Design and Optimization of Detection Antenna for Corona Discharge in High-voltage Transmission Lines

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\textbf{Abstract.} Corona discharge on high-voltage transmission lines is a common phenomenon in power systems. It results from poor contact between insulators and lines, and broken strands on transmission lines. Long-term corona discharges may lead to more serious power grids accidents. Hence, it is of great importance to effectively detect the occurrence of corona discharge. The Hilbert Fractal Antenna is a wide-band, small-sized antenna which can be carried by the unmanned aerial vehicle for close-range detection and accurately position fault points of corona discharge. In this paper, the finite element method is used to study the 5th order Hilbert fractal antenna. The research focuses on the different feeding positions of the antenna. By studying the different feeding positions of the antenna, we determine a miniaturized antenna which can be used for corona discharge detection of high-voltage transmission lines.

1. Introduction

With the improvements of power grid capacity and voltage level, the increasingly serious corona discharge phenomenon of high-voltage transmission lines has attracted people’s attention. A stable and reliable line detection device should be developed to obtain the corona discharge signal in time and determine the exact location of the discharge. With the detection device, the staff can find the discharge position and deal with hidden dangers in time to avoid more serious power grid accidents. Nowadays, detection methods for corona discharge on high-voltage transmission lines [1-6] include: visual observation method, infrared thermal imaging technology, ultraviolet imaging method [7-11]. The visual observation method requires observe corona at night. Since the detection results are affected by the subjective experience of the observers, this method is difficult to meet actual needs. Infrared thermal imaging technology can detect low vision targets by measuring the infrared difference between the target itself and the background, because the background may have a large thermal contrast with the target or the target itself has a large temperature gradient. Nevertheless, the infrared image of corona discharge can only be seen when the discharge of electrical equipment is very serious, which shows that the technology is not sensitive enough. Ultraviolet imaging technology is to detect ultraviolet signals generated when the electrical equipment is discharging. This ultraviolet...
signal is overlapped with the visible image displayed on the screen after processing. Some power companies have adopted ultraviolet imaging devices because of their fast response. However, expensive prices and inaccurate measurements in sunlight indicate that this equipment is not suitable to generalize for maintenance teams. Since the above methods are not widely used due to their respective problems, it is necessary to discover more economical, more accurate measurement results and more portable corona discharge detection device for transmission lines. In this paper, we designed a dedicated radio frequency detection antenna for detecting radio frequency electromagnetic waves of corona discharge on transmission lines [12,13]. This antenna is portable and can detect corona discharge signals in a timely, convenient manner.

A wide frequency band is covered in the electromagnetic pulse signal generated by corona discharge [14, 17], and the detection frequency range of the designed antenna is 50MHz to 300MHz. Hence, the antenna is designed to have wideband detection characteristics. Because of the weak discharge signal in transmission lines and strong environmental interference with electromagnetic signal, the antenna is required to have good gain and directivity to meet the requirements of orientation detection. The research on the antennas for detecting corona discharge of transmission lines are mainly as follows: Li reported a Hilbert fractal antenna which is used for partial discharge of transformer [18], Yunmei Zeng studied a cone antenna which is able to detect the partial discharge in the entire substation [19], Wei Li reported a rectangular planar spiral antenna [20], S. Weigand studied an U-type microstrip antenna [21], Youyuan Wang researched a new microstrip antennas for partial discharge detection of power equipment [22] and Yunfeng Xia studied logarithmic periodic antennas[23].

By combining the existing structures of the detecting antenna, we designed a low-band and miniaturized Hilbert fractal antenna as the antenna structure. The antenna can not only detect the frequency range from 50MHz to 300MHz, but also be equipped with an unmanned aerial vehicle (UAV) for close-range detection. In this paper, the Hilbert fractal antenna is analyzed. In order to assess whether the antenna meets the design criteria in the detection band, we analyzed the reflection coefficient (S11) and the voltage standing wave ratio (VSWR) of the antenna. The results show that the S11 should be less than -10dB and the VSWR should be less than 2.

2. Structure and design of Hilbert fractal antenna

Fractal is regarded as a rough or fragmentary geometry which can be divided into several parts, each of which is an overall reduced shape with self-similar properties. The structure of fractal curve belongs to the category of plane filling curve, which has the characteristics of self-similarity and repeated overlay. The specific structure of the 1st -4th order Hilbert fractal curve is shown in Figure 1.

Figure 1 shows that there is no intersection in the fractal curve. As a continuous figure, this curve has strict self-similarity and high spatial utilization after multiple self-similar iterations.
Hilbert fractal curve enables higher space utilization in the same wiring space. The compact antenna structure can greatly reduce the design size of the antenna, which makes it easy to use on an UAV. Furthermore, the Hilbert fractal antenna has the detection characteristics of the wide band, which is suitable for the detection of corona discharge in transmission lines. The structure of the antenna is shown in Figure 2.

As can be seen from Figure 2, the components of the antenna are antenna layer, media layer and shielding layer. Among them, the antenna layer is a Hilbert fractal antenna structure, the antenna layer and the shielding layer are isolated by the media layer. In order to shield the outside interference, the shielding layer is made up of copper sheet, which is the same size as the antenna's overall model.

![Figure 2. Structure of antenna model.](image)

Since the higher the order of the fractal antenna, the lower the detection band at the same size [18]. We then adopt the 5th-order Hilbert fractal curve as the antenna structure. Its antenna model is shown in Figure 3.

![Figure 3. 5th order Hilbert antenna model.](image)

The basic model of the antenna layer in the antenna that is shown in Figure 3, thus forming the basic structure of the antenna.

### 3. Simulation analysis of Hilbert fractal antenna

Finite element method is adopted to analyze the antenna. The 5th-order Hilbert fractal antenna structure is imported into the antenna simulation software, and the antenna model is shown in Figure 4.

As is shown in Figure 4, the media substrate of the antenna's media layer is set as FR4_epoxy, whose overall size is 200mm* 200mm * 1.6mm. Meanwhile, the shielding layer is set to an ideal conductor surface which has the same size as the media substrate. The antenna layer is the antenna structure consisting of a 5th-order Hilbert fractal curve. We then analyze the antenna feed and coaxial cable feed mode is applied when the impedance parameter is set to 50Ω. In this paper, the same axis cable is set in the center of the antenna model for feeding, the center copper wire of the same axis cable is connected to the antenna and the mesh conductor layer is connected to the shielding layer of the antenna. The feeding mode is shown in Figure 5.
After using the feeding mode in Figure 5, we set the sweep setting range to 50MHz-300MHz and the step to 1MHz. The reflection coefficient curve is shown in Figure 6.

As can be seen from Figure 6, the antenna has more frequency bands below -10dB between 50MHz and 300MHz, indicating that the Hilbert fractal antenna is a wideband antenna. The reflection factor (S11) fails to reach below -10dB in the 150MHz-300MHz frequency band that needs to be detected. Therefore, the antenna does not conform to the design requirements. The VSWR curve for the antenna is shown in Figure 7.
Figure 7 shows that the VSWR fail to be less than 2 within the detection frequency band 150MHz-300MHz, indicating that the antenna standing wave ratio is not in line with the design standards. The results show that this kind of feed dose not achieve the required antenna performance. Since the performance of the antenna is greatly affected by the selection of the antenna feeding position, we consider adjusting the feeding position of the fractal antenna in the process of further optimizing the fractal antenna. The results show that the reflection coefficient curve and the station ratio of the antenna meet the design requirements when the feed position is set in the antenna port. The feed model is shown in Figure 8.

![Feeding point](image)

**Figure 8. New feeding position of antenna model.**

After feeding with the feed model in Figure 8, the reflection coefficient curve of optimized Hilbert fractal antenna is shown in Figure 9. The results show that the reflective coefficient of the antenna can reach below -10dB within the detection frequency band 150MHz-300MHz, which meets the design requirements of the antenna. The voltage standing wave ratio curve of optimized Hilbert fractal antenna is shown in Figure 10.

![Reflection coefficient](image)

**Figure 9. Reflection coefficient of optimized Hilbert fractal antenna.**

![VSWR](image)

**Figure 10. VSWR of optimized Hilbert fractal antenna.**

Figure 10 indicates that the VSWR of optimized Hilbert fractal antenna can meet the requirements of less than 2 in the 50MHz-300MHz frequency band. The radiation orientation of the antenna is shown in Figure 11.
Figure 11. Radiation pattern of 5th order Hilbert fractal antenna.

The results show that the radiation direction of Hilbert fractal antenna is mainly directed towards the upward direction of the antenna plane, which indicates that the antenna has good orientation and is conducive to the precise positioning of the corona discharge position in transmission line.

4. Simulated detection test of corona discharge

In order to verify the discharge detection function of the designed antenna, we construct an analog corona discharge test platform. The circuit diagram of the test platform is shown in Figure 12.

Figure 12. Analog test platform for corona discharge.

Since the corona discharge in the high-voltage transmission line often appears at the connection point between the insulator and the transmission line, the simulated corona discharge test platform is built to simulate the actual corona phenomenon. The physical map of the simulated corona discharge test platform is shown in Figure 13.

Figure 13. Physical picture of analog test platform for corona discharge.

As is shown in Figure 13, by regulating the voltage, high voltage can be generated at the transformer end and applied to both ends of the composite insulator. A stable and reliable corona discharge can be produced by gradually increasing the voltage. We then use the antenna described in this article as a sensor to measure the discharge signal by connecting the high-speed oscilloscope (Tektronix MDO4034B-3). The typical discharge signal is shown in Figure 14.
In Figure 14, the yellow signal is the time domain waveform of the corona discharge signal, while the red signal is the frequency domain waveform of the corona discharge. The spectral distribution of discharge signal shows that the corona discharge distribution mainly appears between 50MHz-300MHz, which conforms to the spectral distribution range of corona discharge.

5. Conclusion

In this paper, a Hilbert fractal antenna is designed for detecting corona discharge of transmission lines. According to the principle that electromagnetic waves are generated by corona discharge, it is an effective method to use an antenna to detect corona discharge. By analysing the electromagnetic spectrum distribution of corona discharge in high-voltage transmission line, the detection frequency band of antenna is determined to be 50MHz-300MHz. Besides, the fifth-order Hilbert fractal curve is proposed as the basic structure of the antenna. We then explored the different feed positions of fractal antennas. It is determined that the copper wire in the centre of the coaxial cable is connected to the antenna layer, the mesh conductive layer is connected to the shielding layer, and feeding in the antenna port position can meet the design requirements of the antenna. The overall size of the antenna is 200mm*200mm*1.6mm. Meanwhile, the antenna has good directivity and can position the corona discharge position. By constructing a simulated experimental platform of corona discharge, we successfully captured the discharge signal through the antenna. It was demonstrated that the spectrum distribution of the signal conforms to the distribution range of corona discharge. The analysis of antenna structure will be further improved and the corresponding high-frequency detection circuit will be developed to miniaturize the technology. Efforts will continue to be made in the direction of UAV carrying.

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