Study on Characteristics of Different Internal UHF Sensors in GIS

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Abstract. The crucial point of the UHF detection is the UHF sensor, which affects the sensitivity and anti-interference ability of the UHF detection. In this paper, the introduction of 5 different kinds of internal sensors of the Ultra High frequency (UHF) technology used to monitor the PD in the GIS was made in detail. With comparison of the external sensors, the anti-interference ability of internal sensors is much better. In order to evaluate the property of different sensors more precisely, several indicators are introduced in this paper. Furthermore, some unsolved issues about the sensor inside the GIS are presented for researchers to solve.

1. Introduction

The detection method using UHF (Ultra-High Frequency, UHF) was firstly proposed in the 1980s. Partial discharge (PD) in GIS is one of the main reasons to harm the operation of power equipment. Therefore, it is very important to detect PD in GIS. It is a type of PD detection by monitoring signals of electromagnetic waves in PD, the insulation state of electric power devices is diagnosed. This method of PD detection has merits of high sensitivity and great anti-interference capability. In the last thirty years, researches in abroad and domestic have led to rapid development of UHF detection technology and have become a popular technology for detecting the state of isolation in the gas-insulated switchgear (GIS) [1]. Apart from the GIS, UHF detection method has also been used in cables, transformers, and other power facility, which has achieved good results.

The current pulse in the partial discharge of the power equipment whose rising edge is nanoseconds can internally excite electromagnetic waves with a frequency up to several GHz. The UHF partial discharge detection technology achieves the purpose of partial discharge detection by detecting such electromagnetic wave signals. The UHF method is often used for the detection [2], location [3] and fault type identification of partial discharge types of power equipment. The UHF method has the following technical features:

1) High detection sensitivity. The UHF electromagnetic wave signal generated by partial discharge is less attenuated when it propagates in GIS, and the electromagnetic wave is reflected in the discontinuity of the insulator in GIS, and the resonance is caused in the GIS cavity, so that the partial discharge signal oscillation time is lengthened, which is convenient for detection. Therefore, the UHF method has high sensitivity compared to other detection methods.
2) Strong anti-interference ability. Due to the large amount of electromagnetic interference in the running thread of the power equipment, it brings certain difficulty to the partial discharge detection. The corona discharge interference of the high-voltage line in the air is the most common interference in the field, and the electromagnetic wave frequency generated by the discharge is mainly below 200MHz. Since the detection frequency band of the UHF method is usually 300M~3000MHz, it can effectively avoid interference such as on-site corona and has strong anti-interference ability.

3) PD source localization [4]. The electromagnetic wave generated by partial discharge propagates in the gas and is approximately the speed of light. The time to reach each special high-frequency sensor is directly related to its propagation distance. According to this principle, the positioning of the PD signal source can be judged, and the efficiency of inspection and maintenance can be improved.

The crucial point of the UHF detection is the UHF sensor [5]. Depending on the various mounting position, there are internal and external sensors. The advantages of the external sensor are easy maintenance, easy use, low dimensions and low mechanical property requirements. However, since the electromagnetic wave signals can attenuate in the propagation process, the result of the external sensor detection can become bad. Nowadays, some GIS basin type insulators are coated with a metal shield loop. It can significantly reduce the detection sensitivity of the external PD signal sensor in this way. Moreover, there are many external environmental influences such as corona, which can affect the detection of the external sensor. So, the external sensor is easy to be interfered. Differently, internal sensors have higher sensitivity and greater suppression property. To drive the progress of UHF detection method in China, the State Grid Corporation promotes the installation of internal sensors in 220 kV GIS.

The research of internal sensor has always been a hotspot in the field of UHF detection around the world. At present, the Britain State Grid Corp (NGC) has standardized the property of internal sensors by defining some related standards [6]. The relevant standards are being developed for home in recent years. This article studies and assesses five internal sensors, according to the property requirements of the UHF detection in GIS. Finally, points are made to existing problems in researching embedded sensors and development of future research.

2. Types of sensors
The operating environment with strong electromagnetic in GIS is hard and complicated, which is harmful to the antenna of the internal sensor. Due to the operating environment, the kind of internal sensor is limited. Some antennas with complex structure do not work in GIS, such as most PCB antennas.

The internal sensor has two main parts. One is the metal electrode, the other is the insulating material composition. The two parts are feed by N type the connector. This paper studies five kinds of internal sensors, including the planar spiral antenna, dipole antenna, loop antenna, conical antenna and disk antenna.

2.1. Disk antenna
Disk antenna is a type of internal sensor used in GIS, which is used most in the UHF detection. Disk antenna is also called circular plate type sensor and the disk type sensor. The reference [7] points out that the disk antenna was used in the earliest UHF detection system. Figure 1 illustrates the structure of disk antenna. The diameter of the typical disk antenna is between the 80~300 mm.

![Figure 1. Structure chart of the disc sensor](image)
The disk antenna is equal to a micro-strip patch antenna, consisting of a dielectric substrate, conductor patches and a conductor ground plate, with coaxial feeding. The corresponding parts represent respectively the medium, hatch cover and coupling disc in the built-in sensors. When the transmitting antenna is operating, the radiation of electromagnetic wave is excited between the conductive paste and the ground plate. The radiation of electromagnetic wave is excited outward from the around patch. According to the impedance bandwidth, the bandwidth of the old micro-strip patch antenna is narrow, whose relative width of band is around 1%~7%. The resonant point of every mode can be calculated by the dielectric permittivity, permeability and disk radius [8].

2.2. Loop antenna

There are two types of the loop antenna. One is the small loop antenna whose size is smaller than the wavelength, the other is the resonance loop antenna whose perimeter is equal to the wavelength of resonant. Resonant loop antennas are often used in the internal GIS sensor, which are usually called ring type sensor. Figure 2 illustrates the construction of the loop antenna. Loop antennas are usually installed on an insulator whose function is supporting in the GIS. The bandwidth of resonant loop antenna is narrow. The cycle whose perimeter is related to the resonant frequency can be considered as a dipole which is folded.

![Figure 2. Structure chart of the loop antenna](image)

2.3. Dipole antenna

According to the theory about antenna, dipole antenna has the advantages of high efficiency and simple structure, which is considered as the most basic type of antenna. Dipole antenna belongs to the resonant antenna, which has narrow bandwidth of working frequency. The working wavelength is two times longer than dipole antenna length so that it is also considered as a vibrator with half wave.

Old type of dipole antenna is inadaptable to be installed into the GIS, which is applied for outside antenna. However, it can be installed in the GIS by changing the structure like disc dipole.

Figure 3 illustrates a disc dipole antenna that is not symmetrical, which is raised from South Korea Hyosung Company [9]. The installation way of disc type antenna and dipole antenna is similar, which is installed inside the GIS through the hatch cover. The influence factors that can affect properties of the dipole antenna is principally caused by the patch radius ratio, the patch area and the groove’s width. The optimal size can be obtained by simulating the work condition, which can reach 9.85% of the width of band and the 1.23GHz of the resonance frequency.
Figure 3. Chart of asymmetrical disc dipole antenna

2.4. Planar antenna

Planar spiral antenna belongs to a type of the antenna that is frequency independent. The structure of antenna can not change with the proportions of it. Therefore, characteristics of operating are not related to the frequency. Impedance characteristics of the terminal truncated planar in the spiral antenna maintain nearly equal to inside the wide range of frequencies. That is the reason why the spiral antenna can reach the octave bandwidth of 10/1. As a result, the spiral antenna is a type of the ultra-wideband antenna. The energy of partial discharge pulse is nearly in proportion with frequency bandwidth of PD [10]. Theoretically, narrowband antenna can accept less energy than planar spiral antenna. The antenna detection range of lower limit and the upper limit is set in 300–500MHz and in 1500–3000MHz respectively in general. Planar spiral antenna belongs to a type of balanced antenna, whose feed way is able to sort out from the terminal of helix by applying a pair of balanced line. However, we usually take coaxial cable feed in use for convenience. The insertion of the balun is used to balance the output, which is called Baron Balancer. Figure 4 illustrates the framework of planar spiral antenna.

Figure 4. Framework chart of the planar spiral antenna

The spiral antenna that is usually used for internal sensors in the GIS is the Archimedes antenna equiangular and spiral antenna. The average effective height of the spiral antenna measured around 6–20cm can reach over 6 mm in the band of frequency [11].
2.5. Conical antenna

Conical antenna is a type of internal sensor that is widely used. Figure 5 illustrates a specific structure of the conical antenna. Toshiba has combined the conical antenna with the loop antenna in the use of the pattern recognition of PD and noise reduction. Since the transient response of the conical antenna is better than the antenna in disc type.

![Figure 5. Structure chart of the conical antenna](image)

Essentially, the conical antenna belongs to a type of the conical monopole antenna. Input impedance is only related to the independent of the frequency and the taper angle, assuming that the length of antenna is not finite. Therefore, its bandwidth is wide. Actually, the size of conical antenna must be limited in the actual manufacture, which makes comparison difficult in the low frequency. Generally, the length of cone is proportional to the property in the low frequency.

The flat conical antenna is considered as a type of design that improves the sensor of disc type. The good matching between measuring cable and cone impedance of sensor is the principle reason that make the sensitivity higher. The property of sensor is able to be advanced by linking the conductor between the ground plane and the conical antenna, which is in accordance with the disc type sensor.

3. Summary

Nowadays, five types of UHF internal sensor are principally used in the GIS. According to the bandwidth of impedance, the disk antenna, dipole antenna and loop antenna are the narrowband antenna. According to sensitivity, the conical antenna and planar spiral antenna are the broadband antenna. Because the measurement method is not suitable for various installation ways, all types of the sensor are able to reach the demands of 6mm average effective height except loop antenna. According to the minimum measured discharge, all types of sensors can monitor 5pC PD in the lab.

It should be noted that conclusions mentioned above are only tenable when the design of sensors is correct. In the practical application, except for sensors form factors, material, the length of antenna, feeding way can influence properties of sensors.

Apart from the sensor property, safety and air tightness need to be taken into account and come up with the mode of connection between all parts of the sensor, which can make the internal sensor work well in the GIS.

In general, the internal UHF sensor in GIS is not an emerging technology, but there are still some problems.

The future research should concentrate on issues below:

1) Improving the property of sensor. Most of sensors are designed following the antenna theory. The design index of conventional antenna like gain and impedance are hard to express the property of sensors. The effective height sensor is able to express properties of sensors according to most researchers. However, there are few studies and related researches that focus on the effective height covering the direction of effective height the effects of sensor structure and polarization properties. Based on the antenna theory, promoting the effective height is a crucial part in the future.
(2) Confirming methods to assess properties of sensors. It is a crucial aspect of UHF method standardization. The lack of integrated indexes to assess calibration and detection effect still exists. Two step detection proposed by CIGRE is a kind of assessment based on quantity. This kind of approach is not suitable for every equipment. The measurement of effective height has some merits. However, the further studies and discussions need to be conducted to promote the related testing method.

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