VISUAL OBSERVATION OF PRE-BREAKDOWN PHENOMENA IN THE MIXTURES OF LIQUID PCB AND PXE

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Abstract

Pre-breakdown discharge development in the liquid insulant PXE, and its several mixtures with PCB at 101.3 kPa were visually investigated in 2-mm point plane gap under 2 ns/200 ns negative impulse voltages. Each of these insulants in their pure forms exhibit similar pre-breakdown discharge behaviour, in that distribution of pre-breakdown leaders in the gap are confined to the space around the tip of the point electrode, while their spatial distributions laterally become more sporadic extending deep into the gap with increasing PXE content in PCB. The results ascertain to use of PXE in its pure form if it is intended to be used in place of PCB.

1. INTRODUCTION

Despite the excellent dielectric properties of PCB, commercially known as transformer oil, and its widespread usage in power equipment, it exhibits some important environmental disadvantages due to its stable chemical structure. After its long-term usage, recovery of the oil after several regeneration processes is time taking and not cheaper, therefore, new oil is sometimes preferred. The remaining PCB is an environmental issue to be solved, if not being decomposed with expensive chemical processes. Further, it is combustible, and combustion products under certain conditions are toxic. Because of these reasons, in 1980, the industry is forced to search possible alternative [1]. Phenyxylene ethane (PXE), isopropyl biphenyl, and similar compounds were found to be possible replacement [2].

In the present work pre-breakdown behaviour of PXE as replacement for PCB, and in their mixtures of 0.1%, 1.0%, and 10% of PCB in PXE at 10-kPa gauge pressure were investigated in 2-mm point plane gap under negative 2 ns/200 ns impulse voltages. The pre-breakdown discharge behaviour were recorded and assessed from the shadow photographic records at different stages of discharge developments from corona initiation to breakdown.

2. EXPERIMENTAL SET-UP

As shown in Fig. 1, the experimental set-up comprises a test cell enclosing a point-plane gap, Blumlein cable impulse generator, an optical system with delay cable and a light spark gap, and a still-picture camera.

Test cell is made of airtight fibreglass in the shape of rectangular prism with two ports on both opposite sides fitted with optically polished lenses. The test gap used throughout experiments is of 2-mm point-plane gap with 5-μm tip radius. The tip is made of tungsten and plane is of brass. The gap separation can be adjusted mechanically to an accuracy of ±10 μm.

Blumlein generator is of two-stage cable generator and is capable of producing 2 ns/200 ns and 80-kV peak impulse voltages. The generator is supplied from a 40-kV dc generator. It comprises two 40-kV dc co-axial cables 19-m in length connected as shown in Fig. 1. The end of the rhs cable was kept open and the lhs one was attached to a spark gap with automatic triggering facility. Whence the cables are charged in parallel to the desired – V dc voltage and triggering the lhs spark gap G1 causes a current wave of magnitude of $I=V/Z_O$ to flow through inductors of the lhs cable discharging all their capacitor charges. When the current wave reaches to the end of this cable, since it is open after triggering and sparking is completed, the wave is reflected back from this end and charging all capacitors of this section back in the reverse direction. The overall operation leaves the cable capacitors of the rhs section as negatively charged and of the rhs section as positively charge, producing $+2V$ across the 2 Z_O load resistor connected at the connection point of the cables.

Synchronisation unit was designed to trigger the spark gap G1 of the cable generator and at the same time the spark gap G2 of the light source sparks through the delay cable after triggering the spark gap SP and G3 (see Fig. 1). This unit operation takes place on switching 10 kV dc source through a special relay isolated to 10 kV.

Delay cable comprises forty segments of 50-Ω coaxial cables connected in series. Each segment is 0.65-m long introducing a delay of 5 ns to yield delays in the range 5 - 200 ns. The cable segments are all connected on a hollow PVC cylinder with an automatic tapping facility.

Optical system was designed to provide the necessary background light to the test gap with required intensity for shadow photography. Recording starts after triggering of the cable generator and of the delay cable unit. Activating for triggering G2 after G3 was adjusted through the delay cable unit.

3. EXPERIMENTAL PROCEDURE

The test cell and the electrodes were cleaned troughly before starting a series of tests. After filling the test cell with the insulants, it was kept under vacuum for a time period of 2 hours in order to remove air bubbles from the insulant.

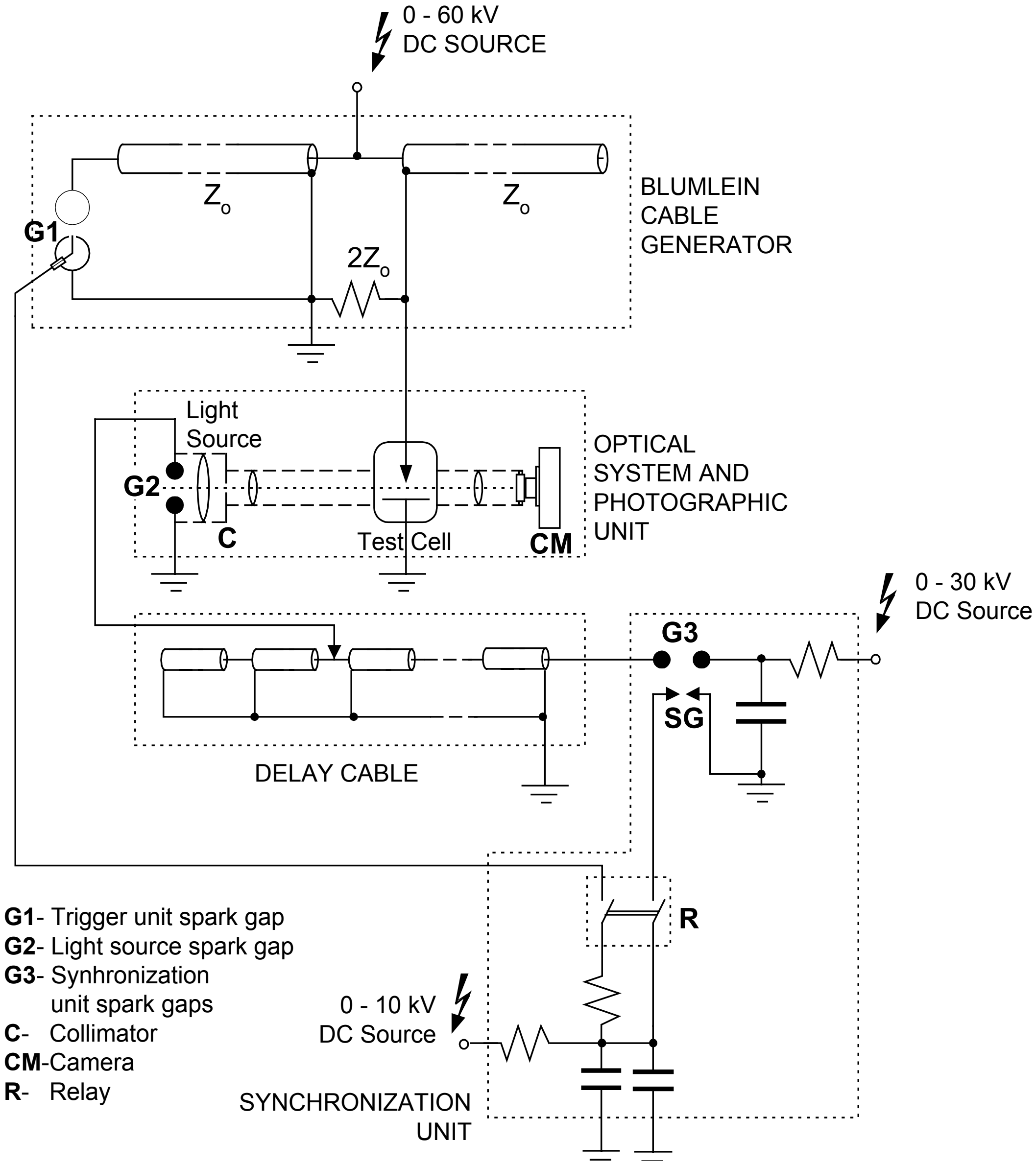


Figure 1. The experimental set-up.

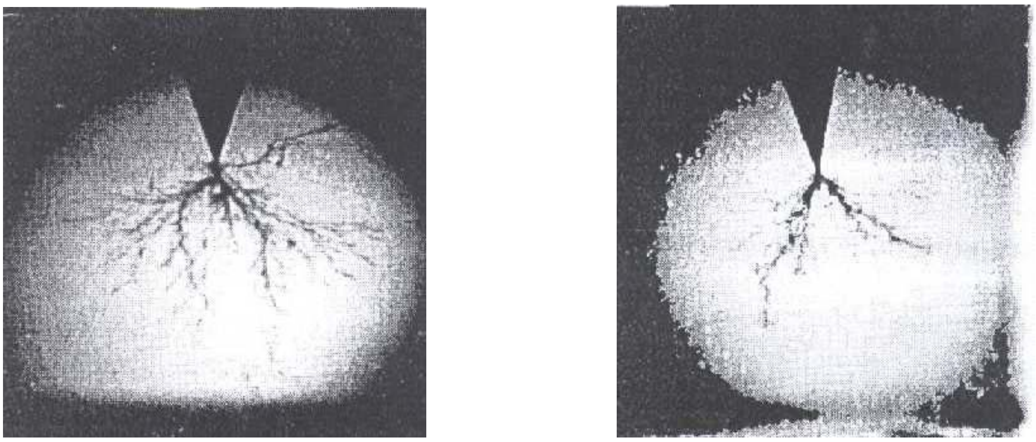
the relay R causes the gap G2 to spark to produce the necessary background light for shadow photography following the sequential triggering the gaps SP and G3. The time delay

The gauge pressure was then returned to the normal when this procedure was completed. The company of origin of PXE is Nippon and of PCB is of BP both are qualified with 99 %purity.

The impulse voltage levels to breakdown were recorded before starting to the tests in order to maintain the original properties of the compound and the test gap.

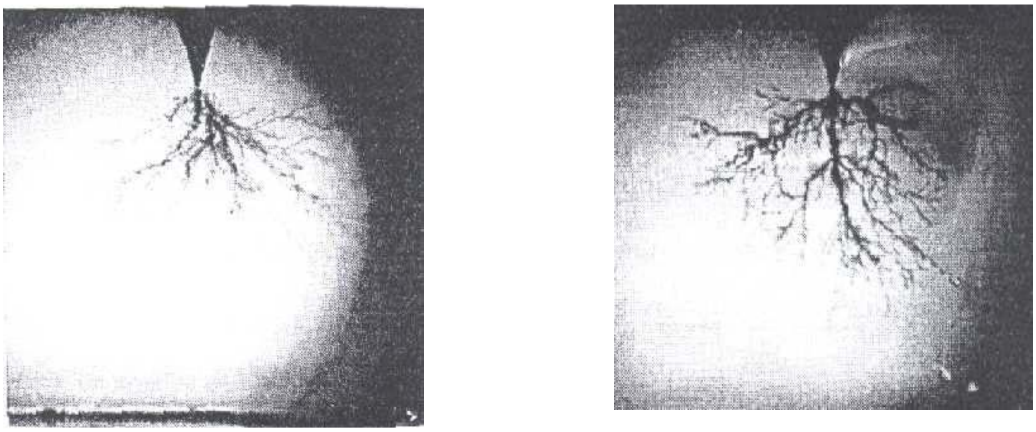
Altough the test cell and the optical system was kept in a dark plastic enclosure, the tests were carried out in a dark room for absolute darkness.

Before recording a shadow frame, the camera shutter was kept open until the background light flashes across the gap G2. With the present arrangement a shadow spark



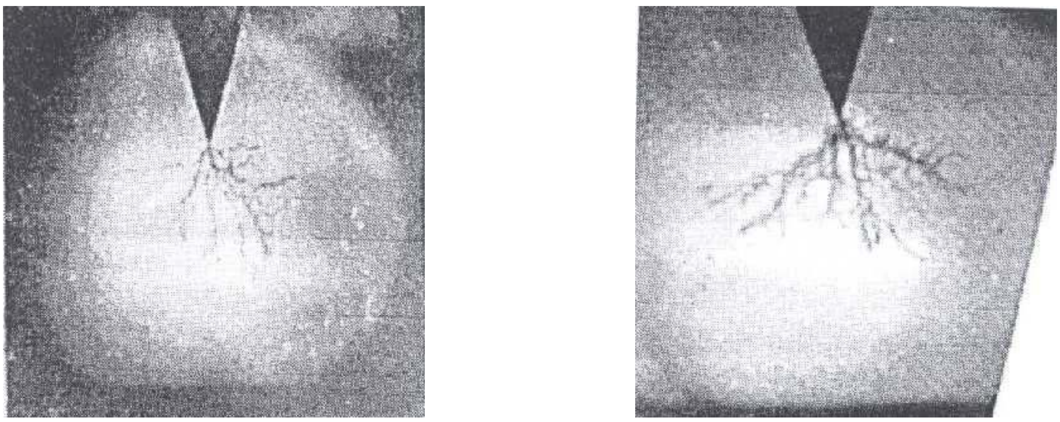
(a) (b)

Figure 2. Pure PCB, -60 kV, delay (a) 10 ns and (b) 20 ns



(a) (b)

Figure 3. 10% PXE-90%PCB, -60 kV, delay (a) 10 ns and (b) 20 ns



(a) (b)

Figure 4. Pure PXE, -60 kV, delay (a) 10 ns and (b) 20 ns

flashes were achieved with a time delay steps of 5 ns up to 200 ns after inception of the discharge from the point of the test gap.

4. EXPERIMENTAL RESULTS AND DISCUSSION

The pre-breakdown discharge records of PXE and its mixture with PCB were displayed in Fig 2 to Fig. 4 for 2 ns/200 ns and –60 kV peak impulse voltages for several time delays to breakdown and for a gap separation of 2 mm. The pressure of the test cell was maintained at 101.3 KPa gauge pressure.

The pre-breakdown discharge development in PCB under –60 kV impulse with 10 ns and 20 ns are shown in Fig. 2 (a) and (b). The noticeable development for 10 ns optical delay is the usual appearance of branched leaders following the paths of streamers. However, at 20 ns delay, leader activities become less branched, but extend close to the plane electrode.

Under the same experimental conditions pre-breakdown activities in the mixture of 10% PXE-90% PCB are shown in the frames of Fig. 3. As the optical delay time was increased from 10 to 20 ns, extensive and lateral leader branching from the point electrode became more effective. It was also observed that this is coupled with lateral branching from the main roots of the leaders. Discharge leaders follow the same channels of previous leaders, and channels are augmented with intensive streamer branching at the tips of leaders close to the plane.

In the mixtures of PXE and PCB a similar pre-breakdown discharge activities follow in that discharge channels are enhanced and laterally spread throughout the gap as the ratio of PXE in PCB increases. The salient features of all discharges are that progressive development of the leader channels with sporadic leader bursts into the gap in the direction of field lines.

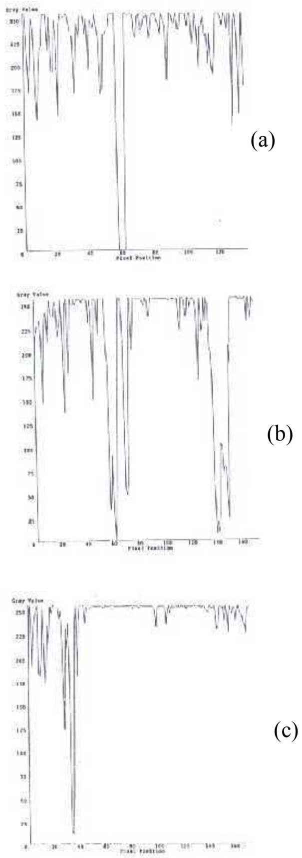


Figure 5. Profiles of grey tones pure PCB, delay 20 ns. Distances from the point tip (a) 0.1 mm, (b) 0.51 mm, and (c) 1.11 mm

To confirm increased leader branching with increasing the content of PXE in PCB , the

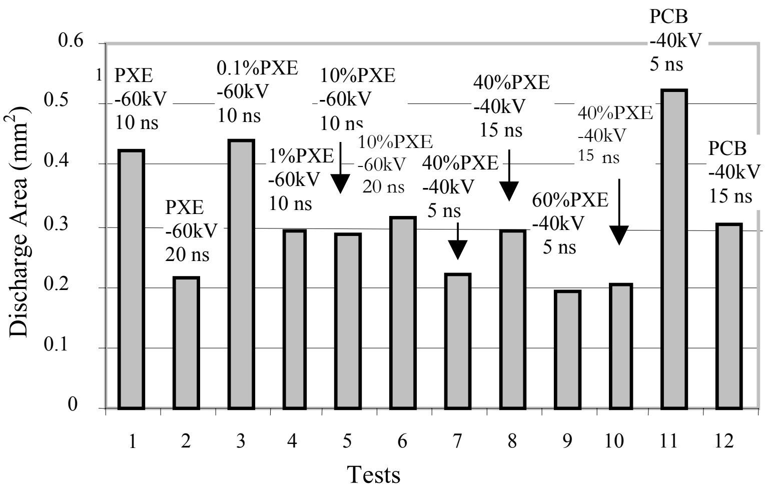


Figure 6. Histograms of grey tones distribution in the development pre-breakdown discharge channels into the gap in various mixtures of PXE and PCB under different time delay and impulse voltage conditions.

shadow pictures were scanned for various mixture contents, time delays and impulse voltages. The scanning processes were carried out for profile 'grey tone' analysis using the 'Global Lab Image' program. Scanning was carried out at several distances from the tip of the point electrode. Three of these example graphs are shown in Fig. 5. In grey value graphs each peak corresponds to length of a channel, and its size corresponds to width of a channel. The profile data was presented in the form of bar charts for discharge area as shown in Fig. 6. The results in this figure are consistent with observations obtained from discharge pictures such that pre-breakdown discharge leader channels activities are enhanced with as the ratio of PXE in PCB increases. In conjunction with this trend, to observe the behaviour of pure PXE under the same experimental condition, the pictures of discharge behaviour were taken with 5 ns and 15 ns delays are illustrated in Fig. 4. The discharge behaviour of pure PXE is interestingly similar to that of the pure PCB with lessened leader and/or streamer activity confined to regions close to the tip of the point electrode.

5. CONCLUSION

The pre-breakdown discharge behaviour of PXE and PCB mixtures is investigated in a 2-mm point-plane gap at 101.3 kPa under 2/200 ns negative impulse voltages. The results revealed the fact all mixtures rendered enhanced pre-breakdown activities with increasing the content of PXE in PCB typical with sporadic leader channel activities. It seems that the charge injection process into the discharge channels is enhanced with increasing PXE content in PCB. On contrary to this fact the pre-breakdown discharge behaviour of both pure PXE and PCB exhibit likeliness with confined leader activities. In practical terms, in replacing PXE with PCB, tank of the transformer or of switchgear should be free from the trace of PCB.

6. REFERENCES

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[2] Forster, E.O., "Progress in the Field of Electric Properties of Liquids", *IEEE Trans. Electr. Ins.,* 25, 45-53, 1990.