COMMUNICATIONS

ON THE DISCHARGE PHENOMENA BELOW INCEPTION VOLTAGE: FURTHER EXPERIMENTAL RESULTS WITH AIR GAPS

Michael G. Danikas *

The problem of possible insulation damage — due to random discharges — below the inception voltage has not attracted, as a subject of research, much attention worldwide. Indications of possible damage below inception in solid dielectrics already exist. In this paper, we examine the existence of random discharges in small air gaps with a fixed applied voltage. It is concluded that random discharges (in some cases quite numerous) may appear in air gaps even greater than the air gap at which normally breakdown takes place.

K e y w o r d s: discharges, inception, air gap

1 INTRODUCTION

The problem of possible insulation damage below inception voltage as well as its importance for the industry have been reported in some publications [1–6]. These papers refer to possible damage of solid insulating materials. This damage is caused from random discharges that take place below inception. In the present paper we will try to show this problem from another point of view, namely that of the air gaps. If what is mentioned in [1–6] is correct, then similar phenomena, *ie*, random discharges, should also appear in air gaps larger than the air gap at which normally breakdown takes place.

In this paper, indications are offered indeed that random discharges in such air gaps may appear. This validates even more the conclusions of [1–6].

2 EXPERIMENTAL ARRANGEMENT AND PROCEDURE

For the purpose of this work, a small Greinacher generator was used [7]. The generator produces invariably 7.5 kV. This is applied to a needle-plane electrode arrangement with the needle electrode having a radius of 0.3 mm. The discharges that take place are detected via a typical R–C circuit ($R = 150\,\mathrm{k\Omega}$, $C = 39\,\mu\mathrm{F}$). When the electrode set-up discharges, it produces the well known Trichel pulses on the screen of a Tektronix oscilloscope (type 7623 A, bandwidth 20 MHz) [8]. There is freedom of movement of the lower plane electrode with respect to the upper needle electrode. The distance between the electrodes is measured with the aid of feeler gauges.

The electrode arrangement normally discharges when the air gap is 1.80 mm (*ie*, the inception voltage for this gap is 7.5 kV). In this case (and of course for distances smaller than that) the recorded discharges are continuous, in most cases bridging the air gap. This means that breakdown of the air gap takes place. Having in mind that the generator gives a fixed voltage, it would be interesting to observe the discharge phenomena at distances larger than 1.80 mm. It is our belief that if there are discharges for distances larger than 1.80 mm, then this might be an additional indication of the fact that discharge phenomena may appear for voltages below inception.

3 EXPERIMENTAL RESULTS AND DISCUSSION

The needle electrode can be seen in Fig. 1, in expanded view. The maximum electric field $E_{\max}$ which is developed at the tip of the point electrode is given by

$$E_{\max} = 2\,s\,E_{\mathrm{avg}} \,/\, \big[r \ln\big(1 + (4s/r)\big)\big] \tag{1}$$

where, $E_{\max}$ is the field at the needle tip, E_{avg} is the average electric field applied in the gap spacing, s is the electrode gap spacing and r is the radius of the needle tip [9]. Having in mind that $s = 1.80$ mm, the applied voltage $V = 7.5$ kV (consequently, $E_{\mathrm{avg}} = 7.5/1.80 = 4.16$ kV/mm), $r = 0.3$ mm, we have $E_{\max} = 15.59$ kV/mm.

For this value of the maximum electric field, continuous discharges were recorded. The recording was carried out with the aid of a detecting and counting electronic circuit (incorporating a programmable micro-controller) and appropriate software which transferred the total number of discharges on the screen of a personal computer. In Fig. 2, the whole experimental arrangement is shown. For field values such as those above as well as larger ones (*ie*,

* Democritus University of Thrace, Department of Electrical and Computer Engineering, Electric Energy Systems Laboratory, 67100 Xanthi, Greece

ISSN 1335-3632

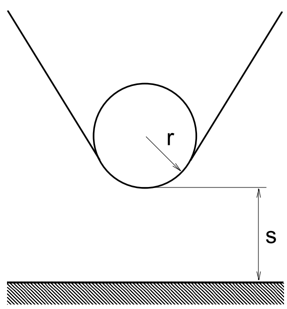

Fig. 1. Expanded view of the needle-plane electrode arrangement.

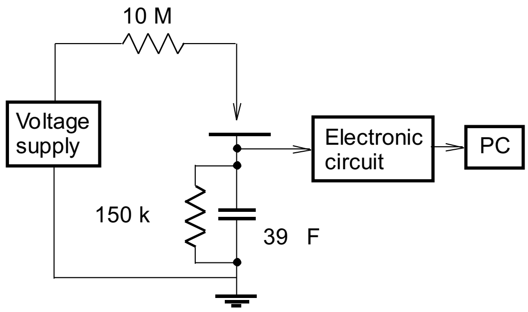

Fig. 2. Experimental arrangement used. By 'electronic circuit' is meant the detecting and counting circuit incorporating a programmable micro-controller which transferred the number of recorded discharges to the PC (personal computer).

Table 1. Results of tests carried out with a gap spacing of 2 mm. Shown are also the test time as well as the number of recorded discharges.

Gap spacing (mm)	Test time (min)	Number of discharges
2	60	1274
2	60	128000
2	60	53000
2	50	5
2	45	26765
2	45	57120
2	45	25789
2	45	0
2	40	2148
2	30	54
2	30	103
2	30	1

with the gap spacing smaller), continuous discharges appear on the screen of the oscilloscope and some tens of thousands of discharges are detected and recorded via the detecting and counting electronic circuit.

If we set the distance between the electrodes at 2 mm, the discharge phenomena become intermittent. In this case, we have, based on Eq. (1) (by setting $s = 2$ mm, $E_{\text{avg}} = 7.5/2 = 3.75$ kV/mm, all other parameters being the same as before), that $E_{\max} = 15.15$ kV/mm.

The recorded discharges can be counted in thousands or become very few indeed. Observation of the discharge events at 2 mm shows that very often such events could not bridge the air gap. On one occasion actually, there were no discharges recorded after a test of 45 min. Table 1 shows the results in detail.

It is worth noting that with the above experimental conditions the discharge behaviour seems to be erratic indeed. In some tests, discharges were recorded in thousands whereas in others there were only very few registered. No complete explanation of such differences can be given for the time being. It is precisely this unpredictability of the discharge behaviour below inception that has to be taken into account in designing insulating systems [10].

The fact that between the two aforementioned cases, the maximum electric field does not differ that greatly means that there is a very fine distinction between the field necessary for the inception of discharges and the field which only occasionally causes discharges. This is an observation not to be underestimated since it agrees qualitatively with the data collected in [1–6], where tests have been carried out with polyethylene. Criticism that may be directed against this work is that the difference between 1.80 mm and 2 mm is very small and in such small air gaps events or transition regimes sometimes become rather blurred. The answer to this is that with repeated experiments 1.80 mm was indeed the maximum gap offering continuous discharges whereas 2 mm was the gap where discharge events started to be intermittent.

If one remembers well the conclusions of [1–6], namely, that there are indications that insulation damage can be caused even below the inception voltage, and that the nature of damage below inception is chemically similar to the damage at or above inception, one can reach similar conclusions also for the case of air gaps. It is indicated here that random discharges may exist even at a gap spacing greater than the maximum air gap which normally discharges at the applied voltage of 7.5 kV. Random discharges, in the case of 2 mm, appear sometimes very few but they can also number some tens of thousands.

4 PROPOSALS FOR FUTURE RESEARCH

It is planned to carry out further experiments regarding various gap spacings above 2 mm. Not only the number of discharges but the magnitude of the detected discharges should also be registered. By doing that we will be able to draw graphs of gap spacing versus discharge magnitude (or discharge current) and we will be able to see whether a sharp transition from non-conduction to conduction exists, as was suggested in [10]. Furthermore, more complex insulating systems should be tested, like, for example, polyethylene sheets covering the plane electrode, relating thus the present work with the work of [1–6]. In this case, a complex system of air/polyethylene is created and its behaviour can be investigated. Chemical analysis can be carried out in such an arrangement for voltages below and at inception and a comparison between the byproducts of both cases will be made.

5 CONCLUSIONS

This short paper gives some experimental data on random discharges that may appear even in air gaps which are larger than the maximum gap which is related to continuous discharge phenomena. Random discharges may exist indeed even below inception. The experimental results offered in the present work confirm qualitatively previous results carried out with solid dielectrics.

References

[1] BRUNING, A. M.—CAMPBELL, F. J.—KASTURE, D. G.—TURNER, N. H.: Voltage Induced Insulation Aging — Chemical Deterioration from Sub-corona in Polymer Void Occlusions, Interim Report, Res. Proj. No. RP8007-1, Washington, D.C., USA, July 1990 (Contractor: Naval Research Laboratory, Washington D.C., USA).

[2] BRUNING, A. M.—KASTURE, D. G.—CAMPBELL, F. J.—TURNER, N. H.: Effect of Cavity Sub-corona Current on Polymer Insulation Life, IEEE Trans. Electr. Insul. **26** No. 4 (1991), 826–836.

[3] DANIKAS, M. G.—BRUNING, A. M.: Comparison of Several Theoretical Sub-corona to Corona Transition Relations with Recent Experimental Results, Conf. Rec. 1992 IEEE Int. Symp. Electr. Insul., June 7-10, 1992, Baltimore, USA, 383–388.

[4] BRUNING, A. M.—DANIKAS, M. G.: Experiments on Polymer Cavity Currents Above and Below CIV, Ann. Rep. Conf. Electr. Insul. Diel. Phen., October 18-21, 1992, Victoria, B.C., Canada, 735–740.

[5] TURNER, N. H.—CAMPBELL, F. J.—BRUNING, A. M.—KASTURE, D. G.: Surface Chemical Changes of Polymer Cavities with Currents Above and Below Corona Inception Voltage, Ann. Rep. Conf. Electr. Insul. Diel. Phen., October 18-21, 1992, Victoria, B.C., Canada, 687–693.

[6] BRANCATO, E. L.: Electrical Aging — A New Insight, IEEE Electr. Insul. Mag. **6** No. 5 (1990), 50–51.

[7] AGUET, M.—IANOVICI, M.: Haute Tension, Ecole Polytechnique Federale de Lausanne, Eds. Georgi, Lausanne, 1982.

[8] KUFFEL, E.—ZAENGL, W. S.: High Voltage Engineering Fundamentals, Eds. Pergamon Press, Oxford, 1984.

[9] MASON, J. H.: Breakdown of Solid Dielectrics in Divergent Fields, Proc. IEE **102** Pt. C (1955), 254–263.

[10] BRUNING, A. M.: Design of Electrical Insulation Systems, PhD Thesis, University of Missouri-Columbia, USA, May 1984.

Received 24 March 2000

Michael G. Danikas, born in 1957, Kavala, Greece, received his BSc and MSc degrees from the University of Newcastle-upon-Tyne, Department of Electrical and Electronic Engineering, England, and his PhD Degree from Queen Mary College, University of London, Department of Electrical and Electronic Engineering, England, in 1980, 1982 and 1985 respectively. From 1987 to 1989 he was a lecturer at the Eindhoven University of Technology, The Netherlands, and from 1989 to 1993 he was employed at Asea Brown Boveri, Baden, Switzerland. He researched in the fields of partial discharges, vacuum insulation, polymeric outdoor insulation, rotating machine insulation and insulating systems at cryogenic temperatures. From 1993 to 1998 he was Assistant Professor at Democritus University of Thrace, Department of Electrical and Computer Engineering. In 1998 he became Associate Professor in the same department. During the academic years 1999-2000 was elected director of the Division of Energy Systems. He was reelected director for the academic year 2000-2001. His current research interests are breakdown in transformer oil, simulation of electrical treeing in polymers, study of partial discharge mechanisms in enclosed cavities, study of circuit parameters on the measured partial discharge magnitude and surface phenomena in indoor and outdoor *hv* insulators.