Impact Factor (SJIF): 3.632

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444
Volume 3, Issue 4, April-2016

Breakdown Characteristics of Liquid Insulation in the Presence of Barrier under Varying Field Conditions

A. Masood[1], M.U. Zuberi[2]

[1, 2] *Electrical Engineering Department, Aligarh Muslim University, Aligarh*

Abstract —Transformer oil is one of the insulating liquid used more frequently for electrical insulation purpose. The dielectric strength of oil gap in divergent electrode systems in presence of insulating barriers has been the subject of only few studies contrary to the air gap where numerous works have been reported. In a gaseous or liquid insulation system of high voltage machines, the insulating capability in the available space can be improved by inserting an insulation barrier in the gap, which alters the space charge distribution. When the discharge develops, the accumulation of charges on the surface of barrier makes the barrier to behave as a floating plane electrode, and the electric field between the barrier and the plane electrode becomes uniform leading to increase in the breakdown voltage. This improvement in the insulation strength called the Barrier effect has been investigated.

The result obtained by the experimental investigation on breakdown characteristics of transformer oil under non-homogeneous field conditions (Cone-Sphere electrode system) as well as moderately homogenous field conditions (Sphere-Sphere electrode system) under alternating (50 Hz) voltage stresses taking into account the effect of gap length and the influence of electrode covering by solid insulators as barriers has been reported. The effect of electrode covering is reported for different types of solid insulating materials. It has been concluded that the effectiveness of the barrier depends mainly on the barrier position, its thickness and dimension as well as its constituting material. The experimental results of the barrier effect will help the manufacturers while dimensioning and designing some insulation structure like power transformer.

Keywords-Transformer oil; dielectric strength; barrier effect; electric field; solid insulation.

I. INTRODUCTION

High voltage transmission of electrical energy has made immense strides during the last decades, and also the high voltage transmission system will be used increasingly in the near future [1]. For some of the equipment, transformer oil/polymer will be the electrical insulation system. So, electrical breakdown characteristics of transformer oil may lead to spectacular consequences on the quality and reliability of high voltage networks. The insulation design of high voltage transformer can only be optimized if the electrical strength properties of the insulation system are precisely known. The main insulation materials used in a power transformer are oil, paper and pressboard. These insulating materials are known to experience homogeneous as well as non-homogeneous field conditions.

Breakdown voltages of homogeneous and non-homogeneous field gaps are known to be largely affected by inserting thin dielectrics "barriers" in the gaps; this is called barrier effect. Thus, it is of great interest to study the influence of such barriers on the breakdown voltage in transformer oil.

The long term performance characteristics of transformer oil is highly difficult to understand, the reason being that the transformer insulation is subjected to thermal, mechanical and electrical stresses causing multi factor ageing which necessitates to study the characteristics of aged transformer oil.

The polymer barrier used with the transformer oil should not contaminate the oil by dissolving in it, thereby reducing the electric strength of oil/performance of barrier. In the recent times it is expected that oil/paper composition will be replaced with oil/polymer composition because of low loss and high electric strength. The effect of transformer oil on polymers have been studied and concluded that proper material should be chosen for such applications. [2]

With the above said in mind and also since the dielectric strength of oil gap in divergent electrode systems in presence of insulating barriers has been the subject of only few studies [3-7] contrary to the air gap where numerous works have been reported [8-12], the experimental study was planned to investigate the application of paper/polymer as barrier in moderately homogenous field conditions (Sphere-Sphere electrode system) as well as non-homogeneous field conditions (Sphere-Cone electrode system) under alternating voltage in transformer oil as medium.

II. EXPERIMENTAL SETUP

2.3. Experimental Samples

Transformer Oil used in the experiment had a breakdown strength of 15 kV/mm at 20ºC on 2.5 mm standard sphere. It had a relative permittivity (ξ_r) in the range of 2.2 - 2.3; Dissipation factor of 0.001 at 50 Hz and the maximum possible water content of 50 ppm. Polypropylene, Polystyrene and Kraft paper sheets were used as barriers having the following specifications as given in Table 1.

TABLE 1

Insulating Material	Density (gm/cm^3)	Relative Permittivity (ξ_r)	Dissipation factor (at 50 Hz)	Thickness (average of 20 measurements) (in micrometer)
Polypropylene	0.8	3.1	0.0004	14
Polystyrene	1.05-1.07	2.5 – 2.8	0.0002	184
Kraft paper	0.9	2-3	0.003	68

2.2. Sphere-Sphere Electrode Configuration

The spherical electrodes were made from brass. The diameter of each sphere was 13 mm and they were mounted horizontally in a test cell made of Perspex with their axis 40 mm above the bottom of the cell. The internal dimensions of the test cell were 60 mm x 110 mm x 120 mm. The test cell was filled with transformer oil. The gap between the electrodes was adjusted by a micrometer (least count 0.01 mm) attached to one of the electrodes, the other electrode being fixed. Before starting the experiment, both the electrodes were thoroughly cleaned, polished and washed with alcohol. The insulating barrier was placed in vertical grooves on the two opposite sides (wall) of the test cell with gaps of 2 mm. For electrode covering, the barrier was placed in contact with the grounded electrode. Figure 1(a) and (b) show the test cell and the schematic of the electrode assembly with insulating barrier.

2.3. Cone-Sphere Electrode Configuration

The conical and spherical electrodes were made from brass. The conical electrode had a diameter of 15 mm and height 7.5mm with round edges. The spherical electrode was having a diameter of 13mm.The electrodes were mounted horizontally in a test cell made of Perspex with their axis 40 mm above the bottom of the cell. The internal dimensions of the test cell were 60 mm x 110 mm x 120 mm. The test cell was filled with transformer oil. The gap between the electrodes was adjusted by a micrometer (least count 0.01 mm) attached to the conical electrode, the other electrode being fixed. Before starting the experiment, both the electrodes were thoroughly cleaned, polished and washed with alcohol. The insulating barrier was placed in vertical grooves on the two opposite sides (wall) of the test cell with gaps of 2 mm. For electrode covering, the barrier was placed in contact with the grounded electrode. Figure 2(a) and (b) show the test cell and the schematic of the electrode assembly with insulating barrier.

2.4. Supply and Measurement of High Voltage

The high voltages were obtained from 30 KVA, 150 KV, 50 HZ, 1 phase testing transformer. The voltages were measured using a voltmeter (accuracy ± 1%) connected at the primary side of the transformer that read the low side voltage. The corresponding high voltages were obtained from a calibration curve drawn using the sphere-sphere electrode system using the diameter of 25 cm (IS-1876, 1961).

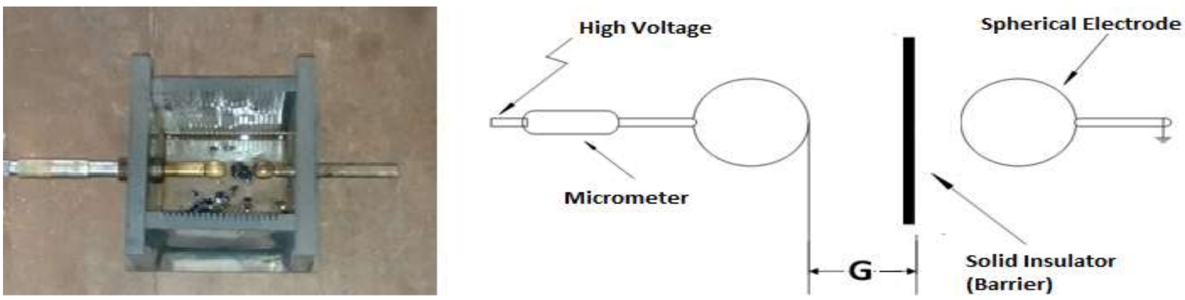

Figure 1. (a) Test Cell and (b) Schematic of Electrodes for Sphere-Sphere Electrode Configuration

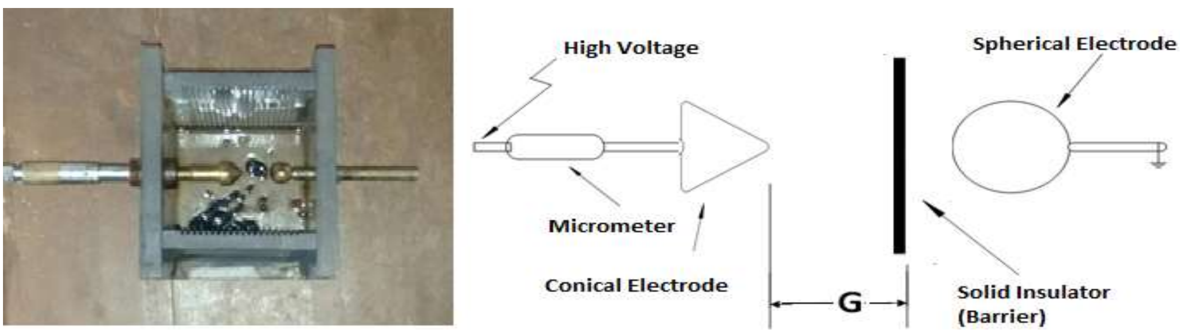

Figure 2. (a) Test Cell and (b) Schematic of Electrodes for Cone-Sphere Electrode Configuration

III. RESULTS

The measurement for barrier effect and electrode covering effect for the sphere-sphere and sphere-cone electrodes configurations were made and are reported in Figures 3-7 and Figures 8-12 respectively.

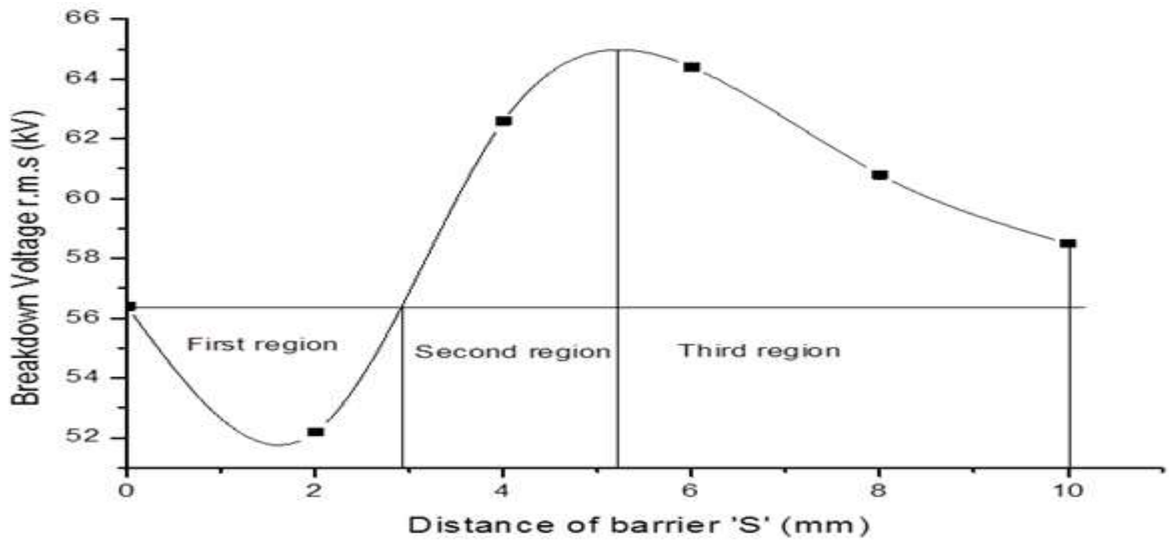

Figure 3. Barrier effect for ac voltage by the insertion of 'Polystyrene' in a 10 mm gap for Sphere-Sphere Electrodes

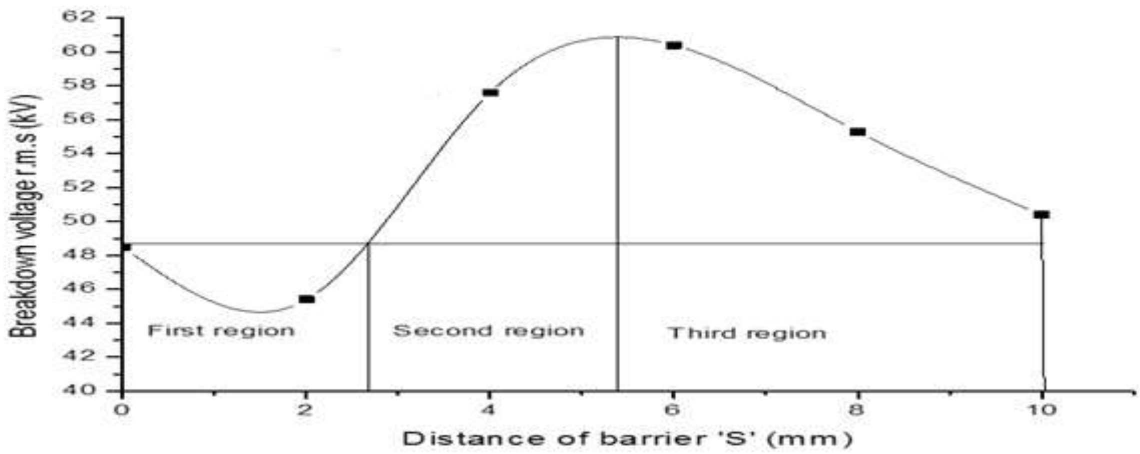

Figure 4. Barrier effect for ac voltage by the insertion of 'Kraft paper' in a 10 mm gap for Sphere-Sphere Electrodes

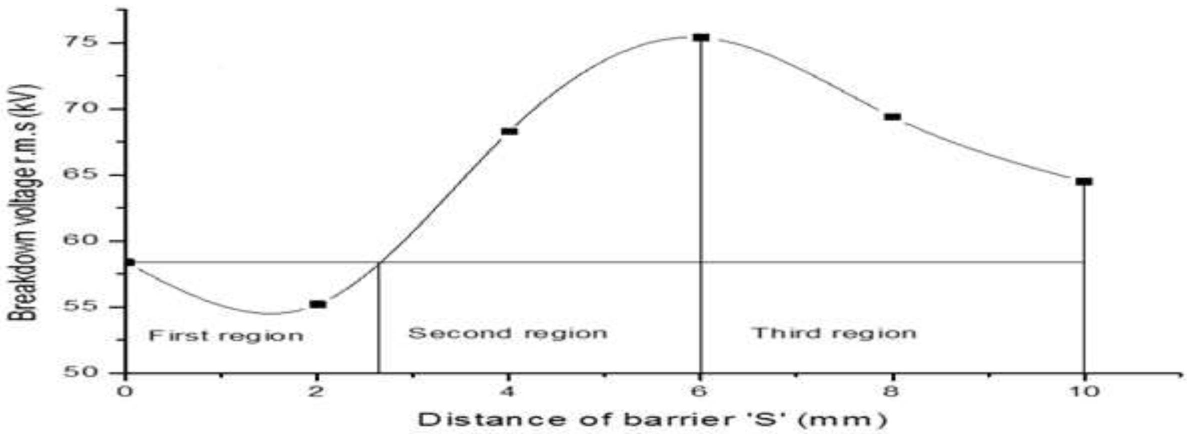

Figure 5. Barrier effect for ac voltage by the insertion of 'Polypropylene' in a 10 mm gap for Sphere-Sphere Electrodes

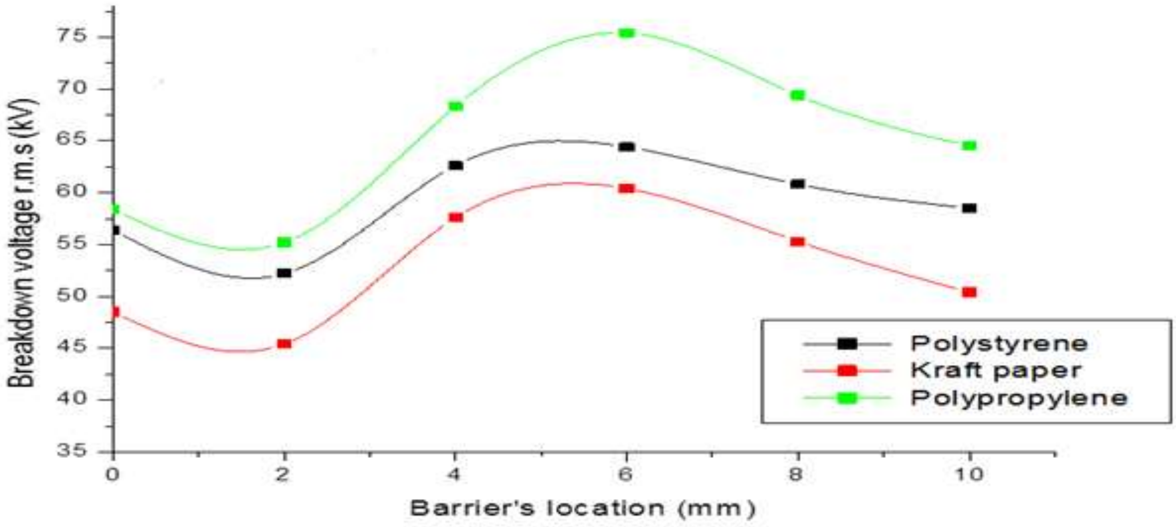

Figure 6. Barrier effect for different types of insulating materials for 10 mm gap for Sphere-Sphere Electrodes

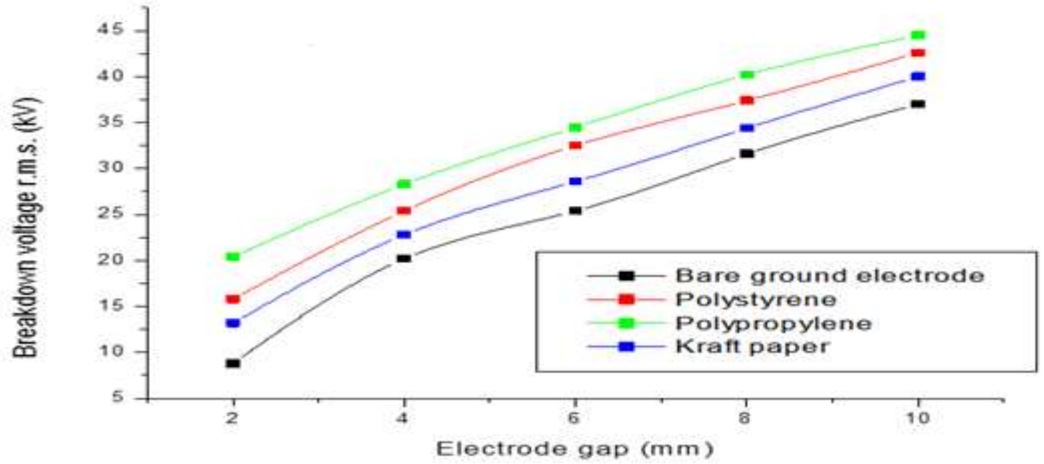

Figure 7. Effect of Grounded electrode covering with different types of insulating materials on breakdown voltage for Sphere-Sphere Electrodes

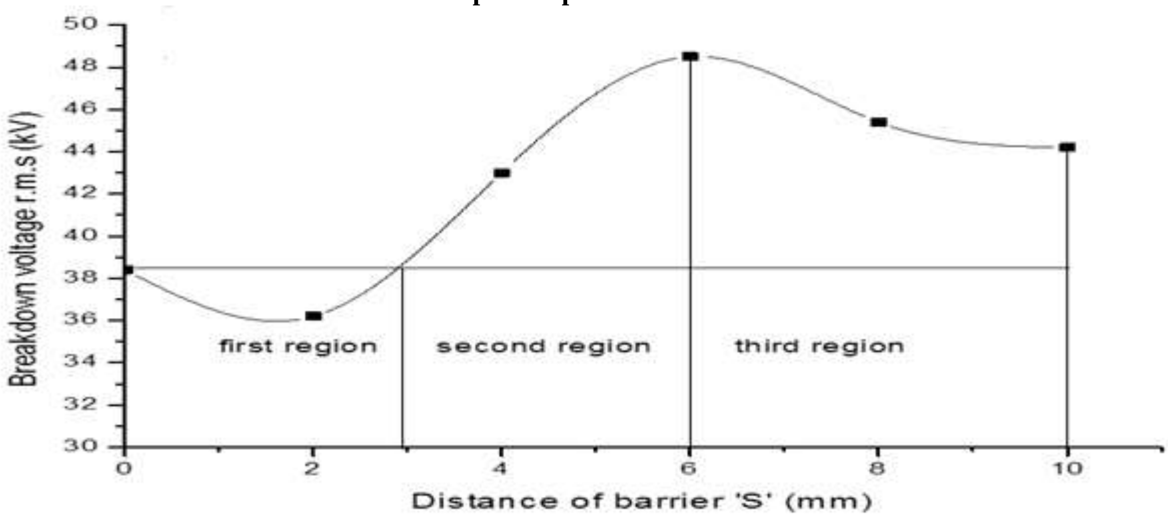

Figure 8. Barrier effect for ac voltage by the insertion of 'Polypropylene' in a 10 mm gap for Cone-Sphere Electrodes

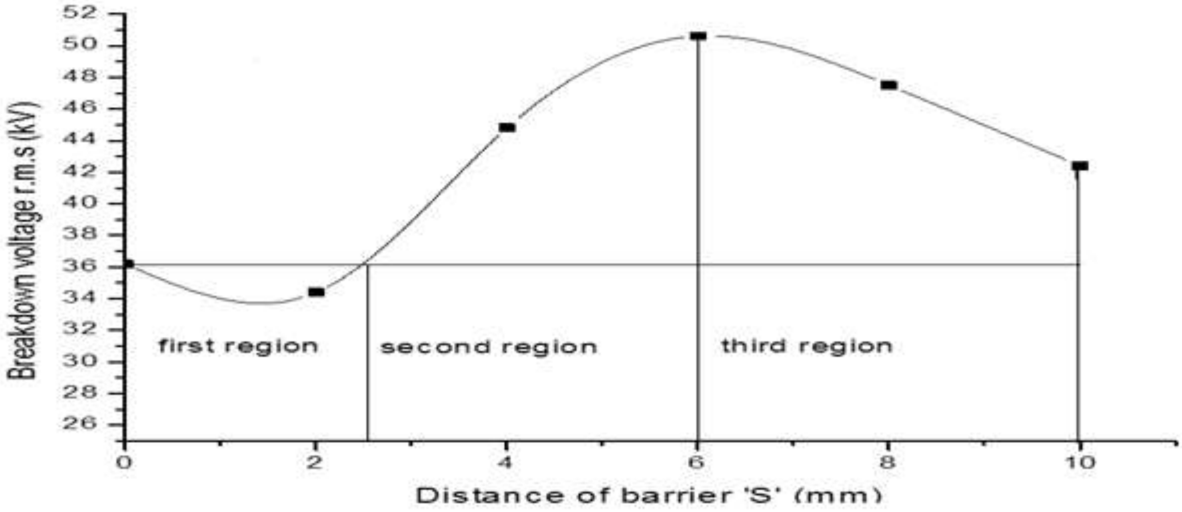

Figure 9. Barrier effect for ac voltage by the insertion of 'Polystyrene' in a 10 mm gap for Cone-Sphere Electrodes

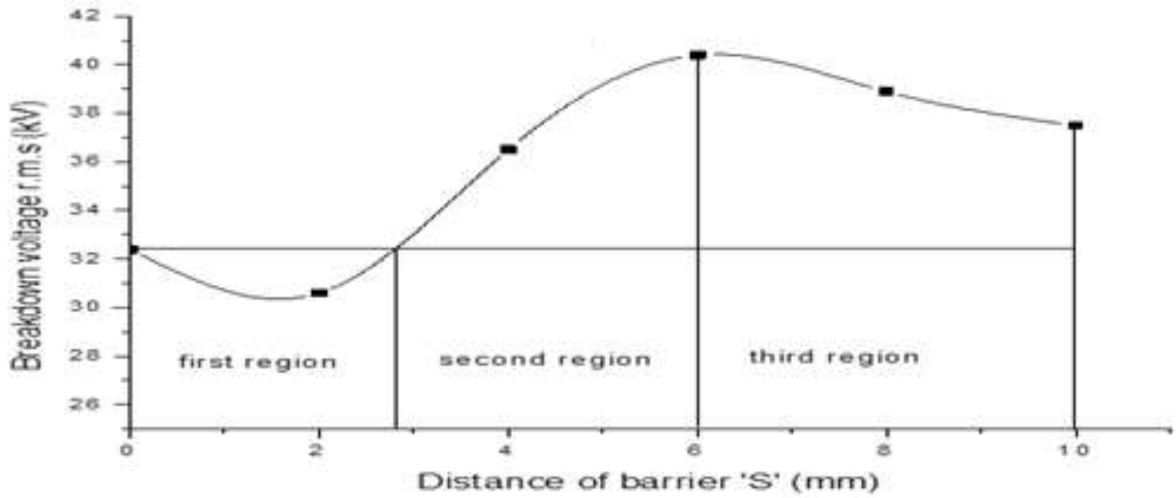

Figure 10. Barrier effect for ac voltage by the insertion of 'Kraft paper' in a 10 mm gap for Cone-Sphere Electrodes

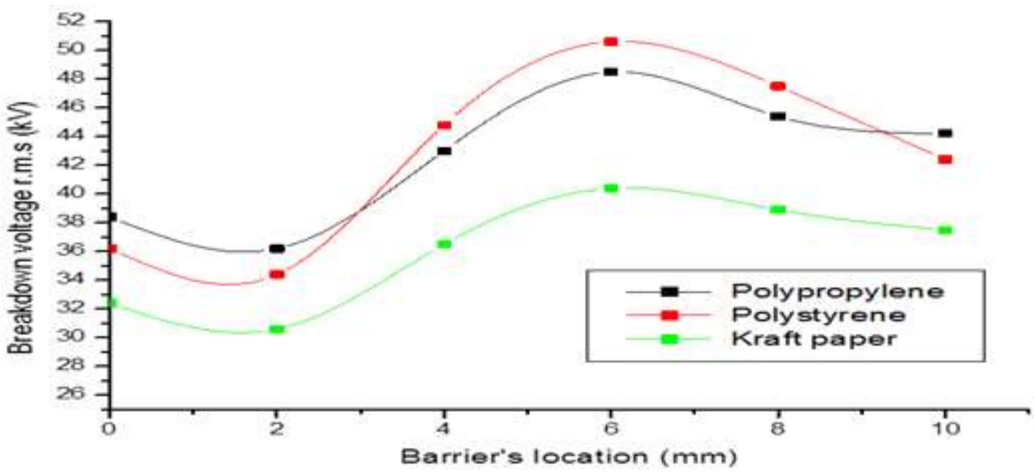

Figure 11. Barrier effect for different types of insulating materials for 10 mm gap for Cone-Sphere Electrodes

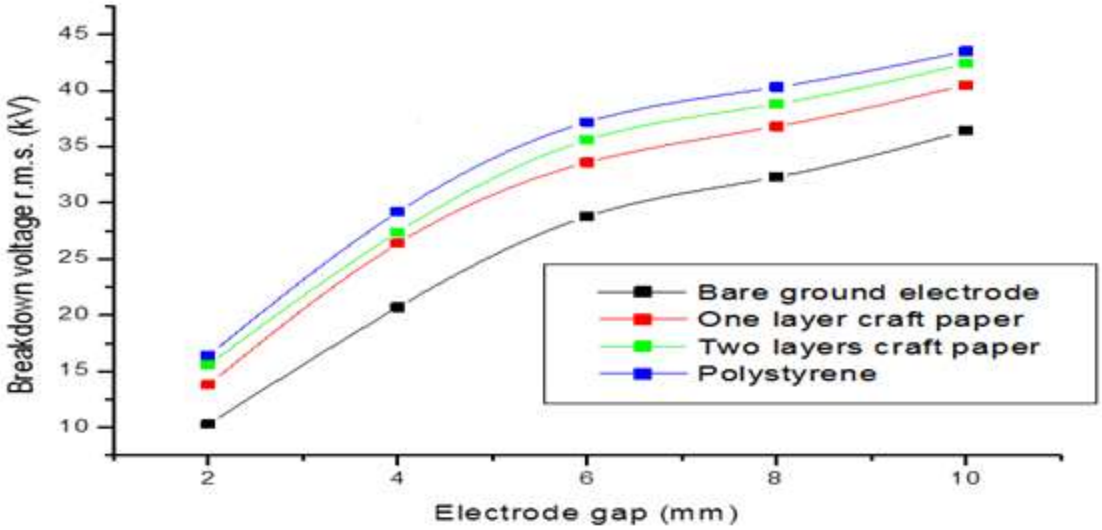

Figure 12. Effect of Grounded electrode covering with different types of insulating materials on breakdown voltage for Cone-Sphere Electrodes

IV. DISCUSSION

4.1. Sphere-Sphere Electrode Configuration

When the ac voltage is applied to one of the spherical electrodes and other spherical electrode is grounded, the electric charges liberated from the high voltage electrode are unable to reach the grounded electrode because of the presence of barrier placed in between the two electrodes and gets deposited on the insulating barrier. This gives rise to stronger field on the grounded electrode side [13]. The variations of barrier locations verses breakdown voltages for 10 mm gap are given in Figures 3, 4 and 5 for Polystyrene, Kraft paper and Polypropylene respectively.

It is evident from the figures that when the distance 'S' between the barrier and the ground electrode increases the breakdown voltage is slightly decreased and then increases remarkably resulting in much higher breakdown voltage than that obtained with the covered ground electrode. The change in the breakdown voltage with the barrier location with respect to the electrodes is discussed with reference to first, second and third regions as shown in the Figures 3, 4 and 5.

In the first region when the insulating barrier is very close to the ground electrode, there is a slight decrease in the breakdown voltage. In the second region, the charge is distributed on the broader area of the insulating barrier and the electric field profile becomes moderately homogeneous resulting in a higher breakdown voltage. However when the barrier is very close to the high voltage sphere electrode i.e. in the third region, the distribution of charge on the barrier shrinks in a very small area and hence the profile of the field gap becomes distorted and as expected the breakdown voltage drops to a greater extent [13].

Figure 6 shows the variation in breakdown voltage for polypropylene is higher than that of the Kraft paper and polystyrene. The effect of covering the ground sphere electrode is shown in Figure 7 for different insulating paper/polymer film. The breakdown voltage is higher with covering the ground electrode as compared to bare ground electrode. This is because the streamers generated from the high voltage electrode initially do not break the covered paper/polymer film.

4.2. Sphere-Cone Electrode Configuration

When the ac voltage is applied to the conical electrode, and spherical electrode is grounded, the charges (electrons) are liberated from the conical electrode due to corona discharge and move towards the spherical electrode and become attached to the insulating barrier. The charge which is distributed on the paper/polymer film (barrier) makes the electric field weaker on the cone side and stronger in the sphere region. [13]

The Figures 8, 9 and 10 shows the effect of barrier on breakdown of transformer oil under ac voltage for different types of barrier materials for Sphere-Cone electrode configuration. It is evident from the figures that when the distance 'S' between the barrier and the spherical electrode increases, the breakdown voltage is initially slightly decreased and then increases remarkably resulting in much higher strength than that obtained with the covered ground electrode. The change in the breakdown voltage generally follows the same variation as obtained with Sphere-Sphere electrode configuration with respect to first, second and third regions.

Figure 11 shows the variation in breakdown voltage for polypropylene is higher than that of the Kraft paper and polystyrene. The effect of covering the ground sphere electrode is shown in Figure 12 for different insulating paper/polymer film. It is again observed that the breakdown voltage is higher with covering the ground electrode as compared to bare ground electrode. Further, increasing the number of layers of the barrier increases the breakdown voltage. The above results are quite in agreement with the results described by Roser [14].

V. CONCLUSION

Barriers can influence the failure-stresses by effectively breaking up a large oil volume into smaller oil volumes and by interfering with particle motion and partial discharge activity. Breakdown voltages are higher in the presence of solid insulating barrier simply because the barrier prevents the discharges from bridging the gap. However, the failure voltages are found to be a function of the location of barrier. Inclusion of barrier in the oil gap improves the breakdown strength of the gap. In general, the increase in breakdown strength is maximum if the barrier is placed in the middle of the oil gap irrespective of the type of barrier. The optimal position does not change when varying the thickness of barrier. However, the increase of barrier thickness leads to an increase in the breakdown voltage.

The barrier effect for the moderately uniform field i.e. sphere-sphere electrode configuration has similar variation as for the sphere-cone configuration. However the electrode covering effect for the sphere-sphere electrode configuration is more linear in nature.

The study of the barrier effect and electrode covering using a thin insulating paper is useful in analyzing the effect of space charge on the breakdown mechanism. Electrodes covered with insulating paper film give higher breakdown voltage for transformer oil compared with those obtained with uncovered electrodes.

REFERENCES

[1] M. S. Naidu, V. Kamaraju, *High Voltage Engineering*, Tata McGraw-Hill, New Delhi, Third Ed. 2004.

[2] Nancy E Frost, Paul B McGrath, Clayton W Burns , " Investigation into the effect of transformer oil on polymers" IEEE trans on power delivery Vol-11 No.1 1996.

[3] M.Darveniza and B.Holcombe, "The switching impulse strength of a long air gap with a plastic sheet barrier", Proc. IEEE, Vol. 64, No.6, pp 1017-18, 1976.

[4] A. Beroual and A. Zouaghi, "Barrier effect on the prebreakdown and breakdown phenomena in long air gaps", 12th ICDL, Rome, Italy, pp 300-303, 1996.

[5] W.Knorr and D.Bereitfelder, IEEE international Symposium on Electrical Insulation, pp 291-296, 1984.

[6] T.Kauno, "Breakdown of composite dielectrics; the Barrier effect", IEEE transaction on Electrical insulation, Vol. EI-15, pp 259-263, 1980.

[7] M.Nagao, S.Jayaram,M.Sugio and M.Kosaki, " Breakdown characteristics of oil polymer composite insulation under ac and dc voltages", Proc. Of 13th ICDL-99, pp140-143, Nara, Japan, 1999.

[8] A. Beroual and A.Boubakeur, "Influence of barrier on the lightning and switching impulse strength of near air gaps in the point/plane arrangements", IEEE transaction on Electrical insulation, Vol. EI-26, pp 1130-1139, 1991.

[9] F.V.Topalis and I.A.Stathopulos, "Barrier effect on electrical breakdown in air gaps", 9th ISH, Graz, Austria, paper 21.47, 1995.

[10] Li Ming, M.Leijon and T.Bengtsson, "Factors influencing Barrier effects in air gaps", 9th ISH, Graz, Austria, paper 21.68, 1995.

[11] Y.Yamano, Y.Takahashi and S.Kobayashi, "Improving insulation reliability with insulating barriers" IEEE transaction on Electrical insulation, Vol. EI-25, No.6, pp 1174-1179, 1990.

[12] R.Sarathi and Murali Mohan, "Selection of barrier insulation material to use along with transformer oil", Insulec-2000, 6th international seminar on electrical and electronic insulating materials and systems, pp-P-IV-39-44, November, Hyderabad, India.

[13] E.Husain, Kamaluddin, I.Ashraf, "Study of breakdown of transformer oil in the presence of barrier", 4th International Conference on Properties and Applications of Dielectric Materials, Brisbane, Australia.

[14] Roser, H. (1932), Schirme zur Erhohung der Durchschlagapannung in Luft . ETZ, vol. 17, pp. 411- 412.