Polarization- and Depolarization Behaviour of Various Oil Impregnated Paper Insulations Stressed by Very High DC Field Strength

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Abstract: The highest voltage required in HVDC power transmission lines has been rapidly increased in the last years. An often used insulation material is oil impregnated paper, which in practical use is winded around a conductor.
For these insulation systems DC tests are big challenges. Directly after the application of the test voltage the electrical field changes from a capacitive to an ohmic distribution. To estimate the electrical field strength in the insulating system by an ohmic distribution the conductivities of the materials is used. But the knowledge of the conductivity is in contrast to the knowledge of the AC behaviour of insulators low. It is known that the conductivity in insulating oil and oil impregnated paper is among others is a function of the time and as well of the field strength.
Therefore in this work oil-impregnated paper insulations are stressed by high DC and the polarization- and the depolarization current is measured. Different forms of oil-impregnated papers are compared. The conductivity behaviour between 10 sec and 2 hours is determined for field strength from 1kV/mm till 30kV/mm.

1 INTRODUCTION

Oil insulated systems like power transformers or bushing are optimized for AC Voltages. If the same system is stressed by a high DC Voltage their may be generated electrical field maxima in places which are not designed for such forces. To determine the electrical field distribution by AC the permittivity values of the materials are used. For DC the conductivities can be taken to estimate the field. The following setup (figure 1) is examined to clarify the contrast:

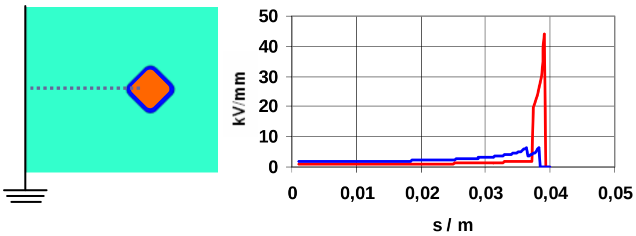

Figure 1: Orange: Electrical conductor on high voltage. Deep blue: Oil impregnated paper. Light blue: Oil. Left boundary: Zero potential.

The field strength on the grey line is shown on the right in the figure 1. The simulations are made with following values:

Table 1: Characteristic values for oil and oil impregnated paper

	relative permittivity	conductivity S/m
Oil	2,2	$1 \cdot 10^{-13}$
Oil impregnated paper	4	$1 \cdot 10^{-14}$

It is seen that the maximal field strength in the DC simulation is much higher then in the AC case. Another nature of the conductivity values is their nonlinearity over the time and the field strength among other in contrast to the permittivity values [1, 2]. This leads to the necessity to examine the conductivity behaviour depending on time and field strength.

2 PROBES AND TEST SETUP

Among others the conductivity of the oil and the oil impregnated paper is a function of the time and the electrical filed strength. To obtain more information about this behaviour an experimental test set up with oil impregnated paper is made. Satined paper is used in cables or windings systems of power transformers.In this experimental setup satined paper with a density of $1 g/cm^3$ is investigated (figure 2).

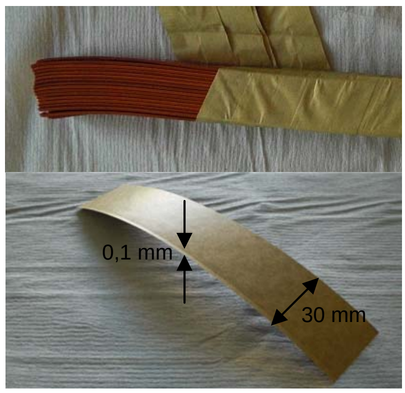

Figure 2: Above: Typical paper insulation.
Below: Satined paper which is used here.

It is important to know if the ducts between the paper bands affect the conductivity. Hence three types of paper lamination are compared (figure 3). First a complete blade is measured. Then one lamination with high density and another one containing ducts between the different bands is tested.

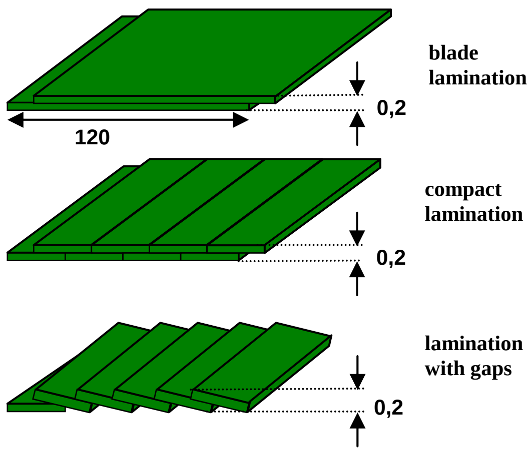

Figure 3: Three types of paper layers are compared. Above: Blade (BL), Centric: compact (CL), Below: lamination with gaps (LG)

The papers are piled into frames. This probe form is chosen to achieve a homogeneous electrical field. In this paper the electrical field strength is simplified to the ratio of the applied voltage U und the thickness of the complete paper lamination. So guessed higher field strength in the small gaps between the different layers is neglected.

The probes are put into a vacuum oven. They are dried 24h by 90°C and 1 mbar pressure. After that new insulator oil Shell Diala D is transported via pipeline into the oven to impregnate the probes. 24 h more are passed till the probes have a temperature of 20°C.

To measure the current exactly a guard ring setup is used. This guard ring setup is designed to be free of partial discharges up to 30 kV.

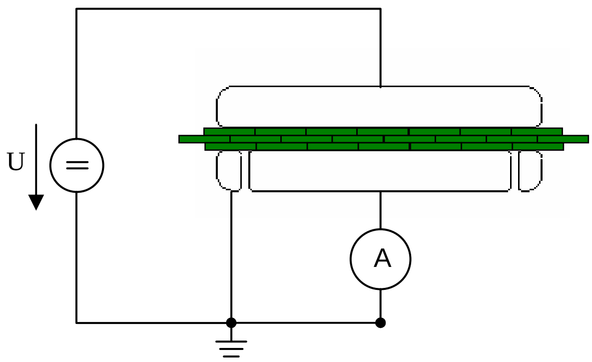

Figure 4: Optimized Guard ring setup for 30kV and paper probe.

3 POLARIZATION AND DEPOLARIZATION BEHAVIOUR

3.1 Measurements

All probes are assemblies of four layers as seen in figure 3. So the sickness of every probe is 0,8mm. The named field strength is the ration of the applied voltage and this 0,8mm probe thickness. The voltage has a rise time smaller than 3 seconds. In the first measurements the different lamination types are compared. The applied DC-Voltages are 8 kV and 800 V are applied to six different probes.

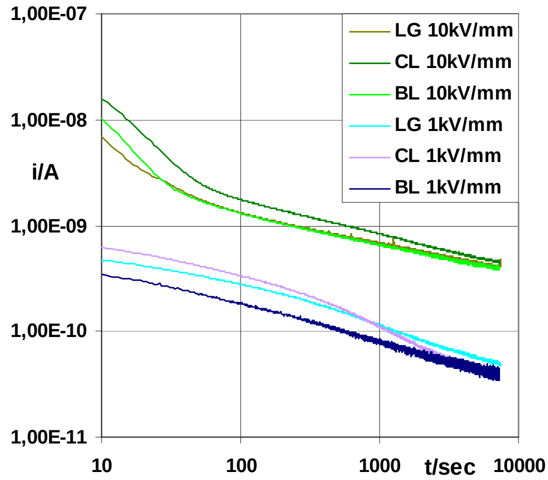

Figure 5: The different lamination types seem not to import the current.

It is obtained that the blade lamination (BL), the compact lamination (CL) and those with the gaps (LG) are very similar (figure 5). It is deducted that the main current flow is in the paper – not in the leakages or in the gaps. Interesting is the characteristic of the current curve with respect to the different field strength. For 10 kV/mm the curve seems to consist of two lines in the double-log-diagram. In contrast by 1kV/mm it is one straight with a little curvy character.

The next diagram points that the polarization and depolarization behaviour in the range 10 kV/mm till 30 kV/mm is similar:

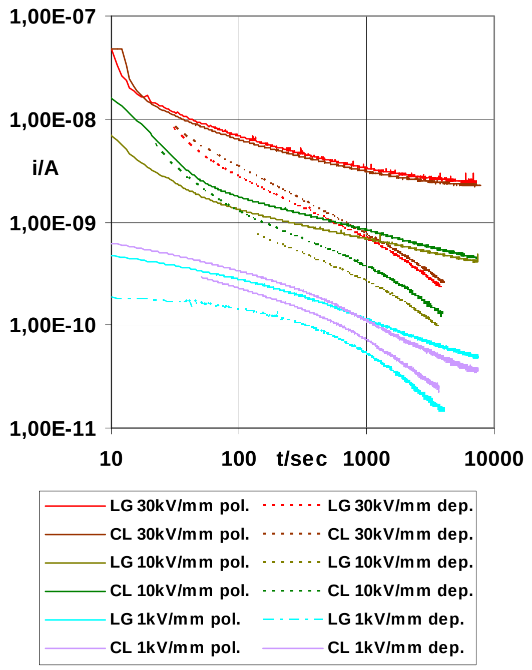

Figure 6: Polarization- and depolarization current for the compact lamination and the gap containing lamination by different field strength.

Only two differences can be seen for the current curves of the high field strength. By 30kV/mm after 2h a static value is reached. By 10kV/mm the change from the first line to the second line comes later.

The conductivity is in the same range for all applied field strengths from 1kV/mm to 30kV/mm.

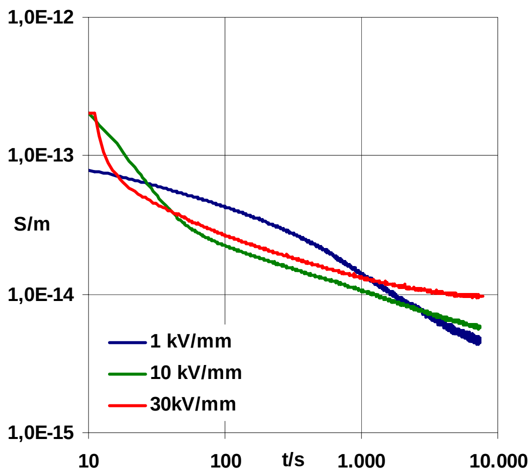

Figure 7: Conductivity for various field strengths.

3.2 RC-Model

The results of the satined paper bands without oil ducts (figure 9) are used to determine a RC-Model for the oil impregnated paper in the field strength range from 1kV/mm till 30 kV/mm for a time from 10 seconds to 3600 seconds.

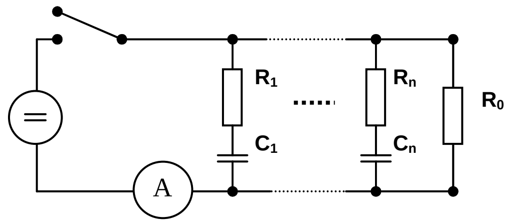

Figure 8: Model

Leg 1 till leg n represents the polarization- and depolarization current (PDC) between 10s and 1h. Leg 0 represents the lost. This can be seen as the difference between the polarization- and depolarization current. It should be equally to the static end value of the current.

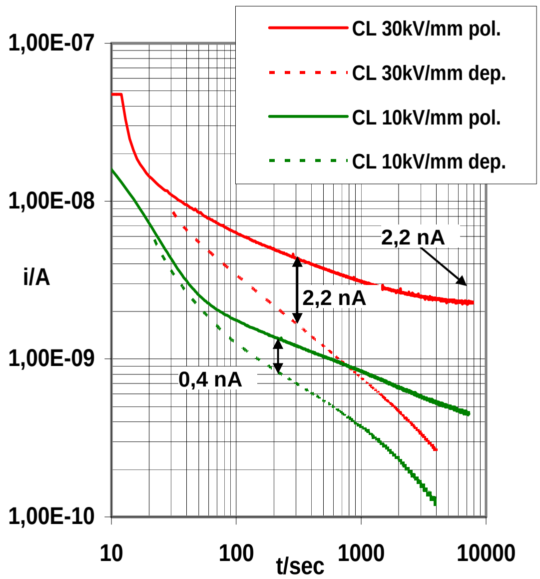

Figure 9: The polarization and depolarization current of the compact lamination used to develop a RC-Model.

In figure 9 is seen very clear a static end value of 2,2nA for the polarization current by 30kV/mm. The same current is obtained when the difference between the polarization and the depolarization current for the 30 kV/mm-curve is calculated. Another value for the R_0 is found by the current curve of 10kV/mm. So the lost seems to be lower by smaller field strength.

Furthermore the RC-legs are approached to the current curve of 30kV/mm field strength – shown in table 2:

Table 2: RC-Values of the RC-Modell

	1	2	3	4	5	6
R/($10^{12}\Omega$)	0,039	2	8,43	10,4	22,7	29,9
C/pF	80	12,2	9,6	25,9	33,4	119

At least the found model is compared to a measurement. In this measurement 16kV are applied to the blade probe. Here should be remembered that the model was determined by paper bands and 24 kV (respective 30kV/mm). In figure 11 is seen that still differences are present but altogether model works:

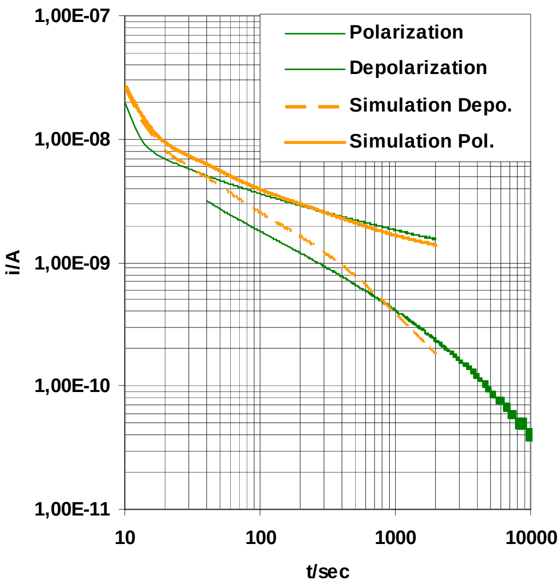

Figure 11: Simulation against measurement.

The typical characteristics are reproduced well by the model. R_0 is set to $15{\cdot}10^{12}\ \Omega$ because of the dependence to the field strength.

4 CONCLUSION

This paper shown the conductivity of oil impregnated paper stressed by high DC-Voltage is a function oft the electrical field strength. It has been proposed a behaviour model based on measurements. Different structures have been compared. It is shown that the influence of the leakages between the paper bands to the current seems to be small. It is highlighted that the existence of a static end value of the conductivity also depends on the electrical field strength.

As well these insights induce new questions like the influence of chemical properties to the curve forms of the current or the existing of a static current end value. Furthermore it should be examined if theses results can be adapted to other types of insulating papers.

5 REFERENCES

[1] A. Küchler: “Hochspannungstechnik”, Springer-Verlag Heidelberg, 2009

[2] Bayer, Boeck, Möller, Zaengl: “Hochspannungstechnik”, Springer-Verlag Berlin, 1986