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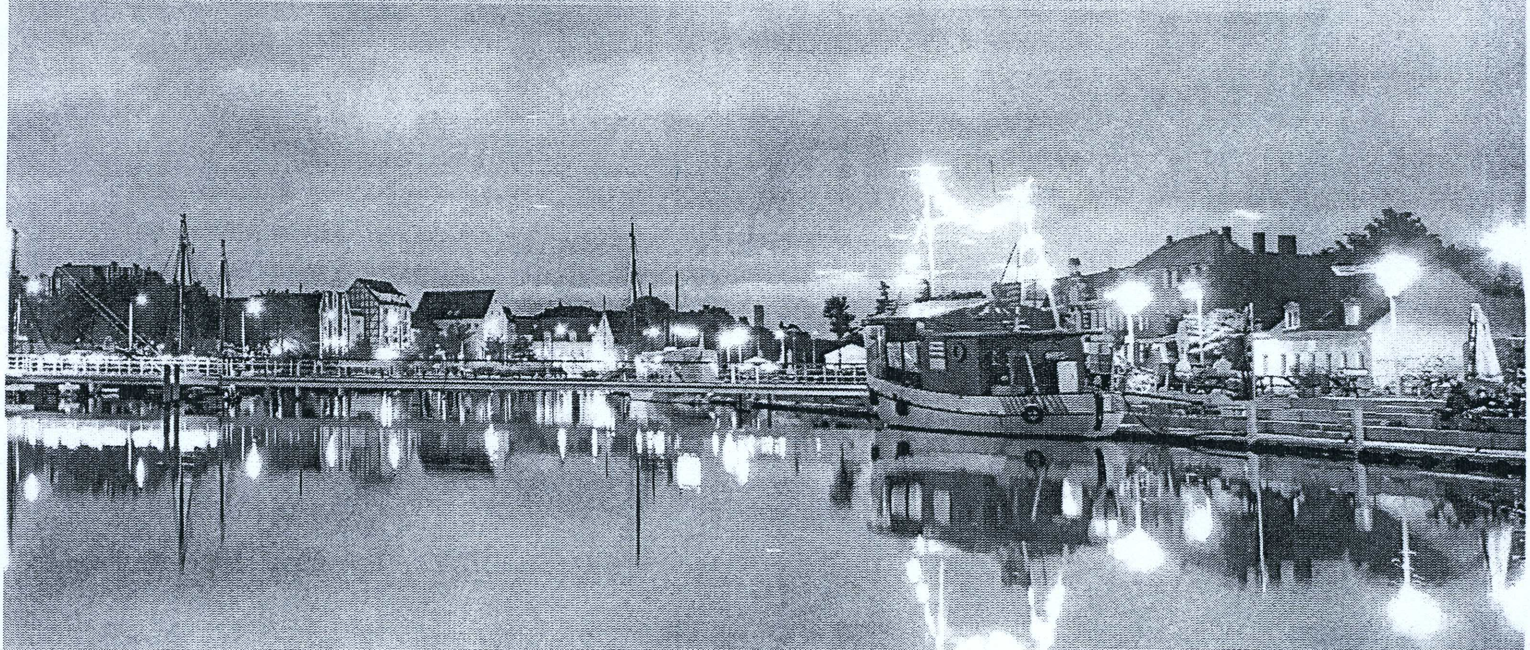

Experimental Investigation of Dielectric Barrier impact on Breakdown Voltage enhancement of Copper Wire-plane Electrode Systems

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ABSTRACT

Non-pressurized air is extensively used as basic insulation media in medium / high voltage equipments. An inherent property of air-insulated designs is that the systems tend to become physically large. Application of Dielectric barrier can increase the breakdown voltage and therefore decrease the size of the equipments.

In this paper, the impact of dielectric barrier on breakdown voltage enhancement of a copper wire-plane system is investigated. For this purpose, the copper wire is covered with different dielectric materials. Depending on the air gap and dielectric strength of the barrier the breakdown can be initiated in the solid or gas dielectric. Theoretically, free charges are affected by the electric field between the electrodes and accumulated at the dielectric surface, this leads to the reduction of electric field in air gap and enhancement of the field in the dielectric layer. Therefore, with appropriate selection of the barrier thickness and material, it is possible to increase the breakdown voltage of the insulation system. The influence of different parameters like inter-electrode spacing, and dielectric material on the break-down voltage is investigated for applied 50 Hz AC and DC voltages. The results indicate that up to 240% increase of the breakdown voltage can be achieved.

1. INTRODUCTION

In gas insulated high voltage systems, pressurized atmospheric air or sulphur hexafluoride are mainly used as insulation medium [1]. The usage of SF6 and its mixtures will most probably decrease in the future due to certain drawbacks of the SF6 technology: environmental considerations, complex construction and the complicated maintenance / handling [2]. Air insulated system with electrodes covered using dielectric materials has been considered as one of the possible solutions to replace SF_6 [3].

In this paper some experimental tests are carried out to determine breakdown voltage of air gap in a copper wire-plane system, where the copper wire is covered with dielectric barrier. These experimental tests mainly deal with the impact of different dielectric materials and air gap distances on the breakdown voltage of the insulating system for different applied voltages (50 Hz and DC).

2. EXPERIMENTAL SETUP

As shown in Fig1, the High voltage electrode used in the experimental tests is a U-shaped copper wire with a diameter of about 2.6mm. The ground electrode is a plane stainless steel electrode with a diameter of about 15cm.

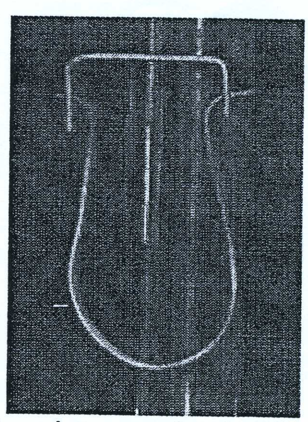

Fig. 1: U-shaped copper wire electrode

The following 3 different types of electrode arrangements have been investigated.

i) Bare copper wire.

ii) Copper wire covered with a 0.055mm thick insulating layer of enamel.
iii) Copper wire covered with a 0.25 mm thick insulating layer of enamel and heat shrinkage.

An oven has been used to fix the heat shrinkage to the U-shaped electrode.

For each type of electrodes, the breakdown voltage has been measured at 3 different inter-electrode distances and at least 10 times for each case. All the tests were performed at the 19.4 degrees of centigrade, humidity of 29.7% and pressure of 656.6 mmHg.

The experimental setups used to apply 50 Hz and DC voltages to test objects are schematically shown in Fig 2 and Fig 3, respectively.

In AC circuit a 2 MΩ resistance was used to limit current and a capacitor voltage divider, in order to measuring breakdown voltage. For rectifying voltage in DC circuit, 2 diodes and a 280MΩ resistance were located in advance.

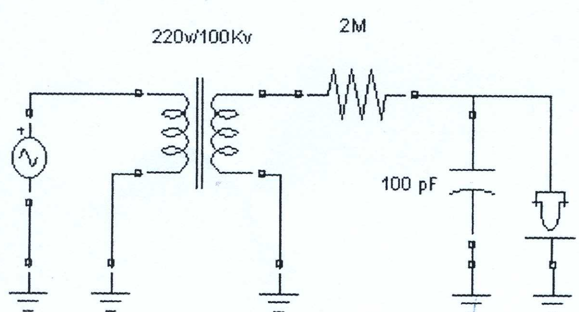

Fig. 2: Test setup for AC breakdown voltage for wire-plane electrodes

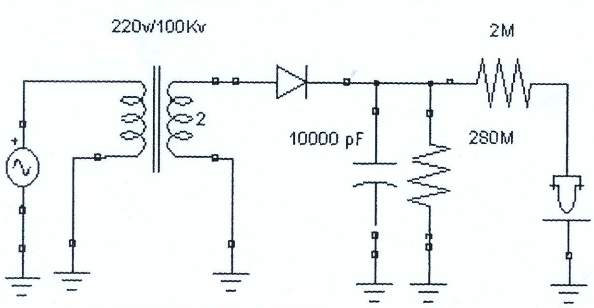

Fig. 3: Test setup for DC breakdown voltage for wire-plane electrodes

3. EXPERIMENTAL RESULTS

In Fig 4, the breakdown between a copper wire electrode and plane is shown.

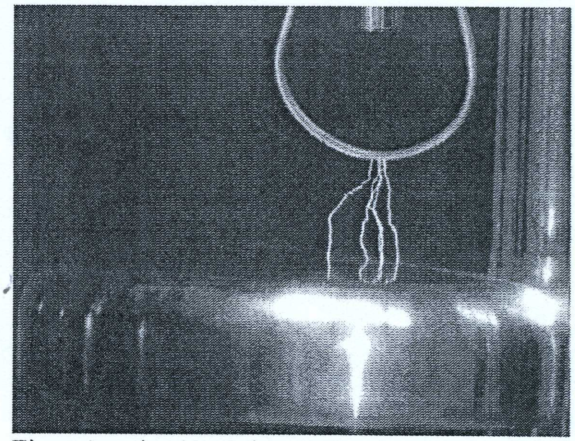

Fig. 4: air breakdown in bare wire-plane electrode system

3.1. AC BREAKDOWN VOLTAGE

Measured AC breakdown voltages for different electrode types (bare electrode, electrode covered with enamel and electrode covered with enamel and heat shrinkage) are summarized in tables 1-3.

Table 1: The breakdown voltage of bare wire-plane electrode under AC voltage

Distance (cm)	Breakdown Voltage (kV)
0.5	19.2
1	25.0
2	33.6
3	44.9

Table 2: The breakdown voltage of wire electrode covered with enamel under AC voltage

Distance (cm)	Breakdown Voltage (kV)
0.5	20.0
1	29.8
2	65.0

Table 3: The breakdown voltage of wire electrode covered with enamel and heating shrinkage under AC voltage

Distance (cm)	Breakdown Voltage (kV)
0.5	24.7
1	53.2
2	73.6

According to data in above tables, in short distance air gap an increase of 30% occurred with adding enamel and shrinkage, and no considerable increase was seen in enamelled electrode in comparison with the bare one. The enhancement factor of the breakdown voltage in electrode covered with enamel compared to the bare one is increasing with the air gap. As it can be seen, in 1cm air gap this ratio is about 20% but in case of 2cm air gap is about 100%. Effect of adding both types of barriers to the electrode was enhancement of 115% in 1cm air gap and 120% in 2 cm.

3.2. DC BREAKDOWN VOLTAGE

The same tests were performed under DC voltage and the results are reported in tables (4), (5) and (6) for different electrode types (bare electrode, electrode covered with enamel and electrode covered with enamel and heat shrinkage).

Table 4: The breakdown voltage of bare wire-plane electrode under DC voltage

Distance (cm)	Breakdown Voltage (kV)
0.5	16.2
1	18.3
2	23.5
3	30.1

Table 5: The breakdown voltage of wire electrode covered with enamel under DC voltage

Distance (cm)	Breakdown Voltage (kV)
0.5	34.6
1	40.6
2	45.2
3	52.8

Table 6: The breakdown voltage of wire electrode covered with enamel and heating shrinkage under DC voltage

Distance (cm)	Breakdown Voltage (kV)
0.5	55.7
1	62.4
2	68.0
3	69.0

Table (4) shows an enhancement in breakdown voltage with growth of air gap distance, but it is less than that in AC voltage especially in greater inter-electrode gaps. Impact of adding barrier in DC is so notable, that breakdown voltage for enamelled electrode and covered electrode with enamel and shrinkage was respectively 2.13 and 3.43 times higher than the bare one in .52cm space between electrodes. This impact decreases with increasing the air gap.

4. DISCUSSION AND CONCLUTIONS

Covering the electrode with a dielectric barrier reduces the maximum field strength in the air gap. This is the main reason for the increased mean breakdown voltage in Fig. 6 and 7. As it can be seen in Fig. 6, mean breakdown voltage does not change linearly with distance. In case of electrode with two barriers, the changes are much more nonlinear. In other words, the impact of heating shrinkage becomes less important in case of large inter-electrode spacing. This can be explained using a simple electrical model for the electrode system (see fig. 5), where the different dielectric layers between electrodes are represented by capacitances C_d and Cg. In addition, the element C_s stands for the stray capacitance of the source. With increasing the air gap, Cg decreases and the voltage distribution changes; i.e higher relative voltages are applied to the air gap and as a result breakdown may occur at relatively lower voltages.

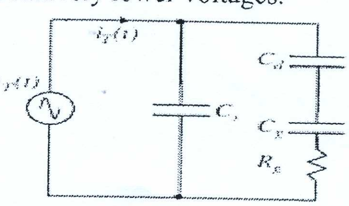

Fig. 5: Electrical model of dielectric layers

In case of DC applied voltages, changes in breakdown voltage with distance are much more linear. This can be explained by the effect of space charges in DC mode. In the case of positive wire, electric field become weaker near anode and stronger far from it and this leads to more uniform field. But in AC stress space charges cannot be created, because time constant of electrode system is much greater than of applied voltage.

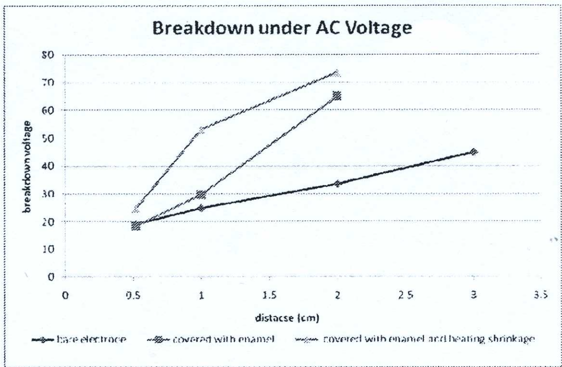

Fig. 6: Mean breakdown voltage of wire-plane electrode system under AC applied voltages

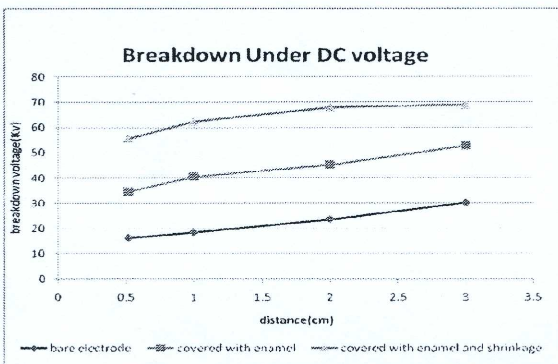

Fig. 7: Mean breakdown voltage of wire-plane electrode system under DC applied voltages

REFERENCES

[1] F. Mauseth, A. Nysveen and E. Ildstad, "Charging of Dielectric Barriers in Rod-Plane Gaps," *in the Proceedings of International Conference on Solid Dielectrics*, Toulouse, France, 2004.

[2] H. J. M. Blennow and M. L-A. Sjoberg, "Electric Field Reduction Due to Charge Accumulation in a Dielectric Covered Electrode System," *IEEE Trans. Dielectrics and Electrical Insulation*, Vol. 7, No. 3, pp. 340-45, 2000.

[3] J. SUNDARA RAJAN, N. SIUNIVASAN, K. DWARAKANATH, "Effect of Insulating Barriers on the Breakdown of Short Gaps in Air And SF6," IEE, ,2001

[4] A. Flores-Fuentes, R. Peña-Eguiluz, R. López-Callejas, A. Mercado-Cabrera, R. Valencia-Alvarado, S. Barocio-Delgado, and A. de la Piedad-Beneitez, " Electrical Model of an Atmospheric Pressure Dielectric Barrier Discharge Cell," *IEEE Trans. Plasma Science*, Vol. 37, No. 1, pp. 128-34, 2009.