The Design of Planar Rectangular Spiral Antenna for Corona Discharge in Transmission Lines

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Abstract: With the increasing grade of high voltage transmission lines, the frequent occurrence of corona discharge has brought great potential safety risk and power losses to power system. Therefore, the detection of corona discharge in transmission lines is of great significance to power system. Rectangular spiral antenna is widely used because of its smooth impedance and better circular polarization characteristics. In this paper, a planar rectangular spiral antenna is designed for the detection of radio frequency electromagnetic waves given out corona discharge of transmission lines. The basic structure of the antenna is determined by optimizing the length, spacing and turns of coil. The feasibility of the antenna is verified by experiments.

1. Introduction

With the development of China's electric power industry, the voltage level of transmission lines is getting higher and higher and the distance of transmission lines is getting longer and longer. High-voltage transmission lines, metal fixtures and line joints could produce continuous corona discharge under high voltage, which will cause the waste of power energy and even threaten personal safety [1]. This problem has attracted wide attention of electrical engineer. It has great significance for the safe operation of power system to develop a set of stable and reliable electrical device for detecting corona discharge in power lines. At present, the detection methods of corona discharge mainly include direct observation method, ultraviolet imaging method, ultraviolet pulse method and infrared imaging method [2]. Direct observation means that the staff can observe the corona discharge position of transmission line directly through human eyes. Although this method is simple and convenient; its accuracy is greatly affected by the subjectivity of human beings. Ultraviolet imaging is mainly used to detect the ultraviolet light emitted by the transmission line during Corona discharge [3]. The influence of sunlight is filtered out in the ultraviolet band of the solar blind zone, which greatly improves the measurement accuracy. This method has the advantages of intuitive observation, good predictability and long observation distance, but the price is very expensive. Ultraviolet pulse method uses the ultraviolet light emitted by corona discharge to count the number of discharges and evaluate the degree of corona discharge. This method is cheaper, but can only detect the distance of about 8 meters. Infrared imaging method detects the temperature change caused by the heat emitted by corona discharge process [4], which can detect a long distance, but its signal-to-noise ratio is so low that it usually detects only at night. There are obvious shortcomings in the above methods. In order to meet the requirements of stability, reliability, accuracy and economy, this study proposes a detection antenna device of radio frequency electromagnetic wave
to measure corona discharge effectively and accurately. Through testing corona discharge of high voltage transmission line in natural environment, the signal-to-noise ratio of corona discharge signal is the highest in the frequency range of 100 MHz to 300 MHz. Based on this environment, we need to design an antenna device with high gain and strong directivity at the center frequency of 200 MHz, which has realized accurate directional detection of corona discharge signal. Li Wei studied rectangular planar spiral antenna, Zhu Li studied single-winding spiral antenna, Zeng Yunmei studied conical antenna capable of detecting partial discharge, S. Weigand studied U-shaped microstrip antenna, Wang Youyuan's new microstrip antenna for partial discharge detection of power equipment, and so on. Considering detection band is 100MHz to 300MHz, to meet the practical engineering requirements, this study intends to design a rectangular planar spiral antenna to detect corona discharge in transmission lines, and verify the design results by two parameters: reflection coefficient(S11) and voltage standing wave ratio(VSWR): S11 < -5dB, VSWR < 3.56.

2. The Structure of Planar Rectangular Spiral Antenna

2.1. Structural of Single-arm rectangular spiral antenna

The antenna is a spiral structure formed by superposition of several rectangles. It takes the origin as the starting point of the coil and a0 as the edge length to make three rectangular edges to obtain a single-turn antenna. The antenna is a spiral structure formed by superposition of several rectangles. It takes the origin as the starting point of the coil and a0 as the edge length to make three rectangular edges, through that can obtain a single-turn antenna. Then the edge length is increased to 2a0 and draw three edges of the second rectangle, and two-turn antennas are obtained. According to this regular, the structure of n-turn rectangular spiral antenna can be obtained by repeated superimposition. Its edge length is na0. The structure of antennas with different turns is shown in Figure 1.

![Figure 1. Structural Charts of Antenna with Different Turns.](image)

2.2. Design of Planar Rectangular Spiral Antenna

Considering the practical application of corona discharge detection in transmission lines, the antenna must be lightweight and portable. So the rectangular spiral antenna is designed as a planar structure. The structure of the antenna is shown in the following figure.

![Figure 2. Antenna model structure.](image)

As is seen from the above figure, the antenna consists of three parts: shielding layer, dielectric layer and antenna layer. The shielding layer plays the role of preventing interference from external signals and reducing radiation loss. Copper sheets of the same size as the whole model is attached. The dielectric layer can isolate the antenna layer from the shielding layer. The antenna layer adopts a planar rectangular spiral antenna structure for receiving signals.

3. Simulation Analysis of Planar Rectangular Spiral Antenna

In order to design and optimize the structure of rectangular spiral antenna, the study decides to use finite
element method to simulation and analysis. Compared with others simulation methods, it can simulate more geometric structure to get a solution, no matter how complicated it is. To meet the need of antenna simulation, the study decides to use HFSS that it is a large 3D simulation software to solve the question. After importing the antenna model in software, the structure picture is shown as below.

![Figure 3. Simulation Model of Planar Rectangular Spiral Antenna.](image)

For single-arm rectangular spiral antenna, the selection of feed location and feed method will influence antenna performance, seriously. To apply to the engineer site more convenient, the study uses coaxial cable whose resistance is 50 ohm to feed. By simulation, the result shows that if we contact the central copper wire of coaxial cable with antenna, the performance of antenna is best. The feed picture is shown as Figure 4.

![Figure 4. Antenna Feed Diagram.](image)

The performance of planar rectangular spiral antenna is greatly affected by the parameters of edge length, line spacing and turns. Therefore, the base parameters are as follows: side length $a_0 = 5$ mm, step value $\Delta a_0 = \pm 0.5$ mm, line spacing $w = 4.6$ mm, step value $\Delta a_0 = \pm 0.5$ mm, turn number $n = 10$ mm, step value $\Delta n = \pm 1$. The simulation result about three parameters and $S_{11}$ is shown as the following table.

| $a_0$(mm) | $S_{11}$(dB) |
|-----------|--------------|
| 4         | -2.97        |
| 4.5       | -3.30        |
| 5         | -4.11        |
| 5.5       | -3.70        |
| 6         | -4.74        |

| $w$(mm)  | $S_{11}$(dB) |
|----------|--------------|
| 1.2      | -3.94        |
| 1.4      | -3.87        |
Table 3. The Relation of Antenna Turn and $S_{11}$

| n  | $S_{11}$ (dB) |
|----|---------------|
| 8  | -2.26         |
| 9  | -2.74         |
| 10 | -4.11         |
| 11 | -4.06         |
| 12 | -6.58         |

In order to describe the relation of three parameters and antenna performance more obviously, the data of tables are linearly fitted as follows.

Figure 5. Fitting Cure of Antenna Side Length and $S_{11}$.

Figure 6. Fitting Cure of Antenna Line Spacing and $S_{11}$.

Figure 7. Fitting Cure of Antenna Turn and $S_{11}$.

To meet the practical application of corona discharge detection in high voltage transmission lines, the size of the antenna should be controlled within 15 mm*15 mm. Taking this area as the constraints of optimization. after continuous simulation and optimization, the antenna edge length is 2.9 mm, the distance is 1.5 mm and the turn number is 21 from 100MHz to 300MHz, the $S_{11}$ of antenna is the least. And the size of the planar rectangular spiral antenna is 13mm*13mm. So it meets design requirements of antenna. Its reflection coefficient curve is shown in the following Figure 8.
Within this frequency band, when the frequency is 275 MHz, Most of the S11 curve is under – 5dB, which meets the design requirements of - 5 dB antenna. The VSWR curve is shown in the following Figure 9.

When the frequency is 275MHz, the VSWR can be less than 3.56, which meets the design requirements of the antenna. For the directivity, the following figure can be used to illustrate.

The radiation direction of the antenna is perpendicular to the plane direction of the antenna, which shows that the antenna has good directivity. So it can be used to detect corona discharge in transmission lines. The physical antenna is shown in the Figure 11.
4. Experimental Verification

In order to verify the design of planar rectangular spiral antenna, we built a corona discharge experimental platform under laboratory conditions shown below Figure 12. By adjusting the voltage value to change the corona discharge intensity, and adjusting the distance between the discharge source and the measurement antenna, we recorded the corona discharge signal through the antenna, and recorded the corresponding radio frequency spectrum distribution curve to judge the performance of the antenna.

![Figure 12. The Corona Discharge Experimental Platform.](image)

The study uses this platform to test the planar rectangular spiral antenna. The corona discharge is simulated by a discharge gun. The corona discharge signal is received by the antenna; we use an oscilloscope which can Fourier transform to analyze the frequency spectrum of the corona discharge waveform. The result is shown as Figure 13.

![Figure 13. The Waveform Received by Antenna of Corona Discharge.](image)

The experimental result shows that the planar rectangular spiral antenna has good performance. When the antenna is 8 m away from the discharge point, the antenna can receive a very clear discharge signal.

5. Conclusion

This paper mainly completes the research of corona discharge detection antenna. Because rectangular spiral antenna has smooth impedance and good circular polarization, it is selected to detect corona discharge of transmission line, the detection frequency band is 100-300 MHz. The size of antenna substrate is determined to be 13 mm*13 mm*1.6 mm by HFSS simulation. The antenna edge length $a_0$ = 2.9mm, line spacing $w$=1.5 mm, turn number $n$ = 21. At this time, the antenna's $S11 <$-5dB, $VSWR <3.56$ has good directivity, so it meets design requirements of the antenna. Finally, the feasibility of the antenna is verified by experiments.

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