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NEW DIAGNOSTIC TOOLS FOR HIGH VOLTAGE BUSHINGS

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Abstract: Dielectric response measurements in the frequency domain (FDS) or in the time domain (PDC) are applied to transformer insulation to determine the water content in the cellulose. These methods can be applied also for high voltage bushings with good success. Measurement results of Oil Impregnated Paper (OIP), Resin Impregnated Paper (RIP) and Resin Bonded Paper (RBP) bushings are presented for new and aged bushings and limits for the assessment are discussed. Practical examples illustrate the importance and the efficiency of capacitance and dissipation factor and particularly dielectric response measurements on high voltage bushings.

1 INTRODUCTION

High voltage bushings are essential parts of power transformers, circuit breakers and of other power apparatus. More than 10 % of all transformer failures are caused by defective bushings. A bushing failure can damage a transformer completely. Therefore a regular diagnostic measurement is essential for a safe operation of transformers.

2 MEASUREMENT OF DIELECTRIC LOSSES

The measurement of the capacitance and the dissipation or power factor is very common since many decades. It was performed at line frequency normally. Table 1 shows the 50/60Hz limits for DF/PF and Partial Discharges (PD) according to IEC 60137 and IEEE C57.19.01

Type	RIP	OIP	RBP
Main insulation	Resin impregnated paper	Oil impregnated paper	Resin bonded paper
DF tan δ (RT) (IEC 60137)	< 0,7% *	< 0,7% *	< 1,5% *
PF cos φ (RT) IEEE C57.19.01	< 0,85% *	< 0,5% *	< 2% *
Typical new values	0.3-0.4% *	0.2-0.4% *	0.5-0.6% *
PD (IEC 60137) Um 1.5 Um/√3 1.05 Um/ √3	 < 10pC < 5cC < 5pC	 < 10pC < 5pC < 5pC	 < 300pC

*** at 1.05 Um/√3 and 20°C / 70° F**

Table 1: Limits and typical DF and PD values

Manually balanced bridges like the Schering bridge or transformer bridges were used in the first beginning. Later the balance of the bridge was automated by a microprocessor. These solutions are good for measuring at certain frequencies. Modern electronics enable the measurement of the Dielectric Response of the insulation that means the measurement of losses over a wide frequency range. This delivers much more information about ageing, moisture and also faulty contacting of measuring taps and capacitive layers. The principle of a typical measurement circuit is shown in figure 1.

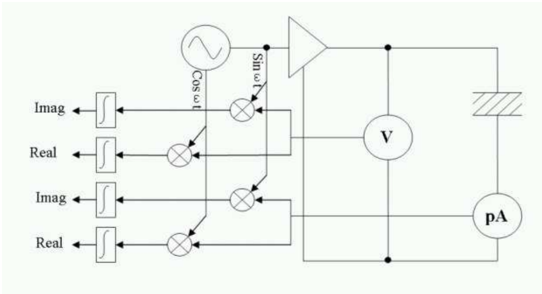

Figure 1: Measurement circuit for automated Dielectric Response measurement

By multiplying the small measured current through the test object with the generated high voltage sin ωt and cos ωt signals and a digitally filtering of the 2ωt AC component, an excellent filtering of the line frequent noise with over 110dB can be realized. Modern instruments are using digital electronics and switched mode amplifiers for generating the test voltages [1]. In figure 2 the bushings of a big power transformer are measured from 15-400Hz with the described system under heavy electromagnetic interference without any problems.

Figure 2: On-site Dielectric Response measurement of HV bushings from 15 to 400Hz

3 MEASUREMENT OF DIELECTRIC RESPONSE ON NEW RIP, RBP AND OIP BUSHUNGS

In figure 3 the tanδ curves of new RIP, RBP and OIP high voltage bushings are shown. The frequency range is 15 to 400Hz, the test voltage is 2kV.

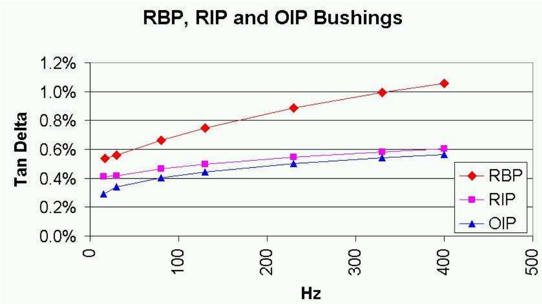

Figure 3: Dielectric Response of new RIP, RBP and OIP bushings

The curves are rather flat, the minimum of the curves is below the lowest test frequency of 15Hz. The values at 50Hz are fulfilling the limits in table 1. In figure 4 a RIP bushing can be seen, which was stored outside without any protection of the oil side.

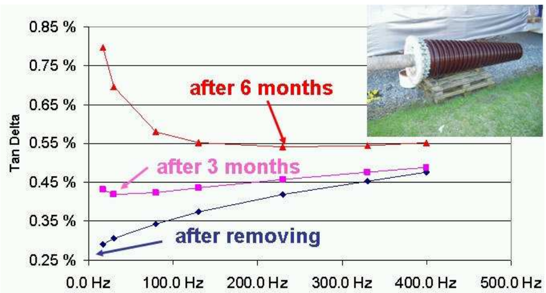

Figure 4: Dielectric Response of a RIP bushing exposed to moisture

The non protected oil side was getting humid during the months and the change of the tan delta can be seen clearly. The moisture increases the tan δ particularly at low frequencies, the minima of the tan δ curves are shifted to higher frequencies with increasing moisture content.

4 CASE STUDIES OF DIAGNOSTIC MEASUREMENTS ON RIP, RBP AND OIP BUSHINGS

The described measurement principle using frequencies between 15 and 400Hz was applied for diagnostic measurements on RIP, RBP and OIP bushings.

4.1 Diagnostic Measurements on a RIP bushing

Normally silicon type RIP bushings have a fiber glass tube which has two functions: it gives the mechanical stability and prohibits that moisture can get into the resin active part. In the 80's some manufactures made bushings up to 245kV without such fiber glass tubes. The silicon was directly put on the resin active part. On those bushings water can diffuse into the active part from outside over the years. This can cause a breakdown of the bushing. In figure 5 the blue curve shows a measurement on a bushing of the described design with high moisture in the active part whereas the red curve is the result of the same kind of bushing without moisture. At low frequencies the differences are most obvious.

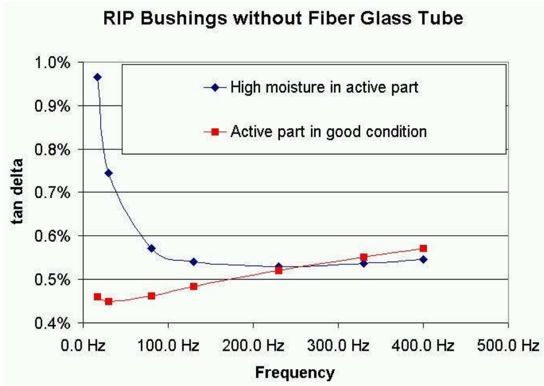

Figure 5: RIP bushings without fiber glass tube

4.2 Diagnostic Measurements on a RBP bushing

A Resin Bonded Paper 123 kV bushing showed a conspicuous Dielectric Response (figure 6, red curve, phase C). The blue curves was measured on the A phase bushing.

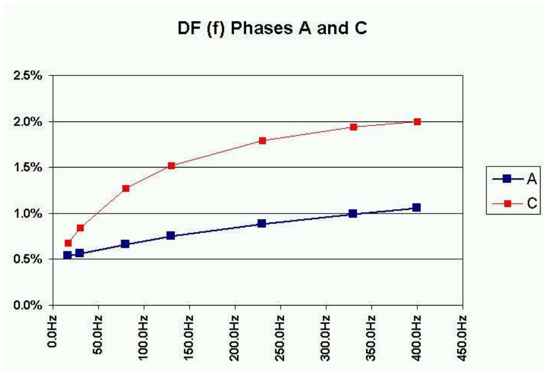

Figure 6: Conspicuous Dielectric Response from a RBP bushing

The strong increase of the tan δ curve for high frequencies is obvious. The bushings were tested afterwards at line frequency and voltages between 2 and 12kV (figure 7). In this diagram the tan δ curve starts with rather high losses and goes down for higher test voltages. This behaviour is known for bad contacts either on the measuring tap or on the contacting of capacitive layers. The bushing was removed from the transformer and dissembled. The measuring tap was well contacted but the inner capacitive layer had no contact to the conductor tube.

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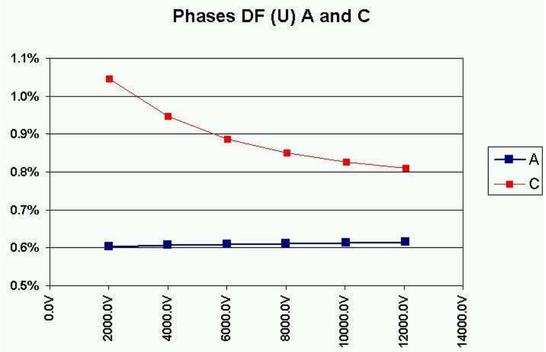

Figure 7: Bad contact of the inner capacitive layer.

Bad contacts can rise the inner insulation temperature. So the exchange of the bushing was the right decision.

4.3 Diagnostic Measurements on OIP bushings

33kV OIP bushings were exchanged because the tan δ was high at high temperatures. It was assumed that the inner insulation of the bushings was wet. Figure 8 shows the DF of OIP bushings at 50Hz for different water contents as f(T) [2].

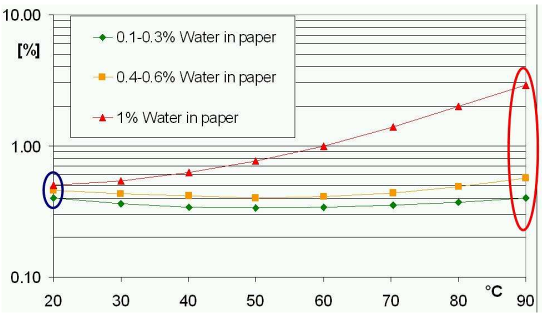

Figure 8: Different moisture: tan δ (T) at 50Hz

The new and the old bushings were tested at 30°C from 15 to 400Hz. High differences could be measured particularly at low frequencies (figure 9).

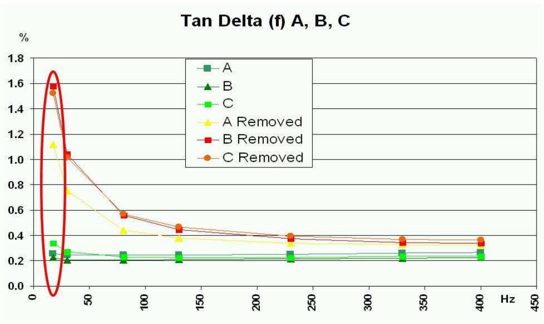

Figure 9: Different moisture: tan δ (f) at 30°C

This example shows very clearly that the tan δ measurement at low frequencies can detect water with high sensitivity.

5 FDS AND PDC MEASUREMENTS ON BUSHINGS

The measurement of losses can be done in the frequency domain FDS (Frequency Domain Spectroscopy) or in the time domain PDC (Polarization Depolarization Current). The data can be transformed from the time domain into the frequency domain and vice versa. The FDS measurement covers the whole frequency range from high frequencies down to very low frequencies, but measurements at low frequency need a long measuring time, whereas the PDC is much faster but can only measure up to about 1Hz. A new approach uses the advantage of both methods and measures the frequencies from 5kHz down to 0.1 Hz with the FDS and 0.1Hz down to 1mHz or even lower with the PDC. The PDC data are transformed into the frequency domain and showed as tangent delta values [3]. Figure 10 shows the principle of the combined FDS-PDC measurement and Figure 11 the Dielectric Response Analyser (DIRANA) with the measurement arrangement. The bushing is shielded with a Aluminium tube to reduce the interference because the measured currents for RIP and OIP bushings can go down to values below 1pA.

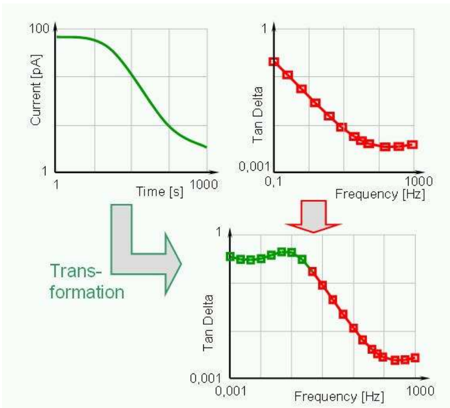

Figure 10: Combined PDC-FDS measurement

Figure 11: Combined FDS-PDC measurement on a RIP bushing with an Aluminium shield for interference protection

In figure 12 typical FDS-PDC results for RBP, RIP and OIP bushings are shown [4].

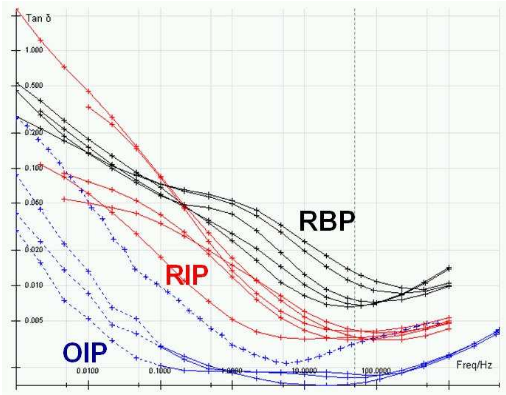

Figure 12: FDS-PDC results for RBP, RIP and OIP bushings.

The temperature influences the results. With increasing temperature the losses at very low frequencies are increased, whereas the losses at higher frequencies are getting lower and the minimum of the loss curve is shifted to the higher frequencies. This has to be taken into account if FDS-PDC results are compared The measurement in figure 13 was performed on a RIP bushing.

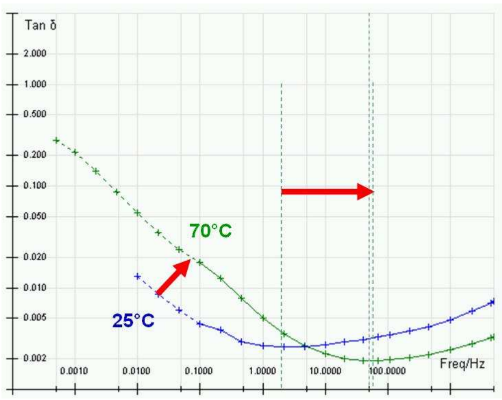

Figure 13: Temperature influence on FDS-PDC curves

5.1 Experiments with a MICAFIL RIP bushing

A MICAFIL RIP bushing was exposed to different moisture and temperature in a climate chamber. The experiment was started at 20° and 38% Relative Humidity (RH). The second day the bushing was heated up to 70°C with a RH of 10% (green curve in figure 14). The next days the bushings was exposed to high RH up to 80% at 70°C. After the 9th day the pink curve was measured at 80%RH and 70°C. On the 10th day the moisture was reduced to 10% again. The red curve was measured during the 12th day with 10% RH at 70°C. The moisture still stays in the resin surface. A last measurement was made on the 13th day. The tan δ values for frequencies above 10Hz are more or less identical, whereas the values at low frequencies still show the evidence of moisture.

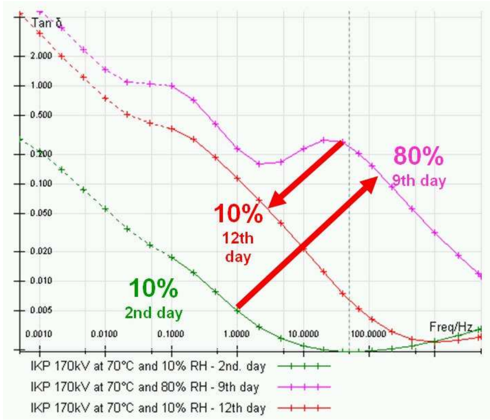

Figure 14: RIP bushing at different moisture

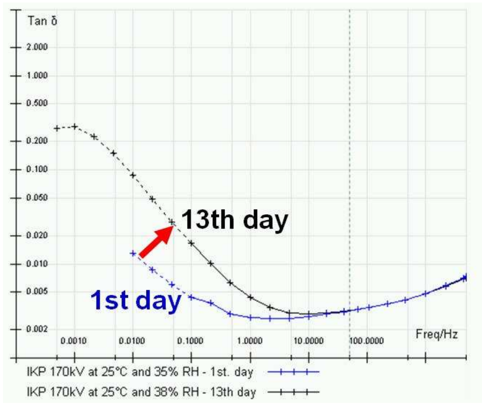

Figure 15: RIP bushing after 13 days

6 DRYING OF RBP AND RIP BUSHINGS

The bushings come normally in a wooden box with some Silicagel in a small bag. A lot of bushings are stored in those boxes for many years, some of them in a humid environment. The bushing is protected against penetrating water on the outdoor side, but on the oil side they are not protected. On this side the resin surface can be damaged by incoming water. In figure 16 the difference between a proper resin surface and a surface which is damaged by water is shown.

Figure 16: Resin surface damaged by water

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Bushings with those damaged surfaces shouldn't be used again [5].

7 CASE STUDIES OF DRYING ON RBP AND RIP BUSHINGS

7.1 145kV RBP oil-oil bushing

The 145kV RBP bushing shown in figure 17 was stored in the original box in a cavern for 30 years.

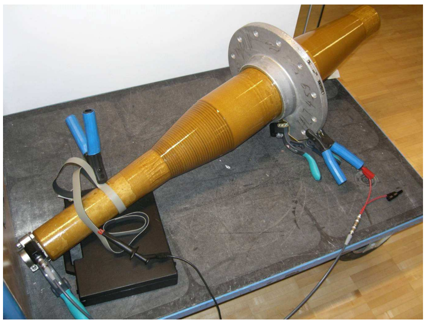

Figure 17: Wrongly stored RBP bushing

The 50Hz tan δ value was 30%! The bushing was additionally measured with FDS-PDC (figure 18). An experiment was carried through with drying this bushing in an oven at 60°C for 12 weeks. The result can be seen in figure 19.

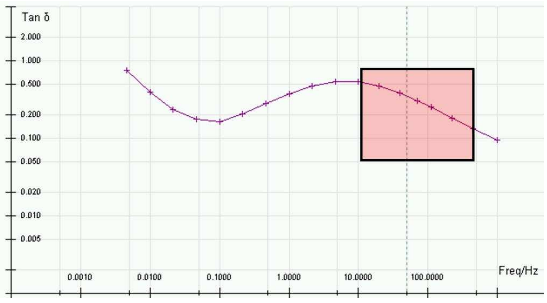

Figure 18: FFS-PDC measurement on the 145kV bushing

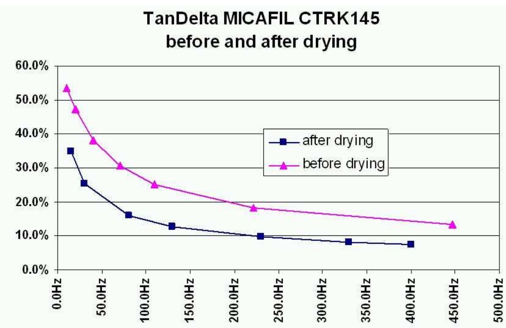

Figure 19: 145kV RBP bushing before and after drying

After the drying period of 12 weeks the measurement still shows a tan δ value of more than 20%. Bushings with such high tan δ values can't be used again.

7.2 45kV RBP oil-air bushings

Also these bushings were stored in the original wooden box. Figure 20 shows the FDS-PDC measurement results on three non dried bushings and one that was dried in an oven for one week.

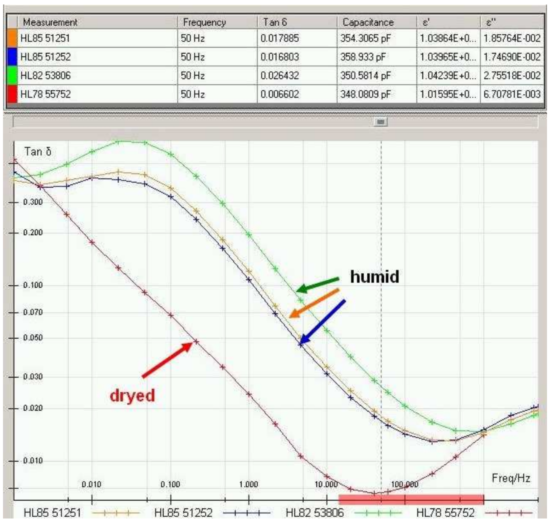

Figure 20: Drying of 45kV RBP bushings

By drying the one bushing a clear improvement can be seen. The 50Hz tan δ value went from more than 2% down to 0.66% which is acceptable.

7.3 145kV RBP oil-air bushing

A 145kV oil-air bushing was dried in an oven for 12 weeks at 60°C. Figure 21 shows the results before and after drying.

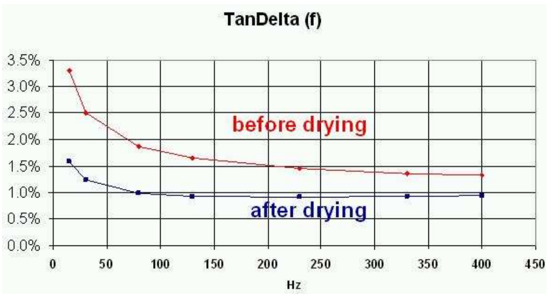

Figure 21: Dielectric Response before and after drying

The 50Hz tan δ value was reduced from 2.2% before to 1.1% after drying. This value is still rather high. A Partial Discharge PD measurement was performed to check, if there were cracks in the resin due to the drying procedure (figure 22).

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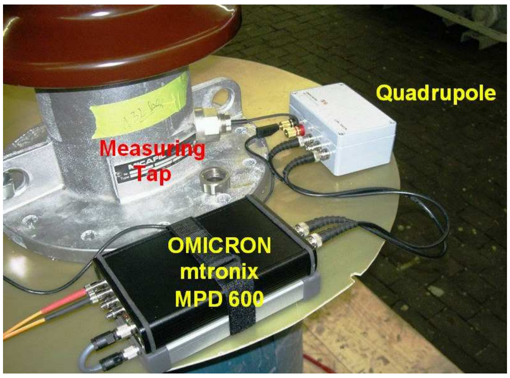

Figure 22 shows the PD instrument and the Quadrupole connected to the measuring tap of the bushing

First a PD measurement was made without using the 3 Centre Frequency Relation Diagram (3CFRD). The sum of all PD signals can be seen in figure 23. This way a pattern recognition is impossible.

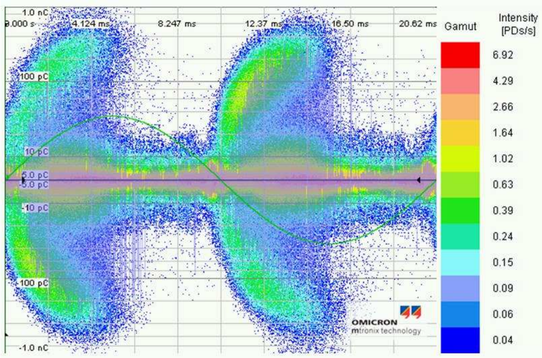

Figure 23: PD measurement without 3CFRD

With the 3CFRD PD measurements are done simultaneously at 3 different centre frequencies, in this case 500kHz, 2.8MHz and 8MHz. With this technique PD signals from different PD sources can be separated from each other and from interference coming from outside (figures 24 and 25). This way also the PD intensity of the single PD sources can be measured.

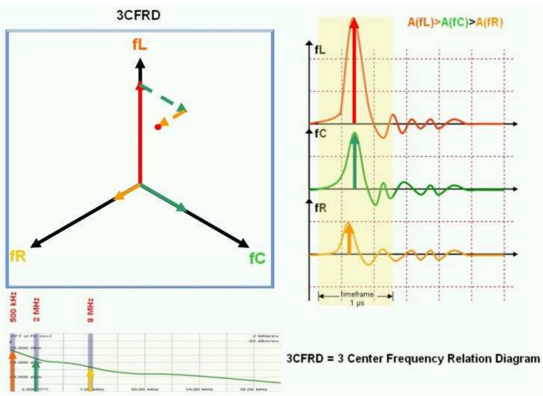

Figure 24: 3CFRD (3 Centre Frequency Relation Diagram)

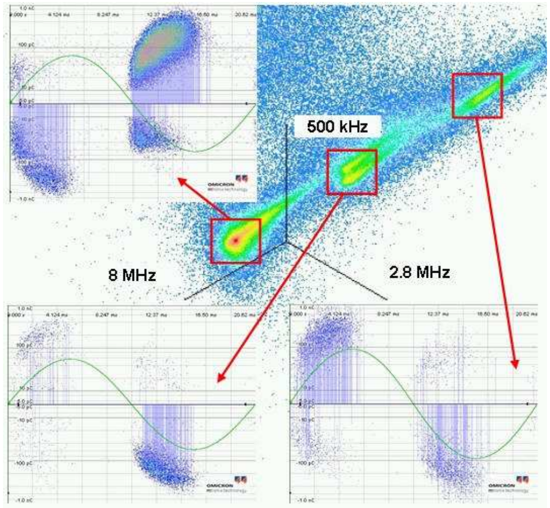

Figure 25: Separation of PD sources with 3CFRD

Due to the high tan δ values and the high PD intensity of more than 1nC is was decided not to use this bushing any more.

8 SUMMARY

Modern technologies enable a very effective diagnostic of high voltage bushings. The Dielectric Spectroscopy is a very promising method to detect ageing and water in the insulation with high sensitivity. With the 3CFRD PD technology also single PD faults can be analyzed and a much better analysis of PD faults is possible.

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