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Influence of humidity on the breakdown voltage of d.c. and a.c. voltages in air

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Work is reported which has had as its objective the investigation of the influence of humidity on the breakdown voltage of spark gaps in air. In the spark gaps investigated, breakdown resulted from the impulseless glow corona. Up to now no complete investigations exist of the effect of humidity on the glow corona. The steps necessary in practice and the regulations for the correction of humidity are indicated.

1. Introduction

In recent years different research work has become available [1] [2] [3] [4], in which investigations have been carried out on the breakdown voltage of air gaps. From these investigations therefore it is seen, that the effect of humidity on the breakdown voltage in air can always be observed, if pre-breakdown precedes the breakdown on a positive electrode. Corresponding to this main condition, humidity does not in practice effect the breakdown voltage in an homogeneous or near homogeneous field. As long as the breakdown occurs without pre-breakdown, the effect of humidity on the breakdown is slight (e.g. 0.25%/g/m” as shown [1]). Similarly the effect of humidity on the breakdown voltage can be disregarded, if pre-breakdown occurs in the spark gap only on a negative electrode [1]. With impulse-like pre-breakdown (streamer) on a positive electrode, the effect of humidity on the breakdown voltage is dependent to a critical extent on the dimensional and durational development of the pre-breakdown.

A study of the literature on the different forms of pre-breakdown, relative to the effect of humidity on the breakdown voltage, shows that, with the exception of the impulseless glow corona, there are already measurement results available which show the main gradients for every form of pre-breakdown. For practical use, there are already correction graphs in existence, although these do not explain the physical reasons for the effect of humidity on the formation of the pre-breakdown and thus of the breakdown voltage.

The following are the principal considerations in the effect of humidity on the breakdown voltage which have been measured up to now :

a) Positive pre-breakdowns :

aa) Dark discharges (no pre-breakdown): Effect of humidity can be disregarded.

ab) Impulse-like pre-breakdown : Greatly influenced by humidity [5].

ac) Impulseless pre-breakdown: Effect of humidity unknown.

b) Negative pre-breakdowns: Humidity has no effect on any known type of pre-breakdown.

Arising from this comparison comes the fact that, up to now, not much notice has been given to the effect of humidity on breakdown voltage, when a impulseless glow corona precedes the breakdown.

For this reason investigations are described in the following, the purpose of which is to measure the effect of humidity on the breakdown voltage of air gaps in which the impulseless glow corona precedes the breakdown at the positive electrode. The impulseless glow corona is a form of discharge which can be observed in a.c. and d.c. voltages particularly at sharp edges and on thin wires. A glow corona in formation acts in a stabilising manner, that is to say, the breakdown voltage of a gap can be increased through this form of discharge. In practice. for example, grid electrodes are used as shield electrodes

2. Test arrangement and evaluation of results

In the following the effect of humidity on the breakdown voltage from the glow corona in d.c. and a.c. voltages is investigated. With lightning voltages impulseless glow corona does not occur [9]. The measurements were taken in the air-conditioned laboratory of the High Voltage Institute of the Technical University, Munich (6.5 x 6.5 x 6.5 m^3) [1] [6]. A 400 kV transformer was used as the source for the a.c. voltage which was supplied from the mains via a single-phase transformer. Measurement of the a.c. voltage was carried out with a capacitive voltage divider (C = 65 pF). It was possible to attach a one-way rectifier (rectifier, smoothing capacitor) to the transformer for the generation of the d.c. voltage, so that the d.c. voltage could be measured with an ohmic voltage divider. With the aid of a bushing the test voltage could be switched through to the test arrangement.

The chosen arrangements ought preferably to build-up the impulseless glow corona. Employed as test objects for this reason were either a vertical built-in rod-plane spark gap (rod diameter: 50 mm rod-end with an edge radius r = 1 mm at a spark distance of a = 10 cm or r = 2 mm at a = 20 cm and a = 30 cm), or a cylindrical spark gap (outer diameter: 40 cm or 20 cm. Diameter of the inner conductor 10 mm or 6 mm).

These dimensions were necessary for the rod-plane gap, in order to prove that the breakdown resulted from the glow corona and not from the shaft of the rod during the action of the glow corona. The cylindrical spark gaps were so dimensioned that the breakdown occurred in the cylinder field.

The measured values of the breakdown voltages were evaluated in accordance with statistical methods. 20 breakdown tests were carried out for each measured point. The average value of the breakdown-voltages, the standard deviation and in the event of a normal distribution also the confidence limits of 95% were determined graphically and by calculation, with the help of the probability-paper. The breakdown voltages were also calculated under the normal conditions (20°C, 760 torr) corresponding to the recommendations of the International Committee of Electronic Techniques (CEI) [7].

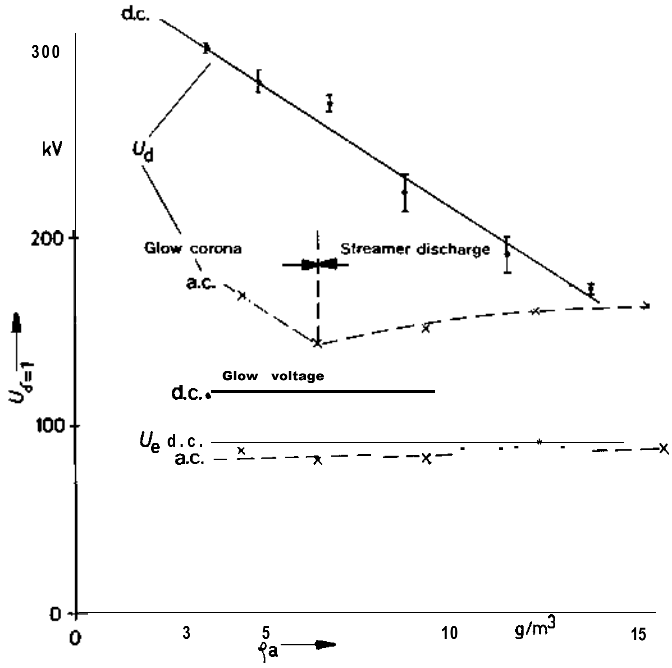

Fig. 1: Effect of absolute humidity φa on the breakdown voltage U_d of a 30 cm rod-plane spark gap
Type of electrode: blunt with 2 mm radius
Parameter: Voltage
Positive d.c. voltage (d.c.)
a.c. voltage (a.c.)
U_e onset voltage
U_d breakdown voltage
φa absolute humidity

3. Results

The results of the effect of humidity on the breakdown voltage for the rod-plane gaps are illustrated in Figs. 1 to 3. It is recognised that the onset voltage U_e in d.c. and a.c. voltages is about equal and increases minimally with rising absolute humidity. After the impulse-like streamer discharge, the impulseless glow corona appeared, in the course of which, the onset voltage of the impulseless glow corona was measured only at the d.c. voltages as in Fig. 1 and 2. The d.c. breakdown voltage shows a decreasing characteristic for all three gaps, that is with increasing absolute humidity, the d.c. breakdown voltage decreases if the breakdown results from the impulseless glow corona. The a.c. breakdown voltage shows the same tendency in the glow corona. Because of the form of the a.c. voltage, the glow corona developing in each half-wave is not so stable, so that the breakdown occurs earlier at lower absolute voltage values. In Fig. 1 it can be ascertained, that if the breakdown results from the impulse-like streamer discharge (from $\varphi a > 6.5$ g/m³), the breakdown voltage increases with rising humidity.

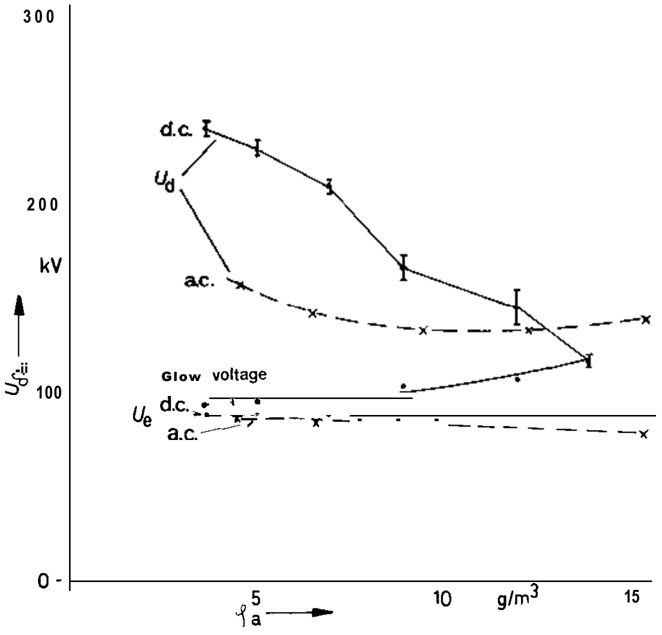

Fig. 2: Effect of absolute humidity φa on the breakdown voltage U_d of a 20 cm rod-plane spark gap
Type of electrode: blunt with 2 mm radius
See Fig. 1 for further notations

In the results in a.c. voltage (Fig. 3) with a 10 cm gap distance, the following is worthy of note. In this arrangement, breakdowns occur in a certain voltage region, for example: at $\varphi a = 9.5$ g/m³ from 68. . . .81 kV, after the onset voltage. The breakdowns however are still not able to heat up a low-ohmic channel. If the voltage is increased further (for example: at $\varphi a = 9.5$ g/m³ at 81 kV), the breakdowns cease. The region in which these breakdowns can be observed is indicated by means of vertical dotted lines in Fig. 3. The breakdown, which also ends in an intensive short circuit arc, occurs at this humidity at about 130 kV. If the voltage is increased, not to the final breakdown at about 130 kV, but only to about 120 kV, then subsequently reduced further then the breakdowns

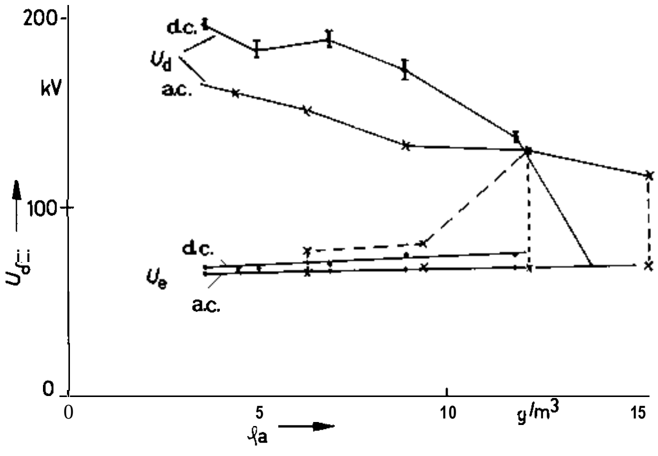

Fig. *3:* Effect of absolute humidity φa on the breakdown voltage U_d of a rod-plane spark gap
Type of electrode: blunt with 1 mm radius
See Fig. 1 for further notations

also occur again in the characterised region ($68\ \text{kV} \leqslant U \leqslant 81\ \text{kV}$), on reduction of the voltage. Explanation of this behaviour lies in the pre-breakdown. An impulse-like streamer discharge which is able to reach as far as the opposing electrode occurs as the first form of discharge following the onset voltage, as the onset voltage for this arrangement is higher (64 kV) than the voltage requirement of pre-breakdown (5 kV/cm for the streamer discharge means 50 kV at 10 cm) up to the opposing electrode. If a impulseless glow corona occurs at all, this has a stabilising effect. That is to say, the breakdown voltage only occurs at a higher voltage.

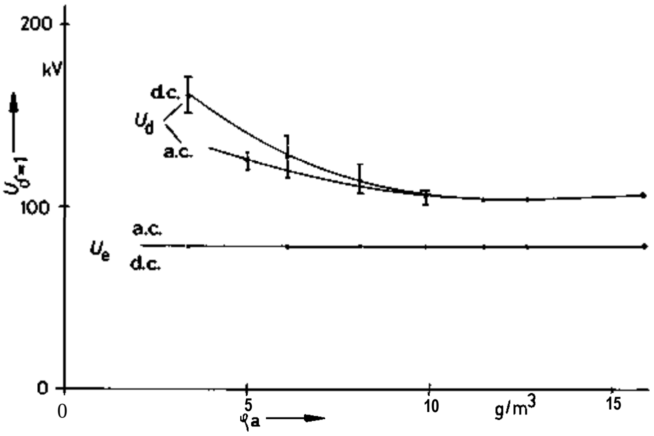

Fig. 4: Effect of absolute humidity φ_a on the breakdown voltage U_d of a cylindrical spark gap
Outer cylinder D = 40 cm, Inner conductor d = 10 mm, Length of the outer cylinder: 90 cm
See Fig. 1 for further notations

Even with the cylindrical spark gap, at which a further considerably stabilising glow corona can be formed, results comparable in practice were achieved. As is to be seen in Fig. 4 and 5, here too, the onset voltage is in practice not affected by the absolute humidity, whilst the breakdown voltage decreases with increasing absolute humidity, as long as the breakdown results from the impulseless glow corona.

4. Discussion on the results

If the breakdown results from the impulseless glow corona, the breakdown voltage thus decreases with the increasing absolute humidity. This drop in the breakdown voltage means that the voltage region in which the glow corona can occur becomes less and less. In high absolute humidity no glow corona can be observed. This limit (in the arrangements investigated) lies under 15 g/m^3.
A possible explanation of the drop in the breakdown voltage could lie in the adsorption of the photons. Whilst this adsorption in streamer discharge works to increase strength, with the impulseless glow corona a weakening of the glow corona occurs, since too few negative ions (which are important to keep the glow corona alive) [8] exist in areas of weak fields.
The falling graph line in rising absolute humidity indicates, that national and international regulations on the correction of humidity must unfailingly concern themselves with the nature of the pre-breakdown, when a correction graph is employed. The correction graphs given in previous recommendations and regulations [7] [10] are only valid, if streamer-corona occur at the positive electrode.

5. Summary

From the measurements it is clear, that the breakdown voltage of spark gaps in a non-homogeneous field is influenced by the absolute humidity. If the breakdown results from the impulseless glow corona on a positive electrode, the breakdown voltage falls with increasing absolute humidity. At high absolute humidities no impulseless glow corona occurs.

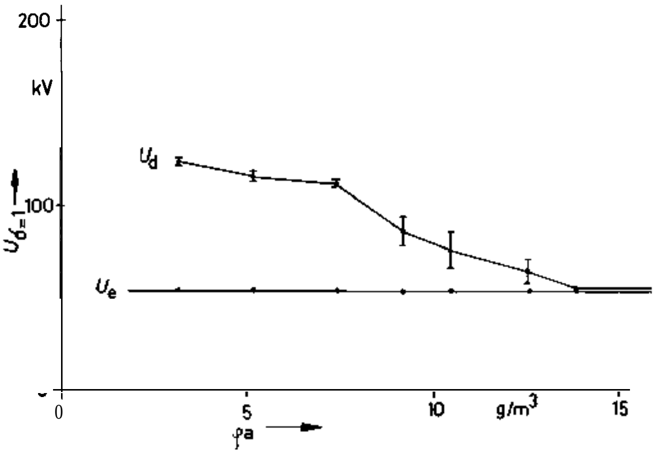

Fig. *5:* Effect of absolute humidity φ_a on the d.c. voltage breakdown U_d of a cylindrical spark gap
Outer cylinder 20 cm. Inner conductor d = 6 mm. Length of outer cylinder 60 cm
See Fig. 1 for further notations

The measurements presented were carried out at the Institute for High Voltage at the Technical University, Munich.

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