Journal of Electrostatics 71 (2013) 739–745

Contents lists available at SciVerse ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Two-dimensional residual charge density distribution measurement of surface leader

Junbo Deng [a], Lu Pu [a,c], Haibao Mu [a], Guanjun Zhang [a,*], Shigeyasu Matsuoka [b], Akiko Kumada [b], Kunihiko Hidaka [b]

[a] State Key Laboratory of Electrical Insulation and Power Equipment, Xi'an Jiaotong University, Xi'an 710049, China
[b] The University of Tokyo, Department of Electrical Engineering, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
[c] Shaanxi Electric Power Research Institute, Xi'an, Shaanxi 710054, China

ARTICLE INFO

Article history:
Received 19 September 2012
Received in revised form
7 April 2013
Accepted 6 May 2013
Available online 18 May 2013

Keywords:
Residual charge density distribution
Electrostatic probe
Scanning system
Surface discharge

ABSTRACT

The charge density distribution of the surface leader has never been measured before. Because the surface leader usually covers a long distance, and the surface potential caused by leader discharge is usually very high, this creates difficulties in measuring the potential distribution of the surface leader. In this paper, with a feedback type electrostatic probe based on a field-nullify technique, a charge density distribution scanning system is developed. A two-layer structure pipe is designed to lower the surface potential after discharge. In this way, the surface potential distribution caused by the residual charge of the leader discharge under the application voltage as high as to 40 kV can be measured. The surface charge density distribution including the leader and streamer is perfectly measured, which is in good agreement with the photograph.

1. Introduction

Surface discharge of dielectric material greatly influences the insulation performance of electrical apparatuses and electronic devices. The surface discharge is initiated by the propagation of a surface streamer, followed by a surface leader formation and a final flashover phenomenon. Fig. 1 shows a photograph of surface discharge. The bright stem is the leader, and the radial filaments are streamers. The surface discharge propagates in a stepwise manner, similar to what is observed for lightning. For every step, there are many streamers located at the head of the leader. Under certain conditions, one or several streamers will transit to leaders, and the discharge propagates forward. Compared to the surface streamer, the surface leader can propagate a much longer distance and with a much lower potential gradient. This can lead to a breakdown. Thus, it is of great importance to clarify the formation and propagation mechanism of the surface leader [1]. Because the charge accumulates on the insulator surface after propagation of the surface discharge [2–4], information about the discharge propagation can be partly obtained from the residual charge distribution.

The potential distribution or charge density distribution of surface discharge has previously been extensively studied with optical and electrostatic probe methods; however, almost all of the measurements are focused on the streamer discharge [4–10]. Because the surface leader usually spans a long distance, and because its potential can be very high, the measurement of the potential distribution of the surface leader is frequently blocked.

High-speed cameras and photomultipliers have long been used to observe the discharge propagation [11–13]. However, only the illumination information of the discharge can be obtained using these methods, while the important electrical information, such as the charge density and field distributions, cannot be obtained.

Optical systems, based on the Pockels effect, have been proposed in order to obtain the two-dimensional potential distribution on planar insulators [6–10]. Resulting optical measurements have enabled the potential distribution scanning of propagating streamers directly with high time (0.2 ns) and high spatial (10 μm) resolution [6]. However, the configuration of the electrodes and insulator is strictly confined, and the spatial measurement range is limited. Examples of this include a 25.4 mm square [7], a 20 mm square [8], and 8 mm square [9]. Due to this restriction, the application voltage is not very high, and the discharge types are usually corona or streamer [6,10].

* Corresponding author. Tel.: +86 29 82668385.
E-mail addresses: dengjb@mail.xjtu.edu.cn (J. Deng), gjzhang@mail.xjtu.edu.cn (G. Zhang).

0304-3886/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.elstat.2013.05.002

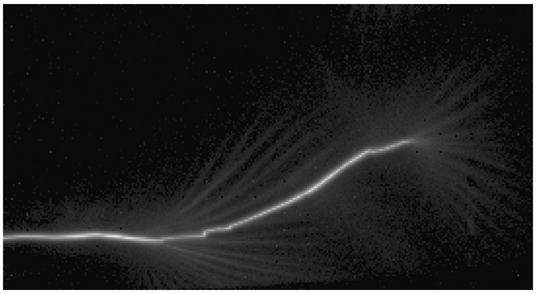

Fig. 1. Photographic image of surface discharge.

The electrostatic probe is a popular tool with which to measure the residual charge density distribution of surface discharge on insulating material [14–18]. Although the electrostatic probe is inferior to the above mentioned optical method from the viewpoint of time resolution, it has the advantage of easy handling and relatively low noise. Using an electrostatic probe, we have measured the residual charge distribution along a positive surface leader with a spatial resolution of 0.3 mm. We also applied a digital image processing technique using two-dimensional spatial domain Fourier transformation and a Wiener filter in order to calculate the charge density distribution, potential distribution and electric distribution. We also evaluated the spatial resolution of the measuring system [14].

By theoretical derivation, Niemeyer claimed that when a sufficient number of streamers have fed their current into a common channel, ionization restarts, and the channel becomes a leader with high conductivity [19]. Seeger and Niemeyer tried to provide a novel quantitative model for the arrested leader, which had been shown to exist in experiments [20,21], but had never been characterized quantitatively [22]. They measured the discharge current and length to estimate the average charge in the leader channel, but the charge distribution characteristics in the leader channel have never been clarified.

Because of the high potential of the surface leader, its charge distribution has never been measured, and the mechanism of streamer-to-leader transition has never been quantitatively described before. To lower the surface potential, we have designed a two-layer pipe. We developed a surface-charge density scanning system with a commercial-electrostatic probe, which is based upon a field-nullify technique. With this system, we measured the residual charge density distribution of the surface leader for the first time [23].

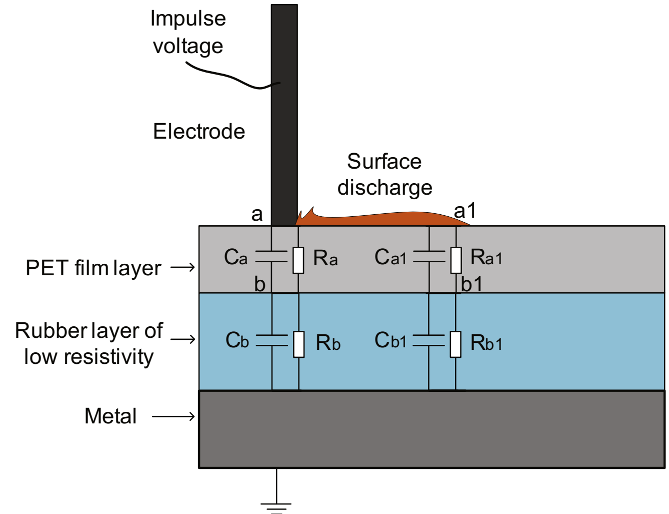

Fig. 3. The schematic circuit of the two-layer structure pipe.

2. Experimental setup

The investigations are performed on a cylindrical insulator configuration with two ring electrodes and one rod back electrode, as shown in Fig. 2. Experiments are conducted in atmospheric air at room temperature with 30–50% relative humidity. The distance between two ring electrodes is 300 mm. The diameter and the length of the rod back electrode are 20 mm and 600 mm, respectively. The lower ring electrode and the back electrode are grounded. A 1.2/50 μs standard lightning impulse voltage is applied to the upper ring electrode so that a surface discharge occurs and propagates on the insulator surface.

A high-speed video camera (Phantom, Vision Research Inc.) is used to observe the discharge. The current is measured with a Rogowski coil (Model 2877, Pearson Electronics Inc., bandwidth: 200 MHz) and the voltage is measured with a high-voltage divider (PR-100GL, Pulse Electronic Inc., bandwidth: 30 MHz). The waveforms are recorded with an oscilloscope (Tektronix 3053, bandwidth: 500 MHz).

To reduce the potential of the accumulated residual charge, the dielectric pipe is designed as a two-layer structure (Fig. 2b). The outer layer is a PET (Polyethylene terephthalate) film, and the inner layer is a rubber layer with a low resistivity. The schematic circuit of the two-layer structure pipe is shown in Fig. 3. A transient simulation is carried out with ATP-EMTP to model the potential at points

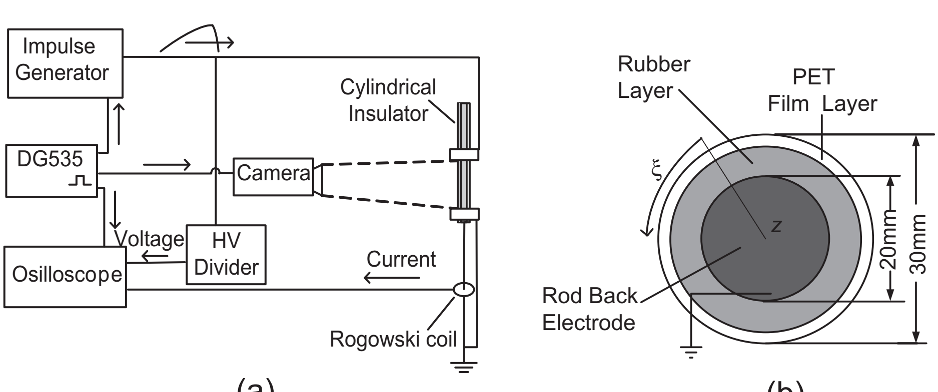

Fig. 2. Experimental setup: (a) Schematic of experimental setup, (b) structure of cylindrical insulator.