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Defective Barrier on Voltage Optimization for Small Airgap

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Author's contribution

The only author performed the whole research work. Author JTA wrote the first draft of the paper. Author JTA read and approved the final manuscript

Research Article

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ABSTRACT

Aim: To investigate the effect of defective barrier on the optimum breakdown voltage, using positive and negative needle electrodes in an air medium of 10cm gap distance.
Methodology: The barriers for the tests were placed at 2.5cm from the point electrode for each test. The defective barriers were created by having holes of 6mm, 8mm, 12mm and 20mm diameter at the centre of the barrier. For each barrier position the breakdown test for positive and negative polarity for needle electrodes were carried out. Also, tests were carried out with non defective barrier and with point-plane airgap (without barrier).
Result: From the test without barrier the negative point electrode offered higher breakdown voltage (1.8 times), than the positive point. When with plain barrier the positive point was optimized to 1.6 times, while the negative point was lowered.
The optimum breakdown voltage decreased gradually as the hole diameter increased and at 20mm hole diameter the effect was like the plain barrier.
Conclusion: From the results, optimization is only effective with positive point's electrode and it endures even with small opening within the ionization zone. It is necessary to check this in practical situations because the specified optimum voltage of an equipment may be lowered.

Keywords: Negative polarity; sharply non-uniform field; gaseous volume; defective barrier; optimum voltage.

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1. INTRODUCTION

Several works have been done on small and medium needle plane airgap using insulating barriers. Marx investigated the influence of the polarity of the impulse voltage to the breakdown mechanism [1,2].

He determined that the positive impulse voltage produces a positive thin streamer discharge from the needle to the barrier with a lot of branching. The streamer cannot penetrate the barrier and stops there, accumulating positive charges on the surface of the barrier that faces the needle. Therefore, the gap between the barrier and the plane becomes uniform with the positively charged surface on the barrier, acting as the positive electrode while the negative one is the plane electrode. The potential is almost equal all over the charged surface of the barrier. That homogenization of the gap prevents the development of the leader, thus increasing the breakdown voltage. Depending on the gap length, the position of the barrier and the breakdown voltage is increased considerably.

Another study was carried out by Roser [3] on small gap (10cm gap). He investigated, among others the influence of the insulating material and of its thickness to the level of breakdown voltage. It was concluded that the critical point is not the thickness of the barrier, given that the thickness and the effectiveness of the provided insulation is negligible as compared to the most important parameters, the gap length, the uniformity of the electric field, the shape of the applied voltage and the position of the barrier inside the gap [4,5].

The barrier effect is not attributed to the additional insulation that improves quantitatively the field strength but to the presence of the barrier that affect qualitatively the breakdown mechanism. In uniform fields barrier effect is of minor importance. Roser's model complies with Marx observations that the discharge accumulates charge on the barrier and homogenizes the barrier-plane gap. In his determination he concluded [5,6] that the breakdown voltage of the non-uniform needle – barrier – plane field is equal to the breakdown voltage of the uniform barrier – plane field. To verify this, he conducted comparative experiments with positive impulse on a needle – plane gap with barrier and on a plane – plane gap (without barrier) with a clearance equal to the distance between barrier and plane of the first gap as shown in Fig. 1.

As was expected, the values of the breakdown voltage of the needle – barrier – plane arrangement was found to be very close to the breakdown voltage of plane – plane gap (the uniform field of the latter is equivalent to the barrier – plane field of the first arrangement). The only deviation appeared when the barrier was placed very close to the high voltage needle or near the grounded plane. If the barrier is placed near the needle electrode, then the discharge is quite short and the accumulated load on the barrier is not enough to modify and unify the remaining barrier plane gap. Therefore the field of the whole arrangement remains non-uniform. If the barrier is placed near the plate electrode, then the uniform barrier plane gap becomes so small that it may slightly influence the whole gap.

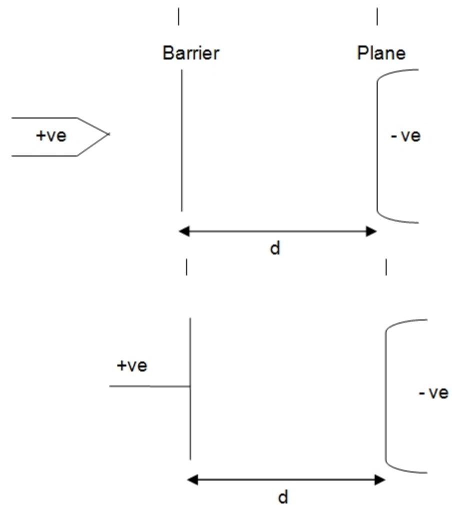


Fig. 1. Non-uniform needle – barrier – plane field and uniform barrier – plane field

1.1 Negative Impulse Voltage Breakdown

For negative point – barrier – plane gap, the negative streamer approaches the barrier without branching and as a result, a small quantity of negative charge accumulates on small area of the barrier. Therefore the field between the gap and the plane remains non-uniform. That is, the field around the needle is quite strong. The dense field lines which connect the needle with the plane through the barrier permit the inception of discharges between the barrier and the plane.

From Fig. 2 the behaviour of negative and positive electrode in air and under barrier conditions are shown with gap distance of 1cm to 12cm [7].

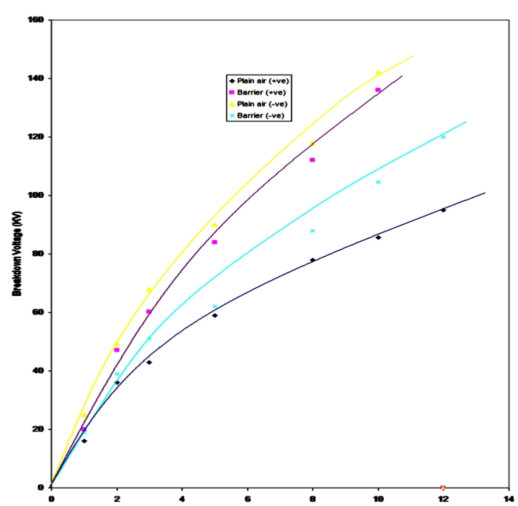


Fig. 2. Breakdown Voltage for Positive and Negative Air Gap with Barrier

1.2 Barrier with Opening

Roser performed dc experiments on a small air gap with barrier place at a specific position. Changing the diameter of the opening he observed that the breakdown voltage decreased but still maintained a high votage level. It proved that the barrier contributed to the dielectric strength even with hole. The breakdown voltage decreased at wider opening but was still higher than the one of the gap without barrier. It was obvious that the accumulation of the load on the surface of the barrier homogenized the field to a certain degree depending on the useful area of the barrier (initial surface minus the area of the opening).

Wasilenko and Olesz investigated [2,9,10] the effect of a barrier with a circular opening. They used impulse voltage as well as ac voltages. Their experiment confirmed that the barrier retains the improved strength of the gap with the circular opening. The diameter of the opening played an important role. Their experiment was on a gap distance of 30cm and a barrier of 45cm in diameter. It showed that the barrier effect was eliminated for an opening of larger hole diameter of more than 8cm.

From several experimental results, [1,7,8] it was established that the optimum voltage can be obtained at a barrier position of 0.25 the normal gap length from the point electrode. The shape of the graphs described the voltage breakdown level for various hole diameters and is shown in Fig. 3 [9].

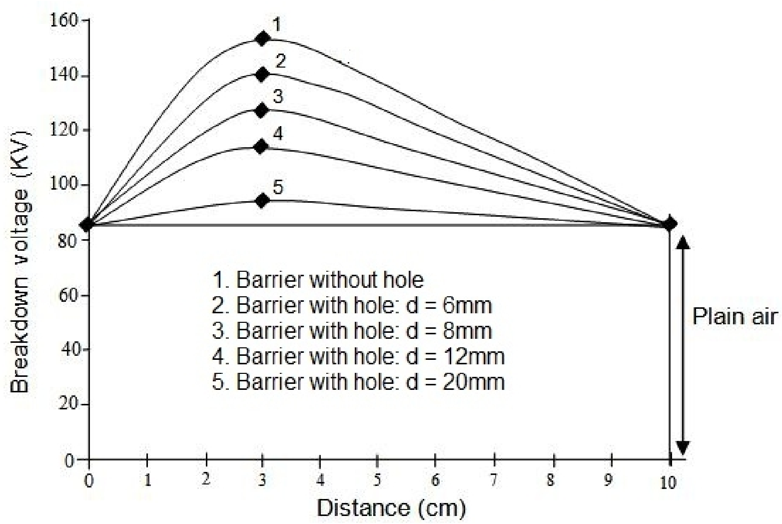


Fig. 3. Voltage optimization for positive needle electrode using barrier of different hole diameters

2. MATERIALS AND METHODS

The breakdown mechanisms and the behaviour of positive and negative point electrodes under barrier were different, therefore it was necessary to experimentally, compare the positive needle electrode and the negative point (needle) electrode under different barrier conditions. Three breakdown tests were then carried out on 10cm gap distance on the following:

i. Breakdown test on point – plane airgap (without barrier)
ii. Breakdown test on point – barrier – plane airgap (barrier without defect), barrier at 2.5cm from point electrode.
iii. Test on point – plane electrode (2.5cm) with barrier of different hole diameter.

The equipment used was the high voltage single phase high voltage test equipment. It has the AC, DC and impulse stages. The maximum impulse voltage was 150kV and generates a standard impulse of 1.2/50 μsec. The stages of the equipment are shown in Fig. 4.

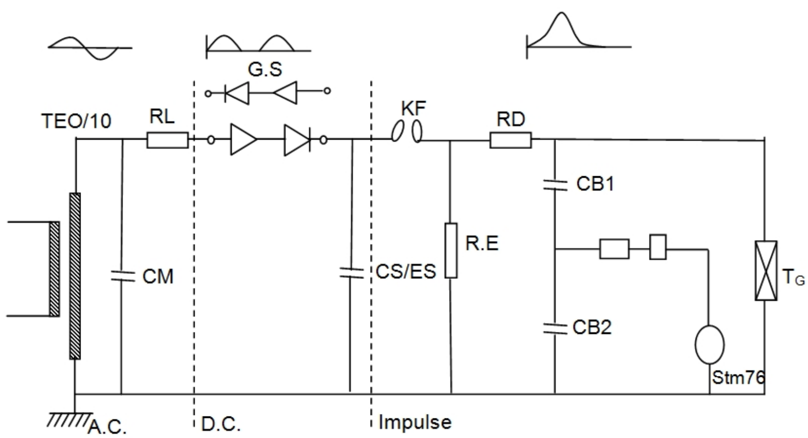
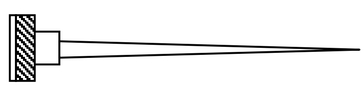


Fig. 4. Stages of test equipment

The needle electrode used for the experiment is shown in Fig. 5 with the tip diameter of 0.25mm.



0.25mm (tip diameter)

Fig. 5. The Needle Electrode

The electrode stand T_G was constructed from dried wood and ebonite pipes as shown in Fig. 6.

Fig. 6. Electrode Stand T_G with the barrier carrier

On the wooden crossbar, a threaded iron rod of 320mm length was made to carry the needle electrode. The plane (plate) electrode was made from mild steel square sheet with folded edges that were earthed.

2.1 Experimental Procedures

The point (needle) electrode was fixed at 10cm from the plane electrode using the electrode stand and was connected to the high voltage terminal. The impulse voltage and the spark gap k_f were adjusted to give some number of breakdown probability. In order to observe the discharge pattern of the negative and positive electrode, a paper was place at the plane electrode. For any breakdown that takes place, a hole was punched on the paper.

With the same arrangement a paper barrier was placed at 2.5cm from the point electrode. The voltage and the spark gap K_f was adjusted and the breakdown probability was observed 10 shots were allowed and the probability ($V_{50\%}$) was taken. With the same arrangement and gap distance the defective barriers were introduced at the same barrier position. The probability of breakdown ($V_{50\%}$) were also observed in each of them.

3. RESULTS

From the fifty percent probability ($V_{50\%}$) the results are tabulated in Table 1.

Table 1. Results of positive and negative needle electrodes ($V_{50\%}$) for different test

S/N	Barrier Condition	Breakdown Voltage		Relative Humidity Percentage mmHg	Temperature ºC
		Positive Point b/d Voltage kV	Negative Point b/d voltage kV		
1.	Plain Barrier without hole	136	105	75	40.1
2.	Hole 6mm	128	140	78	39.4
3.	Hole dia 8mm	114	143	74	402
4.	Hole dia 12mm	108	148	77	39
5.	Hole diameter 20mm	83	148	78	38.9
6.	Airgap without barrier	82	150	76	37.8

N/B: The voltage under reference atmospheric condition V_O is given by

$$V_O = V \times \frac{h}{d} \qquad (1)$$

Where V = Voltage under actual test condition
h = Humidity correction factor
d = Air density correction factor

These values were necessary to standardize the breakdown voltage under reference conditions.

A circle was drawn to enclose all shots for the negative and positive breakdown and are shown in Fig. 7.

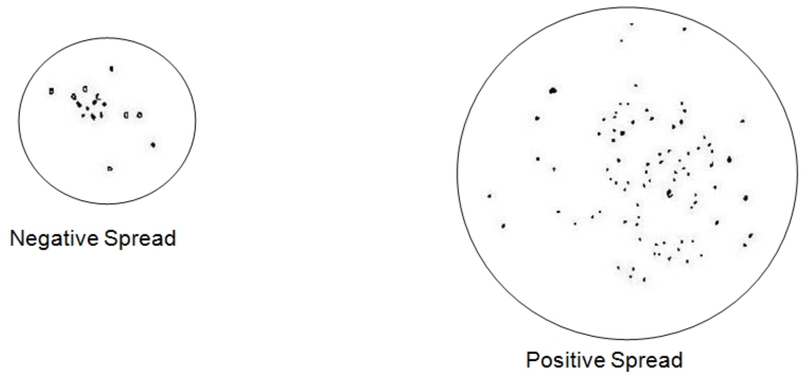


Fig. 7. Spread of shots of Negative and Positive breakdown for plain air gap

From the breakdown probability (Table1), the results for positive and negative test were drawn for all tested conditions and are shown in Fig. 8.

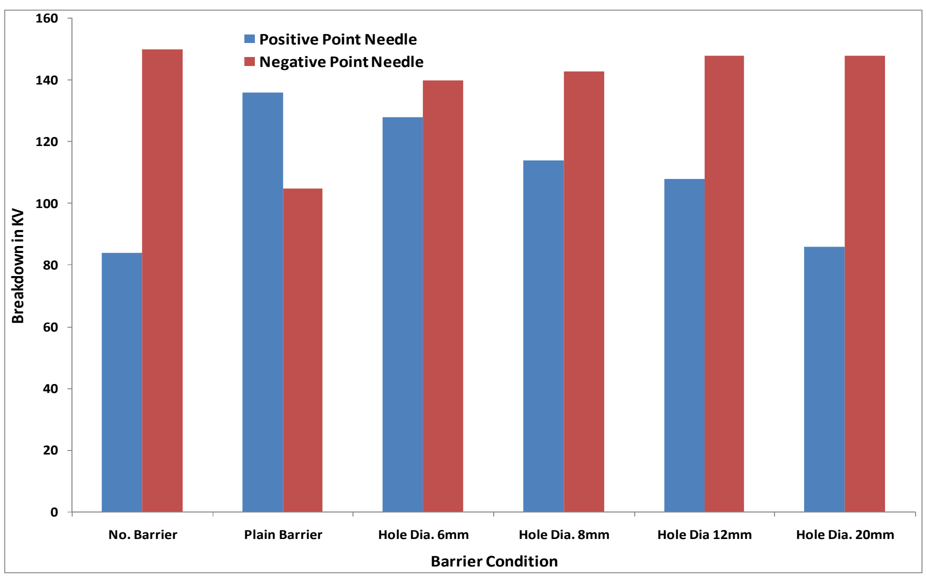


Fig. 8. Breakdown voltage (kV) between positive and negative needle electrode at 10cm airgap

4. DISCUSSION

The mechanism of breakdown for negative and positive streamer is practically demonstrated in Fig. 7. The area of coverage was small for negative streamer which confirms that the breakdown process takes place in step and no branching takes place by filamentary avalanches. That was why the shots were confined to a small circumference. As opposed to the negative streamer, the field at the head of the main avalanche suppliments the external field and promotes the growth of filamentary avalanches which contributes to the breakdown in the gap.

From Table 1, the breakdown voltage (without barrier) for negative point is about 1.8 times the positive point in plain airgap. The effect of barrier optimizes the positive (positive point) field by almost 1.6 times while the barrier effect reduces the breakdown voltage of the negative field. Different researchers gave slightly different explanation but it is reasonable to examine that which was proposed by Roser [3,10] for the positive field.

Roser's model complies with Marx observation that the discharge accumulated charges on the barrier and homogenized the barrier-plane gap. He assumed that the discharge is so intense that the voltage drop across the channel is very low. This means that the potential of the barrier becomes equal to the potential of the needle, that is, the test voltage as it were, was applied directly to the barrier – plane gap. For breakdown to occur the voltage must be high enough to cause the breakdown of the gap. That is the reason for higher voltage for positive point.

As was said earlier, the dense field lines which connect the needle with the plane through the barrier permit the inception of discharges between the barrier and the plane. It could be said that the barrier serves to reduced the space by its position and thereby lower the breakdown voltage.

4.1 Defective Barrier

From Table 1, the breakdown voltage for the plain barrier (non-defective barrier) was 138kV and at 6mm hole diameter, the breakdown voltage slightly decreased (128kV). With positive point, thin streamer discharge are produced with a lot of branching so that the coverage is more compared with the hole diameter (6mm), so the barrier effect was slightly noticeable. As the hole diameter increased the breakdown voltage decreased. At 20mm hole diameter for the same gap distance, no barrier effect was noticed. This suggest that the useful area of the barrier has been removed so that every avalanche produced has a pathway rather than having the barrier as an impediment [11–13].

The breakdown voltage was lower with plain barrier for the negative point as shown in Table 1, and all centrally opened holes on the barrier seemed to have no effect on the breakdown voltage [14]. This could be attributed to the pattern of breakdown (discharge) for the negative point.

5. CONCLUSION

- ❖ Non-uniform electric fields are generally encountere in high voltage power equipment with air as the medium of insulation or in combination of other insulant. In order to achieve maximum strength in such a field the point of the highest stress is controlled. From the experiment it was established that one of the methods of achieving such results is the use of barrier. Optimization is only possible with positive point electrode. When the barrier is defective the optimal voltage is affected. This effect depends on the type and the position of defect.
- ❖ The maximum optimized breakdown voltage is reduced as the holes on barriers are made wider until a point where the barrier effect is not felt. The width of the hole depends on the length of the gap. With very small airgap a small hole on the barrier

surface leads to a significant reduction in breakdown voltage. This also depends on the location of the hole. If it is located at the central point of the barrier it eliminates all of the beneficial effect of barrier. For practical purposes, porous barriers are not recommended for voltage optimization.

- Most practical application favours the use of positive point arrangement but it is seen that the breakdown voltage of negative point is still higher than the maximum optimized voltage of an equivalent positive point.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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