Research on RF antenna for detecting corona discharge of electrical equipment

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Abstract. In power systems, corona discharge often occurs, which is a common phenomenon. If it occurs in electrical equipment, then hidden dangersexist, such as poor contact between metal fittings of insulators and electrical equipment, insulation performance degradation due to equipment agingand strand breakage of transmission lines. These dangers may lead to further serious accidents. So, it is very important to detect and eliminate the hidden dangers. Because corona discharge will radiate radio frequency (RF) electromagnetic waves to the surrounding space, the detection of corona discharge can be realized by detecting RF electromagnetic waves. In this study, two miniaturized antennas are designed to detect corona discharge in electrical equipment. These antennas are rectangular spiral antenna and Hilbert antenna. Through simulation and comparison, it is found that Hilbert antenna unit is the best and the final structure is the 6th order Hilbert antenna. The final size of this antenna is 100 mm×100 mm×1.6 mm, which is portable and lightweight.

1. Introduction
In the development of power systems, the voltage level is increasing, which makes the corona discharge occurs frequently. The main causes of corona discharge are poor contact between insulator and electrical equipment, deterioration of insulation performance caused by equipment aging, and transmission line breaking. These phenomena will lead to the waste of electric energy and even lead to safety accidents[1], so this problem has attracted the attention of a large number of electrical researchers. It is of great significance to develop a set of devices for detecting corona discharge of electrical equipment for safe operation of power system. At present, the detection methods[2] of corona discharge mainly include artificial visual method, ultraviolet imaging, and infrared imaging. Artificial vision method refers to the visible light produced by corona discharge of transmission line directly observed by staff through naked eyes. This method is simple and efficient, but its accuracy is greatly affected by subjective factors. The principle of ultraviolet imaging method is to detect the ultraviolet rays emitted by corona discharge in the blind area of the sun [3]. This method has the advantages of accurate detection results and high detection efficiency, but it is too expensive to be popularized. The principle of infrared imaging method to detect corona discharge is that corona discharge will release heat energy and make the temperature of surrounding space rise [4]. The occurrence of corona discharge can be judged by detecting the area with high temperature. This method can realize discharge detection, but its signal-to-noise ratio is low and has hysteresis. In order to meet the requirements of stability, reliability, accuracy and economy of corona discharge, an
An effective and accurate RF antenna for corona discharge measurement is proposed. Through the corona discharge test of high voltage electrical equipment in, the signal-to-noise ratio of corona discharge signal is the highest in the range of 100MHz ~ 300MHz. Under such a premise, we need to design an antenna with high gain, good directivity and detects the electromagnetic wave band of corona discharge to realize corona discharge detection. At present, some scholars have done related research. At present, some scholars have done relevant research, such as Li Lei’s research on rectangular planar spiral antenna [5], S. Weigand’s research on U-shaped microstrip antenna [6], Xia Yunfeng’s research on log periodic antenna [7], Zeng Yunmei’s research on conical antenna [8], Zhu Li’s research on circular spiral antenna [9], and so on. Considering that the frequency band of discharge detection is 100MHz ~ 300MHz, in order to meet the actual engineering requirements, this study intends to research two antennas which are rectangular spiral antenna and Hilbert antenna, and verify the design results by two parameters: reflection coefficient (S11<-5dB) and antenna size (100 mm×100 mm×1.6 mm).

2. The Structure of two Antennas

The detection of electrical equipment will be limited by space, so considering the practical application of corona discharge detection in electrical equipment, the antenna must be lightweight and portable. Therefore, the antenna adopts a planar antenna structure, as shown in the figure below.

![Antenna model structure](image)

It can be seen from Fig. 1 that the antenna is composed of shielding layer, dielectric layer and antenna layer. The shielding layer can radiate the loss and prevent the external signal interference detection. The dielectric layer is used to isolate the antenna layer and the shielding layer. The size of the dielectric layer is equal to that of the shielding layer. The antenna layer is determined by the selected antenna structure.

2.1. The structure of rectangular spiral antenna

The structure of the spiral antenna is primarily composed of a spiral curve. A spiral curve is a curve that starts from the origin and spirally extends in accordance with the arc or polygon trajectory. Fig. 2 depicts a rectangular spiral antenna [10]. The spiral arm is composed of multiple filaments whose lengths are \(a_0, 2a_0, 3a_0, 4a_0, \ldots, (2N - 1)a_0, 2Na_0, 2Na_0, 2Na_0\), where \(N\) is the turns of antenna.

![Rectangular spiral antenna](image)
2.2. *The structure of Hilbert antenna*

The structure of the Hilbert antenna is based on the Hilbert fractal curve, and the antenna of order 1–4 is illustrated in Fig. 3 [11].

![Figure 3. Hilbert antenna](image)

For a Hilbert fractal antenna with a side dimension \( L \) and an order of \( n \), the length of each line segment \( d \) and the sum of all the line segments \( S \) are given by (1) and (2).

\[
\begin{align*}
    d &= \frac{L}{2^n - 1} \\
    S &= (2^n - 1) \left( 2^n + 1 \right) L
\end{align*}
\]

(1)  
(2)

3. *Simulation of Different Antennas*

In this paper, the finite element method is used to analyse the antenna. The antenna is used for detecting corona discharge of power equipment. Considering the space limitation of power equipment, the antenna needs to be miniaturized and lightweight. Therefore, the antenna size is limited to 100 mm * 100 mm * 1.6 mm. The detection frequency band of the antenna is 100 MHz ~ 300 MHz, and the reflection coefficient of the antenna should be less than -5dB (\( S11 <-5dB \)) in the detection frequency band.

3.1. *Simulation of rectangular spiral antenna*

According to the structure and design requirements of rectangular spiral antenna, the antenna model is obtained, as shown in Fig. 4.

![Figure 4. Model of rectangular spiral antenna](image)
Since the antenna is spiral distribution from the centre, the feed position of the antenna adopts the central feed. In order to realize the impedance matching between the antenna and the coaxial cable, the impedance parameter of the antenna is set to 50 ohms. Firstly, the 12 turns rectangular spiral antenna is analysed, and the simulation reflection coefficient curve of the antenna is shown in Fig. 5.

Figure 5. S11 of 12 turns rectangular spiral antenna

Figure 6. S11 of 13 turns rectangular spiral antenna

Figure 7. S11 of 14 turns rectangular spiral antenna
Through simulation analysis, it is found that the reflection coefficient of 12 turns rectangular spiral antenna fails to reach -5dB in the detection frequency band of 100 MHz~300 MHz, so the antenna does not meet the design requirements. The reflection coefficient of the rectangular spiral antenna can be reduced by increasing the number of turns. Therefore, the 13 turns rectangular spiral antenna and 14 turns rectangular spiral antenna are analysed respectively, and the simulation results are shown in Fig. 6 and Fig. 7 respectively.

It can be seen from Fig. 6 that the reflection coefficient of the 13 turns rectangular spiral antenna still fails to meet the design requirements. It can be seen from Fig. 7 that although there are frequency bands lower than -5 dB in the detection frequency band (100 MHz~300 MHz), compared with the whole detection frequency band, there are too few discharge detections bands, and it is still difficult to realize discharge detection. At the same time, because the size of the antenna is required to be 100 mm *100 mm * 1.6 mm, increasing the number of antenna turns cannot meet the requirements in this small space, so the rectangular spiral antenna cannot meet the design requirements.

3.2. Simulation of Hilbert antenna

According to the structure and design requirements of Hilbert antenna, the antenna model is obtained, as shown in Fig. 8.
For the Hilbert fractal antenna, the feeding position is usually fed at one port of the antenna. In order to realize the impedance matching between the antenna and the coaxial cable, the impedance parameter of the antenna is set to 50 ohms. Firstly, the 5 order Hilbert antenna is simulated and analysed, and the simulation results are shown in Fig. 9.

As can be seen from Fig. 9, the reflection coefficient of the 5 order Hilbert antenna reaches the design requirement of less than -5dB in the corona discharge detection frequency band, which is mainly concentrated in the frequency band of 200MHz~300MHz, but it fails to achieve the reflection coefficient below -5dB in the whole detection frequency band of 100MHz~300MHz. For the Hilbert antenna, the reflection coefficient can be reduced by increasing the fractal order. Therefore, the simulation result of the 6 order Hilbert antenna is shown in Fig. 10.

It can be seen from Fig. 10 that the 6 order Hilbert fractal antenna can meet the design requirements of reflection coefficient less than -5dB in the whole discharge detection frequency band (100MHz~300MHz). It indicates that the 6 order Hilbert fractal antenna can realize corona discharge detection. In order to further explain the detection function of the 6 order Hilbert fractal antenna, the radiation pattern of the antenna is analysed. The radiation pattern is shown in Fig. 11.

It can be seen from Fig. 11 that the 6 order Hilbert antenna has good directionality and can detect the discharge signal in the vertical direction of the antenna.
4. conclusion
In this paper, the electromagnetic wave detection method is used to detect the corona discharge of electrical equipment. The rectangular spiral antenna and Hilbert antenna are mainly studied. Considering that the application scenario of antenna detection is electrical equipment, which will be limited by the detection space, the design size of antenna is limited to 100 mm*100 mm*1.6 mm. The detection frequency range of antenna is mainly determined by the frequency band with high corona discharge noise ratio, which is 100MHz~300MHz. The performance parameters of the reflection coefficient of antenna should be less than -5 dB in the detection frequency band. Through the simulation analysis, it is found that the rectangular spiral antenna is difficult to meet the design requirements in such a small size. But for the Hilbert antenna, the simulation results show that it can meet the design requirements, and the final antenna structure is the 6th order Hilbert antenna. It can be seen from the radiation pattern that the 6th order Hilbert antenna has good directivity. In the future research, it is necessary to make the antenna as a real object, and optimize and adjust the designed discharge detection antenna through corona discharge experiment.

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