AC DISCHARGE CURRENT CHARACTERISTICS AND LI FLASHOVER FIELD INTENSITY OF WATER DROPLETS ON INSULATED SOLID SURFACE

Adolphe Moukengué Imano *

Discharges between water droplets caused by distortion of these droplets are relevant in the processes leading to flashover of hydrophobic insulators. This paper investigates discharge activities between two water droplets on an insulator surface, when a constant AC voltage is applied through an experimental electrode arrangement. The results of the investigations show typical discharge current characteristics during the discharge inception and development with water filaments.

Furthermore, this paper presents an experimental study of the flashover behaviour of single and multiple water droplets placed on the surface of a solid insulator. The influence of the number and location of aligned droplets on the flashover field intensity of the surface model is also evidenced. This was done by measuring the flashover voltage for negative and positive lightning impulse application. We regard only a horizontal surface position of the insulator.

K e y w o r d s: sessile droplet, droplet distortion, outdoor insulation, flashover field intensity, discharge current

1 INTRODUCTION

Non-ceramic insulators are largely used in over-earth transport lines over the world. One of the great advantages of this type of outdoor insulator is their exceptional performance under contaminated conditions, in comparison to ceramic insulators in electric power distribution [1]. In spite of these advantages, the criteria for the selection and design of polymeric insulators are still based on the leakage distances from those prescribed for ceramic insulators. Such an approach of pessimistic design mainly results from the non-understanding of the flashover mechanism of polluted polymeric insulators under AC and also under lightning impulse (LI) voltage stress. It is well known that over-earth transport lines are naturally subjected to LI stress, which appears on the lines within precipitations in Central Africa or in countries with tropical climate. Several works suggest that the key to the problem resides in the understanding of the influence of water droplets on the flashover mechanism along a hydrophobic solid surface. Practically, during the rain water droplets accumulate simultaneously on the insulator sheds and drop there the dielectric intensity of the insulator. This situation remains for a long time, as there are water droplets on the insulator sheds, even after the rain. For AC voltage application, the degradation of the dielectric intensity of each insulator shed is characterized by the vibration, elongation and motion of the droplets deposed on this shed. For sessile or pendant droplets, the droplet elongation leads to the disturbance of the background field, which is attributed to the field enhancement at the droplet tips. These positive phenomena cause also further distortion of the droplets accompanied by a glow or spark discharge, and finally, disruption along the solid surface under certain conditions.

Flashover mechanism of non-ceramic insulators and particularly the influence of water droplets on this mechanism have been the subject of a certain number of experimental works. Swift [2] and Mizuno et al [3] investigate AC flashover behaviour and mechanism for water droplets on non-ceramic insulator. S. Wang et al [4] regarded corona inception stress in the case of multi water droplets placed in one line horizontal with the direction of electric field and in equal distance. A. J. Phillips et al [5] demonstrated that water drops in the sheath regions enhance the electric field and may cause corona which can play an important role in long-term performance.

This paper considers AC discharge current characteristics and LI flashover field intensity of sessile water droplets on an insulated solid surface. The related experimental studies were done in two parts. In the first part, we investigate discharges activities between two water droplets on an insulator surface under AC voltage stress. In the second part of the investigations, the influence of single water droplets on the flashover field intensity of an insulated solid surface under positive and negative lightning impulse stress is regarded. This experimental study was carried out using a simplified electrodes-spacer configuration with one and multiple water droplets under homogeneous field conditions in atmospheric air. Furthermore, for a better understanding of the polarity effect on LI flashover voltage with water droplets, we replaced water droplets with metal particles of 2 mm in length and 0.20 mm in diameter and performed the same measurements as with droplets.

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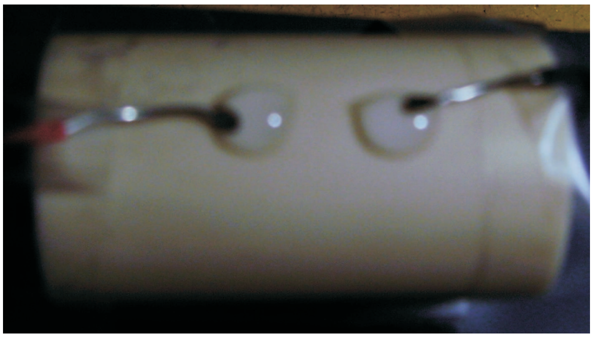

Fig. 1. Test electrode arrangement with two sessile water droplets

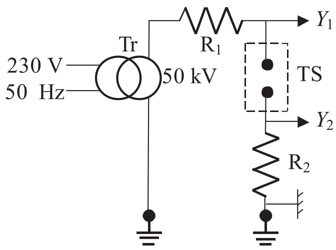

Fig. 2. Equivalent circuit of the experimental set-up

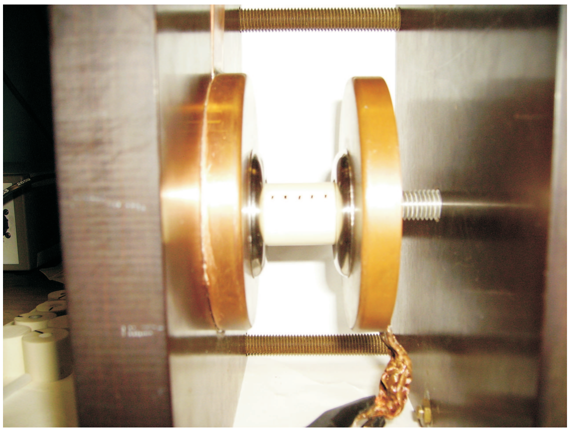

Fig. 3. Electrodes-spacer configuration for flashover voltage measurement

2 EXPERIMENTAL APPARATUS AND PROCEDURE

2.1 Experimental set-up

a) For measurement of AC discharge current

Figure 1 shows the test electrode arrangement with two sessile water droplets used. Both droplets were placed on the surface of a cylindrical solid insulator of 25 mm diameter and 30 mm height. This solid insulator is made from epoxy resin filled with Al_2O_3. Its relative permittivity was determined to be $\varepsilon_r = 5.2$. We used normal drinking water with a conductivity of 320 μS/cm, and the volume of each droplet was 10 μl. The two water droplets are connected respectively to two electrodes, and both electrodes are separated by a gap distance of 11 mm. One electrode is connected through a high voltage resistance of 100 MΩ to the AC high voltage source and the other electrode is connected to the ground, as shown in Fig. 2. The applied AC voltage on the two water droplets is measured using a Tektronix P6015A high voltage probe. The potential drop across the resistance R_2 (75 Ω, 1/4 W) was fed directly to the digital storage oscilloscope (Tektronix) to measure the discharge current characteristics. AC voltage was supplied from a single phase 230 V/50 kV test transformer.

b) For measurement of flashover voltage

The configuration of the electrodes-spacer used is shown in Fig. 3. The triple junction at both ends of the spacer was shielded by two specially shaped electrodes which are made of stainless steel. We used the same cylindrical solid insulator as for the measurement of the discharge current as a spacer model. The simplified electrodes-spacer configuration used was inserted in a specially designed electrodes arrangement composed of two large plate electrodes, a high voltage and a ground electrode. These plate electrodes are made of copper.

One or several water droplets were placed on the surface of the spacer with the help of a glass syringe. The volume of each droplet of normal drinking water was 10 μl, and all droplets on the spacer surface were aligned parallel to the direction of the electric field. The metal particles used of 0.20 mm diameter and 2 mm were cut from a cylindrical NiCr wire. No special tip geometry was used. The particle was fixed at the spacer surface with a small amount of silicon adhesive. Attention was paid that no tip is covered with adhesive.

The standard lightning impulse voltages (LI, 1.2 μs/50 μs) were generated using a Marx generator, and they were measured with a HAEFELY peak voltmeter connected to a capacitive voltage divider. The nominal ratio of this voltage divider was 1:990.

2.2 Determination of the relative flashover field intensity

The impulse voltage was increased from approximately 50 % of the expected flashover value in 4 to 8 % steps until a flashover occurred. The exact value of the flashover voltage and the voltage shape were recorded with a computer aided system from HAEFELY. The measurements for the determination of the flashover field intensity have been evaluated according to the proposed method of IEC 60060/2. It is assumed that all experiments are normally distributed. The indicated bars in Fig. 7 to Fig. 9 show the 95 % confidence interval of the expected values.

Assuming a homogeneous background field between both electrodes (Fig. 3) and considering that the contamination (particle or water droplet) does not disturb this global background field, the measured flashover voltage

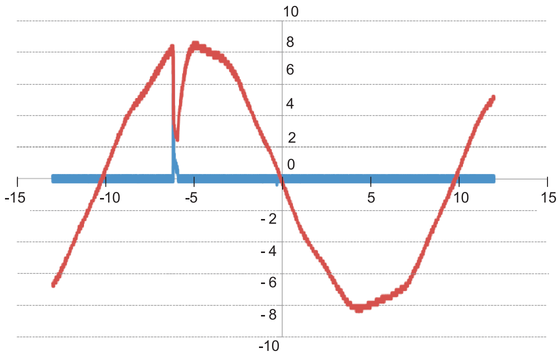

Fig. 4. Typical voltage and current measured during a discharge inception in positive alternation without water filaments

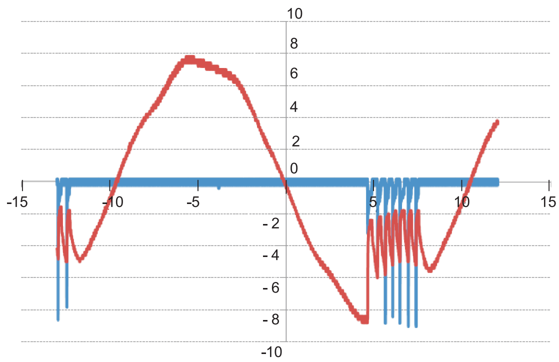

Fig. 5. Typical voltage and current measured during a discharge inception in negative alternation without water filaments

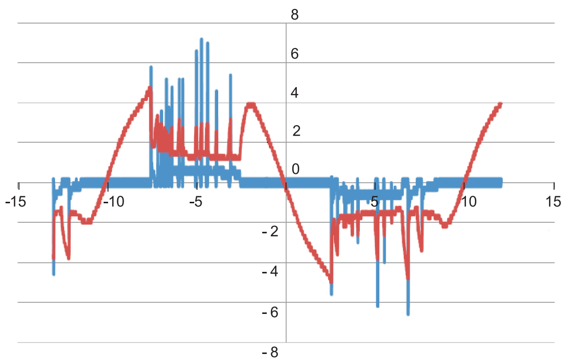

Fig. 6. Typical voltage and current measured during a discharge development with injection of water filaments

U_{FO} can be converted to flashover field intensity E_{FO} with the following relation:

$$E_{FO} = kU_{FO}$$

where k is the maximal value of the tangential component of the normalized electric field given in [6]. With this assumption, a normalized flashover field intensity E/E_d can be defined. Here, E_d and E are respectively the flashover field intensitys of the clean spacer and contaminated spacer.

3 RESULTS AND DISCUSSION

3.1. AC discharge current characteristics of two conducting water droplets

It is well known in general that when the droplet is placed in a high electric field zone, corona discharge occurs at the edge of the water droplet [7, 8]. The same behaviour can be clearly observed for two sessile droplets connected to an electrode, and when both electrodes are stressed with AC voltage (Fig. 1 and Fig. 2). When a sufficient AC voltage is applied on the pair of electrodes, the droplets elongate one towards the other. Once the distance between the edges of both deformed droplets becomes critical, the droplets become mechanically unstable and eject water filaments one after another. Figures 4 and 5 illustrate the voltage and discharge current measured at the instant of discharge initiation without formation of water filaments. It was also observed that the droplets can elongate or vibrate without discharge activities under certain conditions.

The mechanical instability of each droplet increases rapidly with the voltage stress until flashover or until formation of thin film between both droplets. Figure 6 shows an instability stat of the two droplets before formation of thin film along the insulator surface through typical discharge current characteristics.

3.2 Influence of the droplet location on the relative flashover field intensity

The flashover behaviour of a single water droplet at different locations on the spacer surface, and for positive and negative LI voltage polarities, is illustrated in Fig. 7. A significant influence of the droplet location on the droplet initiated flashover field intensity is shown. When the droplet was positioned near the ground electrode, a clear polarity effect could be observed for both LI voltage polarities. The lowest flashover field intensitys were generally observed under negative LI voltage stress, when the droplet was placed near the ground electrode. For positive LI voltage, it is illustrated in Fig. 7, that the lowest flashover field intensitys could be measured, when the water droplet was placed near the HV electrode. The polarity effect observed here show that the disturbance of the electric field by the droplet is much more significant, when the droplet is placed near the electrode with relatively highest potential. This means also that the water droplets can not influence the flashover mechanism along the spacer surface through generation of the first electron needed for the starting of the streamer. Moreover, it is also well know that, water droplets on insulated surface can not accumulate charges, as by a conducting particle [6].

Figure 8 shows that higher flashover field intensitys could be observed when a conducting particle is fixed in the middle of the spacer surface and oriented along the field. The conducting particle was moved from the HV electrode (d = 4 mm) to the ground electrode

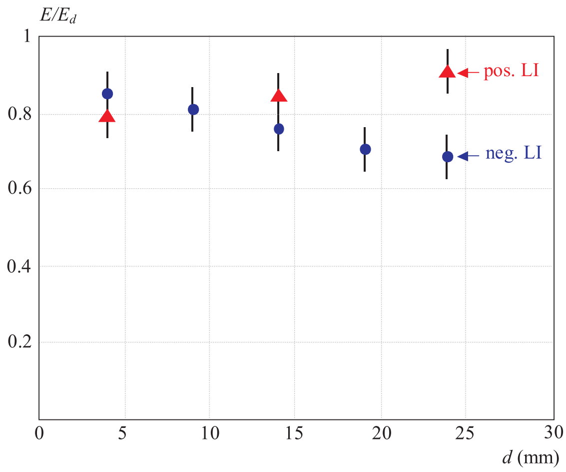

Fig. 7. Relative flashover field intensity of a single water droplet versus droplet location along the spacer surface at different voltage polarity

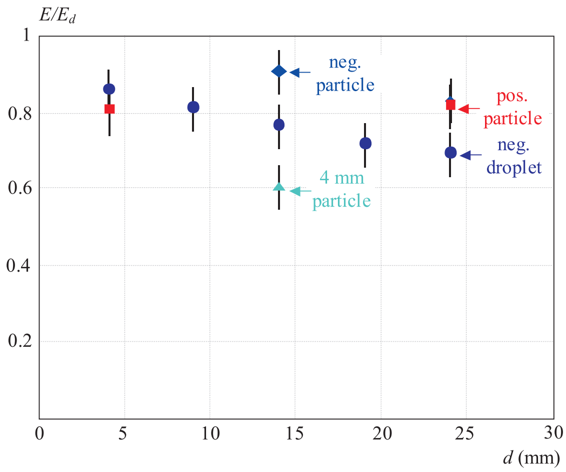

Fig. 8. Relative flashover field intensity of a 2-mm-particle versus particle location along the spacer surface at different voltage polarity

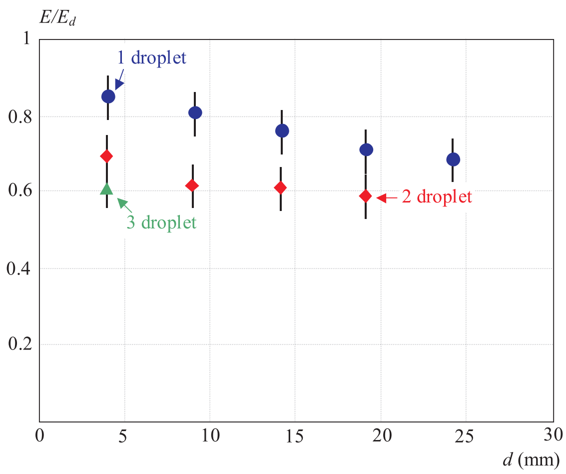

Fig. 9. Relative flashover field intensity of droplets versus droplet location along the spacer surface, for differenet number of droplets

($d = 24$ mm). When reaching both electrodes the relative flashover intensity is decreasing. Thus, Fig. 7 shows clearly the difference in flashover mechanisms between water droplets and conducting particles on an insulator surface.

3.3. Influence of the number of droplets on the flashover field intensity

The results of the experimental study illustrated in Fig. 9 show the influence of the number of the aligned droplets on the behaviour the flashover field intensity compared to clean conditions. Regardless of the location of droplets, the spacer surfaces contaminated with water droplets show generally significant decrease of the relative flashover field intensity, when the number of aligned droplets is increased. This is shown in Fig. 9, for negative LI voltage stress. This behaviour can be attributed to the reduction of the effective flashover distance between both electrodes through the presence of multiple water droplets on the insulator surface. It can be remarked too, that the polarity effect is the same for multiple droplets as for single droplet.

4 CONCLUSION

In this paper we investigated the discharge activities between water droplets when a constant AC voltage is applied. Discharge currents appear and were measured in which the length of a discharge between two droplets is reduced through a particular type of its distortion. This is visually characterized as a water filament or thin film between the water droplets along the insulator surface.

In further investigation in this paper, we regarded the influence of aligned water droplets on the flashover field intensity along a solid insulator surface, under Lightning Impulse voltage stress. Compared with AC voltage application, the water droplets under LI voltage stress have the characteristic not to become deformed until the complete flashover of the insulator surface occurs. This can be explained by very shot application duration of LI voltage and the inertia of each water droplet. Thus, this behaviour of water droplets under LI voltage application enables us to obtain the clear influence of the disturbance of the background field through water droplets on the flashover of the spacer surface. The obtained results enable us also to affirm, that water droplets near higher potential electrode cause lower flashover voltages on a non-ceramic insulator. Moreover, the observed polarity effect of water droplets on the spacer surface completes the fact, that water droplets placed on the surface of a non-ceramic insulator shed elongate or move in the direction of the nearest electrode under AC voltage stress [9].

According to the disparity in the observed polarity effect of water droplets and conducting particles on spacer surface, water droplets on insulator surfaces not show the same flashover mechanism as metallic contamination.

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