# Investigation on silicone polymer and epoxy resin breakdown under AC, DC and combined AC/DC voltages

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## ABSTRACT

*Breakdown voltage as a fundamental parameter of the insulation materials should be known in new developed combined AC/DC systems. In order to investigate the effect of such combined AC/DC field stress on the components, a circuit has been developed which can provide AC, DC and combined AC/DC voltages at both positive and negative polarity up to 200 kV. Moreover, comparative investigations between AC, DC and combined AC/DC breakdown voltage of silicone polymer and epoxy resin have been carried out. The results could help to have a better dimensioning and designing of high voltage component for combined AC/DC systems.*

## KEYWORDS

Breakdown; Combined AC/DC Voltage; Silicone Rubber; Epoxy Resin.

## INTRODUCTION

The increased penetration of renewable energy systems in Germany, mostly from offshore wind turbines, require technological changes for power transmission systems. As an option, integration of a DC transmission system in the existing AC system is proposed. Particular attention is paid to the analysis of combined structures, which consist of mixed overhead line systems in which AC and DC lines are installed in parallel on the same tower. Effect of such combined AC/DC fields on the insulation characteristics of cables, insulators, bushings and other power system components is unknown. Since the requirements for the applied materials in electrical power engineering are very high, the further development of insulators continues to speed up. Using both types of voltages on the same transmission towers or other power supply components, the insulators are exposed to combined AC/DC electric field stress. Effects of such electric fields on the insulation system are not sufficiently investigated and understood yet.

## STATE OF THE ART

The accurate measurement of breakdown strength and breakdown voltage of insulation materials are vital factors when designing HV apparatus. And even more if it is desired to extend the application of these materials to higher stresses. The advantages of silicone rubber and epoxy resin can result in lower assembly and maintenance costs in some cases, making them interesting materials in high voltage. In order to test them correctly, the appropriate method needs to be considered to match technical and economic requirements [1]. Moreover, a good statistical evaluation of the breakdown values is obtained when a suitable electrode arrangement is selected.

On the one hand, silicone rubber turns out to be a frequently used material. For example, in test setups with embedded electrodes, good results have been obtained for breakdown [1, 2, 3, 4, 5]. However, this method is complex in structure, making it difficult to prepare good samples and possibly affecting measurement results [2]. This implies that it is not very suitable for quality control. For example, the multi-electrodes according [4] require a large volume of the embedding material, which is very costly especially when many samples are needed for a good statistical evaluation [2].

According to these studies under AC stress, electrodes such as Rogowski, hemispherical rode-plate and sphere-to-plane electrodes have been used, at different voltage increasing rates and with samples of various thicknesses. The latter is due to the fact that breakdown in specimens with a thickness of 1 mm, as IEC 60243-1 recommends, are relatively insignificant when referring to complex and large insulating systems, according to [6]. [2] considered the disadvantages of some electrode arrangements and created a sphere-to-plane electrode configuration, which permits a single well-defined point of maximum field and gradual reduction of the field away from the point. In addition, his structure allows simple and easy rotation and change of the sphere electrode so that it is suitable for a large number of tests.

Researches on silicones under DC and AC were reported in [7, 8, 9]. All agree that breakdown strength under DC stress is at least twice higher than that under AC stress. Additionally, the use of different ratios of fillers leads to different values of breakdown; Higher ratio results in higher breakdown strength.

Studies on epoxy resin have been reported in [10, 11]. Time to breakdown in AC tests is significantly more varied than under DC bias tests. Roland [10] explains that it may be because fields under DC are substantially higher than under pure AC. Moreover, breakdown comes much faster when combining AC with DC stresses. The differences in positive and negative DC bias tests can be associated with space charge by moderating the field near the electrode under negative bias rather than under positive bias [10].

## EXPERIMENTAL SPECIMENTS

Silicone rubber and epoxy resin are widely used in high voltage applications. Therefore this paper focuses on these two dielectrics. There are plenty formulations of silicone rubber; some may contain fillers to reduce costs or improve properties. For this reason, characteristics resulting from polymer and filler structure are of particular interest and also the ones resulting from additives or surface treatment. Silicone rubber samples in this paper have been mixed in a big supplier of high voltage insulators and cable accessories in Germany. Epoxy resin samples are made with pure epoxy resin. The samples have thickness of 1mm and diameter of 90mm. Figure 1 shows the samples.

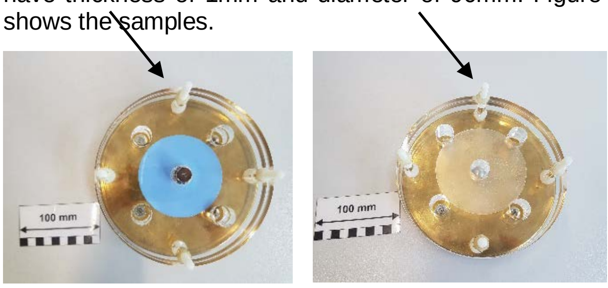


**Fig. 1: Silicone rubber (left) and epoxy resin (right)**

As mentioned different electrodes and methodes exist in order to investigate breakdown strength of the dielectrics. Some of them are useful only for AC tests and some other only for DC tests at the following sections by taking in to account advantages and disadvantages of different methods, the most proper method have been proposed in order to have the best results of breakdown test at AC, DC and combined AC/DC voltages.

## EXPERIMENTAL SET-UP

In order to investigate breakdown strength of the samples, a high voltage circuit has been developed in order to achieve combined high voltages, as well as AC and DC voltages up to 200kV. A picture of the circuit with test object and the schematic drawing of the circuit are shown in Figure 2 and 3 respectively.


**Fig. 2: Circuit with test object**

By changing the value of $R_1$, $R_2$ and $C_s$ it is possible to achieve different voltages. To classify the combined voltages, a “combined ratio” has been defined by the ratio of the DC amplitude ($V_{DC}$) to the peak value ($V_p$) in percent with following formula:

$$\%\, V_{\mathrm{DC}} = \frac{V_{DC}}{V_p} \times 100 \qquad (4)$$

At this paper 75% combined ratio has been used.

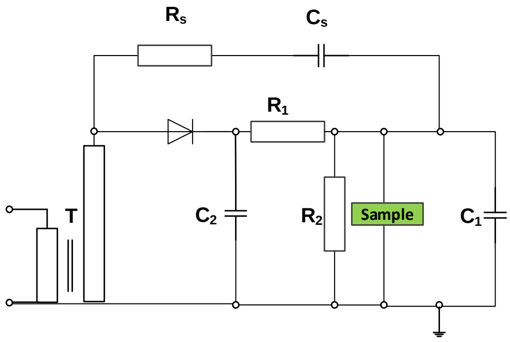


**Fig. 3: Combined AC/DC voltage circuit**

Breakdown mechanisms are different under AC and DC stress. Primary reasons of long term breakdown under AC are partial discharge and electrical tree caused in relatively weak points, while under DC, distribution of space charge is the main reason. This results in the breakdown strength under DC being much higher than under AC. As mentioned, all investigations of breakdown strength under DC and AC confirm that breakdown strength under DC stress is at least twice higher than that under AC, therefore, in order to have comparative investigation between AC, DC and combined AC/DC voltages a new optimized method and experimental setup are needed. Such an experimental set up should meet all requirements of AC and DC breakdown tests. It could be helpful to have a comparative investigation about breakdown strength of epoxy resin and silicone rubber at AC, DC and combined AC/DC voltages.

## ELECTRODES CONFIGURATION

As mentioned the advantages of silicone rubber and epoxy resin can result in lower assembly and maintenance costs, making them interesting materials in high voltage. In order to test them correctly, the appropriate method needs to be considered to match technical and economic requirements [1]. Moreover, more accurate breakdown values are obtained when a suitable electrode arrangements are selected.

In accordance with IEC 60243-1, the appropriate electrode arrangements for tests on boards and sheets perpendicular to the surface, are the cylinder electrodes of equal and unequal diameter presented in Figure 4. Its difference is based on the fact that the equal diameter cylinders have the advantage of providing a lower stress intensifying factor at the edges, which depends on the radius of the curvature at the electrode edges [1]. In addition, they have a higher efficiency factor, from which it is inferred that the distribution of the electric field in cylinders of equal diameter is much more homogeneous than in electrodes of unequal diameter. For these type of configurations, 1 mm thick samples are preferred. Recent researches show that both, cylinder and sphere electrodes, can be embedded into the insulation material to obtain breakdown values. Nevertheless, this method is not very suitable for routine testing; especially for testing in materials research laboratories, since for every test a new sample is needed and many breakdown tests are required to obtain a good statistical evaluation. Moreover, it has been reported that it is difficult to precisely adjust the distance between the electrodes [1].

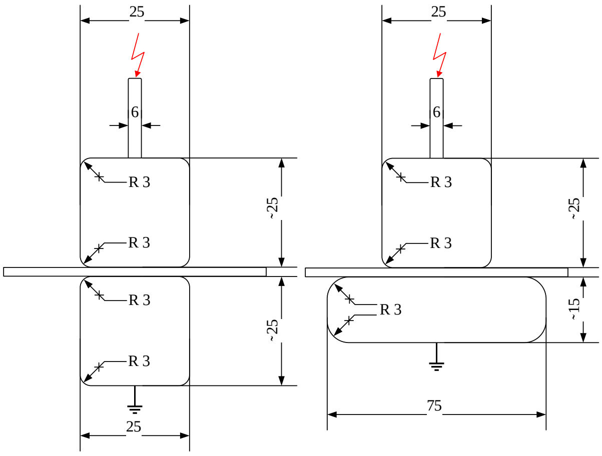


**Fig. 4: Cylinder electrodes of equal (left) and unequal sizes (right); (dimensions are in mm)**

This methods suffer with some possible errors; the electrodes may be not exactly in front of each other in cylinder electrodes of equal size; the electrodes may be not in parallel in both equal and unequal electrodes sizes and two possible errors of cylinder electrodes are illustrated in Figure 5.

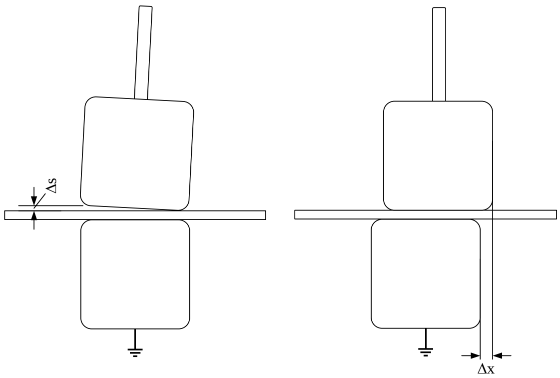


**Fig. 5: Cylinder electrodes with vertical(left) and horizontal(right) errors**

As mentioned another well-known electrode arrangement for breakdown tests is that of spheres of equal diameter, as shown in Figure 6. Due to its advantages, this type of electrodes have been used in AC, DC and combined AC/DC breakdown tests.

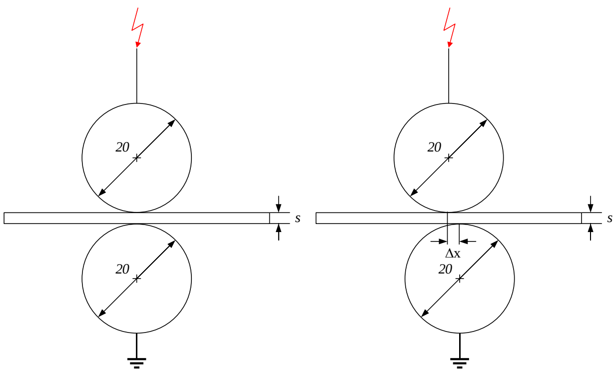


**Fig. 6: Sphere electrodes with equal diameters ideal position(left) and with misalignment(right)**

In sphere electrodes method the errors possibilities reduce to only horizontal error. Among all the previous electrodes configurations which are used for breakdown tests it could be concluded that, due to the existing error possibilities not proper results could be achieved. In order to achieve an improved electrode configuration magnetic spheres have been used. Thanks to magnetic force between tow magnet sphere electrodes, they stay exactly in front of each other. Figure 7 shows the magnetic sphere electrodes and their configuration. This electrode and configuration has been used and the result are presented in the following section.

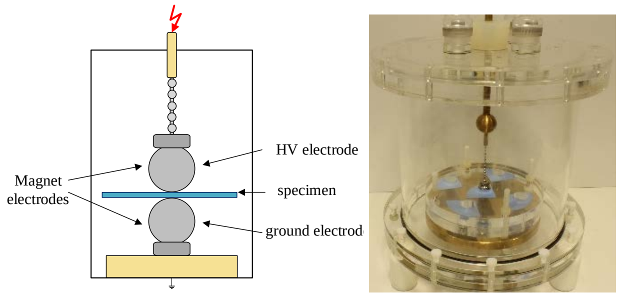


**Fig. 7: Magnetic sphere electrodes**

## EXPERIMENTAL RESULTS AND DISCUSSION

In order to investigate the breakdown strength of the samples a ramp shape increasing voltage has been applied to the samples and breakdown voltage have been recorded, voltage increasing rate was kept 4kV per second. The applied voltage shape is illustrated in Figure 8.

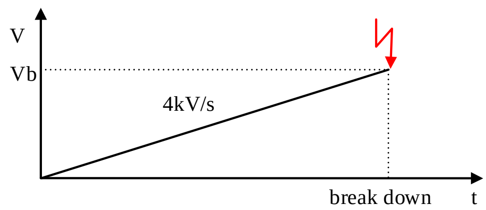


**Fig. 8: The ramp shape increasing applied voltage**

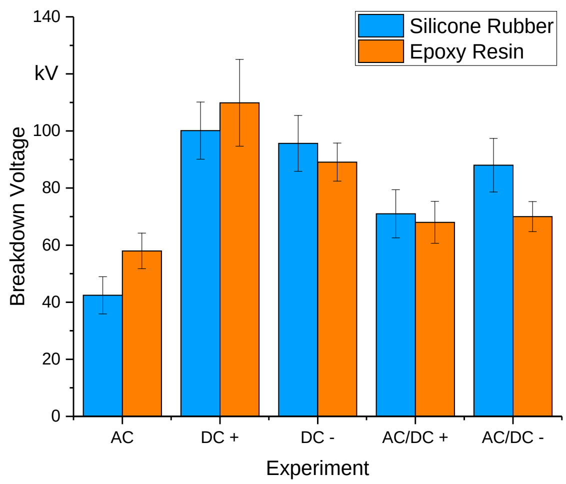

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**Fig. 9: Breakdown voltages of silicone rubber and epoxy resin at different voltage types**

Figure 9 illustrates the comparative results between silicone rubber and epoxy resin under various types of voltages. It should be mentioned that all voltages are peak values.

According to the experimental investigations the following results could be achieved:

- Breakdown voltage at AC voltages are much lower than breakdown voltage at DC and AC/DC voltage.
- Combined AC/DC voltage could decrease breakdown voltage of both silicone rubber and epoxy resin in comparison to the pure DC voltages.
- Breakdown strength of epoxy resin is higher than silicone rubber at AC and positive DC voltage but not at combined AC/DC voltage. It seems that AC/DC voltage has more wrecking effect on epoxy resin.
- Positive AC/DC voltage has more subtractive effect on breakdown strength for both silicone rubber and epoxy resin. Breakdown voltage reduced by 40 percent in comparison to positive DC breakdown voltage.

## CONCLUSION

Different experiment arrangments leads to different breakdown voltages. Each method and electrode arangement are usefull for a special voltage type. In order to compare breakdown voltage of AC, DC and combined AC/DC the equal magnetic sphere electrode arrangment have been used. Such configuration had a minimum standard variations among all other methods resulting more reliable results. The results show a big difference between AC breakdown and DC breakdown. Breakdown voltages at combined AC/DC voltage are in middle of AC and DC breakdown values. In all experiments, breakdown strength are higher at both negative and possitive DC voltages than AC and combined AC/DC voltages. This paper is limited to only one AC/DC ratio and investigation of breakdown at different ratios could be more helpful. One of the effective parameter at breakdown test specially at DC is the applied voltage trend and the time to breakdown. Since at DC and partly at combined AC/DC voltage due to the variable resistivity of dielectrics by time and voltage more time is needed to happen a breakdown. The most detrimental effect have been recorded during positive AC/DC voltage. In some cases breakdown at positive AC/DC voltage happened even at lower voltage than AC for epoxy resin samples. Investigation of different increasing rate of voltage could provide more helpful information to undrestand the combined AC/DC breakdown phenomena.

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