Electrical Discharge Triggered Breakdown Phenomena in Main Gap

A. Settaouti
Electrotechnic Department, University of Sciences and Technology,
P. O. Box. 1505 El-M'naouar, Oran - Algeria,
settaouti@yahoo.fr

Abstract – *In high-voltage techniques, electrical discharges represent complex problem. The results of the research on the breakdown phenomena in high voltage electrical apparatus insulated by gas can be employed to obtain external and internal insulation design. The electrical discharges can be employed in various applications. The mechanisms of the electrical discharge and the breakdown voltage characteristics of air gaps in the presence of third electrode were investigated in this paper. Breakdown voltage variations are discussed with the parameters influencing the discharge mechanism such as the gap geometry and the applied voltage at the electrode discharge. The results with different geometries of electrodes show that the electrical breakdown mechanism depends on the electrode shape and applied voltage.*

Keywords*: Breakdown, Discharge, High voltage, Triggered.*

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I. Introduction

Non-thermal plasmas in air at atmospheric pressure generated by electrical discharges present considerable interest for a wide range of industrial, environmental, bio-medical applications and surface treatment of material. In a multi-gap arrangement with insulation materials, high voltage electrodes and grounded objects, the breakdown may take place on a long interval instead of a short interval. Dielectric breakdown with a trigger electrode for spark switches is the more widely used in the pulsed power system.

Gas breakdown and its prediction possibility are of great importance for gas-insulated system designing, considering the fact that the gases in electrical engineering are mainly used for insulation [1]-[5]. In the application of the plasmas and in the micro and nano electronics industry, it is important to study the mechanisms responsible for the electrical breakdown in gases. The gap spacing for each new generation of devices is of a great importance for the insulation.

The study of the mechanisms responsible in electrical breakdown is necessary to prevent electrical discharges that can cause a malfunction of the device [6]-[10]. Due to the complexity of the process of electrical discharge in gases, the uncertainties exist on the electrical triggering mechanisms. To develop the triggering technology it is essential to understand the physical mechanisms of the electrical breakdown process [11]-[15].

The paper reports the results of an investigation carried out in order to determine the critical dielectric breakdown voltage of the air gaps spacing stressed by DC voltage. Several measurements were performed with different positions and different dimensions of the model designed with three electrodes electrical discharge gap. The electric discharge mechanism is discussed in terms of the influence of the gap geometry and the amplitude of the DC applied voltage.

II. Experimental Procedures

The characteristics of the dielectric breakdown were investigated experimentally for several reasons. Firstly, to study the parameters influencing the dielectric breakdown voltage in the presence of metallic objects in the high voltage power apparatus with air insulation. Secondly, to better understand the physics of the dielectric breakdown mechanism in a triggered electric discharge gap and lastly to determine on how the dielectric breakdown is influenced by the electrical discharge process.

The model used to study the triggered spark gap consists of two horizontal conical rods facing each other together with earth electrode (plane, stem or rod) parallel to them. One of the two horizontal rods is energized and the other one is left grounded through a resistance. We performed various experiments while varying the main gap spacing formed between the high-voltage electrode (two horizontal conical rods) and earth electrode. We also studied the effect of a local spark between the two horizontal conical rods. It is important to understand how such gaps with local electrical discharge can affect the electrical breakdown of the main gap with a DC voltage.

The experimental procedure is done by applying a DC voltage directly to one rod (energized), which produced a local spark between the two horizontal conical rods. This resulted in the DC voltage being applied to the gap consisting of the (two horizontal conical rods) and the earth electrode in the presence of a local discharge.

All measurements and observations were carried out under DC voltage in air at atmospheric pressure.

III. Results and Discussion

To obtain external and internal insulation design data in the high voltage insulated electrical devices, it is important to study the dielectric pre-breakdown phenomena in gases. The gap with three electrodes is widely utilized as trigger in trigger generators, high powers, and pulse powers. To control the high voltage and the switching in high voltage apparatus, the electrical discharge triggered gaps are commonly used. To know the dielectric breakdown performances of air gaps containing conductive objects is important in order to develop the equipments in high voltage.

Experimental works were performed with local discharge electrode in atmospheric air gap under DC voltage, to study the characteristics and mechanisms of the dielectric breakdown triggered by a local electric discharge. The experimental results show that the breakdown voltages for the negative polarity are significantly lower than those for the positive polarity as shown in Fig. 1.

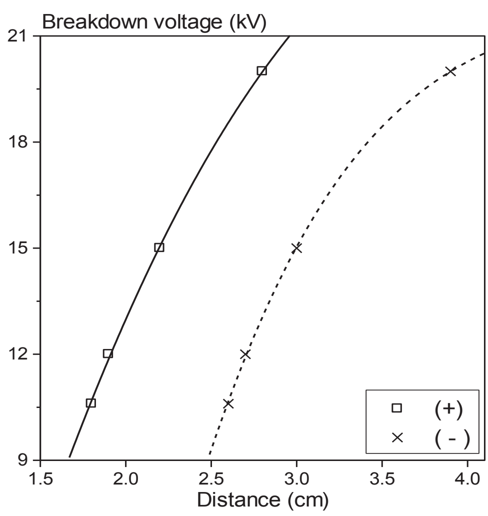

Fig. 1. Electrical breakdown characteristics for both polarities of the local discharge plane gap.

This result is surprising, because in the domain utilising the electric discharges, the dielectric breakdown voltage in negative polarity is higher than breakdown voltage in positive polarity. This observation explains why most of the investigations in electric discharges for study of the dimensions of high voltages equipments are made in positive polarity.

The geometry of the electrodes in air gap has a great influence on the dielectric breakdown voltage. In a highly non-uniform electric field as in a rod-plane electrode configuration, there is a polarity effect on the dielectric breakdown voltage [16]-[17]; dielectric breakdown voltage in a negative polarity applied to the rod is much higher than that in the positive polarity.

However, in the configuration of local electric discharge-plane resulted in lower dielectric breakdown voltages than those of the rod-plane without local electric discharge configuration for all the gap lengths as indicated in Fig. 2. Consequently, for the negative point polarity, the dielectric breakdown voltage of the local discharge plane gap was much lower than that for air alone in the rod-plane gap. The experimental results show that the plasma formed by the local electric discharge can lower the dielectric breakdown voltage.

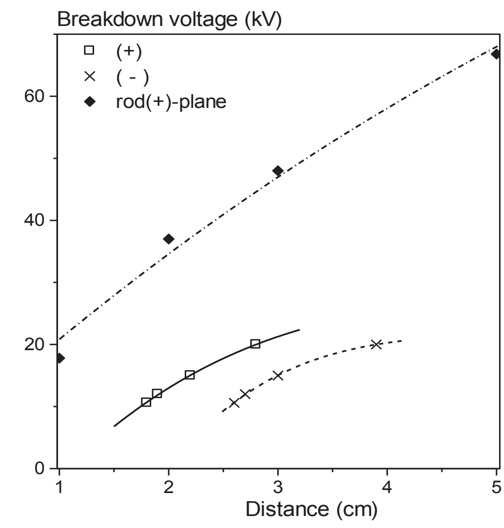

Fig. 2. Electrical breakdown characteristics for both polarities of the local discharge plane gap and positive rod-plane without local electrical discharge.

The experimental results also show that the local electrical discharge-plane configuration resulted in lower breakdown voltages and the breakdown voltages for the negative polarity are lower than those for the positive polarity.

One of the important problems for high voltage electric power transmission is the electric discharge, the flashover on the high voltage insulators is among this problems. A high voltage insulator is an essential component of high voltage electric power transmission systems. Every defect in the performance of high voltage insulators will cause for rupture in the systems. This is a major problem because a lot of industries depend on the availability of an uninterrupted power supply. In the flashover on the high voltage insulators, the electric discharge propagates across the contaminated layer on the high voltage insulator then a flashover occurs. This electric discharge triggers a dielectric breakdown and an interruption of the power supply. The polarity effect on the dielectric breakdown voltage in the presence of a local electrical discharge is in the same relationship with the pollution flashover, as observed on insulators used in high voltage transmission displayed in Fig. 3.

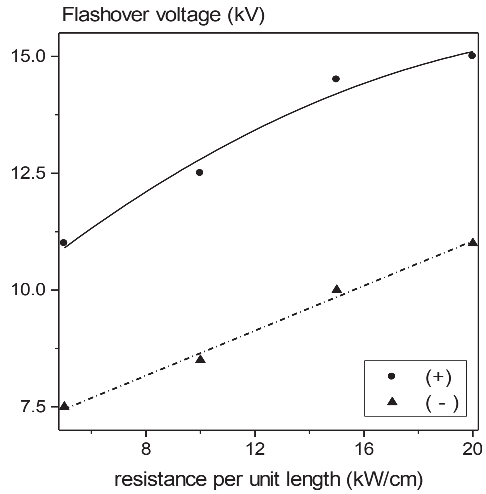

Fig. 3. Flashover voltage characteristics for both polarities

The cause of the polarity effect in the DC flashover voltage when the negative flashover voltage is lower than the positive flashover voltage of heavily contaminated insulators is unclear. When the DC high voltage is applied, several electric discharges may appear on the insulator surface, the propagation of the discharges on the surface of the insulators is the similar to the air gap surface electric discharge in a non-uniform electric field.

The dependence of the breakdown voltage on the polarity is due to the development processes of the pre-breakdown and polarity effect on the electric field enhancement by electric space charges where the local conditions plays a major role in the propagation of the discharge and the complete dielectric breakdown. We employ a second local discharge parallel to the first to decrease the breakdown voltage of the DC discharges as shown in Fig. 4.

Influence of the local discharge on the dielectric breakdown of the main gap, figure 3 displays the variation of the dielectric breakdown voltage with gap spacing for the two types of electrodes systems. The first result shown is that the two local electrical discharges - plane configuration resulted in consistently lower dielectric breakdown voltages than those of the one local electrical discharge-plane configuration.

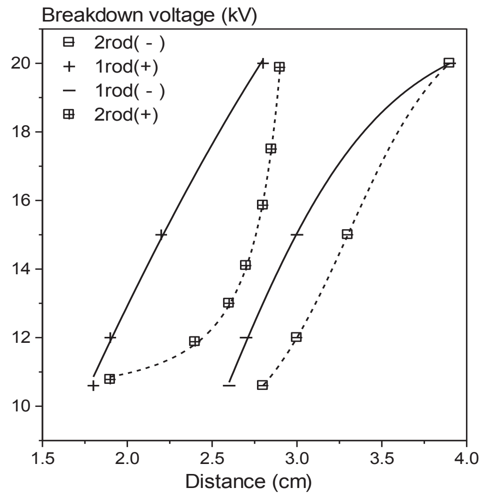

Fig. 4. Electrical breakdown characteristics for both polarities of the local discharge - plane gap and two local discharges - plane electrodes systems

This means that the photoemission intensity of the local electrical discharge has an important role in the mechanism of the dielectric breakdown of the main gap. For the second gap (main gap), the dielectric breakdown is controlled by other factors than the electric field. These factors may be the strong ultra violet irradiation from the first gap (local electrical discharge electrode) electrical discharge channel and the injected plasma from the existing discharge channel of the first gap. The dielectric breakdown conditions for the second gap (main gap) are very likely to happen due to the existence of the local electrical discharge channel in the first gap.

The mechanisms of the main gap dielectric breakdown are difficult to determine because of the complexity of the breakdown processes. The phases of the dielectric breakdown process are the streamer formation and propagation, the channel heating phase of the breakdown processes, and the final development of the breakdown of the main gap.

Dielectric breakdown of the air gap, in a non uniform electric field is generally believed to occur via formation of a streamer. The streamer forms when the large electric field across the gap enables an electron avalanche to form [18]-[19], generating ionization and plasma.

An enhanced electric field near the head of the streamer allows it to propagate to the opposite electrode by inducing further ionization until the streamer provides an electrical connection across the gap.

The difference in the dielectric breakdown process between positive and negative triggered DC voltage can not be described by using only the distribution of the applied electric field in the gap. For agreement with the experimental results, effects of the space charge generated at the trigger electrode must be included in the analysis.

Depending on the potential of the trigger voltage, the positive space charge close to the trigger electrode plays a different role. If the trigger voltage is positive, the dielectric breakdown of the first gap gives the plane electrode a negative potential and the negative charges emitted from the 'local electrical discharge' are repulsed in its vicinity. This result in decrease of the local electric field strength at the local electrical discharge electrode, and the breakdown voltage of the second gap (main gap) becomes higher.

With negative trigger voltage, the dielectric breakdown of the first gap gives the plane electrode a positive potential. The negative charges density created in the vicinity of the 'local electrical discharge electrode' move to the plane (anode) due to the influence of the background electric field. The electric field becomes distorted as the negative charges move to the anode, and the local electric field strength at the local electrical discharge electrode is increased, and hence the dielectric breakdown voltage of the main gap becomes lower.

The reduction of the dielectric breakdown voltage with local electrical discharge triggered electrical discharges makes this kind of electrical discharges so attractive for scientists in this domain. As local electrical discharge is applied ionizing a volume of gas, the streamer can develop with electric fields lower than without a local electrical discharge electrode. Comparison between the negative and positive discharge polarities reveals important differences in the guiding mechanism.

The mechanisms of the dielectric breakdown with local electrical discharge depend strongly on the following conditions: polarity, the shapes of electrodes and distance, properties of the applied voltage. The best method to study this phenomenon is to utilize different geometrical shape of grounded electrode in order to vary the applied electrical field. For this purpose, we utilise a plane, stem or a rod for the grounded electrode, it is important to understand how such gaps with different geometrical shape can affect the electrical breakdown probability of the main gap.

The experimental results for the both gaps local electrical discharge electrode - stem and local electrical discharge electrode - rod show a reduced dependence of the dielectric breakdown characteristics on the polarity of applied voltage as shown in Fig. 5 and Fig. 6. With the exception of the shortest gap in length, the dielectric breakdown voltage in the local electrical discharge electrode - stem gap is higher under positive than under negative polarity (Fig. 5).

For all cases studied the breakdown voltages for both polarities with local discharge configurations are lower than that for air alone. It has been shown that the plasma formed by local discharge can lower the breakdown voltage. The emission and photoemission intensity of the local discharge have an important role in the propagation of the local discharge to breakdown the main gap.

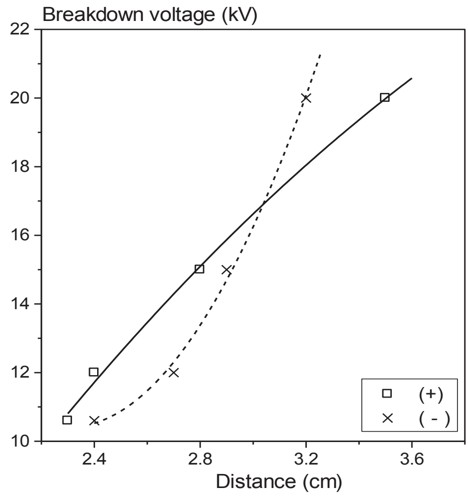

Fig. 5. Electrical breakdown characteristics for both polarities of the local discharge-stem gap

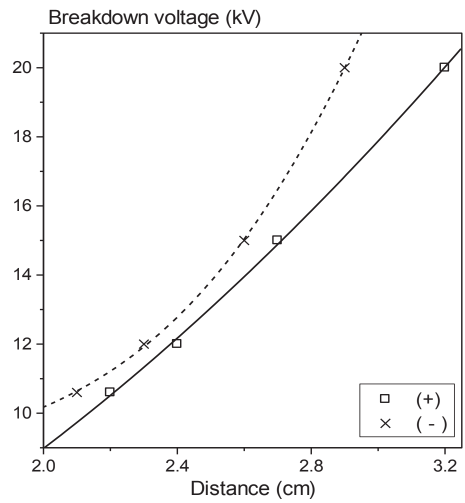

Fig. 6. Electrical breakdown characteristics for both polarities of the local discharge-rod gap

The dielectric breakdown voltage of the main gap depends on the electric field distribution near the local electrical discharge electrode (Fig. 1, Fig. 5, and Fig. 6).

It is reasonable to consider that the complete dielectric breakdown of the main gap for the both polarities were caused by the propagation of the streamer from the local electrical discharge and, therefore the dielectric breakdown voltage of the main gap was much lower than that for dielectric breakdown of air alone. In addition, the streamer growth from the local electrical discharge was assisted by the negative charges emitted from the local electrical discharge electrode.

In the range of gap spacing tested under negative polarity, the dielectric breakdown voltage increases with exponential growth with gap spacing whereas under positive polarity the corresponding curves increase with Boltzman growth as the gap length increases (Fig. 5). However, an opposite polarity effect on the breakdown voltage is observed for the local electrical discharge electrode-rod configuration, the dielectric breakdown voltages for the positive polarity are lower than those for the negative polarity (Fig. 6).

The dielectric breakdown in the presence of a local electrical discharge for different geometrical shape of the grounded electrode depends on the polarities of the electrode connected to the high voltage (Fig. 7 and 8).

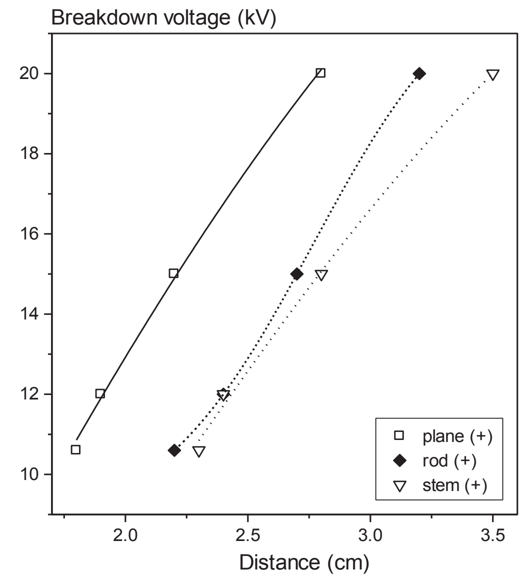

Fig. 7. Dielectric breakdown voltage of the gap with local discharge and different geometries of the grounded electrode in the positive polarity

The strength of the electric field at the grounded electrode has a great role in the dielectric breakdown. For the positive polarity, the strength of the electric field around the grounded electrode is important. This induces a reduction in the dielectric breakdown voltage. This is the case when the grounded electrode is a rod or a stem (Fig. 7). On the other hand for the negative polarity the important stressed electric field around the local electrical discharge decreases the dielectric breakdown voltage. This is the case when the grounded electrode is a plane (Fig. 8).

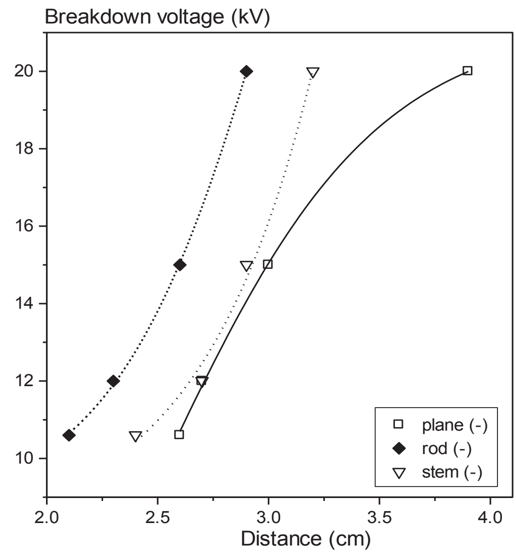

Fig. 8. Dielectric breakdown voltage for negative polarity of the gap with local discharge and different geometries of the grounded electrode

The changing breakdown process with the grounded electrode shape is caused by the difference in the field distribution at both sides of gap. The discharge occurs at atmospheric pressure and the preheated air by the local discharge has an influence on the discharge dynamics. The decrease in the density near the local discharge as the temperature rise will increase the local reduced electric field and then directly impacts the transport parameters and reaction rates for air which are functions of local reduced electric field.

The ionization rate as a function of applied electric field in the presence of local electrical discharge is in the orders of magnitude larger than that obtained for a natural atmospheric air discharge [20]. Therefore, the electrical breakdown of these mean gaps may occur at significantly lower applied electric fields. The gas heating mechanism can reduce the breakdown electric field where the streamer stage and the channel heating phase discharge processes reduce the breakdown voltage of the main gap electrical breakdown.

IV. Conclusion

In order to study the triggered discharge mechanism, the characteristics of dielectric breakdown for the air gas in the presence of a local discharge were investigated.

Experimental procedures were undertaken with different geometries at atmospheric pressure under DC voltage. The breakdown voltage is lower in the presence of a local discharge. This explains that the breakdown voltage characteristic of air gap is affected by the surrounding conditions. In the gap with a local discharge the breakdown mechanism starts at the 'discharge electrode' which influences the emergence and development of discharge from the local discharge. For the same gap, when the local discharge is eliminated (rod-plane) causes a considerable increase in the dielectric strength of the gap.

The photoemission intensity of the local discharge has an important role on the propagation of the discharge dynamics in the main air gap. The dielectric breakdown conditions for the mean gap are favourable by the photoelectrons produced by the existing local discharge in the first gap. The avalanches are then triggered by the pre-ionization process. The experimental results show that the effect of the local discharge in initiating a breakdown depends on the electrical field distribution near the local discharge, and the local conditions play a major role in the spreading of the discharge.

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