Discharge region sensing Technology of High Voltage Equipment Based on The testing of The Corona Radiation Field

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ABSTRACT

High voltage discharge sensing through detecting corona discharge electromagnetic radiation field is an important means to evaluate the reliability and safety of high voltage equipment during operation. However， the traditional corona discharge electromagnetic field sensing method can't determine the discharge region. In this paper, the relationship between the spectral characteristics of the electromagnetic radiation produced by corona discharge and the curvature radius of the discharge region is analyzed theoretically. The modeling and Simulation of the discharge current and the radiation spectrum are given. The radiation characteristics of corona discharge are obtained. The experimental system of corona discharge radiation field is established. The radiation characteristics of the electrodes with different radius of curvature are studied, and the relationship between the curvature radius and the spectrum of electromagnetic radiation is obtained, The results show that the radiation frequency spectrum is determined by the curvature radius of the electrode. A method for determining the curvature radius of the discharge region according to the characteristics of the discharge radiation is proposed. According to the radius of curvature, the target area of the high voltage discharge is locked, so as to determine the discharge location.

Keywords: corona discharge, high voltage discharge sensing, Trichel pulse electromagnetic field

1 INTRODUCTION

The phenomenon of partial discharge (PD) will occur during the operation of high voltage equipment. Partial discharge is one of the main causes of high voltage equipment insulation damage and power system accidents. Therefore, it's very crutial for huge, high-voltage equipments to go through partial discharge sensing and positioning in the progress of manufacturing and operation.

The initial form of PD of the high voltage equipment is corona discharge. It will cause corona power loss, resulting in radio interference and noise interference, and gradually damage the insulation performance of high-voltage equipment. If not timely repaired, such flaw will develop into a spark discharge, causing damage to high voltage equipments, thus resulting in more serious accidents[3,4]. Hence, detecting and repairing the specific discharging components of the high-voltage equipments will eliminate possible accidents and significantly prolong the service life of such devices.

Currently there are several popular corona discharge sensing technologies, which are: artificial visually method, optical sensing method, ultrasonic sensing method and electromagnetic radiation field sensing method. The intensity of Corona discharge is weak, and artificial visual sensitivity is very low, making its result easy to be influenced by environment. Ultrasonic sensing method is mainly used as an auxiliary means of electrical sensing, but can't complete the whole sensing progress independently. Optical sensing has the advantages of high reliability and high positioning precision, and has been widely studied and applied. However, its equipments, including the infrared imaging instrument, UV imaging instrument are both of high cost and call for complicated operation skills. What's more, this method is not suitable for all-weather long-range sensing of corona discharge as it has difficulty in predicting early corona discharge, and ultraviolet radiation attenuates seriously in the air and medium during propagation.

In the process of corona discharge, there will be electromagnetic wave radiated to the surrounding ambience. Currently, corona discharge electromagnetic field radiation sensing methods are mainly for the wide band sensing. This method can only test the presence of corona discharge, but can not determine the discharge region[4]. The latest research shows that the radiation spectrum of corona discharge is related to the curvature of the discharge region, and the radiation frequency increases with the decrease of the curvature radius of the discharge region[5].

In this paper, the radiation characteristics of corona discharge are studied, and the relationship between the discharge spectrum and the curvature of the discharge region is obtained. Finaly, a method for testing the discharge region of high voltage equipments based on corona discharge radiation field sensing is proposed.

2 THEORETICAL ANALYSIS AND SIMULATION

The Corona discharge has been known for a long time as a self-sustained discharge which occurs if the electric field is sharply non-uniform. In the process of corona discharge, a stable repetitive pulse current is produced, which is called Trichel current pulse[6]. The rising time of the Trichel current pulse is effect by the electronic motion process in the electric field near the electronic avalanche[2]. The development of the electronic avalanche under the Townsend mechanism determines the rising time of the pulse current. The rising time of the Trichel current pulse can be expressed by the following equation[4-6].

$$t_{(\tau)} \sim d_c / (\mu_e E) \quad (1)$$

Where d_c is the electronic avalanche distance threshold, μ_e is the mobility of electron and E is the electric field. Under the same voltage, stronger electric field is produced around the tips with smaller radius. As shown in Fig. 2.

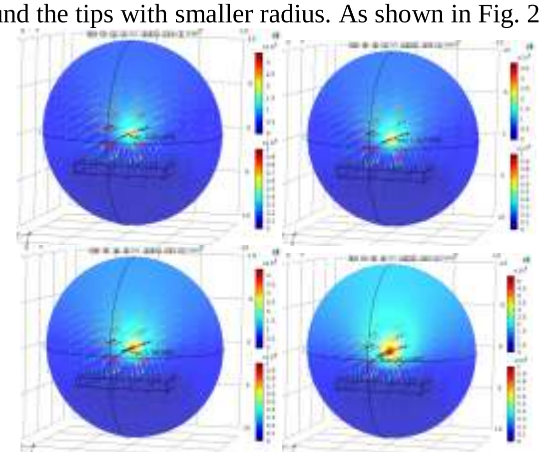

Fig. 2 The electric field strength near the different curvature line electrodes

When the wire electrode is loaded with a voltage of 10000 V, the strength of electric field of the electrode changes from 2.03 $\times 10^7$ V / m to 2.25 $\times 10^8$ V / m as the radius of curvature of the wire electrode changes from 200 μm to 25 μm. Therefore, it is believed that with the decrease of the curvature radius of the electrode, the time of the rising edge of the Trichel current pulse generated in the negative corona discharge is shorter. This conclusion is consistent with the experimentally measured results.

The current of Trichel pulse can be featured as doubleexponential function [5] written as:

$$I(\mathrm{t}) = I_0(e^{-t/\alpha} - e^{-t/\beta}) \quad (2)$$

where I_0 is the maximum of the current, α and β are time constant for the rising and decay. Fig. 3 is the measured single Trichel current pulse waveform and simulation waveform.

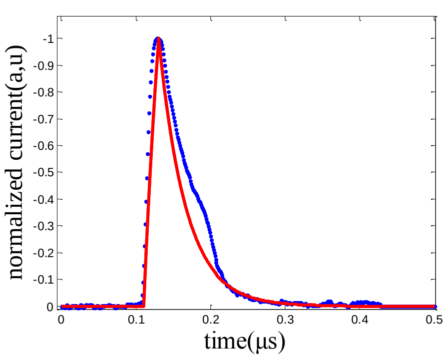

Fig. 3 measure and simulate Trichel current pulses

We can see that when the Trichel current pulse rising edge is 20ns, the FFT transform of the Trichel current pulse exhibits a series of envelope. Fig.4.The center frequency of the base band is 58 MHz, and the center frequency of the double-frequency band is 110 MHz.

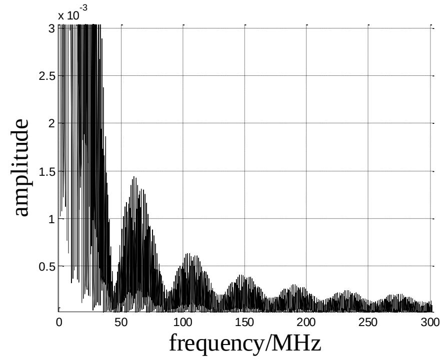

Fig.4 frequency spectrum of the Trichel current pulse

At the same time, the shorter the pulse rise time is, the larger the center frequency of negative corona discharge is. Therefore, it is possible to determine the curvature of the discharge region of the high voltage device by sensing the spectrum characteristics of the negative corona discharge. Thus the discharge region of the high voltage discharge device can be determined.

3 EXPERIMENTAL SETUP

The experimental system of corona discharge electromagnetic radiation field is shown in Fig. 4. The test system is composed of two parts: high voltage discharge module and electromagnetic radiation signal sensing module. Among them, the high voltage discharge module using wire-plate discharge structure. The wire electrode is made of 4 tungsten wires with different thickness. The negative DC high voltage power supply is used for the discharge structure, and the 2M current limiting resistor is connected between the high-voltage power supply and the wire electrode. The 1K sampling resistor is connected between the anode and ground to collect the Trichel current pulse signal. There is only one wire electrode access circuit each time. The electromagnetic radiation signal sensing module uses a antenna(discone antenna XO-08-02，from 20MHz-1GHz) to receive corona discharge electromagnetic radiation signal. The distance between the antenna and the discharge structure is d. The corona discharge current is measured by the oscilloscope(Lecroy 240i 2GHz-bandwidth and 10G/s sampling rate) to measure the voltage at the two ends of the sampling resistor. The antenna receives the signal using the oscilloscope for time domain analysis. At the same time, the frequency domain characteristics of the radiated electromagnetic wave signal during negative corona discharge radiation progress are analyzed by spectrum analyzer(Rigol DSA815 frequency range 9kHz ~1.5GHz).

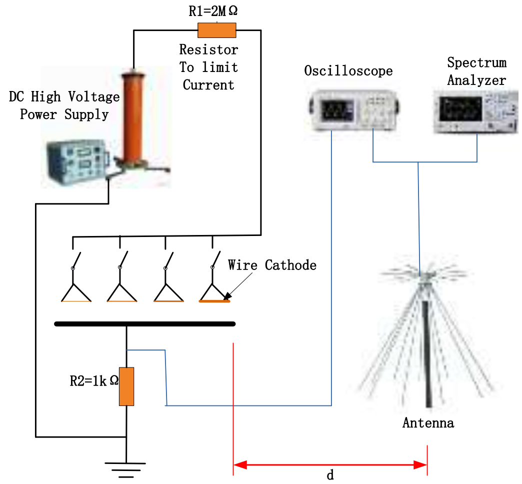

Fig. 4 Corona discharge electromagnetic radiation field test system

4 RESULTS

The diameter of the discharge electrode selected for the experiment was 50 μ m, 90 μ m, 180 μ m and 400 μ m, respectively, while the corresponding radius of curvature was 25 μm, 45 μm, 90 μm and 200 μm. Each discharge process used only one electrode for discharge. Test environment temperature was T = 25 ℃. The relative humidity was 60%.

4.1 Trichel current pulse characteristics

During the experiment, the Trichel current pulse generated by the different curvature electrodes during the negative corona discharge was first analyzed using the oscilloscope. Shown in Fig. 5 is a Trichel current pulse generated by corona discharge at an electrode curvature of 45 μm and a discharge voltage of 76 kV.

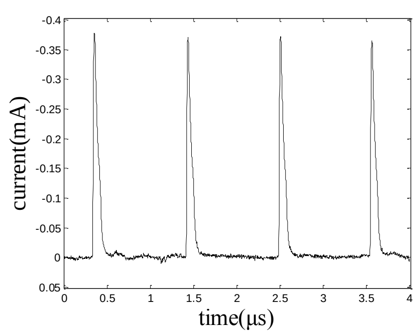

Fig.5 Trichel current pulse waveform

It can be seen that the rising edge of the Trichel pulse is very steep, whose rising time is about 22ns, on the other hand, the decline edge is comparatively flat, reaching hundreds of ns. And the Trichel current pulse has a stable repetition frequency which is about 1 MHz. During the experiment, the rising time of the Trichel current pulse generated by different curvature electrodes was counted. As shown in Fig. 6.

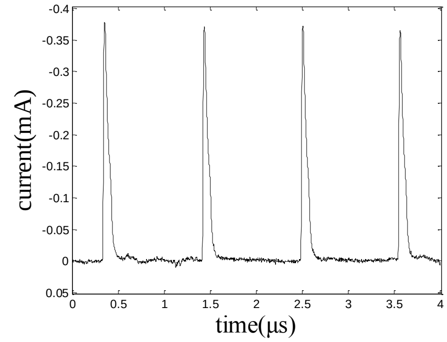
current(mA)
time(μs)

Fig.5 Trichel current pulse waveform

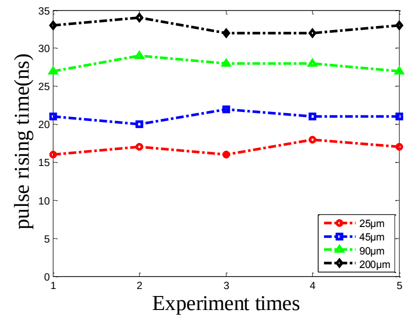

Fig. 6 Trichel current pulse rise time generated by different curvature electrodes

It can be seen from the figure that, as the electrode radius of curvature increases from 25μm to 200μm, the average duration of the Trichel current pulse rising edge increases from 17ns to 33ns. The experimental results are consistent with the theoretical analysis.

4.2 Negative corona discharge radiation characteristics

During the negative corona discharge progress under the Trichel pulse mechanism, there will be electromagnetic wave signal rediation to the surrounding ambience. Such radiated signal has a relatively stable spectrum. Fig. 7 is a spectrum of electromagnetic radiation, in which case, the radius of curvature of the wire electrode corona discharge of 45μm. At this time the antenna is about 3m away from the discharge device. We can see that the center frequency of electromagnetic radiation spectrum baseband is 47.6MHz. The maximum power is -59dBm.

Fig. 7 Radiation spectrum of electrode with curvature radius of 45 μ m

The experimental results show that the spectral characteristics of the negative corona discharge electromagnetic radiation does not vary with the change of discharge voltage and electrode spacing. The discharge spectrum is determined by the curvature radius of the discharge electrode. As shown in table 1.

Table 1 Radiation spectrum under different electrode structures

electrode curvature （μm）	**Pulse rise time （ns）**	**radiation spectrum （MHz）**
25	**17**	**73**
45	**21**	**55**
90	**28**	**50**
200	**33**	**36**

As can be seen from the table, the smaller the curvature of the wire electrode is, the shorter the rising time of the Trichel current pulse generated by corona discharge is, and the higher the center frequency of the electromagnetic radiation produced by corona discharge is. The radiation spectrum is 65.6MHz, 44MHz and 36MHz when the electrode curvature is 25 μm, 45 μm and 200 μm, respectively.

4.3 Discharge region sensing method

It’s verified that the corresponding curvature of the electrode corona discharge process of electromagnetic radiation spectrum characteristics is very stable. Therefore, this paper presents the method of determining the curvature of the discharge site through measuring the frequency of the electromagnetic radiation field generated during the corona discharge, which happens on the damaged parts of the high voltage equipment. And the regions in the high voltage apparatus with the same curvaturev are thereby determined. The key to this method is whether the radius of curvature of the discharge site can be identified by the spectrum of the discharge radiation signal. In this paper, the feasibility of the method is verified experimentally. During the experiment, a discharge electrode with a curvature is randomly selected to perform discharging. An experiment participant observed the radiation generated during the radiation signal spectrum to determine the discharge electrode curvature. Fig. 8 is the spectrum of the discharge radiation signal measured during one of the experiments.

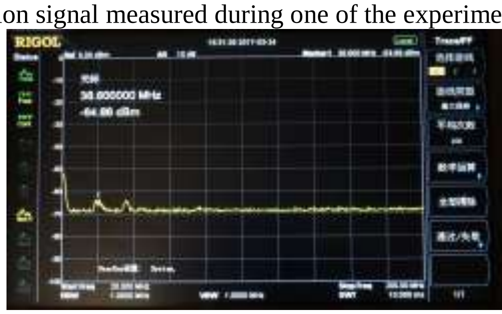

Fig. 8 Corona discharge radiation spectrum

Center frequency was around 38MHz. It was judged that the discharge electrode had a curvature of 200 μm. And the discharge electrode curvature was consistent.

After several experiments, it was verified that the recognition rate of discharge electrode curvature can reach more than 95% by the means of measuring the corona discharge radiation characteristics. Hence the identification method is proved feasiable.

5 CONCLUSION

In this paper, the relationship between the corona discharge radiation spectrum and the radius of curvature of the discharge electrode is analyzed and simulated theoretically, and verified by experiment. The correspondence between the discharge radiation spectrum and the specific electrode curvature is obtained. Based on the previous analysis and experiment, it is propsed that antenna can be used to receive the discharge radiation signal, and the curvature of the discharge site determined by the spectrum of the radiation signal, and the regions on the high voltage device with the same curvature can be thereby determined.

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