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ELECTRICAL ENGINEERING

Effect of Point Polarity on Conduction and Burst Current in an Inhomogeneous Field in Transformer Oil

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Abstract. This paper presents a study of the effect of point cathode and point anode on conduction and burst currents under high fields in transformer oil from a transformer in service. It was found that, the current in point cathode is higher than the point anode, however, the rate of current decrease in point anode is faster. The amplitude of long duration conduction bursts in point cathode is larger than point anode. The total number of bursts per minute is larger for point anode than the point cathode. The conduction mechanism is discussed and the role of the liquid/metal interface is emphasised.

Introduction

It has been reported that the process of charge carrier generation under the influence of a high electrical field is best studied with a point to plane gap since the generation process is confined to a small volume and the influence of polarity can be analyzed [1]. Singh *et al.* [2] studied the effect of point polarity in n-hexane, but the temporal dependence of the conduction current had not been emphasized. In most of the studies reported in the literature, the high voltage was applied to the point electrode as the usual practice.

The present study could shed some light on how the DC conduction mechanism of the point cathode and the point anode is affected by the space charge distribution, the injected carriers and the field ionization process. This work gives experimental results of such a study and their interpretation.

Experimental

Experimental Technique

Aged oil (7 years in operation) was sampled from an outdoor 100 MVA; 115/66 kV transformer, fitted with silica gel breather and oil conservator, with a maximum oil temperature rise of 55°C. This unit has been operating at the eastern province for the last year without any fault. This is a refinery area located in desert but not far away from the sea coast. Ambient temperatures vary from 0 to 47°C and relative humidity range from 60 to 70%.

The oil test samples were dehydrated by passing through one meter long chromatographic column containing silica gel, then filtered through a sintered glass filter of porosity of 5-15 μm.

The plane electrode was 25.4 mm diameter, with 10 mm thickness and edges rounded. To get nickel electrode, brass electrode was nickel plated. For point-electrode, steel sewing needle of tip radius 25 μm was used. The electrode gap was 0.75 mm.

The electrodes were mechanically polished using diamond paste on a rotating disc fitted with green wool cloth and using alumina as a lubricant. A mirrorfinish was achieved for the sphere electrodes, whereas no pits or scratches were visible under a magnification of 200 for the plane electrodes.

The test cell and the electrode assembly were washed thoroughly, everytime the electrodes or oil was replaced with petroleum ether and then immersed in n-Heptane subject to the ultrasonic energy for 30 minutes. After cleaning, the test cell was dried inside an evacuated dessicator containing silica gel for about 15 minutes.

The schematic diagram for the experimental set up is shown in Fig. 1. Every possible measure and precaution was taken to minimize leakage current and interfering signal. The applied high voltage not exceeded by 80% of the D.C. dielectric strength

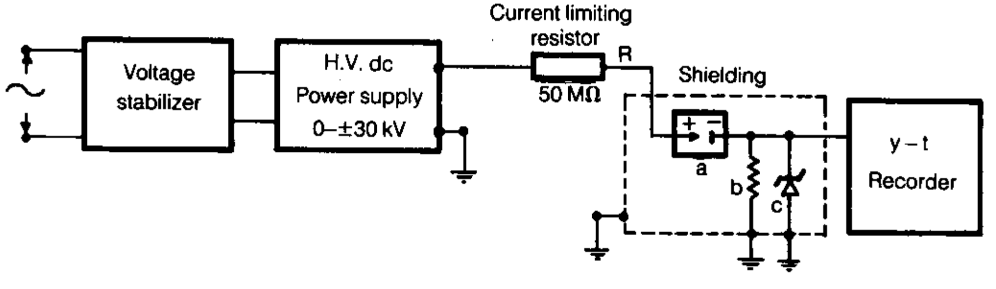

Fig. 1. Experimental setup for conduction current measurement
(a) Test Cell
(b) Detection resistor (10k Ω)
(c) Surge supessor (6.1 volt)

of the oil sample. Conduction currents were then recorded at room temperature for a duration of 900 seconds after the application of voltage. Before each measurement the sample was conditioned by short circuiting and grounding the electrodes for about 60 seconds in order to remove the influence of the preceding experiment.

Result and Discussion

Influence of Point Polarity on the Quasi Steady State Conduction Current

Fig. 2 shows the i-t characteristics of both cases. The conduction current varied with time of application of voltage (t) according to the equation

$$i = kt^{-n}$$

where $(10 < t < 600s)$, k and n are constants dependent on the point polarity.

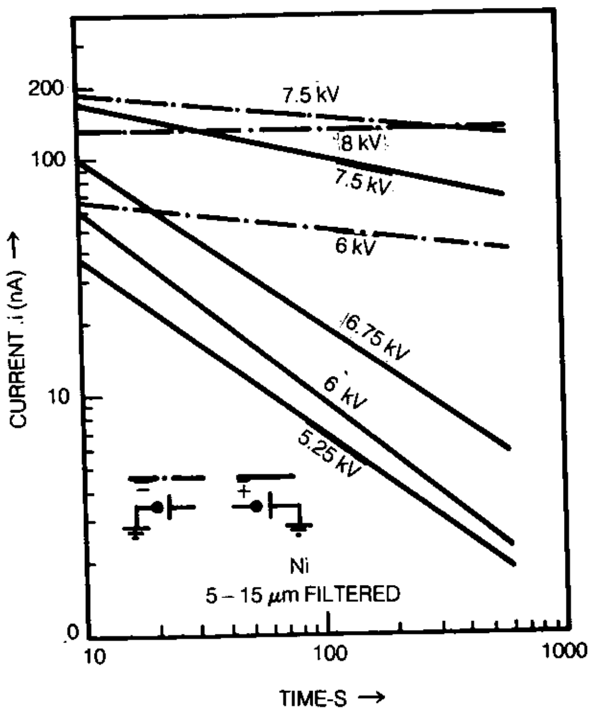

Fig. 2. i-t characteristic at room temperature

The more rapid current decay for the point anode can be explained by the fast formation of an insulating film at the cathode plate. A whitish film was deposited on plane electrode. This insulating film was thicker when the plane electrode was the cathode. It has been reported earlier [3] that the charged particles resting on electrode are composed of metallic impurities, Fe, Cu, and Pb. Oxygen and the acidity in the oil will partially oxidize these metallic impurities with time, forming an insulating film which tends to decrease conduction. However, some of these particles will not oxidized leading to the formation of a positive space charge layer. The effect of the positive space charge layer and the insulating film on conduction current are in opposition. The insulating film decreases the conduction, while the positive space charge layer tends to increase the local voltage at the anode and hence carrier collection [4]. For the case of the point cathode the insulating film deposited on the plane electrode was thinner than for the case of the point anode, so the conduction current decay is slower.

Impact of Point Positive and Point Negative on Burst Activities

Typical burst shapes are shown in Fig. 3. The amplitude of UDI-Burst for point-cathode is larger than for point anode in the voltage range of 5.5 to 8.0 kV, which a ratio of about 5.5:1 at 6.0 kV and 14:1 at 8.0 kV. Similar data have been found by Zaki and Hawley [5] who reported that the noise level is higher with point negative; the ratio was 7:1 in an Oxygen saturated oil. It emphasises the role played by the anode/ liquid interface on the conduction mechanism. Table 1 shows the effect of point cathode and point anode on burst activity for aged oil. The point anode exhibits all types of burst, *i.e.* uni-directional increasing (UDI), uni-directional decreasing (UDD), and Bi-directional (B), while, for point cathode, most of the bursts are UDI.

Fig. 4 shows the variation of total number of bursts per minute (BPM) with applied voltage. For point positive the BPM increases with voltage up to about 7 kV after which it starts decreasing. This could be attributed to the ejection of sub-micron sized particles away from the stressed region, or they may become neutralized at either electrode. The deposition of the neutralized species ultimately lead to the formation of the insulating film on the plate electrode. The stated earlier this insulating film is thicker when the point is anode.

It is well known that electrohydrodynamic (EHD) moiton in liquid dielectrics is due to the transfer of momentum from charge carriers to liquid molecules and to the migration of ions from one electrode to the other. In the presence of an electrical field the whole cluster (ions and liquid molecules) migrates in the field direction. It appears that this EDH motion is one of the major factors that control the parameters of the burst activity. When the point is anode, the burst activity curve has two distinct regions; the burst number and size increase as the field increases up to 7 kV and thereafter decreases as the EHD becomes dominant. It has been reported [2,6] that

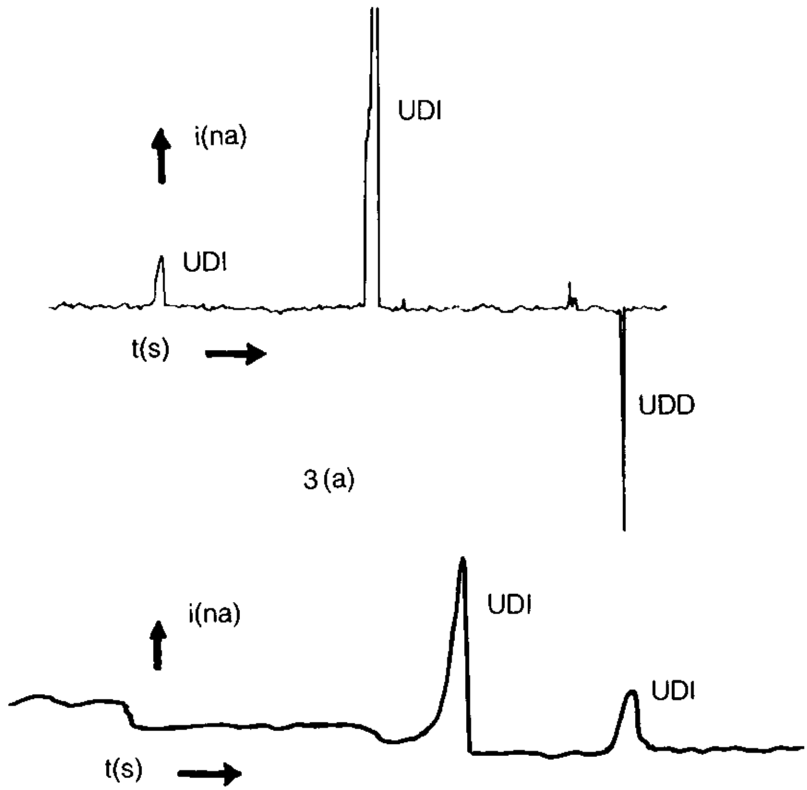

Fig. 3. Burst activity
(a) Point anode (b) Point cathode

a spray of bubbles is present in a liquid jet under nonuniform conditions when the applied voltage exceeds a certain value. As the sub-micron particles have a large mobility their time of transition in the stress gap is much smaller, resulting in a reduced number and size of large during bursts. When the point is cathode the number and size of the bursts are dependent on the field. As the field increases, both the number and size of the long duration bursts increase. The comparatively large amplitudes of the burst in this case are due to the slower carrier mobility. It has been shown [7] that the drift velocity of the negative charge carriers in air and SF6 saturated transformer oil is smaller that in degassed oil. All these experimental observations lead us to conclude that conduction phenomena is strongly governed by the relative polarity of the stressed electrodes, whereas the long duration conduction burst activity is strongly influenced by EHD motion generated under electric stress.

Table 1. Effect of polarity on burst activity for aged oil filtered with 5-15 μm pure glass filter at 33°

Applied voltage kV	Burst activity	Point anode			Point cathode		
		UDI	UDD	B	UDI	UDD	B
6.0	i nA	1.8 – 3.4	4.9	4.9	10 – 20	–	–
	i (s)	0.8 – 4.0	2.0	2.0	1.8	–	–
	BPM	0.9	0.3	0.3	1.0	–	–
7.0	i nA	2.0 – 7.6	2.4 – 7.0	–	–	–	–
	t (s)	0.6 – 3.2	0.8 – 2.2	–	–	–	–
	BPM	4.3	1.5	–	–	–	–
7.5	i nA	–	–	–	10 – 20	–	60
	t (s)	–	–	–	1	–	2.0
	BPM	–	–	–	–	–	2.7
8.0	i nA	1.5 8	4	1.8	40 – 80	–	–
	t (s)	1.2 2.4	0.8	2.4	1	–	–
	BPM	1.2	0.3	0.3	3.3	–	–

i = burst amplitude (nA), t = duration of burst, BPM = number of burst per minute

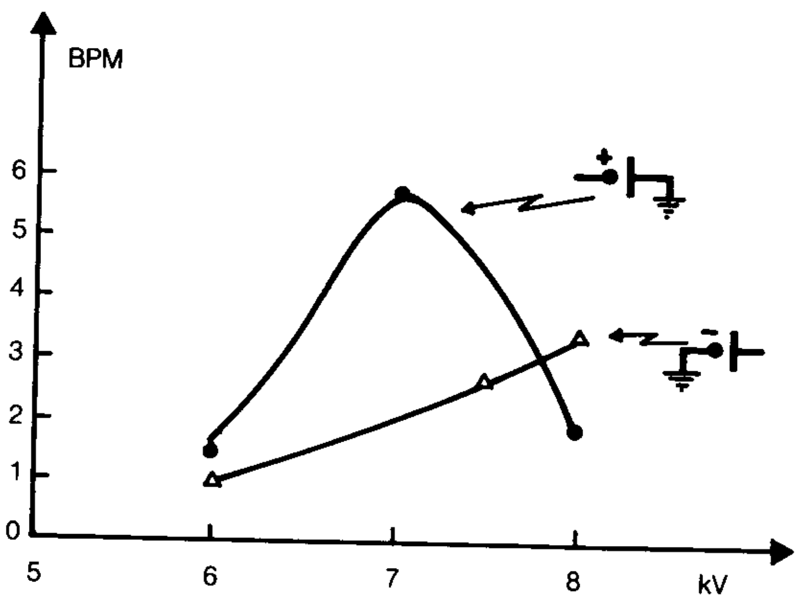

Fig. 4. Variation of BPM with applied voltage

Conclusions

The effect of point polarity on conduction and burst currents in inhomogeneous field in transformer oil was studied. The following conclusions were derived from this work:

1) Conduction and burst currents in the point cathode are higher than in the point anode.

2) The rate of current decrease with time of voltage application is faster in the point anode. On the other hand, the bursts per minute is larger for the point anode.

3) Conduction mechanisms are mainly governed by the nature of the metal-liquid interface and therefore is polarity dependent.

4) Long duration bursts activity can be attributed to the EHD motion in the oil bulk

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تأثير القطبية على تيار التوصيل والنبضات للمجال غير المتجانس في زيوت المحوّلات

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ملخص البحث. يتطرق هذا البحث إلى دراسة تأثير الجهد العالي على تيار التوصيل ونبضات تيار التوصيل في خلية مكونة من قطب مدبب وآخر لوح مستوٍ، وذلك عندما يكون القطب المدبب هو المهبط ومرة أخرى عندما يكون هو المصعد.

وتوصلت هذه الدراسة إلى أن تيار التوصيل يزداد عندما يكون القطب المدبب هو المصعد، لكن نقصان معدّل التيار مع الزمن يكون أسرع. وتزداد قيمة نبضة التيار (ذات الوقت الأكبر) عندما يكون القطب المدبب هو المهبط. ويكون إجمالي عدد النبضات في الدقيقة أكبر في حالة القطب المدبب عندما يكـون هو المصعـد. وقامت الدراسة بمناقشة ميكانيكية التوصيل وإبراز أهمية الدور الذي يلعبه تقابل السائل مع سطح القطب.