A Novel Sensor Detection Method of Partial Discharge in GIS based on the UHF Electromagnetic Wave

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Abstract. UHF electromagnetic wave has been widely used in various PD measurements of GIS (gas insulated switchgear) because of its high sensitivity, strong anti-interference ability, large effective detection range, fault location and pattern recognition. In this paper, a new method of detecting partial discharge of pouring hole on GIS insulator is studied. The transmission characteristics of UHF electromagnetic wave are simulated by FDTD. Based on the computer simulation technology (CST), a dipole antenna UHF sensor is developed. Finally, the sensitivity and validity of the sensor are tested on the 110kvgis experimental platform. Compared with the conventional method, the sensitivity of PD detection in GIS is obviously improved.

1. Introduction
In recent years, GIS Partial Discharge ultra high frequency (UHF) detection technology has been greatly developed and widely used in the power industry with its advantages of high sensitivity, strong anti-interference ability, large effective detection range, fault location and pattern recognition [1]. At present, UHF Sensors are mainly divided into two categories according to different installation methods, namely, built-in UHF Sensors and external UHF Sensors. The so-called built-in UHF sensor is to open a hole on the side wall of the GIS cavity, and then install the sensor in the hole. The UHF electromagnetic wave propagating in the GIS cavity can be received by the built-in UHF sensor when passing through the sensor mounting hole. The external UHF sensor is installed on the outer surface of GIS insulator. When UHF electromagnetic wave passes through the insulator, it will propagate outward through the dielectric material, so it can be received by the external UHF sensor [2-3]. Because the built-in UHF sensor is in the closed environment of GIS cavity, its signal-to-noise ratio and sensitivity are higher than the external UHF sensor. But because the UHF detection technology of PD is a new technology, most of the current GIS in operation do not have built-in sensors.

Most GIS insulators have metal rings on the edges because the GIS case needs to be reliably grounded and to avoid chemical corrosion of the insulation material. A small hole is reserved on the metal ring to inject insulation into the GIS, called a pouring hole. Due to the existence of the metal ring, a large number of electromagnetic signals are shielded by it. In this case, the UHF electromagnetic wave can only radiate to the outside world through the pouring hole. Due to the small size of pouring hole, the propagation of UHF electromagnetic wave is bound to be limited by it, which leads to the attenuation and distortion of UHF signal [4-5].Therefore, it is necessary and urgent to deeply study the influence of flange opening on GIS local signal transmission, and to develop external UHF sensor. At present, the research on UHF electromagnetic wave propagation characteristics is mainly focused on the GIS cavity, while little attention is paid to the effect of pouring holes on UHF signals.
In this paper, FDTD method is used to simulate the propagation characteristics of UHF electromagnetic wave through the pouring hole, and a UHF sensor based on dipole antenna is developed. Finally, the detection sensitivity and effectiveness of the sensor were tested on the 110kvGIS experimental platform.

2. Propagation characteristic of UHF electromagnetic wave

GIS is a fully enclosed metal structure with a basin insulator between each adjacent two cavities. Currently, most basin insulators are equipped with metal rings on the outside, which can play the role of corrosion protection, radiation protection and safe grounding in the operation of GIS [6]. A small hole is cut in the metal ring, which is used as a casting hole in the manufacturing process of the insulator, through which the epoxy resin medium is injected into it. The cross section of the pouring hole is approximately a rounded rectangle. The size of the pouring hole and the metal ring varies according to the manufacturer and the voltage level. Currently, the common pouring hole sizes are: long side 45mm, short side 20mm, depth (that is, the thickness of the metal ring) is 25mm.

The GIS simulation model is shown in figure 1. The model consists of two cavities labeled as A and B, with conductor diameter of 359mm and insulator thickness of 8mm. The outer diameter of insulator case is 414mm. Each insulator is provided with a metal ring and a pouring hole is arranged on it. The holes are labeled with no.1, no. 2 and no. 3. 1 pouring holes whose surfaces are parallel to the XOZ plane and no. 2 and no. 3 pouring holes whose surfaces are parallel to the ZOY plane. The length of the pouring hole is 45mm and the width is 20mm. The boundary condition on both sides of the model is set as PML (perfectly matched layer). The inner and outer conductors of the metal ring and GIS are arranged as ideal electric conductors [7-8]. The basin insulator material is made of epoxy resin, and its relative dielectric constant is 3.8. The interior of the cavity is set as freespace.

![Fig 1. The simulation model of GIS](image)

On the inner conductor of A cavity, a metal spike with a length of 10mm is set as the local power supply, and its direction is z-axis forward. The output waveform adopts gaussian pulse, and the time-domain expression is:

\[
I(t) = I_0 \exp \left[ -\frac{4\pi(t-t_o)^2}{\tau^2} \right]
\]

Where, \(I_0\) is the pulse peak; \(\tau\) is a constant, and the width of gaussian pulse depends on this parameter. The peak pulse occurs at \(t=t_o\). In the simulation, the pulse peak value is set to 10mA and the pulse width is set to 1ns

At the observation point 1, take the surface of the conductor in A cavity; at the observation point 2, take the surface center of the pouring port 2; at the observation point 3, take the surface center of the pouring port 3. The electric field intensity components in three directions (Ex, Ey and Ez) of the observation point are simulated. The electric field intensity amplitudes of the three observation points are recorded in table 1. The results show that Ex of observation point 1 is relatively close to Ey and Ez. However, the electric field intensity Ex amplitude at the observation point 2 is the largest, which is about 20 times higher than that of Ey and Ez. Ex of observation point 3 is the same as Ex of observation point 2. The Ex direction of measuring points 2 and 3 is parallel to the short side of the pouring mouth. This
means that for the UHF electromagnetic wave signal on the surface of the pouring hole, the direction of its electric field intensity is almost parallel to the direction of the short side, and has nothing to do with the relative angle between the discharge source and the pouring hole.

| observation point | Ex V/m | Ey V/m | Ez V/m |
|-------------------|--------|--------|--------|
| 1                  | 0.2576 | 0.2139 | 0.1682 |
| 2                  | 0.1213 | 0.0065 | 0.0071 |
| 3                  | 0.1105 | 0.0030 | 0.0052 |

Figure 2 shows the Ex frequency distribution of observation points 1 and 2. The results show that the main frequency range of UHF electromagnetic wave in the cavity is concentrated in 0.3-2GHz, while the main frequency range of UHF electromagnetic wave radiated from the pouring hole is concentrated in 0.8-2GHz.

3. UHF sensor installation

UHF sensor is the receiving device of electromagnetic wave signals emitted by GIS, which is essentially a receiving antenna. According to the antenna theory, the frequency range and gain of the antenna are closely related to the current path length of the antenna. As the size of the pouring hole is only 45mm×20mm, the opening of the antenna should not be too large. Theoretically, the smaller the antenna size, the narrower the effective frequency range of the antenna. The current direction of the dipole antenna is parallel to that of the dipole arm. Take gate 3 in Fig. 2 as an example, the direction of the dipole arm should extend along the short side of the gate. The short side is only 20 mm. When the dipole arm reaches the short edge, it can be bent along the Z axis to increase the length of the current path. Engineering practice has proved that increasing the length of dipole arm along the Z axis can make the dipole arm bend and thus widen the frequency range of the antenna. However, if the bending length is too large, this may lead to the splitting of the radiation pattern and the loss of gain.

In symmetric dipole antennas, half-wave dipole antennas are widely used in short-wave and ultra-short wave fields. Suppose the electromagnetic wave has a frequency of 1.5 GHZ and a wavelength of 200mm. The length of one side of the half-wave dipole arm is a quarter of the wavelength, equal to 50 millimeters. Since the short side of the pouring mouth is only 20 mm in length, electromagnetic waves will be reflected at the end of the dipole arm. To reduce reflection, a resistor is usually loaded at the end of the dipole arm. The load resistance can expand the frequency range, but too much resistance will also cause the gain to drop.

Figure 3 shows the parameter curve of voltage standing wave ratio of dipole antenna. It can be seen that the frequency range of standing wave ratio less than 2 is concentrated in 820MHz-2.4GHz, completely covering the frequency range of 0.8-2GHz.
The gain range of dipole antenna is 0.8-2GHz, as shown in Fig. 4. In the range of 0.8-1GHz, the gain is negative. The results show that the shielding efficiency of dipole antenna is low in this frequency range. As the frequency increases, the gain increases. In the range of 0.8-2GHz, the average gain of dipole antenna is 1.5dB.

Figure 5 shows the radiation mode of dipole antenna. It can be seen that as the frequency increases, the dipole antenna becomes more and more directional.

The equivalent height of the external UHF sensor was detected on the gigahertz transverse electromagnetic chamber (GTEM) platform, and its equivalent height curve is shown in Fig. 6. According to the figure, the average equivalent height of the sensor in the frequency band of 0.8-2GHz is 8.1mm, and the curve is relatively flat in this frequency band, so as to ensure that the external sensor can receive UHF electromagnetic wave signals at the pouring hole more effectively.
4. Analysis of sensitivity

A 110kV GIS was used as the experimental platform to verify whether the sensitivity and other performance indicators of the UHF sensor meet the requirements. The overall diagram of the experiment is shown in figure 7. The high voltage end of the discharge model is fixed on the GIS inner conductor, the low voltage end is connected to the GIS housing through a wire, and the UHF sensor is placed on the pouring hole of the insulator far away from the discharge model.

Figure 7 shows the simulation of three GIS local power supply models, such as : (1) metal protrusion. A 40mm copper wire is fixed to the inner conductor. The distance between the copper terminal and the cavity housing is 55mm. (2) surface contamination. A shield cloth was cut into a slender diamond. The shielding cloth adheres to the insulator along the direction of the electric field in the cavity. To avoid floating electrode discharge, the shielding cloth should be placed away from the inner conductor. (3) free metal particles. Put 15 copper wires with a diameter of 0.1mm and a length of 5mm into a plastic box. The plastic box is fixed on the inner surface of the cavity. A light slide electrode that connects a plastic shell to an inner conductor. The test of UHF sensor fault detection model is summarized in figure 8. Obviously, the sensitivity of the dipole antenna sensor to the UHF electromagnetic wave diffused from the pouring hole is less than 25pC. With the increase of discharge times, the voltage amplitude of the dipole antenna sensor gradually increases.

![Fig 6. Equivalent height](image1)

![Fig 7. Experimental platform and faulty models](image2)

![Fig 8. Partial discharge detection](image3)
5. Conclusion

A Sensor Detection Method of Partial Discharge in GIS based on the UHF Electromagnetic Wave is studied in this paper. The pouring hole the propagation characteristics of UHF electromagnetic waves in GIS are studied by means of simulation. And a new type of UHF sensor design requirements is put forward. The final will be developed in the UHF sensor under the environment of 110kV GIS platform, the results show that the UHF sensor performance is excellent, developed can be applied in the field of UHF partial discharge detection.

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