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Effect of Floating Objects on Critical Impulse Breakdown of Air

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Abstract: The characteristics of breakdown voltages against the position of floating metallic particles in atmospheric air are investigated experimentally to provide fundamental parameters determining the breakdown voltage in the presence of floating objects around high voltage power apparatus by an air insulation. Experimental results show that the main factors affecting the breakdown voltage are the shape and the size of floating objects, the object location and the gap length. The possible mechanism by which the local spark initiates the main breakdown would seem to be associated with the high electric field around the local spark channel enhanced by unnecessary streamers protruding from its surface. The model is in excellent agreement with experiment results.

Key words: Breakdown, dielectric strength, electrical field, floating electrode

INTRODUCTION

In order to develop compact and large capacity dc transmission system, an increase of working electric field in the equipment and a high reliable insulation design for such high stresses are essential. Breakdown characteristics in air gap with floating objects are some of the data which are required for an external insulation design of equipment installed in open air containing various floating particles such as insects, rain drops, leaves and other objects. With respect to gaseous breakdown phenomena influenced by foreign particles, extensive studies have been performed with SF₆ for an internal insulation design of gas insulated systems since the middle seventies^[1-5] and severe effect of the breakdown voltage characteristics have been reported. The study in air concerning an external electrical insulation design is limited as compared with those in SF₆. Maintenance work can either be accomplished with the linesman at ground potential manipulating an insulating tool (hot stick) or by performing aerial work with the linesman bonded to the high voltage conductor (bare hand work)^[6-8]. Safety of the workers and equipment during live line work has always been of utmost importance. Since live line maintenance work is not performed during thunderstorms, switching overvoltages become determinant for dielectric strength at the work site. Of particular interest is the situation when a floating conducting object, such as a linesman wearing a conductive suit, a work platform, a helicopter or a robot,

may be temporarily present within an electrically stressed air gap. Although testing of air gaps with conducting floating objects will always be required, the complexity and large number of parameters involved in such tests necessitate rationalization of experiments and require analytical tools for better physical understanding and generalization of test results. The study was conducted to treat the problem by making the conditions as simple as possible by simulating the restricting sparks by a local spark from an energized rod to a floating rod. The dielectric strength of air gaps in presence of floating objects was determined experimentally for different configurations and the way of approaching energized conductors.

MATERIALS AND METHODS

The breakdown characteristics were investigated experimentally. The three electrode gap consists of two horizontal conicals rods (of diameter 0.8 cm) facing each other together with a ground rod. (Rod of diameter 1.5 cm conical and which the angle (θ) takes the values 15 and 120°) vertical to them. One of the two horizontal rods is energized and one is left floating. Performed various experiments while varying the (energized rod) - (floating rod) distance d (0.3, 1, 2 and 3 cm) and the (energized rod - (floating rod)) - (grounded rod) distance L .

We studied the effect of a local spark between the energized rod and the floating rod. Where one rod is electrically floating and supported on the wall of the

experimental tank by an insulator. Floating electrodes are found in some lightning protection systems either because some metallic objects are not connected to the system or because oxidation can introduce gaps in the lightning protection rods. It is important to understand how such gaps with floating objects can affect the breakdown probability of the rods with a lightning impulse voltage. The experimental procedure is, we applied a lightning impulse voltage directly to one (energized) rod, which produced a local spark between the two horizontal conicals rods. This resulted in the impulse voltage being applied to the gap consisting of the (two horizontal conicals rods) and the rod with different angles in the presence of a local spark. All measurements and observations were carried out under 1.2/50 μ s impulse voltage in air at atmospheric pressure.

RESULTS AND DISCUSSION

In practice, electrode systems with floating objects are of many types and configurations, but conceptual diagram of an electrode system with floating objects is as described in experimental procedure which is a possible case in high voltage apparatus. The experimental results show that the polarity of applied voltage does not affect the breakdown characteristics as shown in Fig. 1 and 2.

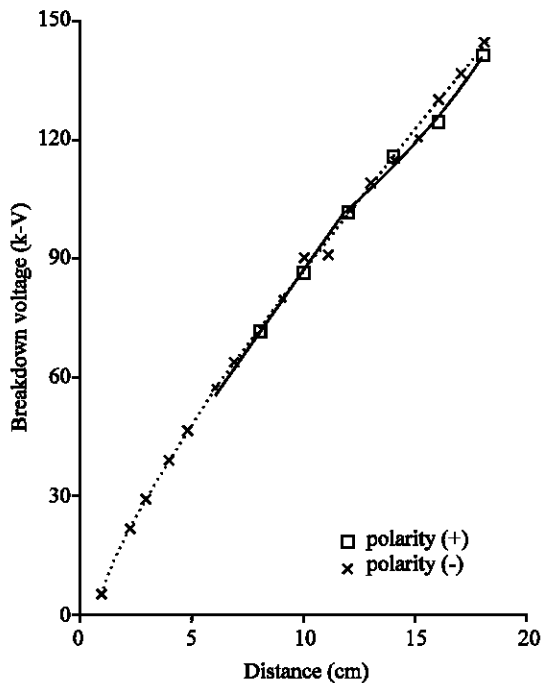


Fig. 1: Breakdown voltage as a function of distance (grounded conical rod $\theta = 120^\circ$) for both polarities ($d = 1$ cm)

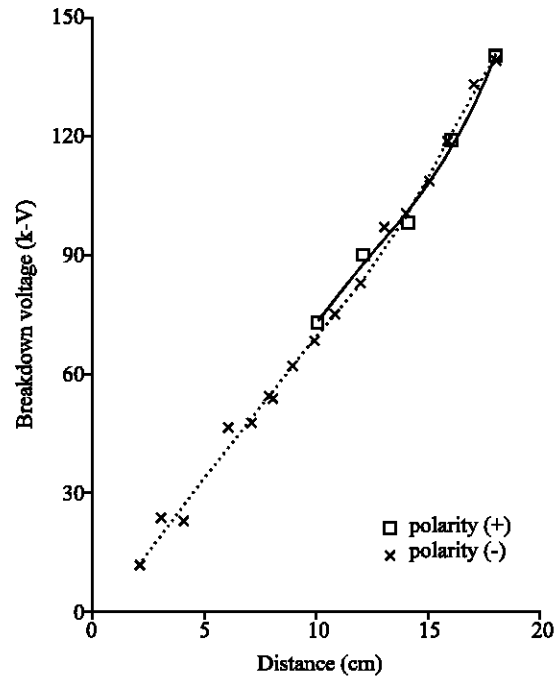


Fig. 2: Breakdown voltage as a function of distance (grounded conical rod $\theta = 120^\circ$) for both polarities ($d = 2$ cm)

The characteristics of breakdown as a function of distance for negative polarity are very similar as the positive. We have shown that the breakdown voltage to ground is lower when a rod discharge actually exists than when does discharge is simulated by a wire. When the length of the local spark are 0.3 cm and 1 cm we noticed that the breakdown voltage at negative polarity becomes lower than the one at positive polarity, when the angle of the third electrode is 15° (Fig. 3 and 4). This influence increases when one increases the energized rod to the floating object distance d , (Fig. 3 and 4). Such a result is surprising. Indeed, in the phenomena using the discharges, the negative polarity is usually considered less severe; hence a high breakdown voltage corresponds to it^[9-13]. It is in part this observation which explains that most of the studies are made under positive polarity which is decisive for the dimensions of high voltage systems. The local discharge occurs between the energized electrode and the floating particle. After the discharge bridging between the energized electrode and floating object, the electric field at the floating object becomes abruptly enhanced. Hence it is expected that such field enhancement on the floating object induces the development of discharge in the floating object and is followed by the complete breakdown. Figure 5 shows the field distribution along the energized rod and floating

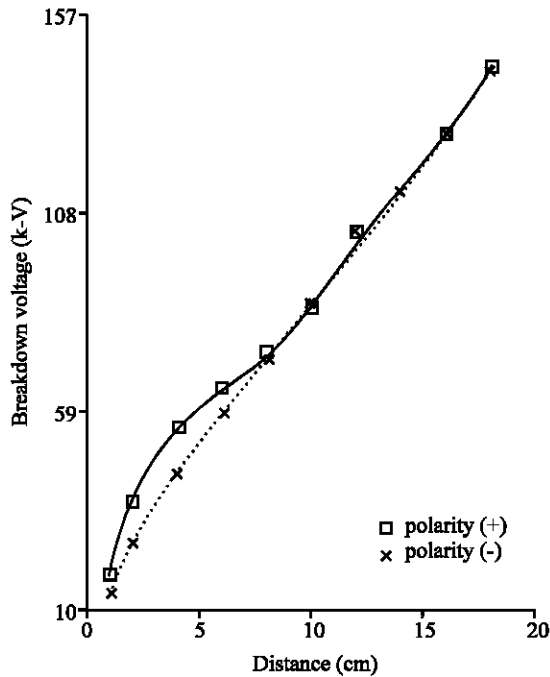


Fig. 3: Breakdown voltage as a function of distance (grounded conical rod $\theta = 15^\circ$) for both polarities ($d = 0.3$ cm)

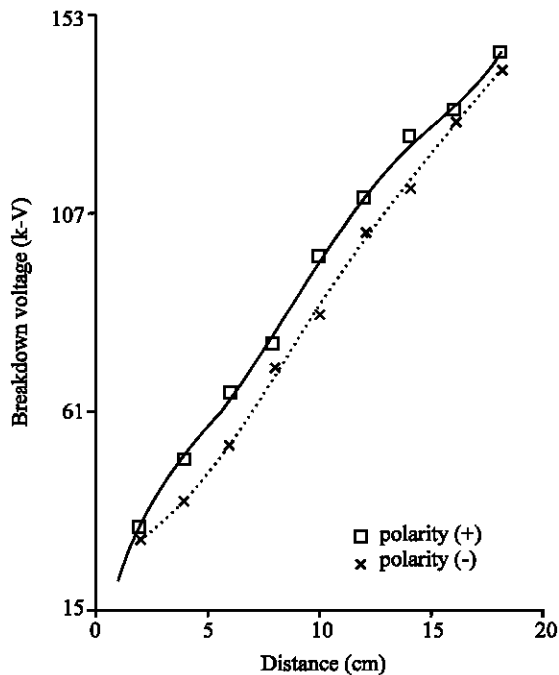


Fig. 4: Breakdown voltage as a function of distance (grounded conical rod $\theta = 15^\circ$) for both polarities ($d = 1$ cm)

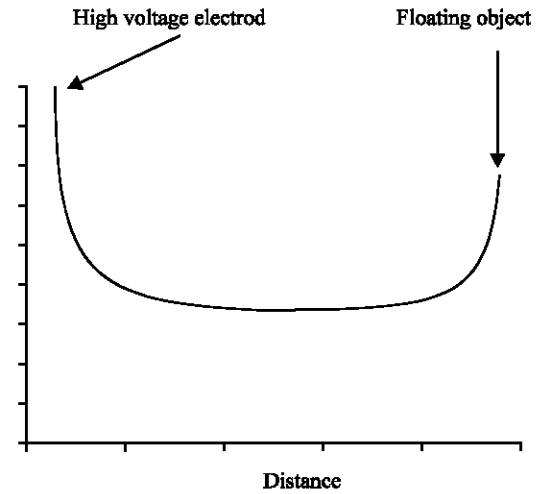


Fig. 5: Calculated electric field distribution of energized electrode to floating object gap.

object gap axis. These field distributions are calculated by the charge simulation method^[14]. With a floating rod in a energized rod to grounded rod gap, the electric field at the floating rod is drastically enhanced. Then, it is concluded that the discharge from the floating needle dominates the breakdown characteristics. The following breakdown process is believed to occur from the above field calculation. Generally, the primary discharge is started at the highest field point. When the floating object is near high voltage electrode, a partial breakdown between the energized rod and floating rod appear. Immediately after the formation of partial breakdown between the high voltage electrode and floating rod, the electric field at the floating object is abruptly enhanced and the partial breakdown, triggers the complete breakdown (between the energized electrode and the grounded electrode). In order to develop a compact and large capacity equipment in high voltage, it is necessary to know the breakdown performance of air gaps containing conductive floating objects in addition to that without objects. We noticed a remarkable influence on the breakdown voltage, in the presence of a conducting floating objects and without objects (Fig. 6 and 7). When the floating metallic particle is near the high voltage electrode, the partial breakdown occurs between the high voltage electrode and floating particle at a low applied voltage and triggers the complete breakdown. When we increase the distance between the energized electrode and the floating object, the breakdown voltage for the main gap is lower without floating object than with the object below 12 cm (angle for grounded electrode 120°) and 14 cm (angle for grounded electrode 15°). Become lower for above this distance with floating object than without.

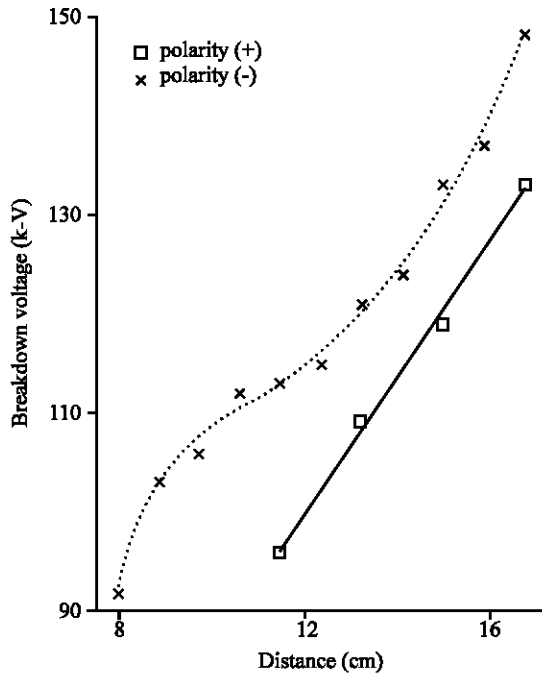


Fig. 6: Breakdown voltage as a function of distance (grounded conical rod $\theta = 120^\circ$) for both polarities ($d = 3$ cm)

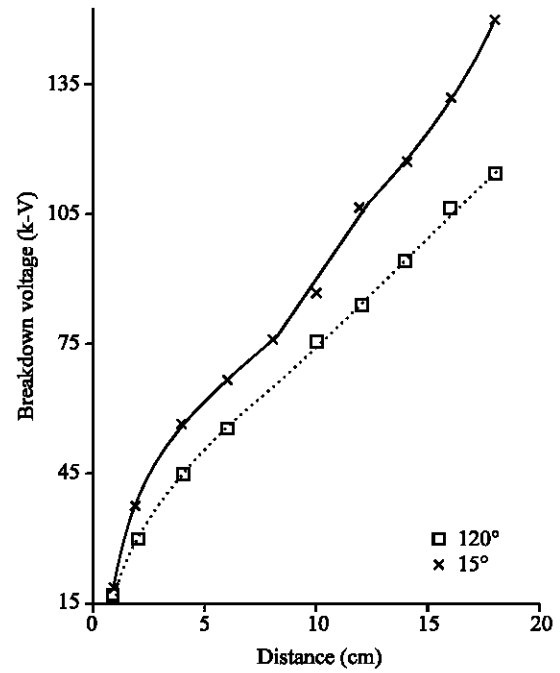


Fig. 8: Breakdown voltage as a function of distance (grounded conical rod $\theta = 15^\circ$ and 120°) for the positive polarity ($d = 0.3$ cm)

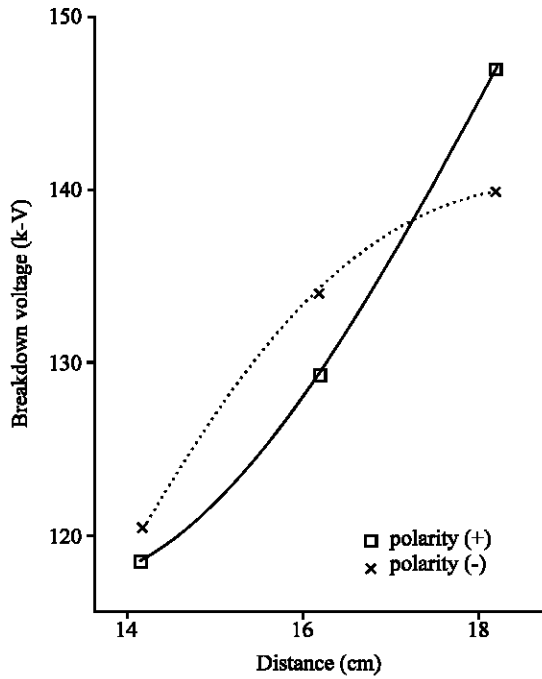


Fig. 7: Breakdown voltage as a function of distance (grounded conical rod $\theta = 15^\circ$) for both polarities ($d = 3$ cm)

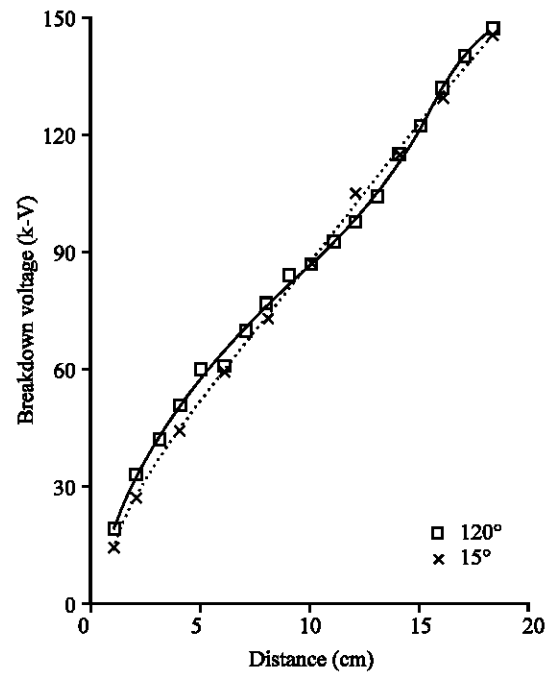


Fig. 9: Breakdown voltage as a function of distance (grounded conical rod $\theta = 15^\circ$ and 120°) for the negative polarity ($d = 0.3$ cm)

One notices the influence of the grounded electrode geometry on the breakdown voltage for the positive polarity (Fig. 8). The experimental results show that the geometry of the grounded electrode does not affect the breakdown characteristics for the negative polarity as shown in Fig. 9. The studies with the switching impulse voltage giving the minimum breakdown voltage for a given gap showed that the guiding electric field strengths for the propagation of the positive and negative streamers were E_{s+} equal 5 to 7 kV/cm⁻¹ and E_{s-} is equal 10 to 16 kV/cm⁻¹, respectively. The contained discharge processes in the present experimental conditions are considered as the partial discharge occurs between the high voltage electrode and the floating object at first and the bridging between floating object and the grounded rod by partial discharge at the floating object or at the grounded rod follows it. When the floating object with a small curvature is in the gap, the discharge at the floating object, is dominant and the flashover process is taken as the process stated above, the complete flashover can be estimated by following equation:

$$V_F = E_{s+} \cdot d + E_{s+} \cdot L$$

where, E_{s+} is the electric field streamer for both polarities.

The experimental and theoretical results for positive polarity are given in Fig. 10 and 12 the calculated and measured characteristics of breakdown voltage have a similar tendency. The partial discharge between the high voltage electrode and floating object and the complete breakdown are by the development of positive streamer. For the negative polarity as shown in Fig. 11 and 13, the partial discharge between the high voltage electrode and floating object are by the development of negative streamer and the breakdown is completed by the development of positive streamer to the grounded rod.

In general, breakdown without floating objects depends only on the distribution of electric field in the gap and its change in time. The existence of floating objects is considered to have direct and indirect effects on the discharge conditions. In the presence of floating metallic particle, two difficulties arise, change of boundary condition on the floating particle with time due to the electrification of the particle and appearance of ion free zone which exists on the electric line of force from the floating particle to corona free electrode. A moving object changes the boundary where discharge will occur as well as the magnitude and distribution of the electric field between the object and the electrode. Its rate of change can reach the value of the standard impulse voltage. The field distribution is influenced by the charge on the object

if there is an extremely non uniform electric field and corona from the main electrode precedes discharge from the object.

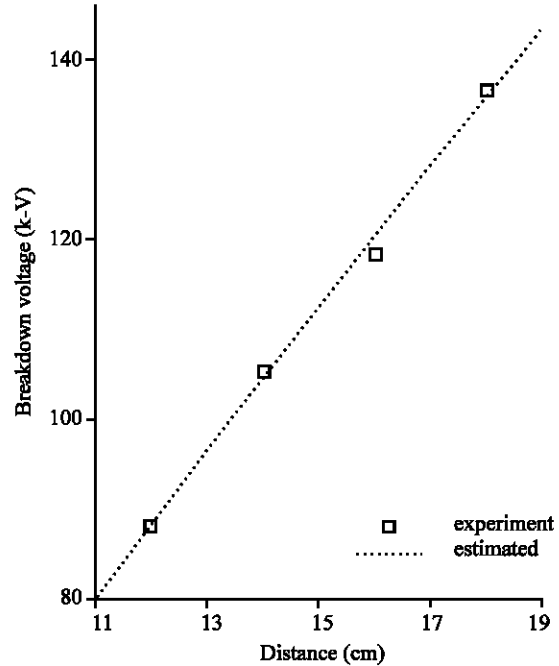


Fig. 10: Measured and estimated breakdown voltage as a function of distance (grounded conical rod $\theta = 120^\circ$) for positive polarity ($d = 3$ cm)

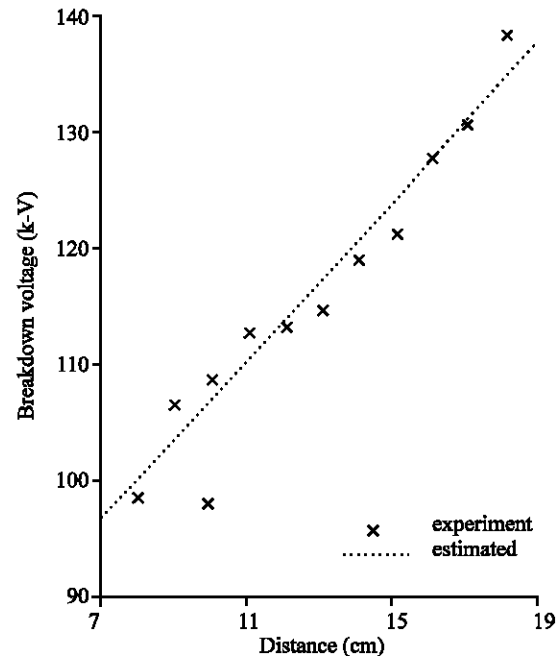


Fig. 11: Measured and estimated breakdown voltage as a function of distance (grounded conical rod $\theta = 120^\circ$) for negative polarity ($d = 3$ cm)

CONCLUSION

In this paper, the breakdown voltage in the gap with a floating metallic particle was estimated on the basis of the field calculation. The reduction of the dielectric strength to ground due to a rod discharge or local spark depends on the rod to floating object distance d , the geometry of the grounded electrode and on the (rod-floating object) to grounded electrode distance L . The local spark reduces the main breakdown voltage particularly for high values of d and L . In these conditions, the dielectric strength to ground is reduced to the local spark inception level. According to these results, the impulse breakdown voltages of air gaps with floating metallic particles depend on several factors, the location, shape and size of floating particles, the gap length and the polarity of applied voltage. In both polarities, the minimum breakdown voltage is always lower than that without the floating needle. The mechanism by which a rod discharge lowers the dielectric strength was discussed in terms of the discharge behavior. The possible cause of a breakdown from a rod discharge would seem to be the high local electric field around the rod discharge arc enhanced by streamers protruding from its surface.

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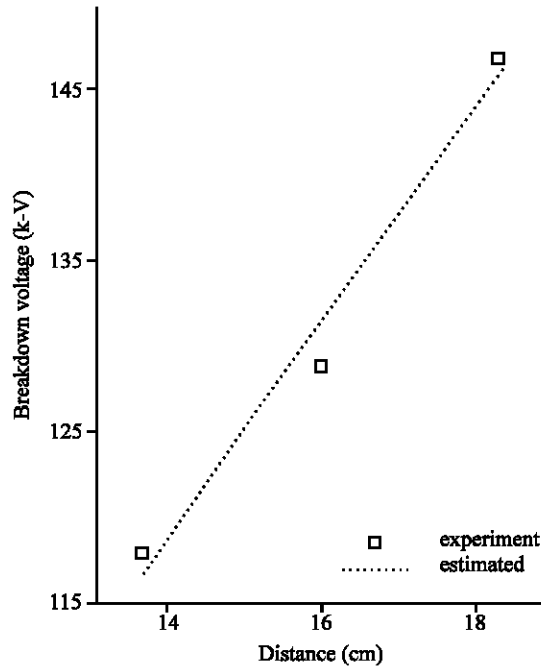


Fig. 12: Measured and estimated breakdown voltage as a function of distance (grounded conical rod $\theta = 15^\circ$) for positive polarity ($d = 3$ cm)

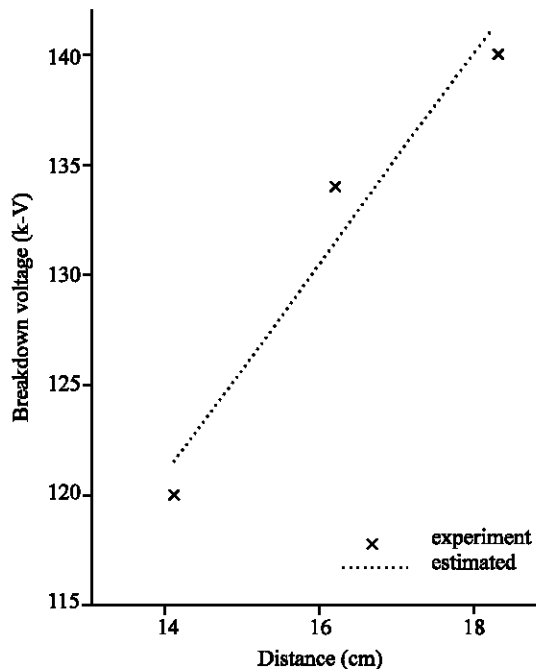


Fig. 13: Measured and estimated breakdown voltage as a function of distance (grounded conical rod $\theta = 15^\circ$) for negative polarity ($d = 3$ cm)

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