

HVAC PARAMETRIC STUDY AND NUMERICAL CALCULATION OF PARTIAL DISCHARGE INCEPTION OF WATER DROPLET AT THE SURFACE OF HYDROPHOBIC INSULATOR

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Abstract: This paper is aimed to the experimental study and numerical calculation of the partial discharge inception of water droplets at the surface of PTFE insulator in HVAC. The experimental results show that the partial discharge inception voltages depend on the size of the droplets, their number and the separate distance between them. It's also show that the inception voltages are function of the size of the droplet in contact with the HV electrode and depends also on the size of opposite droplet and the separate distance between them. The calculated electrical field shows that the maximum field intensity is situated at the interface between the droplets and the dielectric and change with the size, number and the separate distance between them.

Key words: Flashover, hydrophobic, droplet, insulator, partial discharge, corona.

1. Introduction

Flashover of polluted insulator is one of the most important problems in electrical networks [1, 2]. Many studies have been done for understanding this phenomena and its interaction with the atmospheric pollution [3,4]. In the earlier years, composite insulator was used and they present good performances in polluted areas because these hydrophobic characteristics [5-7]. However, this hydrophobicity is lost and the dielectric will be hydrophilic. Then the behaviour of the insulator depends on the time of recuperation of the hydrophobicity [8-11].

On other hand, the presence of water droplets will changes the electric field and the voltage distribution along an insulator surface and may cause corona and partial discharge at the dielectric surface [12-17] that leads to flashover. Many investigations have been carried out in order to study the effect of corona discharge and partial discharge on the performances and the degradation of polymer insulating material by corona discharge from water droplet [12-23] on HVAC and HVDC.

Corona discharges –CD- and partial discharges –PD- that appear at the droplet of water provoke the deterioration of the dielectric and increase the hydrophobicity recuperation time [8-11]. Those discharges appear at the

surface of the droplet or on the interface between the droplet and the dielectric [24-28]. The inception conditions are function of the instability electrical critical field of the droplet as mentioned in several studies [12-23]. The physical mechanism of these discharges is explained with the streamer theory in divergent field [25,26]. The corona onset electrical field at the surface of polymeric insulator with the presence of water droplet is about 5kV/cm and 7kV/cm [25,26]. Those values are function of the droplet size and the contact angle of the droplet with the dielectric surface. On other hand, the distance between the droplets has an influence on the PD inception voltage and their localization. So, behaviour of water droplets under voltage application has not been sufficiently and quantitatively investigated. For this reason, we present in paper a parametric study of the PD inception voltage and electrical field at the surface of hydrophobic flat insulator as function of the volume and the number of water droplet and the separation distance between them.

2. Experimental setup and results

The experimental device is presented in Fig. 1. It is constitutes of an HVAC generator 50 kV/ 5 kVA, the test object and a camera connected to a monitor for the visualization of the discharges. The test object is a flat insulator on Plexiglas coated with 1 mm of thickness of PFTE (Fig. 2). The total length of the insulator is 10 cm and its width is 2 cm. The high voltage is applied to a cooper rod of 2.5 mm². The grounded electrode is an aluminium band. The applied voltage is measured with peak voltmeter on the control panel.

The droplets of water are deposited at the surface of the insulator. Their size, number and disposition are variable. Each test is realized with total darkness in order to visualize the PD. We measured at each test the PD inception voltage of the droplet in contact with the HV electrode. We choose two sizes of the droplet; $V_1 = 100 \mu\text{l}$ and $V_2 = 150 \mu\text{l}$. In the case of two droplets, the separate distances between them are; $X_1 = 2.5 \text{ cm}$ and $X_2 = 5 \text{ cm}$.

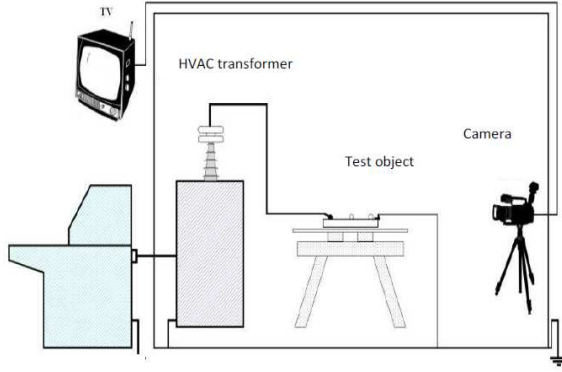


Fig.1: Experimental device.

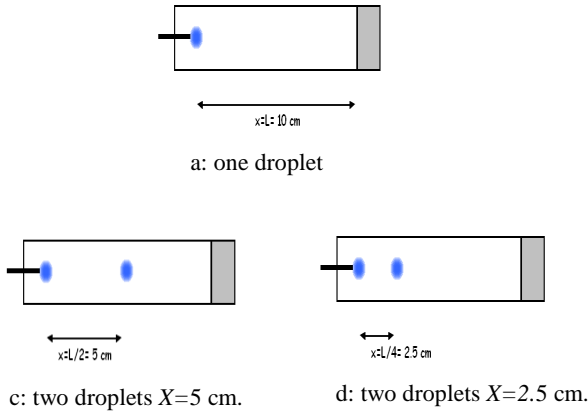


Fig. 2: Studied Configurations.

Fig. 3 to 6 illustrate the variation of the PD inception voltage U_{PDinc} as function of its volume and the number of droplets with different values of separate distances between them X .

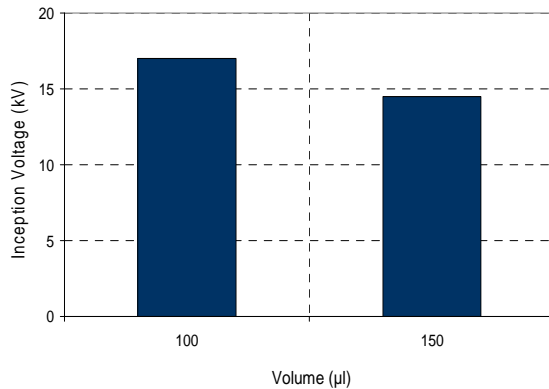


Fig. 3: Variation of U_{PDinc} with different volumes.

In the case of one droplet in contact with the HV electrode, Fig. 3 shows that the PD inception voltage U_{PDinc} decreases with the increasing of the droplet

volume (size). In first step, it can be explained with the relation proposed by Melcher and Smith that suggest that the critical electrical field of a droplet is inversely proportional to its volume [28]

$$E_{cri} = k \cdot \left(\frac{m g}{r^3 \gamma} \right)^{1/4} \quad (1)$$

where r is the radius of the droplet, m its mass, γ is the mechanical interface force and k a constant.

The instability of the droplet occur when the intensity of the electrical critical field E_{cri} became stronger then the water gravity force g and the force γ . This instability engenders “Taylor cones” that provoke corona discharge that involves to local partial discharges.

In the case of two droplets, we remark that the PD inception voltage U_{PDinc} is function of the volume of the droplet in contact with the HV electrode, the volume of the opposite droplet and the separate distance between them. When the volume of the droplet in contact with the HV electrode is V_1 (Fig. 4), we observe that U_{PDinc} is approximately constant when the separate distance is 2.5 cm. The same observation is for the case of a droplet V_2 in contact with the HV electrode and $X=2.5\text{ cm}$ (Fig. 5). The presence of the second droplet stabilized the voltage inception.

When the separate distance is $X=5\text{ cm}$, we remark that the volume of the droplet present an effect on the PD inception voltage (Fig. 4 and 5). When the volume of the droplet in contact with the HV electrode is V_1 , we observe that U_{PDinc} increase with the volume of opposite droplet (Fig. 4). In the case of a droplet V_2 in contact with the HV electrode, we observe that U_{PDinc} decrease with the volume of opposite droplet (Fig. 5).

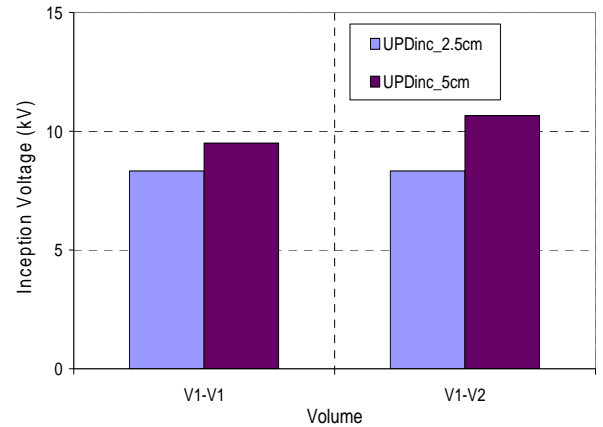


Fig. 4: Variation of U_{PDinc} for a droplet of volume V_1 in contact with the HV electrode for $X=2.5\text{ cm}$ and $X=5\text{ cm}$.

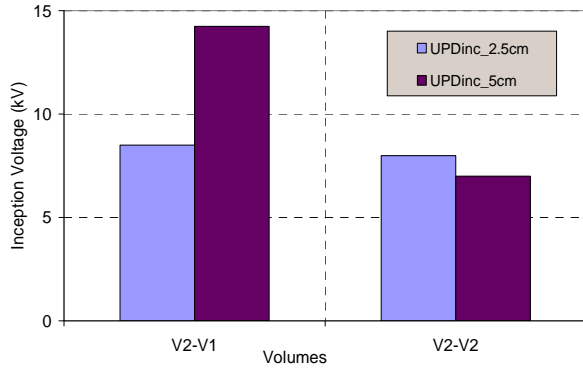


Fig. 5: Variation of U_{PDinc} for a droplet of volume V_2 in contact with the HV electrode for $X=2.5$ cm and $X=5$ cm.

Fig. 6 present a synthesis of the measure and illustrates the variation of the of the PD inception voltage U_{PDinc} as function of the separate distance X with different volumes of droplets.

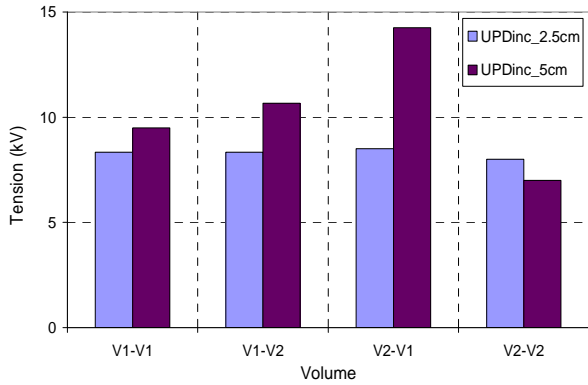


Fig. 6: Synthesis of the variation of U_{PDinc} with different volumes for $X=2.5$ cm and $X=5$ cm.

The results of Fig. 4 to 6 show that the PD inception voltage U_{PDinc} is function of the volume of the droplet in contact with the HV electrode, the volume of the opposite droplet and the separate distance between them. The values of U_{PDinc} are proportional to the volume (size) of the droplets and the separate distance between them. The presence of a second droplet have an influence on U_{PDinc} however the distribution of the volume of the droplets.

3. Electrical field calculation

In order to estimate the PD electrical field inception of the droplet, we used the FEM method in 2D. The droplet are represented as quasi-sphere with a respectively radius of 4.25 mm for $V_1 = 100 \mu\text{l}$ and 4.75 mm for $V_2 = 150 \mu\text{l}$. The values of the relative permittivity are 80 for water, 3.3 for Plexiglas and 2.1 for PTFE. The voltage is applied to the rod in contact with the droplet. Fig. 7 and Fig. 8 present the used

model.

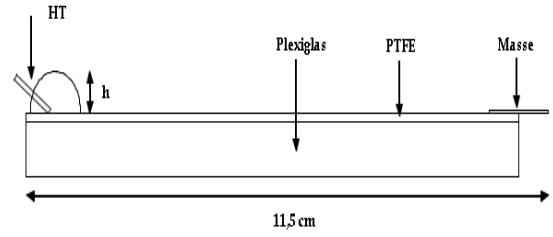


Fig. 7: Numerical FEM 2D one droplet model.

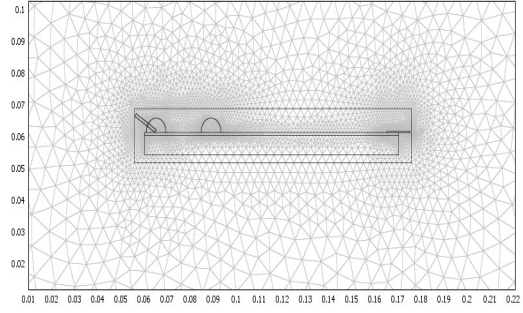


Fig. 8: Numerical FEM 2D two droplets model.

Fig. 9 to 11 illustrate example of the distribution of the electrical field and the voltage in the case of one droplet and two droplets with different separate distance X and volumes.

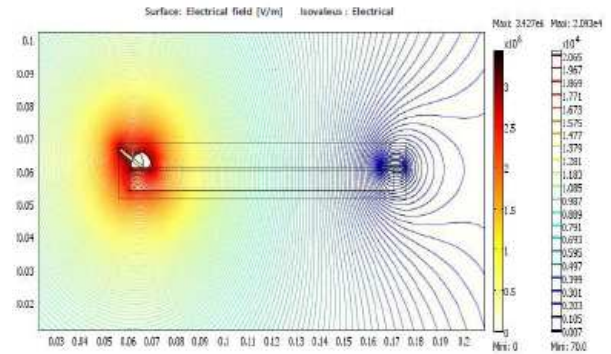


Fig. 9: Distribution of electrical field and voltage for a configuration of one droplet.

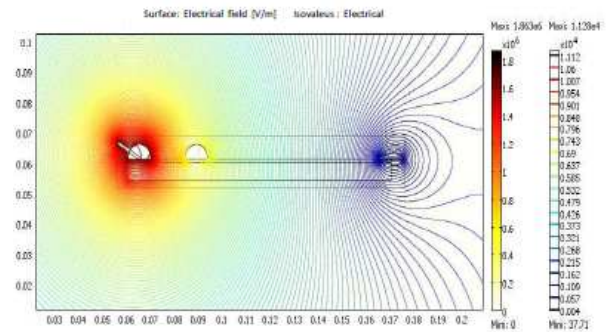


Fig. 10: Distribution of electrical field and voltage for a configuration of two droplets V_2-V_1 for $X = 2.5$ cm.

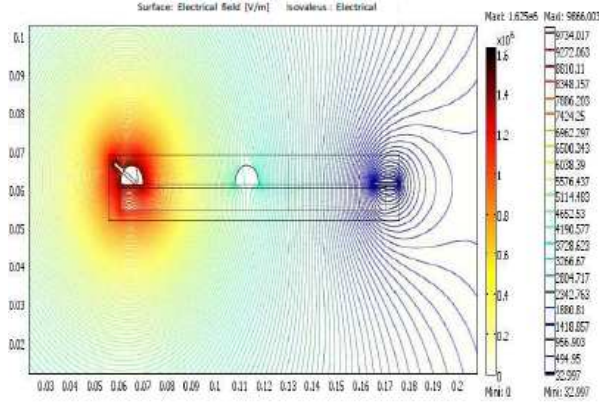


Fig. 11: Distribution of electrical field and voltage for a configuration of two droplets V_1 - V_2 for $X = 5$ cm.

Fig. 12 and 13 present the variation of electrical field and the equipotential lines for a configuration V_1 - V_1 with a separate distance $X = 5$ cm. We remark that the electrical field is important at the interface between the droplet in contact with the HV and the dielectric. This result is available for all the studied configurations.

The intensification of the electrical field at the interface can become a source of corona discharge. The inception of corona discharge at solid dielectric surface is linked to the tangential component of the longitudinal electrical field. The second step see the apparition of streamers generated by the charges because the normal electrical field. These charges are diffused do the tangential component of the longitudinal electrical field that provoke the probable elongation of the streamer and contributes to the deformation and the vibration of the water droplet.

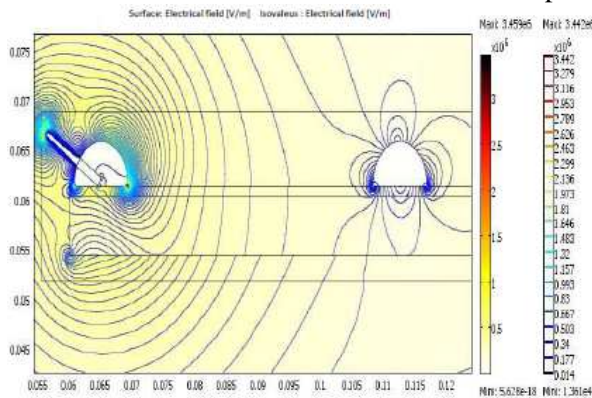


Fig.12: Electrical field distribution for two droplets V_1 - V_1 .

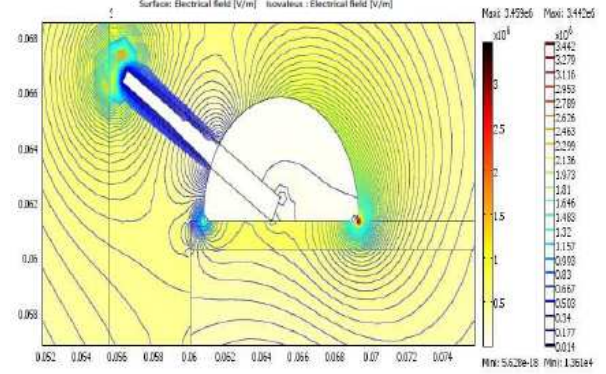
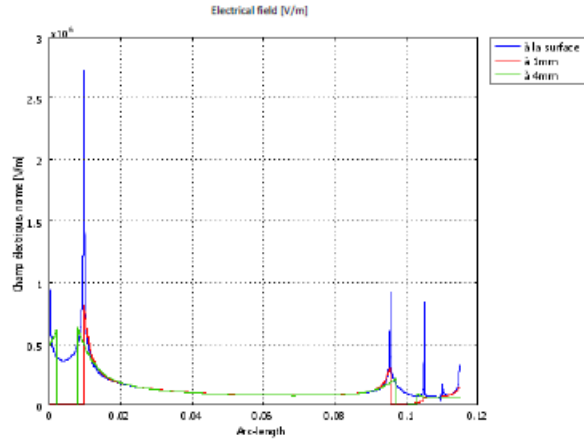


Fig.13: Zoom of the electrical field distribution for the droplet in contact with the HV electrode for V_1 - V_1 .

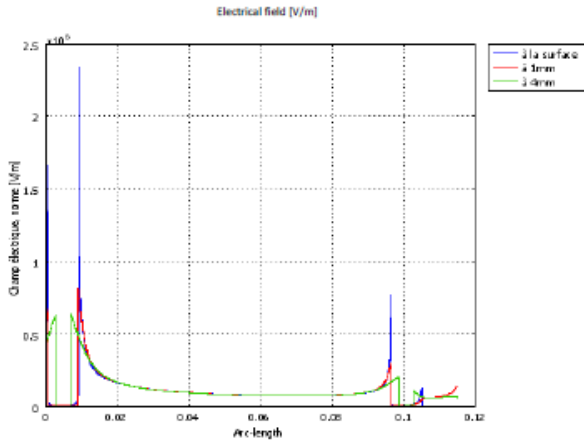
Fig. 13 to 15 give examples of the variations of the electrical field along the insulator as function of the volume of droplets, their number and the separate distance between them. The calculations are done for different height form the insulator surface; at the PTFE, 1 mm from it and 4 mm.

We remark that the electrical field is high at the first droplet especially at the interface and decrease with the different chosen height; the maximum value is at the PTFE surface. The calculations show also that the electrical field intensity depend on the volume of the droplets, their number and the distance X . According to those figures, the electrical field inception is proportional to the size of the droplet in contact with the HV electrode, the size of the opposite droplet and the distance between them.

Fig. 16 presents the maximum electrical field of the droplet in contact with the HV electrode for different height. We remark that the intensities of the electrical field are about than 5 kV/cm at the PTFE surface. From this result, we can conclude that the partial discharge inception electrical field is depends on the the size of the droplet in contact with the HV electrode, the size of the opposite droplet and the distance between them. The minimum inception electrical field is about 5 kV/cm.



(a) : volume V_1



(b) : volume V_2

Fig. 13: Longitudinal variation of the electrical field for one droplet.

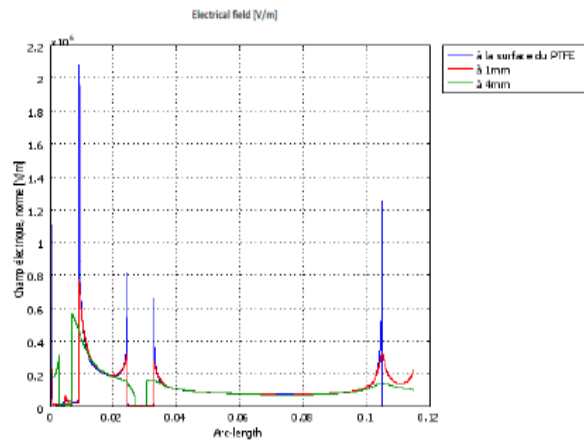


Fig. 14: Longitudinal variation of the electrical field for two droplets V_1 - V_1 with $X=2.5$ cm.

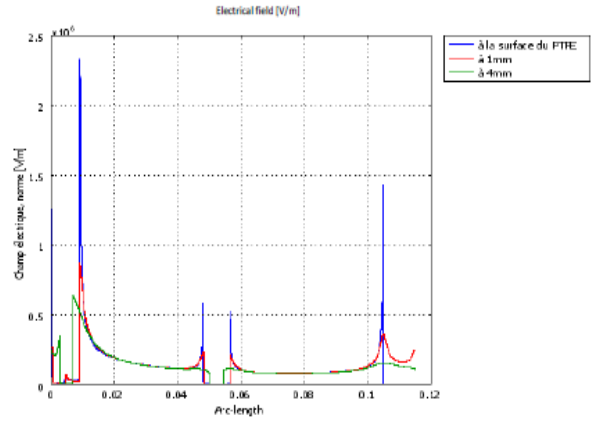


Fig. 15: Longitudinal variation of the electrical field for two droplets V_1 - V_1 with $X=5$ cm.

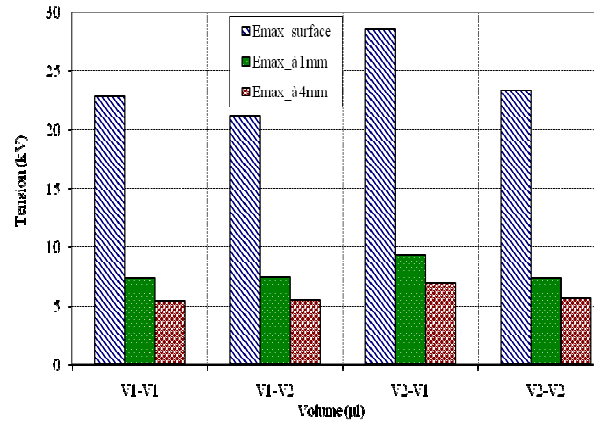


Fig. 16: Variation of the maximum longitudinal electrical field for the droplet in contact with the HV electrode with different height from the surface of the insulator.

4. Conclusion

In this study we investigated the effect of the number of water droplets, their volume and the separate distance between them on the inception of partial discharge at the surface of a PTFE insulator. The experimental results show that:

- In the case of one droplet, the inception voltage is inversely proportional to the volume.
- In the case of two droplets, the volume of the droplet in contact with the HV electrode has a influence on the inception voltage.
- The distance between the droplets affects the values of the inception voltage; more are the droplets closer, more is U_{PDinc} approximately constant.
- When the volume of the droplet in contact with the HV electrode is V_1 , U_{PDinc} increase with the volume of opposite droplet.
- In the case of a droplet V_2 in contact with the

HV electrode, we observe that U_{PDinc} decrease with the volume of opposite droplet.

- The 2D-FEM model computing shows that the electrical field is important at the interface between the droplet in contact with the HV and the dielectric. The intensification of the electrical field at the interface can become a source of corona discharge.
- The calculations show also that the electrical field intensity depends on the volume of the droplets, their number and the distance X . The electrical field inception is proportional to the size of the droplet in contact with the HV electrode, the size of the opposite droplet and the distance between them.
- The computed intensities of the electrical field are about 5 kV/cm at the PTFE surface. From this result, we can conclude that the partial discharge inception electrical field depends on the size of the droplet in contact with the HV electrode, the size of the opposite droplet and the distance between them.

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