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# Insulation properties of composite dielectric arrangements

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**Abstract**

This paper examines the barrier effect on the dielectric strength of non-uniform electric fields, stressed by impulse voltages. The electric field is a rod-plane air gap with length up to 40 cm. The barrier is a sheet of craft paper that is placed to several positions between the grounded plane and the high voltage rod. The experimental results show that the position of the barrier influences substantially the dielectric strength of the gap. Another parameter that is also investigated is the electrode configuration. The diameter of the rod electrode and the shape of the tip affects the uniformity of the field and therefore the dielectric strength. The dependence of the breakdown voltage upon the shape of the impulse stress is also investigated. The experimental tests show that the strength of the gap decreases with the time to crest of the impulse. It becomes minimum under voltages with a time to crest of some tens of microseconds and starts increasing under slower impulses with time to crest of some hundreds of microseconds. The obtained results seem to be very useful for the design and the optimisation of the internal insulation of high voltage electrical equipment.

**Keywords:** Air gaps, barrier effect, insulation, dielectric arrangements

## 1. Introduction

The use of insulating materials in air gaps is often used because it has been noticed that their dielectric strength increases essentially after the insertion of a barrier in their electric field [1-6]. Technically and economically speaking, the quality and the thickness of the barrier is not the most important criterion for the insulation co-ordination. It was found out that variations in the thickness of the insulating material slightly affect the mechanism of the breakdown/puncture of the barrier [7]. Noticeable changes in the breakdown voltage have been observed only when the thickness is considerably increased [1, 3]. On the other hand, it should be mentioned that the breakdown voltage is not affected even the barrier is already punctured or even more, it possesses an opening [8].

The aim of the paper is the investigation of the parameters that affects substantially the breakdown mechanism and the strength of the gap qualitatively and quantitatively. Rod-plane air gaps with small and medium distances are tested experimentally under impulse voltage stresses. The investigated parameters are the gap length, the diameter and the tip radius of the high voltage electrode, the position of the barrier and the shape of the impulse voltage.

## 2. Experimental

The test arrangement is a rod-plane air gap with length in the range of 10 to 40 cm. The rectangular plane is at the earth potential while the high voltage is applied to the rod electrode.

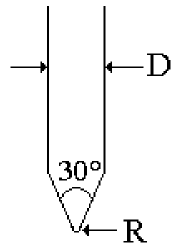


Fig. 1: High voltage rod electrode
D: diameter, R: radius of the tip.

Five different rods (Fig. 1) are used, three of them with diameter $D$=12 and the other two with $D$=16 and 23 mm. The tip of the rod is terminated with a cone. The angle of the tip is 30°. The rod of the three electrodes with $D$=12 mm ends to a spherical surface with radius $R$=1, 2 and 4 mm respectively. The tip radius of the other rods ($D$=16 and 23 mm) is 1 mm. The material of the electrodes is brass.

The insulating barrier is a sheet of paper, enriched with epoxy resins, which is used for the insulation of transformer windings. It has the following technical characteristics: thickness 0.39 mm, weight 481 g/m2, breakdown voltage in air 4.5 kV, pH in water solution 6 ÷ 8, moisture 8%, nitrogen 2% and ashes 1%. The dimensions of the barriers are always greater than the dimensions of the grounded plate in order to avoid a flashover. The barrier is placed perpendicular to the axis of the rod-plane gap (Fig. 2) at a distance $x$ from the high voltage rod. The distance $x$ is varying between 0 (barrier in touch with the high voltage rod) and G (barrier in touch with the grounded plane), in steps of 0.25G.

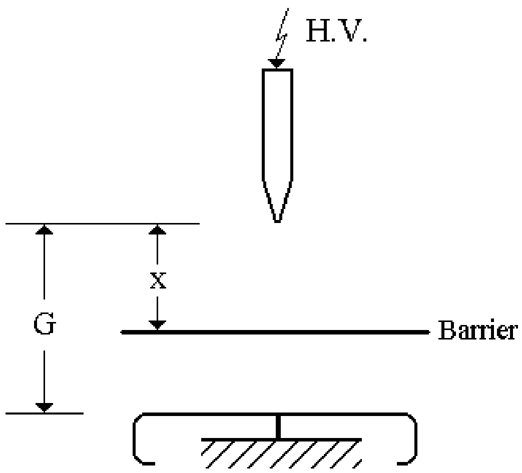


Fig. 2: Rod-plane air gap with insulating barrier
*G*: Length of the gap
*x*: Distance between the barrier and the high voltage rod.

The gap is stressed by high impulse voltages of positive polarity with time to crest $T_{cr}$ varying in the range of 2 ÷ 435 µs. Among them are the standard lightning impulse 1.2/50 µs and the standard switching impulse 250/2500 µs. The test voltage is produced by an 8-stage Marx impulse voltage generator, with a charging voltage of up to 200 kV and an energy of up to 2 kWs per stage. The voltage is measured by a 1.2 MV damped capacitive divider connected, via a 20 m coaxial cable, to a digital oscilloscope and a peak voltmeter. The instruments are placed in a Faraday screened chamber.

All tests are performed in a temperature and humidity controlled climate chamber, completely made of insulating materials. Its volume is approximately 12 $m^3$ (2.4 m X 2.2 m and 2.2 m height). The absolute humidity during the experiments is between 7 and 16 $g/m^3$, the air pressure between 1000 and 1013 mbars and the temperature almost constant at 20°C. All the measured values of the breakdown voltage are corrected, according to IEC 60, to the standard climatic conditions $T$=20°C, $p$=760 mmHg and $H$=11g/$m^3$.

The experimental procedure for the determination of the breakdown voltage is the multiple level method as it is described in the literature and the international norms. The breakdown voltage without the barrier of each electric field configuration is measured before the insertion of the barrier and the performance of the tests. The barrier is replaced by a new one after each breakdown/puncture. A breakdown of the gap due to flashover, without puncture of the barrier, is very rare and it is not taking into account.

## 3. Results

The dielectric strength of the gap is strongly influenced by the position of the barrier in the gap. The dependence of the breakdown voltage upon the distance *x* from the high voltage electrode is shown in Fig. 3. It is obvious that the strength of the gap is not influenced if the barrier is placed on the grounded plate (*x*=*G*). The value of the breakdown voltage starts increasing when the barrier is moved towards the high voltage rod. It takes its maximum at a distance x ≈ G/10 from the rod and starts decreasing when the barrier is brought to the rod.

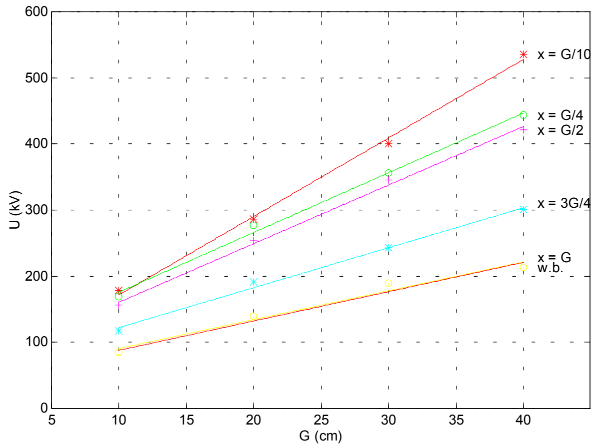


Fig. 3: Effect of the position of the barrier on the dielectric strength under the standard impulse voltage 1.2/50 µs
$D$ = 12 mm, $R$ = 1 mm
w.b.: breakdown voltage without the barrier.

The increase of the dielectric strength of the gap that it is gained with the thin barrier is substantial. It should be noticed that this increase can't be explained using simply the theory of electrostatic fields. On the contrary, the breakdown process is completely changed. The insertion of the barrier in the gap changes the distribution of the electric field lines. The strong electric field stress causes Corona discharges at the neighbourhood of the high voltage electrode which accumulate electrostatic load on the surface of the barrier facing the electrode. Simultaneously, opposite load appears to the other side of the barrier. It can be claimed that two gaps are formed, connected in series: a) a rod-to-plane gap where the barrier is the plane and b) a plane-to-plane gap where the one plane is the barrier and the other is the grounded plane. The barrier is the common plane electrode in both gaps. When the voltage reaches its critical value, the first gap with the rod is bridged. The breakdown of the second gap follows instantaneously.

The accumulation of the load on the barrier is faster when the barrier is placed near the high voltage rod where the field strength is high enough. In this case the gap is bridged at lower values of the stress voltage. Generally, the propagation of the streamer, initiated from the high voltage rod, is impeded by the insulating barrier. Therefore, the streamer is not extended below the barrier towards the grounded plane.

The influence of the shape of the high voltage rod is a less important parameter of the breakdown process in the gap (Fig. 4). As it is expected, the breakdown voltage increases with the increase of the diameter or/and the radius of the tip of the rod because the electric field near the rod weakens.

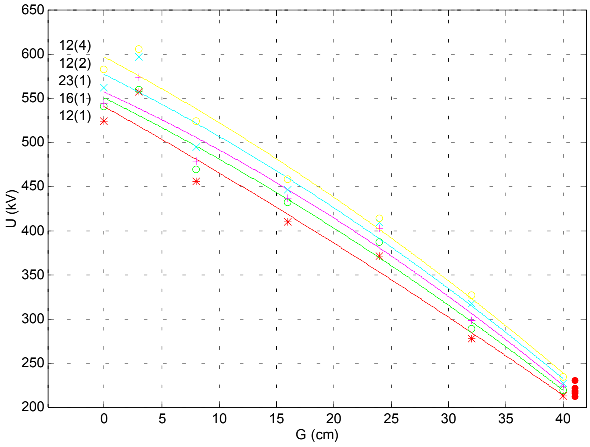


Fig. 4: Effect of the shape of the rod electrode on the dielectric strength under the standard impulse voltage 1.2/50 μs
$G$ = 40 cm, $D$ = 12, 16, 23 mm, $R$ = 1, 2, 4 mm.

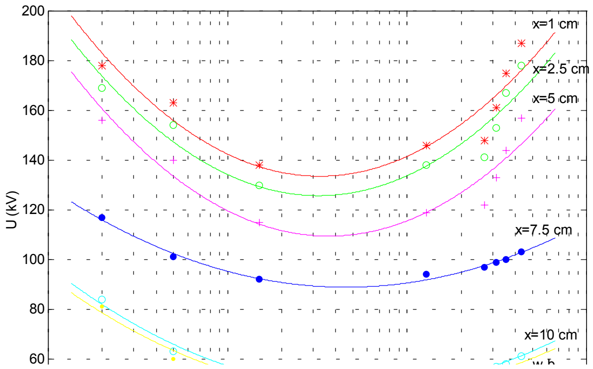


Fig. 5: Breakdown voltage vs. the time to crest $T_{cr}$ of the test voltage
$G$ = 40 cm, $D$ = 12 mm, $R$ = 1 mm
w.b.: breakdown voltage without the barrier.

Another parameter which affects considerably the strength of the air gap is the shape of the impulse voltage stress. The time to crest $T_{cr}$ (time from zero to the peak of the impulse) is an important factor of the breakdown mechanism. The influence of $T_{cr}$ of the applied voltage on the strength of the gap is demonstrated in Fig. 5. It is obvious that the breakdown voltage follows the well known form of the U-curve which is characteristic of the air gaps (without the barrier).

The breakdown voltage decreases (Fig. 6i) with the increase of $T_{cr}$ and takes its minimum when $T_{cr}$ is in the order of some decades of microseconds. Then ($T_{cr}$>100 μs) the value of the dielectric strength starts increasing (Fig. 6ii) and finally ($T_{cr}$>400 μs) exceeds the one under the standard lightning impulse 1.2/50 μs.

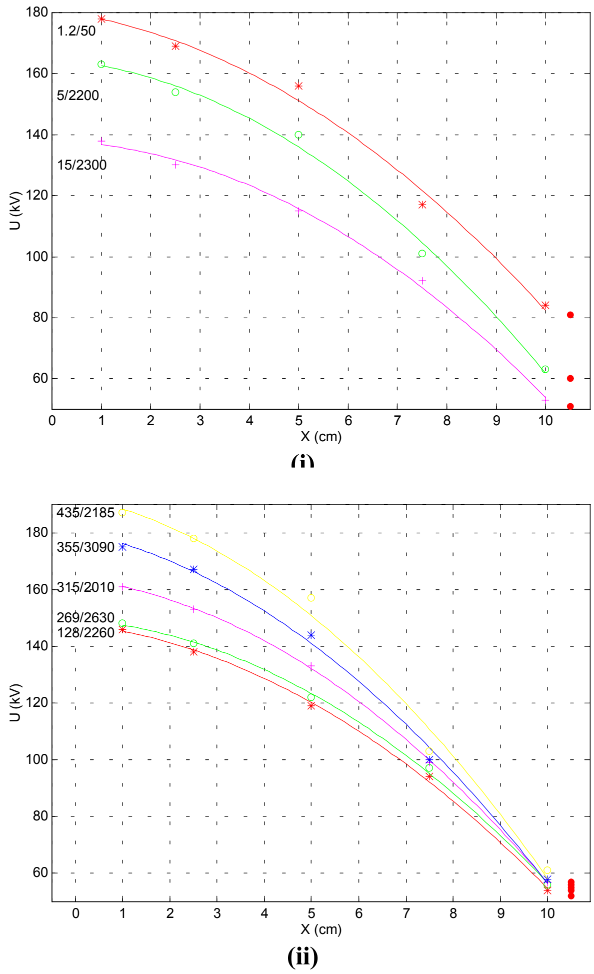


Fig. 6: Effect of the shape of the impulse on the dielectric strength
$G$ = 10 cm, $D$ = 12 mm, $R$ = 1 mm
• breakdown voltage without the barrier
(i) test voltage: 1.2/50 μs, 5/2200 μs, 15/2300 μs
(ii) test voltage: 128/2260 μs, 269/2630 μs, 315/2010 μs, 355/3090 μs, 435/2185 μs.

The determined curves, one for each gap arrangement, describe completely the insulation properties of the gap and provide a useful tool for the optimization of the insulation co-ordination of medium and high voltage installations.

## 4. Conclusions

The use of insulating materials in air gaps is an efficient technique for the insulation dimensioning and co-ordination because the increase of the withstand voltage of the gap that is attained is considerable. Generally, the best position of the barrier in the gap in order to attain the optimum results is at the vicinity of the high voltage electrode. According to the experimental results of this investigation, the best position seems to be at a distance equal to 1/10 of the length of the gap. This distance was found to be longer from other researchers, almost ¼ of the gap length. It is believed that those deviations between the test results are owed to the different insulating materials (thickness, insulation properties, homogeneity etc.) and to the different experimental apparatuses and test techniques. Very interesting is the conclusion of Remde and Boecker in [2] where it is stated that the peak value of the applied voltage is not the only criterion for the determination of the breakdown properties of the gap. The value of the surge capacitor of the impulse voltage generator and therefore the energy of the generator is quite critical. If the capacitor can not give the required current, the breakdown process stops even the voltage is high enough.

Generally, all the researchers agree that the highest dielectric strength is attained when the barrier is placed near the high voltage electrode but not close to that. Position of insulating materials near the grounded electrode is useless except it is too thick. In this case the cost is high and the results moderate. The aim of the designer is to alter the breakdown mechanism (thin barrier near the high voltage electrode) and not just to improve the distribution of the electric field lines with thick and sometimes expensive materials.

## 5. References

[1] E. Marx: "Der Durchschlag der Luft im unhomogenen elektrisschen Felde bei verschiedenen Spannungsarten", ETZ, Vol. 33, pp. 1161-1165, 1930.

[2] H.E. Remde, H. Boecker: "Voltage-current characteristics during propagation of a surge breakdown of a point-to-plate gap with insulating barrier", IEEE Summer Meeting and International Symposium on High Power Testing, pp. 271-276, Portland, U.S.A., 1971.

[3] K. Hidaka, M. Chiba, T. Kouno: "Barrier effect on electrical breakdown in air", Proceedings of the IXth International Conference on Gas Discharges and their Applications, pp. 479-482, Venice, Italy, September 1988.

[4] A. Beroual, A. Boubakeur: "Influence of barrier on the lightning and switching impulse strength of mean air gaps in point/plain arrangements", IEEE EI-26, No. 6, pp. 1130-1139, 1991.

[5] F.V. Topalis, I.A. Stathopoulos: "Barrier effect on electrical breakdown in non-uniform small and medium air gaps", Proceedings of the XIth International Conference on Dielectric Materials and Applications, pp. 439-442, Manchester, United Kingdom, September 1992.

[6] L. Ming, M. Leijon, T. Bengtsson: "Factors influencing barrier effects in air-gaps", Proceedings of the IXth International Symposium on High Voltage Engineering, Paper No. 2168-1, Graz, Austria, August 1995.

[7] F.V. Topalis, I.A. Stathopoulos: "Barrier effect in small and medium air gaps", Proceedings of the VIIth International Symposium on High Voltage Engineering, Paper No. 42.23, Dresden, Germany, August 1991.

[8] E. Wasilenko, M. Olesz: "Effect of solid barrier with circular opening on impulse breakdown voltage of rod-plane air-gap", Proceedings of the Xth International Conference on Gas Discharges and their Applications, pp. 636-639, Swansea, United Kingdom, September 1992.