electrode	37.9	37.9	0

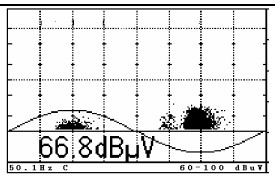
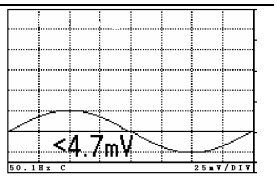
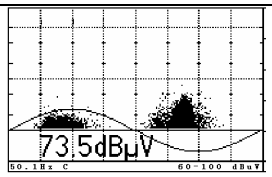
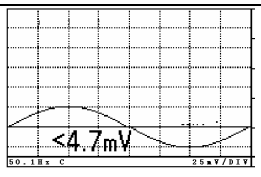
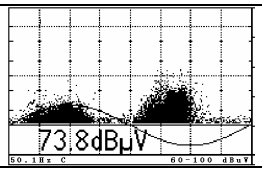
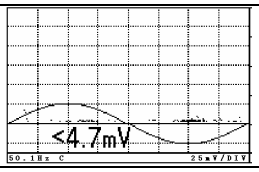
From the above table, it is found that among all the five defect models, the UHF sensor detect the PD signals firstly (V_1<V_2). For poor contact of high voltage electrode model, V_1 is the same as V_2. For the partial discharge triggered by the free metal particle on the insulator surface and ground electrode defect models, there is a not remarkable difference between V_1 and V_2. The largest difference between V_1 and V_2 is found in the Metal particle stuck on the insulator surface and High voltage electrode defect models.

3.3 The comparison of phase resolved partial discharge (PRPD) spectrogram

The applied voltage is gradually raised to make the discharge severe. The raising step is different among each model. And the phase resolved partial discharge (PRPD) spectrogram of UHF signals and acoustic emissions are recorded. Considering that the PRPD spectrogram will be very intensive after 5min under each specific voltage, which brings about difficulties to compare the sensitivity between these two methods, the duration time under each voltage level is chosen to be 5 minutes. The test results are as follows:

Metal particle stuck on the insulator surface:

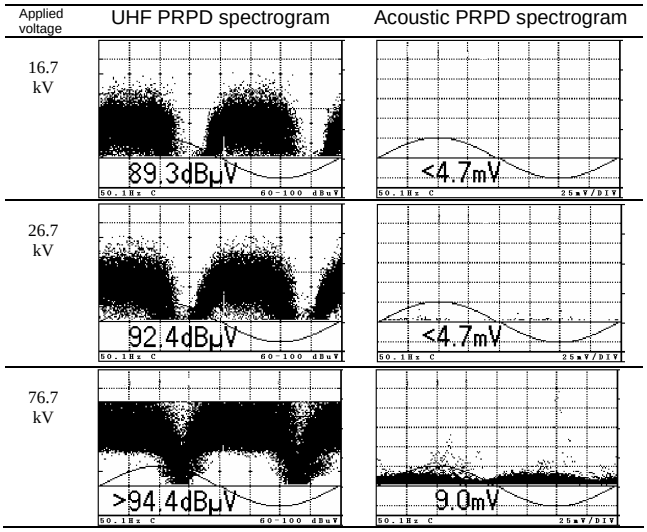
Table 2: comparison on PRPD spectrogram of metal particle stuck on the insulator surface

Applied voltage	UHF PRPD spectrogram	Acoustic PRPD spectrogram
60.9 kV		
75.9 kV		
85.9 kV		

From the above table, it is found that in the preliminary stage of partial discharge, the UHF sensor can capture a certain amount of PD signals while the ultrasonic sensor can detect nothing. As the applied voltage goes up, according to the density and the signal amplitude of the spectrogram, the number of discharge and the average discharge amplitude detected by the UHF sensor are always larger than the ultrasonic sensor. The ultrasonic sensor could only detect a few signals when the discharge becomes severe.

Free metal particle on the insulator surface:

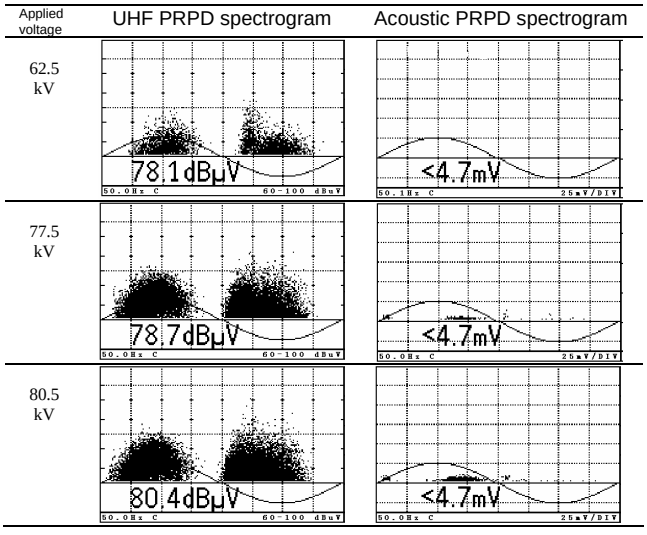
Table 3: comparison on PRPD spectrogram of free metal particle on the insulator surface



According to table 3, the UHF sensor detects large amount of discharge signals in the early stage of discharge. Under each voltage level, the discharge count and amplitude detected by the UHF sensor are larger than the ultrasonic sensor. The ultrasonic sensor could detect weak discharge signals when the applied voltage is relatively low. As the applied voltage goes up, the signals detected by the ultrasonic sensor become dense, along with the larger discharge amplitude and wider discharge phase interval.

High voltage electrode defect:

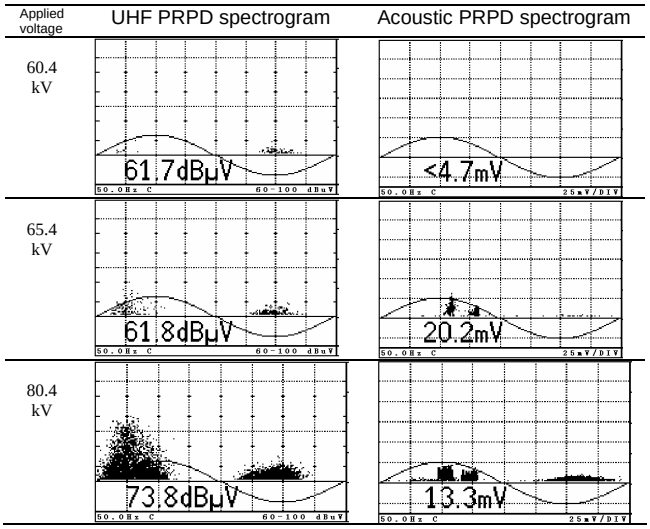
Table 4: comparison on PRPD spectrogram of defects of high voltage electrode



From table 4, it is indicated that in the early stage of partial discharge, the UHF sensor can capture a little number of PD signals while the ultrasonic sensor can detect nothing. Under each voltage level, the UHF sensor could capture more signals than the ultrasonic sensor. When the discharge becomes severe, the discharge signals detected by ultrasonic sensor become intensive and are distributed in two phase intervals, just the same as UHF signals.

Ground electrode defect:

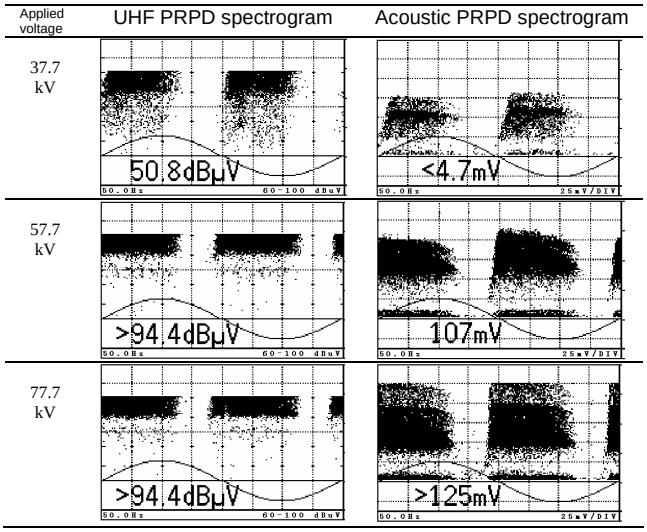
Table 5: comparison on PRPD spectrogram of defects of ground electrode



From table 5, it is indicated that in the early stage of partial discharge, the UHF sensor can capture a little number of PD signals while the ultrasonic sensor can detect nothing. Under each voltage level, the UHF sensor could capture more signals than the ultrasonic sensor. When the discharge becomes severe, the discharge signals detected by ultrasonic sensor become intensive and are distributed in two phase intervals, just the same as UHF signals.

Poor contact of high voltage electrode:

Table 6: comparison on PRPD spectrogram of free metal particle on the insulator surface



According to the table 6, for the partial discharge triggered by the poor contact of high voltage electrode model, both the UHF sensor and ultrasonic sensor can detect PD signals with high sensitivity. All the spectrograms are very intensive

under each voltage level. As the applied voltage increases, the discharge counts detected by both methods are almost the same.

3.4 The results discussion

The analysis upon the comparison of the PD inception voltage and the phase resolved partial discharge (PRPD) spectrogram is as follows:

1) The UHF method could detect all five defect models adopted in this paper with higher sensitivity. It is well known that GIS is filled with SF_6 which has high insulation property. When the partial discharge occurs in a very small-localized region, the procedure of gas breakdown is so fast that a steep pulse current is generated. This pulse current will emit electromagnetic wave from several hundreds Hz to GHz. The coaxial cylinder structure of GIS is equivalent to a coaxial wave-guide, which is very fit for electromagnetic wave transmission. In addition, the UHF signals are absolutely shielded by the sheath of GIS. So it is reasonable that UHF method show higher sensitivity in detecting partial discharge signals.

2) The ultrasonic method shows very low sensitivity in detecting the metal particle stuck on the insulator surface model and high voltage electrode defect model. This is because that the ultrasonic signals generated by partial discharge have to travel through the insulator and SF_6 to reach the ultrasonic transducer. And the attenuation of ultrasonic signals in these dielectrics is significant.

3) For the partial discharge triggered by free metal particle on the insulator surface model and ground electrode defect model, the detection sensitivity of the ultrasonic transducer is fairly high. The free metal particles on the insulator surface can emit ultrasonic wave not only from the partial discharge but also from the vibration of them selves subjected to the high intensity alternating electric field; for the ground electrode defect model, considering that the metal wire is adjacent to the GIS sheath, the attenuation of ultrasonic signals is rather weak in process of transmission. So the ultrasonic method could be used for these two styles of partial discharge, although it shows less sensitivity than the UHF method.

4) These two methods show little difference in detecting the poor contact of high voltage electrode model. Because this model style could initial very intensive partial discharge. In comparison with the significant amount of the UHF and ultrasonic signals, the attenuation is considered negligible, so that both the methods show very high sensitivity in detecting this kind of partial discharge. methods show very high sensitivity in detecting this kind of partial discharge.

4 CONCLUSION

1. For the five defect models studied this paper, the UHF method shows higher sensitivity in detecting them

2. The ultrasonic method is sensitivity in detecting the partial discharge triggered by free metal particle on the insulator surface model, ground electrode defect model and poor contact of high voltage electrode.

3. According to these results, it is suggested that the UHF method should be used as the main means for PD site test. Due to its advantage of convenient installation and anti-electrical interference, the ultrasonic method could be used as the main-assistant PD detection method.

5 ACKNOWLEDGMENTS

The present research is sponsored by The National Basic Research Program of China (973 Program) (2009CB724508).

6 REFERENCES

[1] Joint working Group 33/23.12.Insulation coordination of GIS: Return of experience, on site tests and diagnosis. Electric Techniques, 1998,176:67～97.

[2] Jin Lijun, Liu Weidong, et.Examination and Research of the Partial Discharge of Metallic Particles in GIS [J].High Voltage Apparatus. 2002, 10, 38

[3] W.Ziomek, E.Kuffel. Activity of Moving Metallic Particles in Prebreakdown State in GIS [J]. IEEE Transactions on Dielectrics and Electrical Insulation, 1997, 2, 4(1)

[4] IEC270,High-voltage test techniques — partial discharge measurements[s], 2000

[5] Shigemitsu Okabe, Tokio Yamagiwa, Hitoshi Okubo. Detection of Harmful Metallic Particles inside Gas Insulated Switchgear Using UHF Sensor [J]. IEEE Transactions on Dielectrics and Electrical Insulation, 2008, 6, 15(3)

[6] Yin Hua,Hu Panfeng,et. The Application of UHF Detection to Partial Discharge in GIS caused by Fixed Metal Particle[J]. High Voltage Apparatus, 2004, 40(6):409.

[7] Zhou Qian, Tang Ju, et. Mathematical Model of Four Typical Defects for UHF Partial Discharge in GIS [J].Proceedings of the CSEE, 2006.4, 26(8).