# Pre-breakdown behaviour of oil-board-arrangements under lightning impulse stress

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***Abstract:*** **Standard lightning impulse tests with oil-board-arrangements were performed by applying impulses with the specific shape (e.g. 1,2/50µs) on the test object and measuring the peak value with a divider and a peak voltmeter and controlling the shape with an oscilloscope. The test object passed the lightning impulse test if there occurs no breakdown or flashover which can be controlled by scope and usually noticed acoustically. But what about pre-breakdown mechanism? In this paper it will be shown that even in uniform oil-board-arrangements pre-breakdown mechanism under lightning impulse stress occurs. These pre-breakdowns produces bubbles and a charging of the board surfaces which influence the electrical strength of the oil-board-arrangement. With the conventional impulse measuring technique (divider and oscilloscope) these pre-breakdowns cannot be detected. An optical observation is not always possible because for big oil-board-arrangements you need steel vessels and the pre-breakdown channel can be covered by other board barriers. With the charging measurement after each impulse a new procedure for the certain pre-breakdown recognition is presented.**

## INTRODUCTION

The main insulation of high power transformers consists of pure oil gaps subdivided with board barriers. This insulation system is proved over many years. The insulation of new transformers is tested with the operating voltage (alternating current) and with impulse voltage (lightning impulses). The relevant standards describes the necessary voltage levels and the test procedure. It is assumed that if the transformer passed these tests his insulation withstand the voltages which occur in service for a long operation time and that his insulation got no damage by the tests. But can we be sure that the oil-paper-insulation got no damage by testing, especially by impulse testing? The standard impulse test procedure is only focused on the question if there appears a breakdown at the specified voltage level or not. Therefore the applied impulses got recorded by impulse divider and oscilloscope or transient-recorder. Figure 1 shows the picture if the test object withstand the lightning impulse voltage and if a breakdown occurs after the chopping time Tc (dotted line).

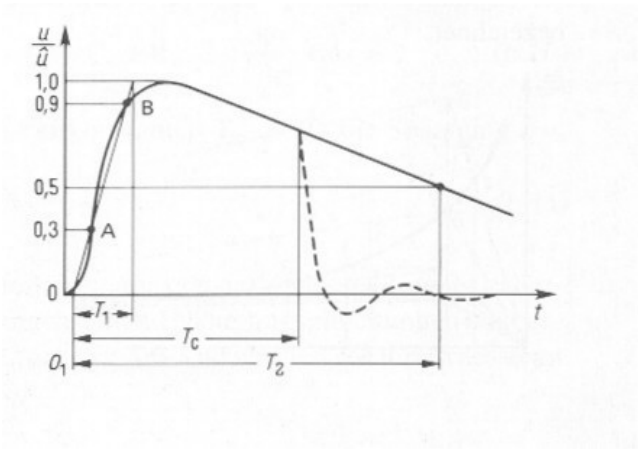


Figure 1: positive impulse voltage with the qualifying parameters

But is it possible that pre-breakdowns occur in the oil-paper-arrangement during the impulse tests before breakdown and are they detectable?

## EXPERIMENTAL SETUP

To investigate the pre-breakdown behaviour of a oil-board-arrangement under lightning impulse stress tests with a small glass vessel (volume 17 liter) were performed. To generate a uniform electrical field rogowski-electrodes with 80 mm diameter of the uniform area were attached horizontally in this test vessel. The electrode distance was adjusted to 5 mm. A second vessel which can be filled with 470 liter oil was used as storage tank. The oil flows from the storage tank to the test vessel only of the hydrostatic pressure difference which exist due to different surface levels of oil in the test vessel and the storage tank. With a pump the oil can be transported back to the storage tank. The used oil was a Technol US 3000, breakdown voltage, water and gas content were controlled during tests. Typical values were:

Breakdown voltage: > 60 kV/2,5mm (VDE test)

Water content < 15 ppm (Karl-Fischer method)

Gas content < 5%.

If the oil in the test vessel not fulfilled the above values it got changed.

It was possible to insert board barriers between the electrodes. Circular board barriers with 2mm thickness and 180 mm diameter were used for the investigations.

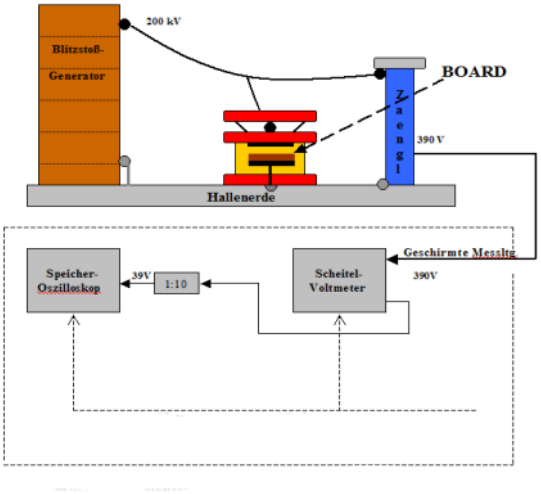


Figure 2: Test arrangement

Figure 2 shows the used test arrangement and the voltage levels which occurred at the test place (upper part) and in the measuring room (lower part). To avoid flashovers on the outside of the test vessel the polarity of the impulses was negative.

## MEASUREMENT

At the beginning of the impulse test the new board specimen was conditioned with alternating current of about 50% of the partial discharge onset voltage. This voltage (about 20 kV) was maintained for 20 minutes. Then the impulse test starts. The impulse voltage was raised up in 5 kV steps beginning with 130 kV. The impulse curve was recorded by oscilloscope and the test arrangement in the glass vessels was optical observed, therefore the test hall was darkened. Figure 3 shows a typical impulse curve on the oscilloscope screen. At this impulse no visible discharge at the test arrangement occurs. Figure 4 shows an impulse where optical visual pre-breakdowns in the oil-board-arrangement appeared, figure 5. If ones compared figure 3 and figure 4 there is no significant difference, which means that pre-breakdowns are not detectable by the conventional impulse measuring technique. In figure 6 the effect of pre-breakdowns, bubbles in the oil gap, is visible.

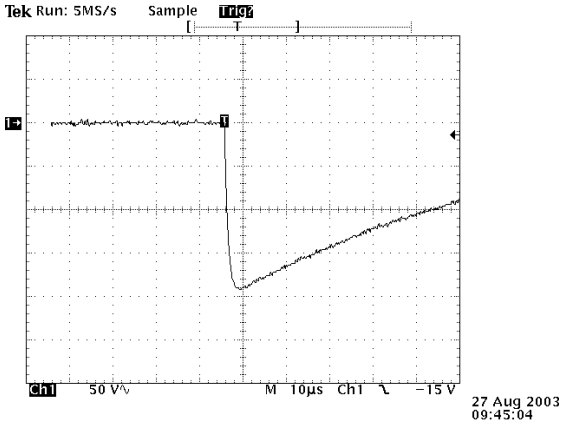


Figure 3: lightning impulse without pre-breakdown

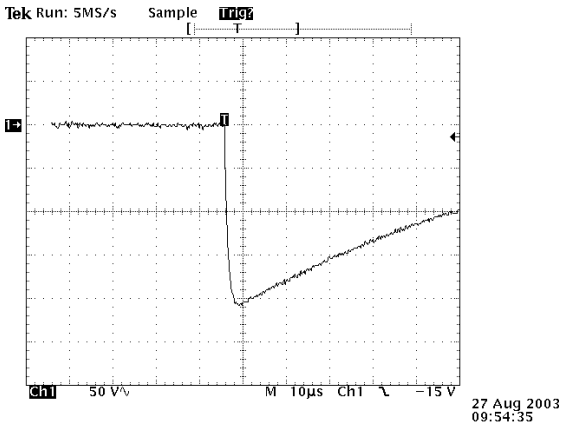


Figure 4: lightning impulse with pre-breakdown

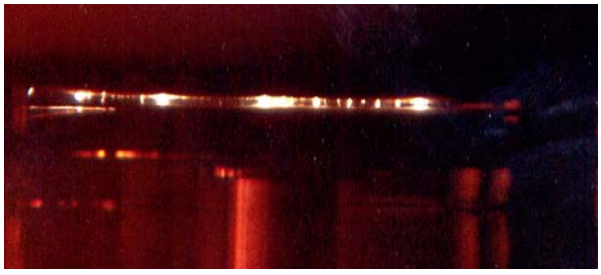

Figure 5: pre-breakdown in the test vessel

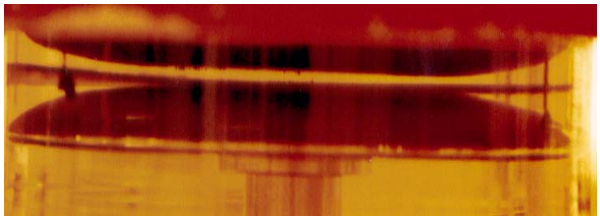

Figure 6: bubbles in the oil gap after pre-breakdown

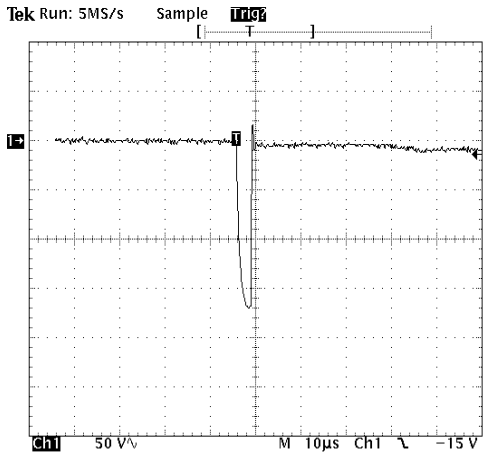


Figure 7: lightning impulse with breakdown

Only a breakdown in the oil-board-arrangement can be detected with the conventional impulse measuring technique, figure 7. But not only bubbles were generated due to pre-breakdowns also a charging of the board surface takes place. So it is possible to measure this charging between the electrodes. With a field mill (high input resistance) charging voltages up to 1000 volts after a pre-breakdown can be measured. A further results was a different behaviour of board specimen with conventional surface and board specimen with smooth surface (the smooth surface was reached with a planing machine). Figure 8 shows the lightning impulse pre-breakdown onset voltage of conventional and smooth boards. A difference of about 25 percent is discernible. The reason lies in the bigger disturbance of the uniform electrical field of the rogowski-electrodes by the surface structure of the boards with conventionally surface. The smoother the surface the smaller the influence of the electrical field the higher the onset voltage.

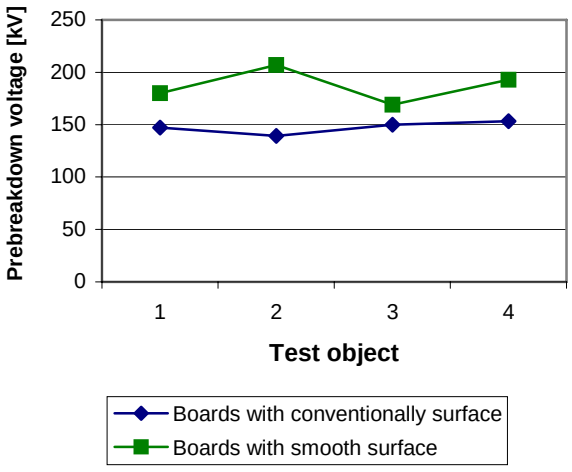


Figure 8: pre-breakdown onset voltage of board specimen

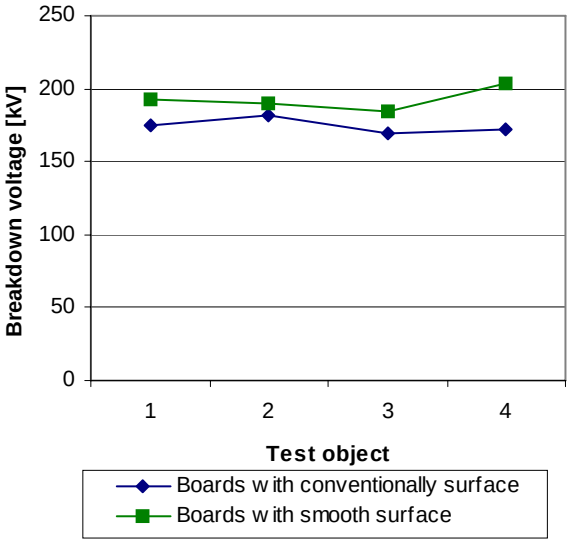


Figure 9: breakdown voltage of board specimen

The difference in the breakdown voltage between conventional and smooth board surface structure, figure 9, is smaller (about 10 percent) than the difference between the pre-breakdown onset voltage, figure 8.

## CONCLUSIONS

Oil-board-arrangements in electrical devices get stressed mainly with alternating current and lightning impulses. As the performed experiments with lightning impulses shows, prebreakdowns can occur in oil-board-arrangements even under uniform field conditions. These prebreakdowns generates bubbles and a charging of the board surfaces and influence the electrical strength of the oil-board-arrangement. With the conventional impulse measuring technique the prebreakdowns are not detectable. Possibilities of detection are optical detection or the charging measuring. Further the big influence of the board surface structure on the height of the prebreakdown onset voltage could be shown.

## REFERENCES

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[2] W. Lick: “Electrical strength of long breakdown distances in oil-board-dielectric” Doctoral Thesis, Graz, University of Technology, 2002.