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Electrical field on non-ceramic insulators and its relation to contact angles for constant volume droplets

Davi M. Soares [a], Serge Mendonça [a, b, *], Estácio T.W. Neto [a], Manuel L.B. Martinez [a]

[a] High Voltage Laboratory, Federal University of Itajubá - UNIFEI, Av. BPS, 1303, Pinheirinho, Itajubá, MG 37500-903, Brazil
[b] INESC P&D Brasil, Rua José Caballero, 15Bairro Gonzaga, Santos, SP 11055-300, Brazil

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A B S T R A C T

The presence of water droplets on the surface of insulators provides intensification of the electric field, which are caused by the non-uniform voltage distribution and dielectric properties of the different materials. The degree of Electric field (E-field) intensification at the triple joint, the region where water, the non-ceramic dielectric and the air are in contact, must be carefully analyzed, because under certain conditions, breakdown voltages can be reached, sometimes, under very little or no contamination at all, which can cause the insulator wettability, tracking, flashover and degradation. In this paper, variations of the electrical field over two polymer compounds widely used in the insulator manufacturing industry, Silicone Rubber (SIR) and High Density Polyethylene (HDPE), are analyzed on a 2D geometry with respect to contact angles of constant volume water droplets. The Electrical field is also computed as a function of relative water droplets distances.

1. Introduction

Non-ceramic insulators were first developed during the 1960's [1] mainly due to its advantages when compared to porcelain and glass insulators such as lighter weight, easily handling and maintenance, lower susceptibility to vandalism, excellent moisture and contamination resistance due to hydrophobicity.

The hydrophobicity is the capacity of a material to avoid contact with water as well as to seek as far as possible nonaqueous environment [2]. In the case of dielectric materials this aims to avoid formation of continuous films of water along insulator's surface, mitigating, in this way, leakage currents to flow on the surface. These currents cause erosion and tracking phenomena which leads then to a possible flash over and consequent insulator failure.

Nevertheless, the electric field on the surface of the insulators can be distorted by the presence of water droplets due to different interfaces, which can be composed by the combination of gaseous, liquid and solid phases, being designated as triple-joint, three-phase contact line or three-phase common line when there are three phases on a contact region. The results obtained were relevant specially when analyzing the three-phase contact line.

Based on the E-field disturbance, the present study aims at verifying the effects of different profiles of water droplets on non-ceramic dielectrics surfaces as well as their electric field behavior for different dielectric materials. Additionally, an analysis of which dielectric material and hydrophobicity angle is the best in order to obtain less E-field stress as possible is presented considering several water droplets shapes. Additionally, an analysis utilizing work of adhesion is also performed in order to evaluate such parameter with the E-field intensity.

For all the profiles taken into account in this paper, even though the geometry and dimensions of water droplets were different, they were adjusted to keep the droplet volume constant, thereby having E-field evaluations for different water droplets shapes with the same volume of water.

2. Experimental model and sets

2.1. Model insulator

In order to carry out the simulations, a system known as Simple

* Corresponding author. High Voltage Laboratory, Federal University of Itajubá - UNIFEI, Av. BPS, 1303, Pinheirinho, Itajubá, MG 37500-903, Brazil.
E-mail address: sergemendonca@gmail.com (S. Mendonça).

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Electrode was used and the results were computed by COMSOL®, a Finite Element Model (FEM) software.

The electrode system consists of two electrodes, 100 mm apart, and a solid dielectric material of thickness 5 mm placed between them. The voltage of 100 V was applied to one electrode, while the other was grounded, as shown by Fig. 1. Such voltage value was chosen as the simulation was performed using module AC/DC and electrostatics physics on COMSOL®, which means that there were no electric currents flowing through system's interfaces and therefore the applied voltage must be below the breakdown threshold value. In other words, the electric field obtained must as low as 24 kV/cm in order to avoid the flashover phenomena [3].

The surface of an insulator has two main regions, specified as sheath and shed. The first is simulated having the dielectric sheet as a spacer, as shown by Fig. 1(a) and the second is represented as having the dielectric sheet positioned in parallel between the two electrodes, as shown by Fig. 1(b).

The dielectric materials on the simulations are High Density Polyethylene (HDPE) and Silicone Rubber (SIR) as they are widely used nowadays in non-ceramic insulators. Several water droplets profiles were considered regarding their shapes.

2.2. Contact angle

For every surface with water droplets on it, it is possible to measure the degree of wetting, by the angle of interaction between the liquid and solid material. The parameter resulting from this measurement is the "*contact angle*". As shown by Fig. 2(a), a surface that has a contact angle lower than 90° is called hydrophilic, as it corresponds to a high wettability level, in the other hand, surfaces that have contact angles higher than 90° are known as hydrophobic, as shown by Fig. 2(c) [4].

Fig. 2(c) shows that in hydrophobic surfaces the water droplet takes approximately the shape of a circumference in 2D, even though it is not exactly part of a sphere. The droplets were assumed to be spherical by reason of their small drop volume and negligible gravitational effect [3]. [4].

In rectangular Cartesian coordinates, if $p_o\,(x_o, y_o)$ is the center of the droplet and p (x, y) any point on its surface, the representation follows below [3]:

$$\frac{(x-x_0)^2}{a^2}+\frac{(y-y_0)^2}{b^2}=1 \tag{1}$$

In this paper, 2D simulations were carried out using a droplet circumference shape, as presented in Fig. 3. In order to keep constant the volume of the water droplets the contact angle was computed as shown by (4). All units of length, volume and degrees are given respectively in mm, mm^3 and radians.

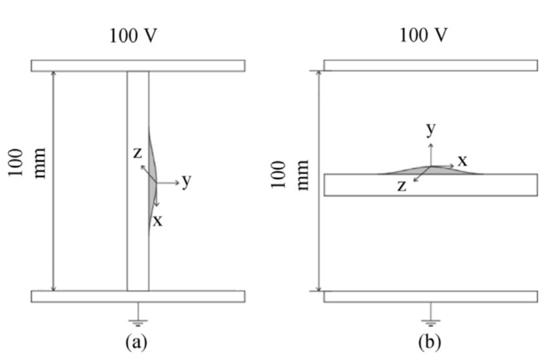

Fig. 1. Simple electrode system used in the simulations: (a) Sheath region; (b) Shed region.

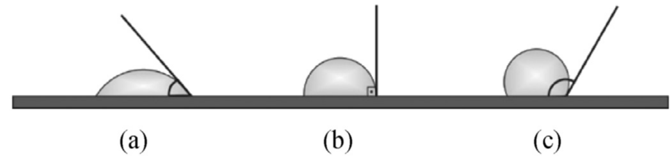

Fig. 2. Interaction between two different materials in liquid and solid states and their contact angles. The volumes of the droplets presented on (a), (b) and (c) are the same.

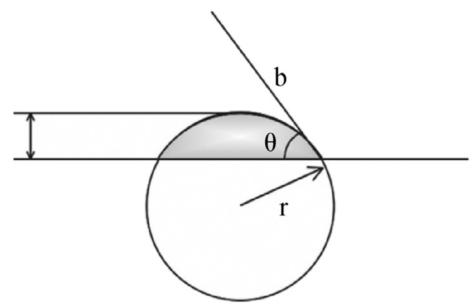

Fig. 3. Contact angle theoretical model calculation [3].

$$\theta=\frac{\pi}{2}-\tan^{-1}\left(\frac{r-b}{\sqrt{2rb-b^2}}\right) \tag{2}$$

$$\alpha=2{*}\cos^{-1}\left(\frac{(r-b)}{r}\right) \tag{3}$$

$$A_{segment}=\frac{r^2}{2}(\alpha-\sin\alpha) \tag{4}$$

A MATLAB® algorithm was written using in order to parameterize the water droplets profile, obtaining profiles with constant surface area as a function of the angle as shown by (1)–(4) once it is possible to infer that droplet volume is analogous to the surface area, as it is a matter of axial revolution.

The water droplet volume adopted was 100 μl, which is approximately the volume of a droplet of radius 3 mm [3].

3. Electric field analysis on a surface with water droplets

Aiming at identifying changes in the electric field magnitude, water droplets were modeled as having different contact angles yet maintaining the volume mentioned previously. It is possible then to evaluate consistently the E-field stresses for the same amount of matter.

The simulations were based on a 2D model. The relative permittivity of air, water droplet, HDPE and SIR are 1, 80, 2.3 and 4.3 respectively [5]. [6] [7].

The absolute computed limit for E-field is [8]: [6].

$$V=100\ V$$

$$\left|\overrightarrow{E_0}\right|=\left|-\nabla\cdot\overrightarrow{V}\right|=-\frac{(0-100)\ [V]}{100\ [mm]}=1\left[\frac{kV}{m}\right] \tag{5}$$

The voltage value considered was chosen by virtue of its value to be a way below the breakdown value in air, also, to obtain a convenient E-field value for a clearer subsequent analysis.

The effects of the Electric field on HDPE and SIR surfaces were simulated and analyzed separately for the shed and sheath region. The maximum contact angles considered for the simulation on the