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BARRIERS INSULATING INFLUENCE ON THE PRE-BREAKDOWN CURRENT OF TRANSFORMER OIL GAPS (BORAK22) UNDER AC APPLIED VOLTAGE

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Abstract— The experimental study in this paper deals to examine the influence of insulating barriers on the pre-breakdown current of transformer oil gaps (Borak22) under alternating voltage at power frequency 50 Hz in a point-plane electrode system. We studied the effect of different geometrical parameters such as the inter-electrode distance, the relative position of the barrier, its nature and its dimensions. These tests allowed the visualization of the pre-breakdown currant of the two systems studied (with and without barrier) and to compare them.
Keywords- Insulating Barrier, Transformer Oil (Borak22), Dielectric Strength, Configuration Point-Plan, Pre-breakdown Current, Oscilloscope (TECTRONIX TDS 3052 B).

I. INTRODUCTION

Liquid insulators have a great importance in High-Voltage technology, because they play a dual role: insulation and cooling. They are integrating as dielectric in 1887 by G. Westinghouse [1]. Hydrocarbon oils are currently the most commonly used in the power transformer industry [2]. They are used as impregnates of solid insulations or as filling products for a wide variety of electrical equipment. Liquids are also used for their power to extinguish electric arcs (in the breaking chambers of on load switches and certain circuit breakers), in due to their lubricating power for equipment containing moving parts (tap selectors, submerged pumps) and in some cases, to improve the resistance to fire (distribution transformers) [3]. All electrical or electronic equipment consists of a judicious arrangement of conductive materials that serve to carry out the electrical energy (or information) where it must be used and insulating materials that prevent it from getting lost by taking the “shortest” path from one potential to another [3]. Liquids for electrical insulation are subject to different constraints that must be taken into account in the design of many high voltage devices. In oil-filled high voltage apparatus, the insulating barriers are widely used, particularly in power transformers. The three main functions of insulating oil are:

- evacuate energy losses
- insulate in the strict sense (i.e. slow down the oxidation of the insulation solid).
- insulate in the electrical sense.

It is necessary to add the function of fire resistance, including the power to extinguish the electric arcs, and the power lubricant for the equipment containing moving parts [4].

Many works reported in the literature that the essential factors influencing the shape and frequency of appearance of streamers, therefore, the shape and the magnitude of the corresponding current and charge are: the magnitude and polarity of the applied voltage, the geometry of the electrodes exceptionally the radius of curvature of the point, the inter-electrode distance, the nature of the liquid, the hydrostatic pressure, the temperature etc... Indeed, research work [5-8] has shown that the frequency appearance of streamers is all the more important as the applied voltage level is high. According to some researchers [9-11], the final length of streamers in a system point-plane under alternating and impulsive voltage, increases with the increase in the applied voltage. The current and the load corresponding to the streamers evolve in the same direction as the applied voltage [6, 12-16] and the radius of curvature of the electrode point [13]. However, they are all the lower as the inter-electrode distance is high [6, 13].

To understand the breakdown and pre-breakdown phenomena in point-barrier-plane oil gaps, most previous works was carried out under DC and lightning impulse applied voltages [1-6]. It appears from these investigations that the effectiveness of an insulating barrier depends on the polarity of voltage and that is higher in the case of the point under negative polarity [1–6]. Also, the knowledge of the conditions of electrical discharges initiation and propagation is of great interest to well understand the mechanisms leading to breakdown [7, 8]. The pre-disruptive current is an important parameter can inform about the physical phenomena implicated in pre-breakdown phase [9-10].

In this paper, we present the variation of the effective value of the pre-breakdown current as a function of the applied voltage for different inter-electrode distances in the transformer oil point-plane gaps with and without barriers.

II. EXPERIMENTAL SET-UP

The experimental set-up consists of a high-voltage test transformer 300kV/50kVA/50Hz, a capacitive voltage divider and a transparent test cell of 175 liters volume. The test cell is made of Plexiglas (70 cm × 50cm × 50cm). It contains a point–plane electrode arrangement mounted horizontally (Fig. 1 and Fig.2). The point electrode is made up of brass and has a radius of curvature of 6 µm. The plane electrode is made up of steel and has a circular shape of 35 cm diameter. The electrode gap varies between 1 and 12 cm. The voltage is progressively increased from zero up to breakdown with a speed ramp of 2kV/s.

The insulating barriers have a circular shape and are made of Bakelite and Press-pahn. They have a diameters D=14and 20cm and thicknesses e=2and 4mm [9-13].

Fig.1 View of real test cell

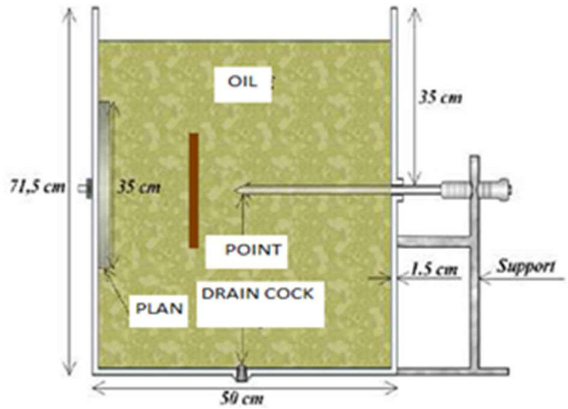

Fig. 2 Scheme of the test cell

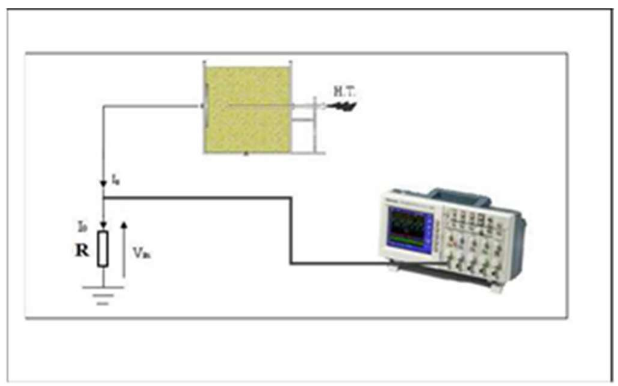

Fig. 3. Current measurement circuit

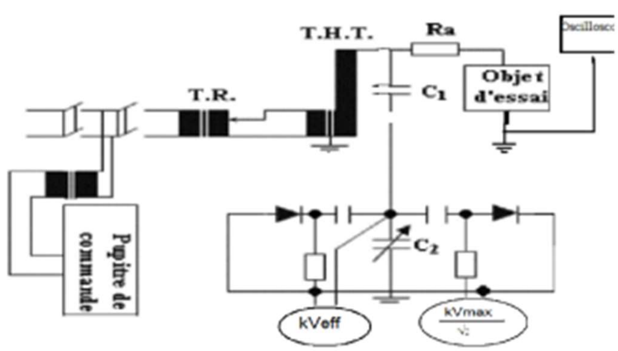

Fig.4. Test Station

The barrier is mounted vertically between the electrodes. Its surfaces are checked after each breakdown. They are cleaned with alcohol or completely changed in the case of perforation. The position of the barrier is defined by the ratio 'a/d', where 'a' is the point–barrier distance and 'd' is the point–plane electrode gap.

The used mineral oil is the "Borak22" it is a naphthenic type and is used in HV power transformers [9-13].

The characteristics of the materials used are given in Table 1.

Insulating Materials	Relative Permittivity	Dielectric Strength kV/mm
Mineral oil	2.12	9.4
Bakelite	5	30
Press-pahn	3	100

Table .1: Dielectric Properties of the materials used

Figure 4, presents the test station includes the following components:

- **Tuning transformer.**
- Nominal primary voltage: U1n = 220 V (50 Hz).
- Secondary voltage adjustable from 0 to 500 V.
- Rated apparent power: Sn= 50 kVA.
- **Test transformer.**

It outputs the voltage applied to the test object. It is of the single-phase type, its characteristics are as follows:

- Primary voltage U1n=0.5 kV (50Hz).
- Nominal secondary voltage: U2n=300 kV.
- Nominal apparent power: Sn=50 kVA.
- Short-circuit voltage: Ucc= 5.46%.
- Damping resistance: Ra = 30 Ω/kV of test voltage,
- Resistance of the LV winding: r1= 0.0365Ω, that of the HV winding: 4893Ω.
- Short-circuit current: Isc = 3A
- Short-circuit power: Ssc = 916 kVA
- **Capacitive voltage divider.**

It is powered by the secondary voltage of the test transformer and delivers a reduced voltage at the terminals of the voltmeters installed on the control console. The capacitive divider is made up of an H.T capacitor (C1 = 400pF), in series with a variable B.T. C2 is a capacity allowing the test voltage to be reduced by 1/1000 (Uread=U(C2)=U(C1)/1000). This connection makes it possible to obtain the ratings of measurements: 75 kV, 150 kV and 300 kV. The voltage collected at the terminals of the variable capacitor is measured using an electrostatic voltmeter giving the effective voltage value, and a galvanometer scaled in kVmax allowing to read the voltage peak value.

- **Control desk.**

This later is supplied with 220V independently of the voltage regulator and the test transformer through an isolation transformer. There we find the measuring devices for reading the current at the secondary of the transformer adjustment, as well as the peak and rms voltages at the secondary of the transformer test.

- **Auxiliary protection devices.**

The alimentation laboratory is supplied from a general switchboard located in the laboratory, but outside the test platform (the Faraday cage). The high voltage transformer and its regulator are independently protected by a fuse and a 250A thermal relay. These protections are linked with the circuit of the main contactor coil, which gives sufficient protection against transformer overloads and short-circuit currents.

III. EXPERIMENTAL RESULTS

III.1 MEASUREMENT CIRCUITS

The measurement of the pre-breakdown current was carried out through a resistor of 1kΩ connected in series with the test object through a storage oscilloscope (TECTRONIX TDS 3052 B) with a sampling frequency of 500MHz to avoid the influence of the electric field, which could introduce interference into the signal collected, the resistor was introduced into a metal box Aluminum grounded, also forming a screen (the field inside the box being zero).

The measurement of the breakdown voltage has been done in previous works [34] using an electrostatic voltmeter. This measurement makes it possible to determine the voltage levels (less than 50% of Ubr) to be applied for recording pre-breakdown current.

Before carrying out the measurements, the insulating barriers are thoroughly cleaned with alcohol then inserted between the two electrodes for different positions and distances inter-electrodes.

During the tests, we observed that the application of the voltage sinusoidal between the electrodes leads to a periodic current (Figure.5).

For each measurement, we were interested in the effective value of the current; the value taken is the average of six values [14].

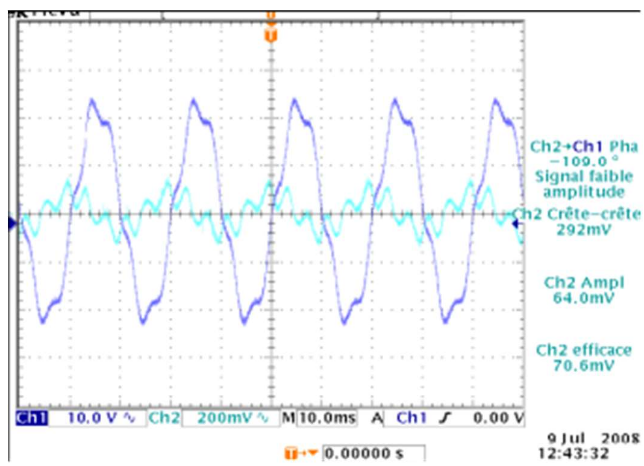

Fig. 5. Pre-disruptive current in system without Barrier, applied voltage U=15kV, d=4cm.

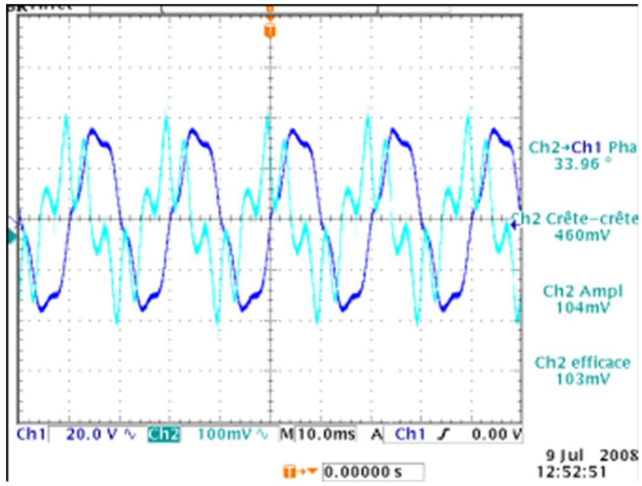

Fig. 6. Pre-disruptive current-voltage in system without Barrier, applied voltage U=25kV, d=4cm

Figures 5 and 6 show the current waveform, we observe that the current varies periodically with some distortion in both positive and negatives alternations. The phase-shift between current and applied voltage is approximately equal to 90°. This result indicates the capacitance character of the current confirming the results reported in others investigations [13].

III.2 TESTS WITHOUT BARRIERS

III.2.1 EFFECT OF THE APPLIED VOLTAGE ON PRE-BREAKDOWN CURRENTS

We present in figure 7 the variation of the effective value of the current of pre-breakdown as a function of the applied voltage for different inter-electrode distances (4,6,8,10 and 12cm).

It appears from the results obtained that the pre-breakdown current increases with increasing the voltage applied between the two electrodes. This augmentation is nearly linear and the slope is nearly constant.

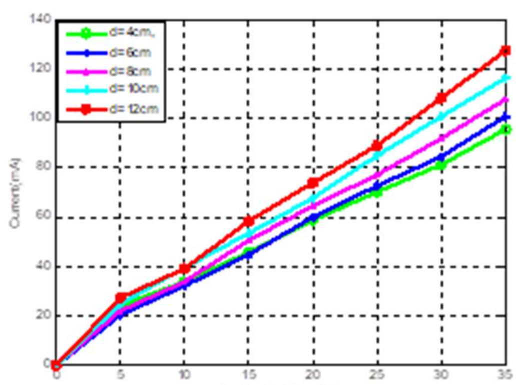

Fig. 7: Variation of pre-breakdown current as a function of applied voltage for different inter-electrode distances.

III.2.2. EFFECT OF THE INTER-ELECTRODE DISTANCE ON THE CURRENTS OF PRE-BREAKDOWN

The pre-disruptive current decreases when the distance between electrodes increases (figure 8). This decrease is more important when the applied voltage increases from U≥15kV. Less than this previous value the current remain constant. This is due to the influence of the electric field [11-13].

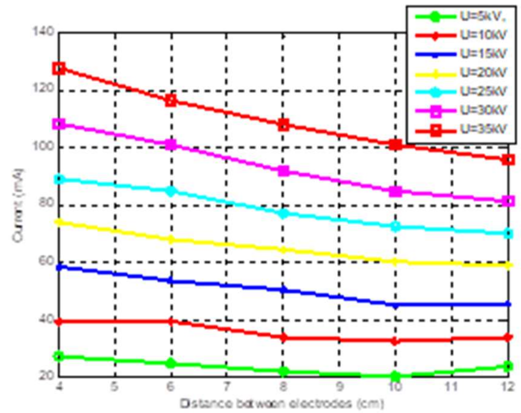

Fig. 8: Variation of pre-breakdown current as a function of inter-electrode distances for different applied voltage

III.3 TESTS WITH BARRIERS

Figure 9 presents the waveform in the arrangement with barrier. The signal of the current is also periodic with more distortions.

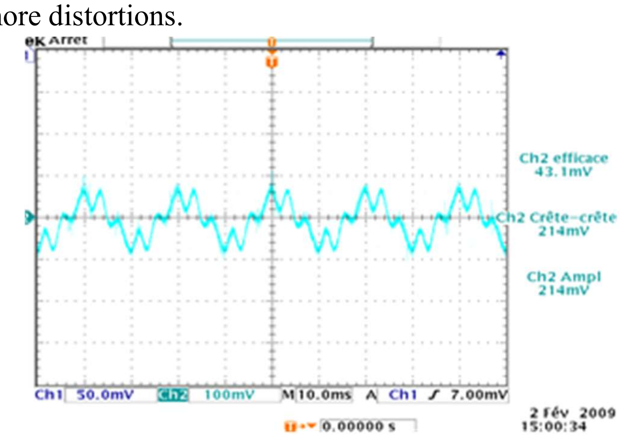

Fig. 9: Pre-disruptive Current, Barrier of Bakelite, U=10kV, d=4cm, e=4mm, D=14cm, a/d=0.

III.3.1. EFFECT OF THE INTER-ELECTRODE DISTANCE ON THE CURRENTS OF PRE-BREAKDOWN

Figure 10 shows the variation of the pre-disruptive current with the applied voltage for different distances, for the barrier of Bakelite situated near the point electrode at a/d=20%. However the current increases linearly with the applied voltage. The insertion of the barrier decreases the current versus the distance inter-electrode.

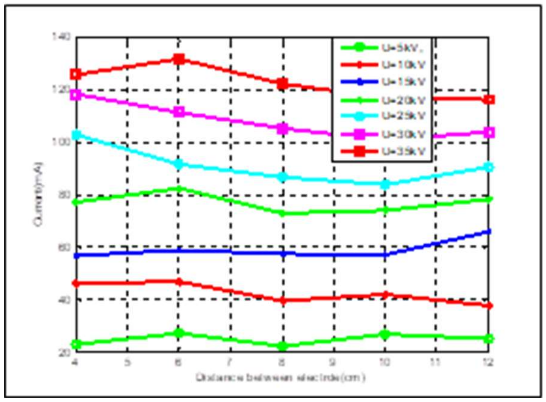

Fig. 10: Pre-disruptive current versus distance between electrodes for different applied voltage, Barrier of Bakelite, D=14cm, e=4mm, a/d=0.2.

A comparison between the point-plane gap without and with barrier is presented in figure 11. In this case, the presence of the barrier decreases the pre-disruptive current. Elsewhere, the current increase with the barrier diameter: This is due to the fact that the barrier acts as a geometrical and electrostatic obstacle to the discharge.

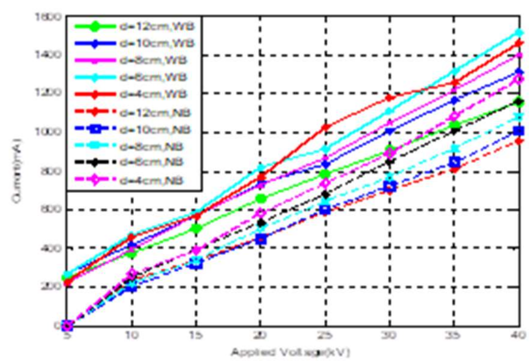

Fig. 11: Pre-disruptive current versus applied voltage for different distances between electrodes, Barrier of Bakelite, D=14cm, e=4mm, a/d=0.2.

III.3.2. EFFECT OF THE INSERTION OF THE BARRIER

The experimental results in figures (12-14) show the influence of the barrier position on the pre-disruptive current. It appears from these characteristics that the position of the barrier has not effect on pre-disruptive current. Moreover, the capacity of the system is constant for all positions.

We confirm this result also by the characteristic I=f(U) for different barrier positions figure (15). This is justified by the fact that there were no discharges between the electrodes, since the voltage levels are relatively moderate (< 50% of the breakdown voltage). The variation of the diameter of the barrier (14 and 20cm), for different inter-electrode distances (4,6,8,10 and 12cm) and for different thicknesses (2 and 4mm) show that the diameter of the barrier does not modify the value of the pre-breakdown current, since there were no discharges which would disturb the distribution of the electric field. Remember that during the tests we did not exceed 50% of the break-down voltage.

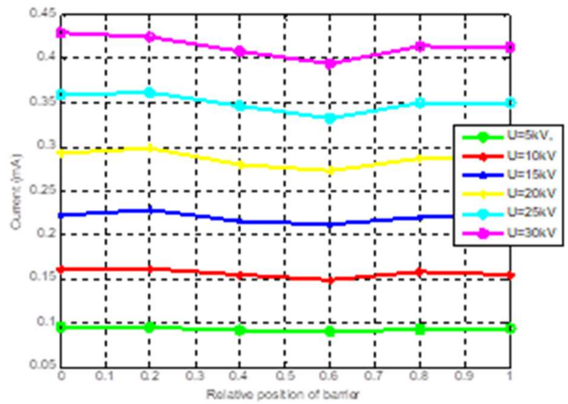

Fig.12. Pre-disruptive current versus distance between electrodes for different diameters, Barrier of Bakelite, e=4mm, a/d=0.2.

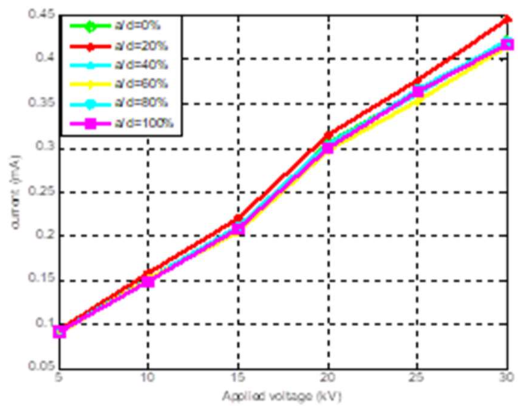

Fig.13. Pre-disruptive current versus applied voltage for different relative position of the barrier of press-pahn, e=4mm, D=20cm, d=4cm .

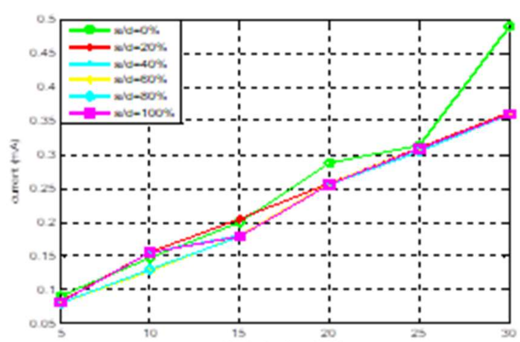

Fig.14. Pre-disruptive current versus applied voltage for different relative position of barrier, barrier of Press-pahn, e=4mm, D=20cm, d=8cm.

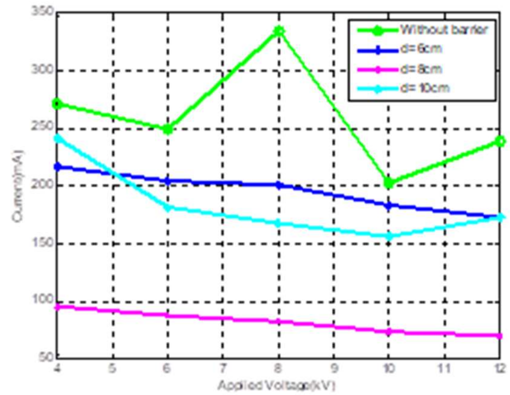

Fig.15. Pre-disruptive current versus distance between electrodes for different diameters, Barrier of Bakelite, e=4mm, a/d=0.2.

IV. CONCLUSION

The pre-disruptive current increases with the applied voltage and the distance between electrodes.

The current-voltage characteristic is linear, which confirms that the capacitance C of the system is constant in the two systems with and without barrier.

The insertion of the barrier decreases significantly the pre-disruptive current.

The presence of the barrier in point-plane arrangement decreases significantly the pre-disruptive current; this is due to the fact that the barrier is a geometric and electrostatic obstacle of the discharge. The increase of the barrier diameter leads to the increase of the current.

The growth of the current versus the applied voltage for both configurations with and without barrier shows that the oil gap has a capacitive behavior.

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