A Study of the Behavior of Water Droplets Under The Influence of Non-Uniform Electric Field in Silicon Rubber

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Abstract—Water droplets on the surface of silicon rubber were investigated under the influence of non-uniform electric fields. Several parameters of water droplets were investigated, such as the positioning of the droplets regarding the electrodes. The most striking conclusion is that the flashover voltage and electric field distribution depends on the positioning of the droplets from the electrodes.

Keywords—water droplets; non uniform Electric field; COMSOL; finite element; insulating barrier; silicon rubber

I. INTRODUCTION

The insulating materials used for equipment of high voltages during operation for many years, are stressed by various factors, such as moisture, particles, and pressure [1, 2, 3, 4]. The objective of this study is to investigate the dependency of the electric field on moisture and water droplets using a silicon rubber.

Water drops or water films in high voltage equipment, why and where did that occur? The answer to this question allows us to classify the high voltage equipment in indoor and outdoor equipment [5].

In indoor high voltage equipment, for example high voltage switchgear and bus bars, synthetic materials are frequently used and the surfaces of this class of material can accumulate water drops. These accumulated water drops can also later become water films.

For outdoor high voltage equipment’s, rainwater drops are usually deposited on the surfaces of exposed equipment parts during or after precipitation. So by, conductors of overhead lines and sheds of outdoor insulators are those of most equipment parts, which can considerably accumulate multiple water drops on the surfaces [6-7].

In this work we examine the influence of the position of the insulating barrier and the water droplets on the electric field distribution in non-Uniform electric field system using silicon rubber.

The numerical study of the electric field distribution in rod-plane systems avoids generally expensive destructive testing. Indeed, we make a digital study to determine the values of the electric field by using the computer software Comsol [8].

II. SYSTEM MODELING

a. System presentation

The study system (Fig.1) consists of an arrangement of rod-plane electrode gap of d, between the two electrodes is inserted an insulating barrier of width w, thickness e and relative permittivity $\varepsilon_{\text{solid}}$, placed at the distance x from the rod electrode. The rod electrode of radius $r_p$, is connected to the high voltage HV and the plane electrode of width $L_p$, is grounded. The system studied containing air of relative permittivity $\varepsilon_r$.

![Fig. 1. Study System](image-url)
To evaluate the effect of the barrier on the behavior of the system, it assumes that a change in the electric field is induced by the presence of the insulating barrier; its distribution depends on dimensions and position of the barrier.

In this paper the gap distance, barrier width and thickness and plane width are constants and they are 5cm, 4cm, 2mm and 9 cm respectively.

b. Electric Field computation

The field values are obtained by solving the Maxwell equations governing the static state.

\[
\text{Div} \vec{D} = \rho \tag{1}
\]

With:

\[
\vec{D} = \varepsilon \vec{E} \tag{2}
\]

\(\varepsilon\): Dielectric permittivity, \(\rho\): Charge Density, \(\vec{E}\): Electrical field.

Taking into account the local form of the Ampere law:

\[
\text{Rot}\vec{E} = 0 \tag{3}
\]

Where:

\[
\vec{E} = -\text{grad}(V) \tag{4}
\]

\(V\): Electrical voltage.

Combining equations 1 and 4 gives the Poisson equation in the case of a homogeneous material:

\[
\Delta V = -\frac{\rho}{\varepsilon} \tag{5}
\]

Neglecting the space charges and considering the calculation on the x-y plane, this equation is written as:

\[
\frac{\partial}{\partial x} \left(\frac{\partial V}{\partial x}\right) + \frac{\partial}{\partial y} \left(\frac{\partial V}{\partial y}\right) = 0 \tag{6}
\]

The resolution of this equation in the study system can be done only by a numerical calculation. To do this, the COMSOL software [5] is used, with considering a Neumann boundary condition on a rectangular border around the system:

\[
\frac{\partial V}{\partial n} = 0 \tag{7}
\]

III. RESULTS AND DISCUSSION

From Fig. 2, 3, 4, 7, 8 and 9 it is evident that the droplet water plays a significant role in determining the flashover voltage in silicon rubber. Moreover, from these figures is indicated that the positioning of silicon rubber and droplets influences the flashover voltage and electric field distribution (if we compare the electric field contour when the barrier with droplets is placed at 0% from the rod electrode and the electric field contour when the barrier with droplets is placed at 20%, 60% and 100% from the rod electrode, unless if we compare between the electric field contour when the barrier is placed 0% from the rod electrode but the droplets are in different horizontal position from the rod electrode (0cm, 0.25cm and 0.75 cm).

From the results it is evident that the droplet leads to a reduction of the flashover and electric field [9]. This is clearly shown in Fig. 5 and 10. The positioning of the droplets from the electrodes play a vital role. This can be explained by the fact that near the electrodes ionizing phenomena are easier to obtain, so with easier ionization the flashover voltage becomes lower. The latter is reminiscent of the relative easiness with which partial discharges take place in solid dielectric cavity, when one side of the enclosed cavity touches one of the electrodes [10].
In Fig. 10 to 13, a direct comparison between the electric field distribution in dry silicon rubber and wet silicon rubber, is made. From the results it is clear that the dry silicon rubber tends to give higher electric field results than the wet silicon rubber. This is a strong indication that dry silicon rubber improves the flashover voltage.

The position of the insulating barrier and water droplets effect the electric field values, it takes a maximum values when the barrier is near the rod electrode and decreases if the barrier moves to the plane electrode. The electric field on the barrier surface without water droplets is higer than the electric field with water droplets, it decreases from 450 kV/cm to 290kV/cm respectively at x=0% fig.10, but the values is almost the same if we compare between the the barriers used with and without droplets at 20%,60% and 100% from the rod electrode fig.11 to 13.
In this paper, water droplets positioned on Silicon rubber were investigated under the influence of non-uniform electric fields. Droplet positioning horizontally on the barrier surface plays a dominant role in determining the flashover voltage.

According to the results, it is clear that by using water droplets, the value of the flashover voltage and electric field decreases. Other obtained results enable us also to affirm, that the electric field applied to the water surface is controlled by the electrode geometry and spacing between water surface and the electrode.

REFERENCES

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