Impact of parameters variations on deterioration phenomena due to water droplets on polymeric surfaces.

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Abstract-Outdoor insulators are subjected to electric stress and weather conditions like rain, fog and dew. These conditions give rise to the danger of leakage currents forming on contaminated or wetted surfaces and finally leading to insulation degradation and failure. Thus, outdoor insulation materials not only have to withstand the electric stress during service, but also they must be resistant against ageing phenomena by dust or humidity. The polymeric insulators were widely used in the last decades because of high contamination resistance, lightweight, mechanical strength and hydrophobicity of their surfaces. The electric stress in the presence of water droplets provokes partial discharges giving way to local reduction of hydrophobicity of insulator surfaces. In the present study the degradation arising from applying uniform AC electric field on wetted polymeric surfaces has been studied. The electric field distribution around droplets located over polymeric insulator has been calculated by Boundary Element Method. Different factors affecting the behavior of insulating materials under wet conditions have been investigated. An attempt to improve the behavior of epoxy resin insulating materials using different types of fillers has been introduced.

1 INTRODUCTION

The insulating materials of high voltage equipments are stressed in service over years by several environmental factors. One ageing factor is the humidity which in combination with the electrical stress causes changes of the conditions on the insulating surface. In the recent years, the application of polymer insulators has been increasing widely because of their advantages of high contamination resistance performance, lightweight, mechanical strength, etc. Especially surface hydrophobicity is one of the important factors that contribute to the superior performance of the silicon rubber to resist wetting due to its low free surface energy. Around the water drops the electrical field intensifies, especially at the triple point between the water drop, air and insulating material. The sessile drops will be deformed, always elongated along the direction of the lines of force of the electric field. These distortions shorten the insulating distance and cause partial discharges on the silicon rubber surface and finally can lead to deterioration [1]. For polymeric or non-ceramic insulators, hydrophobicity loss or reduction causes serious effects. Hydrophobicity affects the polymeric silicon rubber materials / insulators in two ways. Firstly, the loss of hydrophobicity causes reduction in electrical insulation and pollution withstand performance. Secondly, it is also prominently influences the ageing process of silicon rubber (SIR) insulators.

Outdoor insulators are subjected to electric stress as well as to environmental conditions like rain, fog and dew. Being the interface between solid material and ambient air, the surface need special attention. If conductive layers form on the surface, there may appear a leakage current which leads to a degradation of insulation and eventually to flashover. To avoid this danger, the hydrophobicity of silicon rubber is used. Humid layers will appear as discrete droplets rather than forming continuous wet areas [1-3]. In the present work, factors that affect the hydrophobicity level and the electric field distribution over the insulators under wet conditions have been illustrated. Finally, a proposed idea looks for improving the electrical behavior of polymeric insulator, by adding different types of fillers, under wet conditions will be presented.

2 EXPRIEMENTAL SETUP

Regarding the field distribution over the insulators in over head transmission lines, there are areas where the line of electric flux either is perpendicular or parallel to the surface.
The stress provoked on the material may differ according to the geometry of the electric field near the surface**.** Therefore it is of a great interest to carry out an investigation on electric field distribution over the surface of the insulator at wet conditions. Inception voltage and breakdown voltage have been also reported for different polymeric samples subjected to uniform alternated electric field at wet conditions.

In order to simulate both kinds of stresses, two different setups have been used. The first setup with a tangential field direction to the assayed sample surface is presented in Figure 1.a. It consists of two metal parallel plates having 6 cm diameter. This diameter is constant at the both setups. One electrode is contacted to high voltage and the other is grounded. The air gap distance between the plates varies from 2 to 5 cm and the insulator samples used are inserted between the plates. The second arrangement with normal field direction to the assayed sample is represented in Figure 1.b. The insulator samples are placed on the lower (grounded) electrode. These electrodes were rubbed down with ethyl alcohol to restore uniform starting conditions after each breakdown test. The AC voltage that has been applied between the electrodes has r.m.s values varying between (0 – 80) kV. The droplets have been presented over the insulators with the using of micro - pipette. The impact of changing droplets number, volume, shape, and position with the respect to the electrodes has been studied because of their correlation to the insulators degradation.

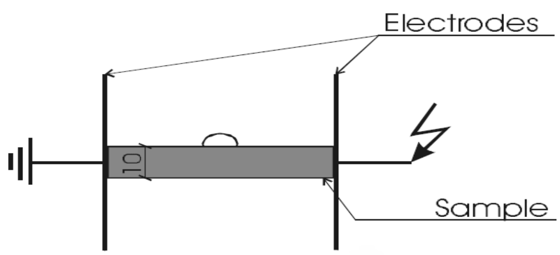

Fig. (1.a)

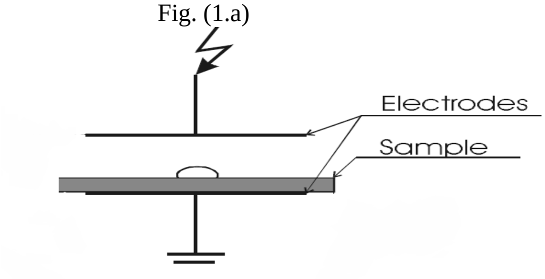

Fig. 1.b

Figure 1: Schematic diagrams of the experimental setups. (1-a,b) Tangential and Normal arrangement

3 BOUNDARY ELEMENT METHOD

The boundary element method does not rely upon fictitious charges; instead it seeks to calculate the charges distributed over boundaries. Then, approximating the real charge distribution rather than assigning values to non physical ones. The electric potential due to surface charge density is written as in [4, 5].

$$\Phi(r) = (1/(2\alpha\pi\varepsilon)) \int_l \rho_s(r')\Phi^*(r,r')dl(r') \qquad (1)$$

Where Φ(r) represent the potential at location r ,
α: is a constant equal to 1 or 2 for two or three dimensional respectively,
ρs (r'): is the surface charge density at position r',
l: represent the boundary between different regions.
r: denotes a field point, r' denotes a source point,
Φ*(r, r'): is the fundamental solution of the potential problem.

Equation (1) is the basic equation of the source formulation of boundary element method. A system of boundary conditions is required for determining the unknown charge density. After successive simplification, a set of linear equations that required to satisfy the Dirichelt boundary conditions on energized conductors and flux continuity through dielectric boundaries are obtained and expressed by:

$$[A].\,[\rho] = [\Phi] \qquad (2)$$

Where [A]: is a known potential-coefficient vector matrix, [ρ]: is the unknown surface charge density vector matrix, and [Φ]: is the potential vector matrix.

By solving this system of equations, the unknown values of charge density can be found. Consequently, using this charge distribution, potential and electric field values can be calculated. In the following part, the electrical field distribution at wet conditions, which has been calculated by boundary element method, will be illustrated.

4 ELECTRIC FIELD CALCULATIONS

PD inception voltage is a function of the distance of the electrodes and the volume of water drops. Thus the PD inception field strength values are given and compared. The field strength values are calculated for the test arrangement in absence of water drops. But we have to keep in mind that the electric field distribution is significantly changed by the water drop. Permittivity, drop shape and volume are the relevant parameters, which also influence the PD inception condition. The static drop shape depends on the surface energy of the material. The inception field strength on normal field stress condition is about 1 kV/mm. This measured result is valid for different drop sizes and different material. This result is not unexpected, because the PD inception conditions are given by the field distribution along the path between drop and upper electrode.

Figure 2 Shows the electrical field distribution over Silicon rubber material and NH4CL solution for spherical droplet shape for two different setups (namely perpendicular and tangential arrangements). The results indicate that, the highest field strength due to present of spherical water droplet in case of perpendicular is higher than in the case of tangential arrangement. In the tangential arrangement, the highest electrical field stress is located in the lower part of the water drop and towards the electrodes. In the perpendicular arrangement, the critical points are at the top of the water drop where the highest electrical field stress is reached. In reality the drop is changing its shape irregularly; therefore the field distribution will be different.

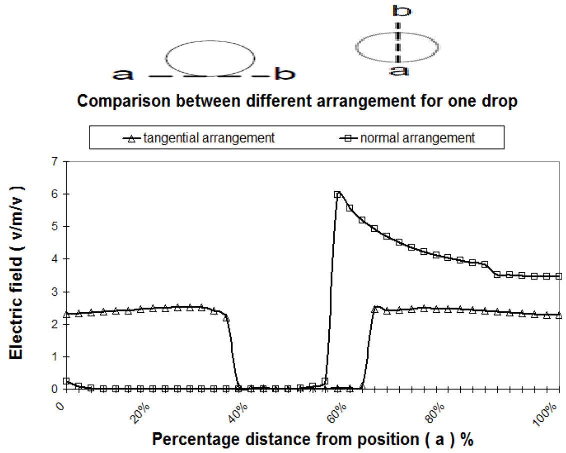

Figure 2: distribution of the electric field at a spherical water drop of radius 1 mm for both arrangements

The droplets number is another vital parameter that affects the electric field distribution. During the study of this factor the droplets were arranged in the center of the silicon rubber sample in order to minimize the effect of being close to the electrodes. In this test silicon rubber sample assumed to have an excellent hydrophobic property as the droplets must not overlap with each other; however they are arranged in too closed volume. The electric field distribution results are represented in Figure 3 in the case of one, two, and three drops, with 1 mm radius, located on silicon rubber sample which is subjected to tangential electric stress. These results show that the highest electric stress is reported at the case of three drops. The localization of the electric stress at the boundary of the droplets increases with the increasing of the number of the droplets.

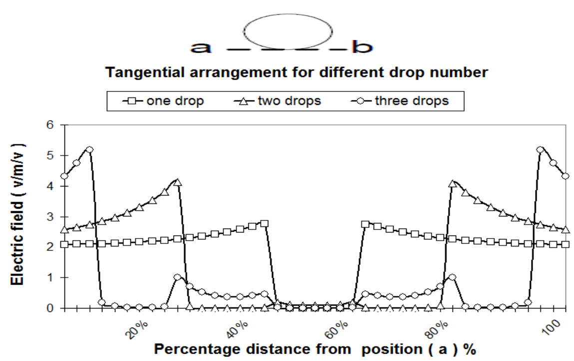

Figure 3: the electric field distribution with different droplet numbers at tangential arrangement.

The position of the droplet on the insulator surface is another parameter that influences the field distribution. Figure 4 shows the impact of positioning the droplet, near Low voltage (L.V) electrode, near high voltage (H.V) electrode and at the center of silicon rubber sample, on the electric field distribution. The electric stress was assumed to be tangential to the silicon rubber assayed sample. It is fitting to say that the electric field is uniformly distributed till the boundary of the droplet. It is previously indicated that, the electrodes play a determining role for the flashover voltage since; as the droplets are near the electrodes, the electron emission and / or the electric field applied provoke much intense phenomena. The higher electric field is related to so called "triple point" i.e. to those common points where the electrodes, the polymeric surface and the water droplet meet each other.

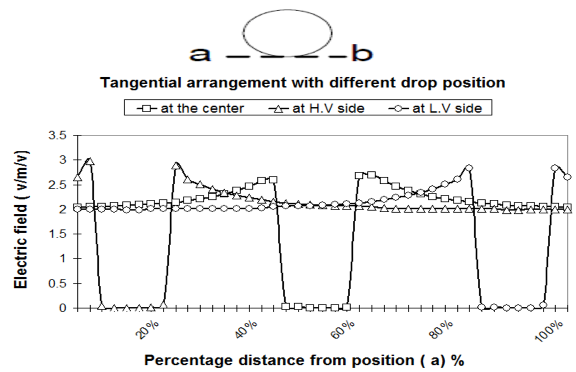

Figure 4: the electric field distribution with different droplet positions at tangential arrangement.

5 EXPRIEMENTAL RESULTS

In the present study, the breakdown and inception voltage characteristics, in the perpendicular and tangential arrangement setups, are studied experimentally in the presence of spherical water drop. The breakdown voltage plotted in the figures is determined as the main value of at least ten measured values of the breakdown voltage. To determine the inception voltage the applied voltage is raised until the first pulse appears on the oscilloscope from which inception voltage can be determined. The study was done on Silicon rubber (SIR), Epoxy resin (EP), Polyvinyl-Chloride (PVC), and Bakelite (BA) as insulating surface. The number of water drop was changed from one to three at the center of the insulating surface. There are two different solutions of water drops used in this work, namely, NACL and NH4CL with different by mass of salts dissolved in distilled water.

Figure 5 show the inception voltage characteristic for silicon rubber (SIR), epoxy resin (EP), Polyvinyl - Chloride (PVC), and Bakelite (BA) samples when they are subjected to tangential electric stress and when different number of droplets are presented over their surfaces. It is crystal clear that (SIR) sample has the best behavior in the presence of water droplets; however the worst behavior has been recorded in the case of (BA) sample. The behavior of (EP) is a bit worse than the behavior of (SIR) but still better than (PVC) and (BA).

Silicon rubber has demonstrated better hydrophobicity and lower surface energy than most organic polymers. Surface of silicon can recover its hydrophobicity between contaminations and/ or PD episodes, while other materials progressively deteriorate. PD exposure temporarily increases the "wet ability" of silicon rubber, a phenomenon associated with the increase of the surface oxygen contents. After rest period, the water repellency of the material returns. This hydrophobic recovery is though to be a result of diffusion of low molecular weight (LMW) of (PDMS) (polydimethylsiloxane) fluid to the insulation surface. The speed of hydrophobic recovery is directly proportional to the amount of LMW components left inside the bulk of silicon insulator [6].

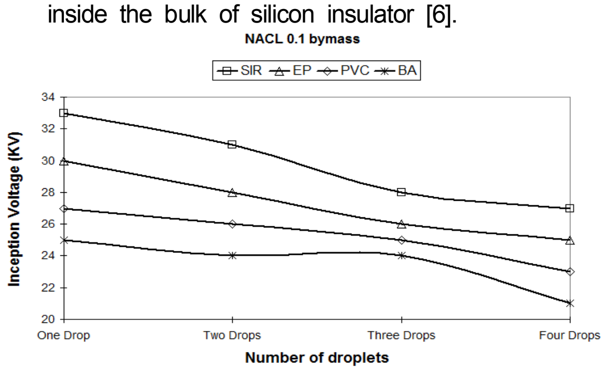

Figure 5: relation between inception voltage and different droplet number over the sample of the surface at tangential arrangement.

Figure 6 illustrate the impact of changing the contaminant solution between Chloride Sodium (NACL) and Chloride Ammonium (NH4CL) with different by mass of salt ,between 0.1 and 0.2 by mass, dissolved in distilled water and the dielectric sample has been subjected to normal electric stress. It is evident that the (NH4CL) has the worst impact on the insulator behavior because of its high conductivity. Another worthwhile result show that, the higher by mass of salt dissolved in distilled water, the lower inception voltage. It is also remarkable that the higher inception voltage has been recorded at case of one droplet and the lower inception voltage is at the case of three droplets.

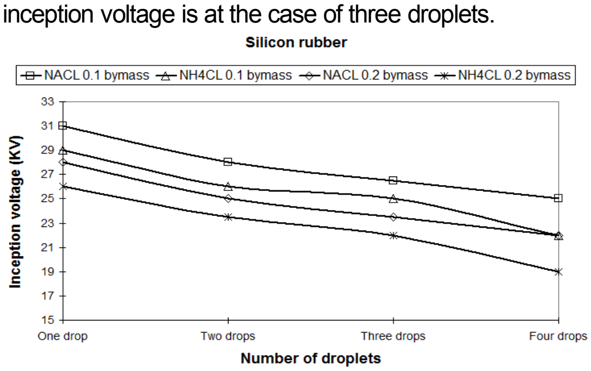

Figure 6: relation between inception voltage and different droplet number over the sample of the surface at normal arrangement.

Figure 7 shows relation between inception voltage and number of drops at PVC sample of insulating surface, for 2.5 cm gap distance and NH4CL solution for two different setups namely, perpendicular and tangential arrangements. The Fig. indicated that the breakdown voltage is proportion inversely with the number of water drops. The breakdown voltage decreased with increasing the number of water drops and its values for perpendicular arrangement are higher than for tangential arrangement.

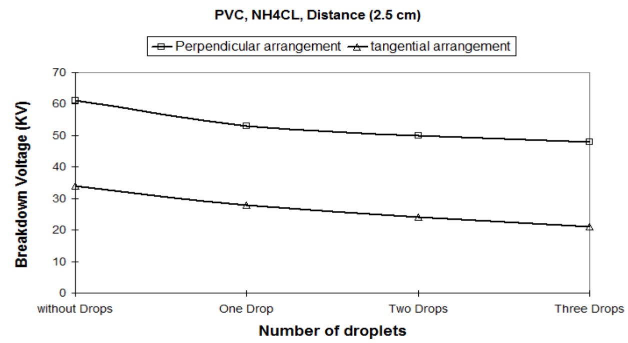

Figure 7: relation between breakdown voltage and different droplet number over the sample for different arrangement setups

6 IMPACT OF ADDING FILLERS

Epoxy resin is widely used as an insulation material in many electrical apparatuses because of its excellent electrical and manufacture characteristics.. As an attempt to improve the electrical behavior of EP resin insulating material, different types of fillers has been added in order to achieve the best performance of the insulator material. In this study, three types of fillers are used; rough and smooth Silica (SiO_2) which are used in industry during fabrication of electrical equipments and tri-hydrated alumina (THA), (Al_2O_3, $3H_2O$). The prepared specimens have filler concentration of 10 phr (Phr: parts of filler per hundred parts of resin).

Figs. 8,and 9 illustrate the impact of adding different types of fillers to EP resin insulating material on inception and breakdown voltages of this insulator. These electrical characteristics have been recorded in the presence of three droplets of 0.3ml of NACL contaminant solution with 0.1 by mass under tangential electric stress.

The first remarkable result is that THA filler greatly improves the electrical properties of the EP by making it less sensitive to wet conditions. It is also clear that, the rough Silica EP has the lower impact on improving the EP behavior under wet conditions. The behavior smooth silica EP is worse than that at THA EP but still better than the behavior of rough silica one. Finally adding fillers to EP insulator improve its electrical properties.

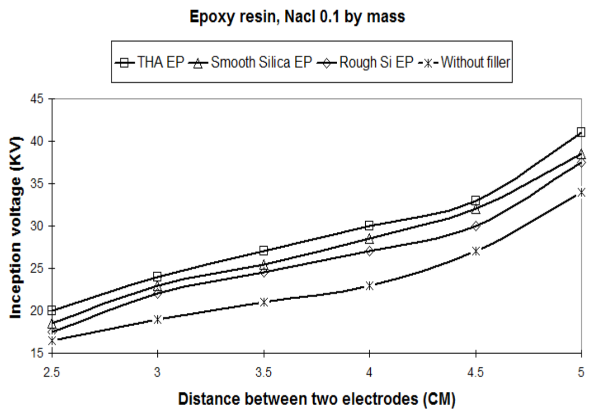

Figure 8: relation between inceptions voltage of different EP samples and distance between the electrodes at tangential arrangement

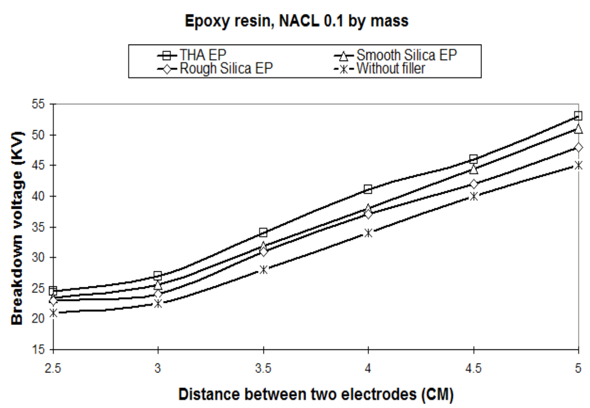

Figure 9: relation between breakdown voltage of different EP samples and distance between the electrodes at tangential arrangement

The impact of adding fillers to Ep resin sample has been also recorded when normal electric Stress is applied. Figs. (10 and 11) show the inception and breakdown voltages of different EP samples with different fillers added.

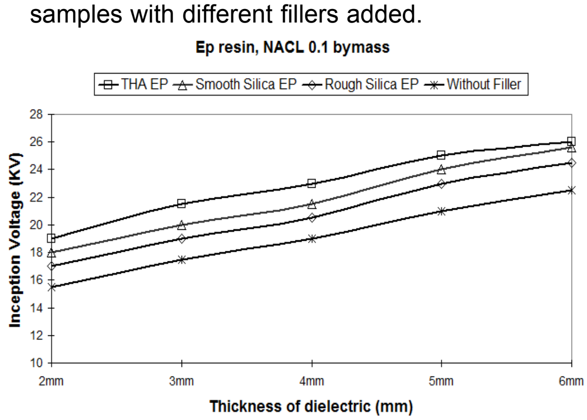

Figure 10: relation between inception voltage of different EP samples and distance between the electrodes at normal arrangement

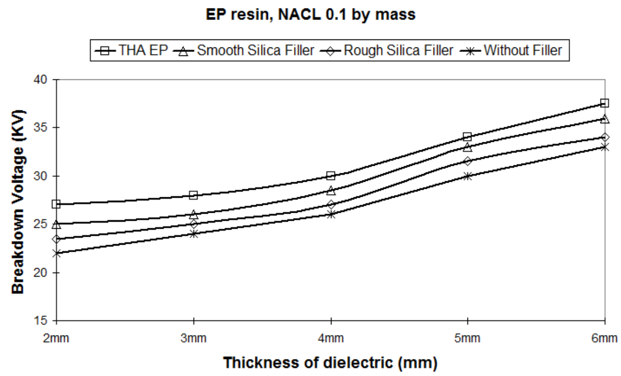

Figure 11: relation between breakdown voltage of different EP samples and distance between the electrodes at normal arrangement

An explanation to the impact of adding filler on improving the EP insulation properties has been previously introduced. This explanation concentrated on the role of fillers as an obstacle that encounters the tree propagation. The tree propagation rate of moisturized specimen is faster than it's rate of non-moisturized one, in the case of epoxy resin and epoxy - filler interface. The tree propagation rate in moisturized specimen in the case of epoxy resin without filler was much faster than that in case of epoxy resin with filler. The number of tree branches increase with the increasing of filler concentration. The discharge energy dispersion in tree branches would suppress the tree propagation, leading to the lower tree propagation rate in filled epoxy resin [7].

7 CONCLOSION

This paper describes investigations on inception and breakdown voltages at water drops. Experimental investigations are made to describe and understand the phenomena accruing at water drops on insulating surface exposed to the electric field. In that direction, measurements are made using two different test arrangements. The water drops number and location are changed. There are two different by mass solutions of water drops used in this work, namely, NACL and NH4CL. The main conclusions can be summarized as follows:

1) Complete understanding of water droplets behavior on organic material surfaces under the influence of electric field is necessary to quantify the ageing mechanisms of composite insulators.

2) In the tangential arrangement, the highest electrical field stress is located in the lower part of the water drop and towards the electrodes. In the perpendicular arrangement the critical points are at the top of the drop Where the highest electrical field stress is reached.

3) Increasing the droplets number greatly reduces the inception voltage of polymeric insulators. Surface roughness and hydrophobicity of the insulating material are important factors which eliminate the impact of increasing the droplet number on polymeric materials degradation.

4) SIR insulating material has the best performance under wet conditions and BA insulating material has the worst one. SIR water repellency decreases the wetted area by the water droplets. SIR can recover its hydrophobicity by diffusion of low molecular weight (LMW) of (PDMS) (polydimethylsiloxane) fluid to the insulation surface.

5) The behavior of the electrolyte with an applied voltage has a great influence on the electrical properties of polymeric materials. NH4CL electrolyte solution has the worst impact on the polymeric material in the presence of electric stress.

6) Regardless the type of electrolyte, increasing the electrolyte by mass leads to higher conductivity of this electrolyte and as a result affects the electrical characteristics in a negative way.

7) A tri-hydrated alumina -filler greatly improves the electrical properties of the polymeric material by making it less sensitive to water contents.

8 REFERENCES

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