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Similarities Between Creeping Discharges Propagating at Solid/Liquid and Solid/Gas Interfaces: Variation Laws of the Stopping Length

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Abstract—This paper is aimed at the existing similarities between surface discharges propagating radially at solid/liquid and solid/gas interfaces basing on the experimental outcomes acquired during the last twenty years. In addition to the highlighting the similarities between the shape, associated current and electrical charge of these discharges, it is shown that there is a linear relationship between their stopping length L_f and the applied voltage as well as between L_f and pressure.

Keywords—creeping discharges, solid/liquid interface, solid/gas interface, stopping length, variation laws of stopping length.

I. INTRODUCTION

From electrical insulation viewpoint, the triple junction constitutes the weakest point in any high voltage component or equipment (bushings, transformer windings, switchgears, insulators, gas circuit breaker, gas insulating lines, cable ends and connectors, power capacitors ...). Indeed, when the applied voltage, and thence the electric field, reaches a critical value, partial discharges (PDs) can be initiated in the vicinity of this zone. The increase of the voltage leads these PDs to develop and to transform into surface discharges (creeping discharges) which, by propagating over the insulators surface, can lead to flashover. This results in partial or total deterioration of the insulation system requiring the repair of equipment or even their replacement. To avoid such situations, the designers of high voltage apparatus have to know the characteristics of these discharges and their evolution (morphology and length) depending on the physical and geometrical properties of solid insulator, nature of fluid (liquid or gas), pressure, the electrodes geometry and the voltage (waveform, amplitude and application time). Therefore, the knowledge of the optical and electrical parameters of these discharges and their evolution during the operation of high voltage switchgear is of great interest for industrial applications in order to minimize maintenance requirements and reduce the risk of failure. Numerous studies have been devoted to the characterization of this type of discharge versus various parameters as well as to the mechanisms involving in their development [1-21]. Thus, the shape of these discharges and the variation of their stopping length L_f (maximum radial extension) and of the associated current and electric charge as a function of the physical and geometric properties of the solid and fluid constituents of the insulation system, the waveform of voltage and pressure, have been studied [8-20]. The influence

of capacitive phenomena on the shape and length of these discharges has been also investigated [21, 22].

This paper deals with the existing similarities between the parameters characterizing the surface discharges propagating radially at solid/liquid and solid/gas interfaces basing on the experimental outcomes acquired by my group on this subject the last twenty years. It is mainly concerned with the stopping length of this type of discharges and the highlighting variation laws of this characteristic parameter as a function of voltage and pressure. These are very useful for the design and sizing of mixed insulation systems.

II. EXPERIMENT

The experimental set-up used for the characterization of creeping discharges is practically the same for the two types of immersion fluids: liquid and gas. It has been described in numerous already published papers [9, 14-16]. The only difference in the experimental setup is the hydrostatic pressure application system in the case of solid/liquid interfaces and the gas admission and control system in the case of solid/gas interfaces. For the continuity, we recall here its main components. It comprises a cylindrical test cell containing the insulation system (solid/liquid or solid/gas) and a point-plane electrode system (Figure 1); a voltage source (DC, AC or lightning impulse voltage); a visualization/photography and recording system as well as a current measurement probe. The upper cover of test cell is of Plexiglass (transparent material); it serves as a support of the point high voltage electrode and for the observation and monitoring of discharges. The bottom cover of brass serves as a ground electrode (plane electrode). The point electrode of tungsten has a radius of curvature r_p of 10 μm .

The samples of the considered solid insulators are circular with thicknesses ranging from 2 to 20mm and dielectric constants varying between 2 and 5; they are inserted between the electrodes so that the tip is placed perpendicularly at their center to allow the radial propagation of the discharges. The investigated immersing liquids are mineral oil, natural and synthetic ester oils; and the gases are SF₆, N₂, CO₂ and their mixtures.

The visualization and recording system of discharges consists of a high SVGA resolution CCD camera connected to a computer through a video acquisition card (Meteor-II/Multi-Channel).

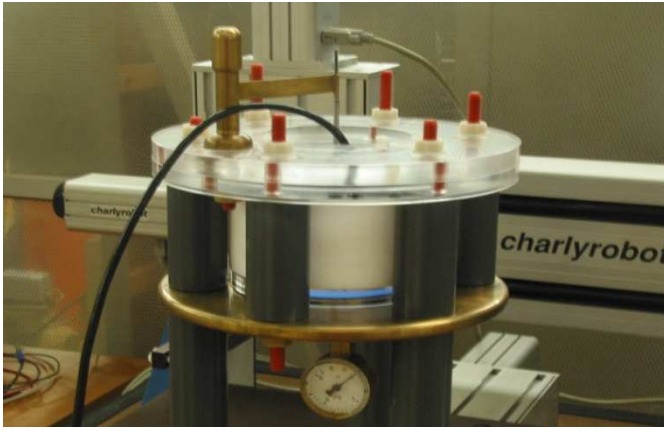


Fig. 1. Scheme of the test cell

III. EXPERIMENTAL RESULTS AND SIMILARITIES

The creeping discharges at solid/liquid and solid/gas interfaces present several similarities in their shape, the associated current and electrical charge. These characteristic parameters as well as their length depend on the type of fluid (liquid or gas), the type of insulator and its thickness, dielectric constants of both constituents of insulation system, applied voltage waveform and pressure. Figure 2 shows two examples of discharges propagating on an insulating solid surface, immersed in a liquid and a gas, respectively. In both cases, the discharges propagate radially.

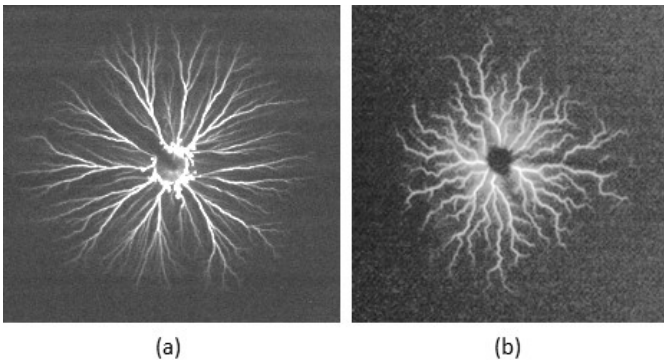


Fig 2: Photographs of discharges propagating over (a) Bakelite (phenoplast resine) sample of 2 mm thickness immersed in mineral oil, under negative lightning impulse voltage the crest value of which is $U_{crest}=28$ kV; and (b) Glass sample of 2 mm thickness immersed in SF_6 at an effective pressure of 0.1 MPa under positive DC voltage of 30 kV.

It is also observed that the associated current waveforms with these discharges consist of primary currents corresponding to the main discharges followed by secondary currents of opposite sign to that of the main discharge whatever the type of interface (solid/liquid or solid/gas interface) [11, 16]. As the currents, the measured total electrical charge associated to these discharges is also influenced by the applied voltage, the thickness and the dielectric constant of solid materials; it increases with the applied voltage and/or the dielectric constant of insulator and/or when the thickness of insulator is reduced [9, 12, 16].

The stopping length of creeping discharges L_f is of a great interest for the sizing of insulating systems. Thus, the knowledge of the variation laws of L_f versus the experimental parameters is fundamental.

IV. STOPPING LENGTH OF CREEPING DISCHARGES AND VARIATION LAWS

A. Solid/liquid interface

1. Influence of voltage

The stopping length of surface discharges varies quasi-linearly with voltage whatever the voltage waveform [11, 12]. Figures 3 to 5 give some examples for solid/liquid interfaces for DC, AC and lightning impulse voltage.

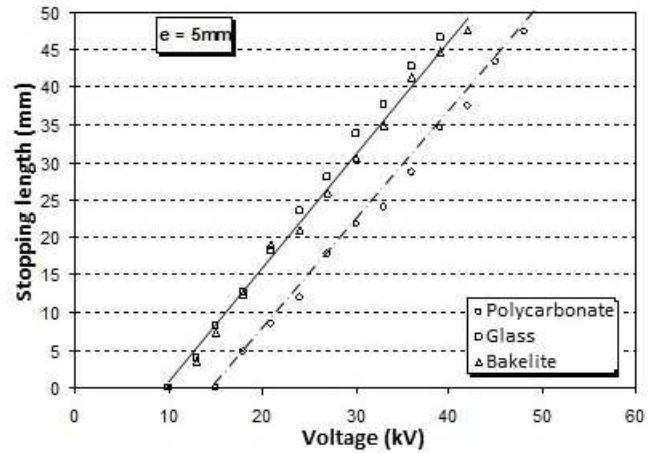


Fig. 3. Stopping length of creeping discharges propagating over three type of insulators of 5 mm thickness immersed in mineral oil versus AC voltage. The dielectric constant (ϵ_r) of insulators are 2.9 for Polycarbonate, 5 for glass and 4.8 for Bakelite.

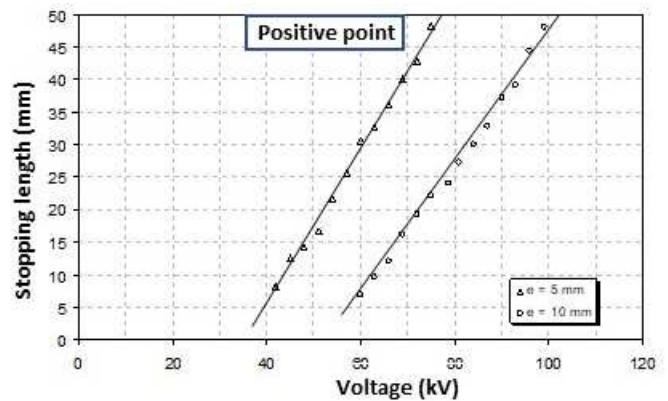
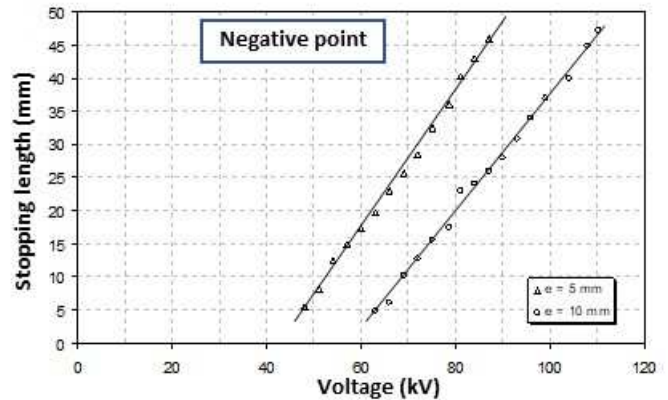


Fig 4. Stopping length of creeping discharges propagating over Bakelite sample of 5 and 10mm thickness immersed in mineral oil versus negative and positive DC voltage.

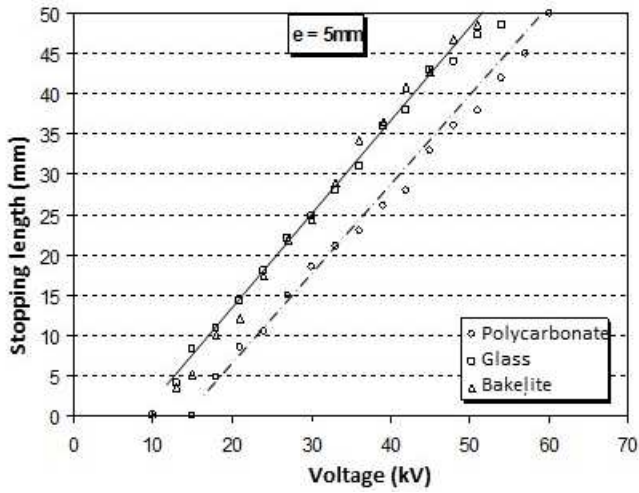


Fig. 5. Stopping length of creeping discharges propagating over three types of insulators of 5 mm thickness immersed in mineral oil versus the crest value of negative lightning impulse voltage (1.2/50 μ s); the insulators being Polycarbonate, glass and Bakelite.

Therefore, the $L_f=f(U)$ characteristics can be described by the following relationship

$$L_f(U) = k_v(U - U_0) \quad (1)$$

where k_v is the slope of straight lines. It is a constant that depends on both materials constituting the insulation system (solid and liquid). U_0 is the threshold voltage over which the discharge is initiated. It can be deduced from extrapolation at $L_f=0$.

2. Influence of hydrostatic pressure

By plotting the stopping length of creeping discharges L_f versus the hydrostatic pressure P for different values of the voltage U , we observe that for a given U , L_f decreases quasi-linearly when P is increased [13]. L_f is all the shorter as the pressure is high. And, for a given voltage and thence a given shape of discharge, there is a pressure for which the discharge disappears. Figure 6 gives an example of the variation of L_f of negative creeping discharges propagating over Bakelite immersed in mineral oil under negative lightning impulse voltage for different crest values of the voltage.

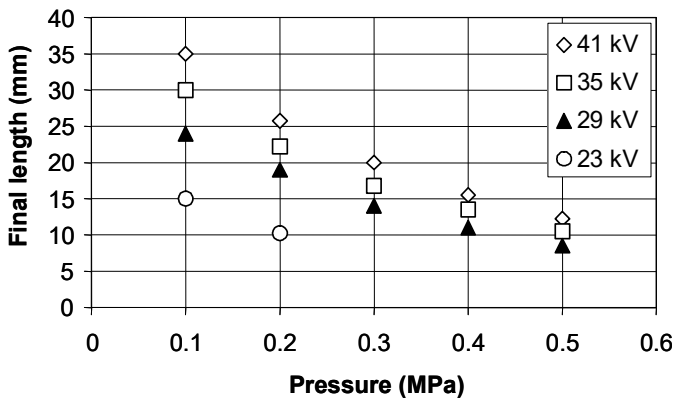


Fig. 6. Variation of the stopping length L_f of the negative creeping discharge propagating over Bakelite immersed in mineral oil under negative lightning impulse voltage for different crest values of the voltage.

So, from these characteristics, one can deduce the disappearance pressure of discharges P_{disp} by extrapolation at

$L_f=0$ mm at a given voltage. Thus, the $L_f=f(P)$ characteristics can be described by the following relationship

$$L_f(P) = k_p(P - P_{disp}) \quad (2)$$

where k_p is the slope of straight lines. As k_v , k_p is a constant that depends on both materials constituting the insulation system.

B. Creeping discharges over solid/gas interface

1. Influence of voltage

As for the solid/liquid interfaces, L_f varies quasi-linearly with the voltage, whatever the voltage waveform [18, 19]. Figures 7 and 8 give examples of the variation of L_f versus the voltage, for different types of insulators, immersed (a) in SF₆ at 0.3 MPa under AC voltage; and (b) in CO₂ at 0.3 MPa under DC voltage.

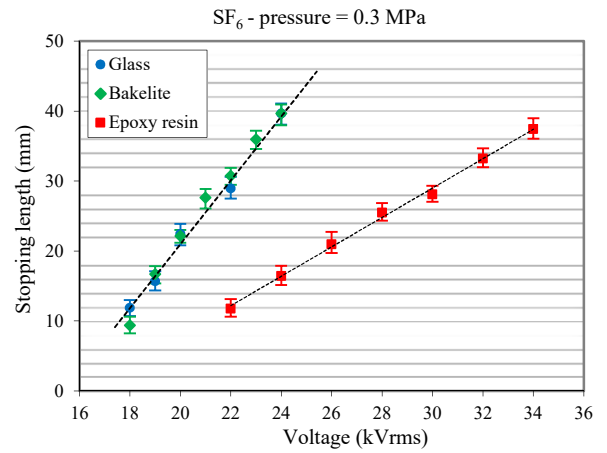


Fig. 7. Stopping length of creeping discharges versus the voltage, under AC; the insulators (glass, Bakelite and epoxy resin) being immersed in SF₆ at 0.3 MPa.

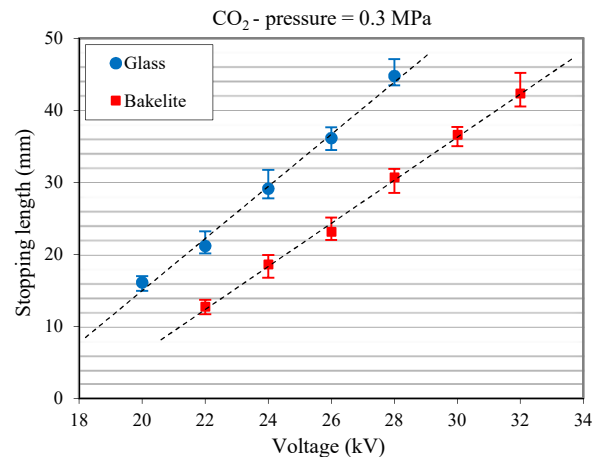


Fig. 8. Stopping length of creeping discharges versus the voltage, under DC; the insulators (glass and Bakelite) being immersed in CO₂ at 0.3 MPa.

Thus, for a given pressure, the $L_f=f(U)$ characteristics can be described by a similar relationship as for liquid/solid interface.

$$L_f(U) = k_v(U - U_0) \quad (3)$$

2. Influence of gas pressure

As for solid/liquid interface, we also observe that for a given voltage (U), L_f decreases quasi-linearly with increasing the gas pressure P [19]. L_f is all the shorter as the pressure is high. And, there is a pressure for which the discharge disappears. One can thus deduce the disappearance pressure of discharges P_{disp} by extrapolation at $L_f = 0$ mm. Figure 9 gives an example of the variation of L_f for three types of insulators under AC voltage.

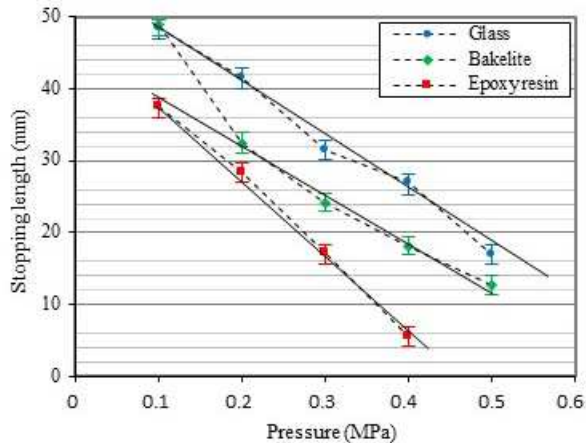


Fig. 9. Stopping length of creeping discharges versus the pressure for glass, Bakelite and epoxy resin samples of 2 mm thickness in N_2 under AC voltage; $U = 14$ kV.

It thus possible to write a similar relationship as for solid/liquid interface

$$L_f(P) = k_p (P - P_{disp.}) \quad (4)$$

V. CONCLUSION

In addition to the highlighting the similarities between the shape, associated current and electrical charge of creeping discharges propagating over insulators immersed in gases and liquids submitted to different voltage waveforms, it is shown that there is a linear relationship between the stopping length of creeping discharges L_f propagating at both types of interfaces (solid/liquid and solid/gas) and the applied voltage as well as between L_f and pressure. This is very useful for the dimensioning of solid/fluid insulating systems.

REFERENCES

- [1] Y. Nakao, H. Itoh, Y. Sakai, H. Tagashira, "Studies of the Creepage Discharge on the Surface of Liquids", IEEE Transactions on Electrical Insulation, Vol.23, No.4, pp.677-687 (1988).
- [2] P. Atten, A. Saker, "Streamer propagation over a liquid/solid interface", IEEE Transactions on Electrical Insulation, Vol.28, No.2, pp.230-242 (1993).
- [3] R. Hanaoka, T. Kohrin, Y. Genba, R. Ishibashi, T. Miyamoto, and T. Nishi, "Impulse creeping discharge along the surface of polyethylene wire immersed in transformer oil", Elect. Electron. Insul. Conf. and Elect. Manufacturing Coil Winding Conf., Rosemont, USA, pp. 113-117, 1995.
- [4] Y. Nakao, M. Naruse, Y. Suzuki, H. Itoh, Y. Sakai, and H. Tagashira, "Influence of insulating barrier on the creepage discharge in transformer oil", IEEE Trans. Dielectr. Electr. Insul., Vol. 4, pp. 775-779, 1997.
- [5] L. Lundgaard, D.Linhjell, G. Berg, and S. Sigmond, "Propagation of Positive and Negative Streamers in Oil with and without Pressboard Interfaces," IEEE Transactions on Dielectrics and Electrical Insulation, vol. 5, pp. 388-396, 1998.
- [6] Q. Liu and Z. D. Wang, "Streamer Characteristic and Breakdown in Synthetic and Natural Ester Transformer Liquids with Pressboard Interface under Lightning Impulse Voltage", IEEE Transactions on Dielectrics and Electrical Insulation Vol. 18, No. 6; December 2011, pp. 1908-1917
- [7] H. Yamamoto, S. Uozaki, R. Hanaoka, S. Takata, Y. Kanamaru, and Y. Nakagami, "Creeping discharges in transformer oil under lightning impulse voltages over 100 kV peak value", IEEE Intern. Conf. Dielectr. Liquids (ICDL), Poitiers, France, pp. 1-4, 2008.
- [8] N.K. Bedoui, A. Beroual and F. Chapuis, "Creeping Discharge in Transformer Oil under DC Voltage", IEEE Annual Report, 2000 Conference on Electrical Insulation and Dielectric Phenomena, Victoria, British Columbia, Canada, October 15-18, 2000.
- [9] L. Kebbabi and A. Beroual, "Influence of solid insulating thickness on the morphology of creeping discharges propagating over solid/liquid interfaces – Fractal analysis, J. of Physics D: Appl. Phys., 39, pp.177-183, 2005.
- [10] L. Kebbabi and A. Beroual. "Influence of the properties of materials and the hydrostatic pressure on creepage discharge characteristics over solid/liquid interfaces", IEEE Conf. Electr. Insul. Dielectr. Phenomena (CEIDP), Albuquerque, New Mexico, USA, October 19-22, 2003, pp.293-296.
- [11] L. Kebbabi and A. Beroual, "Optical and Electrical Investigations on Creeping Discharges over Solid/Liquid Interface under Lightning Impulse Voltage", IEEE Trans. Dielectrics and Electrical Insulation, Vol. 13, No. 3, pp. 565-571, 2006.
- [12] A. Beroual and L. Kebbabi, "Influence of the Voltage Waveform and Hydrostatic Pressure on Morphology of Final Length of Discharges Propagating over Solid/Liquid Interfaces, IEEE Trans. Dielectrics and Electrical Insulation, Vol. 16, No 6, pp.1574-1581, 2009.
- [13] A. Beroual and L. Kebbabi, "Influence of hydrostatic pressure on morphology and final length of creeping discharges over solid/liquid interfaces under impulse voltages, 16th IEEE - International Conference on Dielectric Liquids (ICDL), Poitiers, France, 30 June – 4 July 2008.
- [14] A. Beroual and Viet-Hung Dang, "Characterization of Surface Discharges Propagating over Pressboard in Mineral and Vegetable Oils and their Fractal Analysis", IEEE Trans. Dielectrics and Electrical Insulation, Volume 20, Issue 2, pp. 1402-1408, 2013.
- [15] A. Reffas, H. Moulai, A. Beroual, "Comparison of dielectric properties of olive oil, mineral oil, and other natural and synthetic ester liquids under AC and lightning impulse stresses, IEEE Trans. Dielectrics and Electrical Insulation, Vol. 25, Issue 5, pp.1814-1821, 2018.
- [16] A. Beroual, M-L. Coulibaly, O. Aitken and A. Girodet, "Effect of Micro-fillers in PTFE Insulators on the Characteristics of Surface Discharges in Presence of SF6, CO2 and SF6-CO2 Mixture, IET Generation, Transmission and Distribution, October 2012, Vol. 6, Issue 10, pp. 951 – 957, 2012.
- [17] A. Beroual, M. L. Coulibaly, O. Aitken and A. Girodet, "Investigation on Creeping Discharges Propagating over Epoxy Resin and Glass Insulators in Presence of Different Gases and Mixtures, The European Physical Journal – Applied Physics, Volume 56, Issue 03, December p. 30802 (8 pages), 2011.
- [18] F. Sadaoui and A. Beroual, "DC Creeping Discharges over Insulating Surfaces in Different Gases and Mixtures", IEEE Trans. Dielectrics and Electrical Insulation, Vol. 21, No. 5, pp. 2088-2094, 2014.
- [19] F. Sadaoui and A. Beroual, "AC Creeping Discharges Propagating over Solid/Gas Interfaces", IET Science Measurement & Technology, Vol. 8, Issue 6, pp. 595-600, 2014.
- [20] F. Sadaoui and A. Beroual, "Surface Discharges over Insulators of various materials in presence of SF6, CO2, N2 and SF6-CO2 and SF6-N2 Mixtures under DC voltage, CEIDP 2013, Shenzhen, China, 20-23 October 2013.
- [21] A. Beroual and L. Kebbabi, "Influence of Capacitive Effects on the Characteristics of Creeping Discharges Propagating over Solid/Liquid Interfaces under Impulse Voltages, 2008 Conference on Electrical Insulation and Dielectric Phenomena (CEIDP - IEEE), Québec City, Canada, October 26-29, 2008.
- [22] A. Beroual and U. Khaled, "Evidencing of the capacitive effects on the development of creeping discharges at solid/fluid interfaces", IEEE Conference on Electrical Insulation and Dielectric Phenomena, October 21-24, Cancun, Mexico. pp. 386-389, 2018.