Diagnostic Measurements and Condition Assessment of High Voltage Bushings

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Dr. Michael Krüger, OMICRON
Cigre A2.37 Transformer Failure Statistics
22,000 grid transformers with 150,000 service years

Causes for transformer breakdowns

Bushings = 17,16 %

Tenbohlen et. al.: „ DEVELOPMENT AND RESULTS OF A WORLDWIDE TRANSFORMER RELIABILITY SURVEY“ CIGRE SC A2 COLLOQUIUM 2015, Shanghai
Cigre A2.37 Transformer Failure Statistics

External effects of bushing failures

- Fire 30%
- Explosion, Burst 10%
- Others 7.83%
- Leakages 5.22%
- None 45.22%
- Collateral Damages 0.87%

Tenbohlen et al.: "DEVELOPMENT AND RESULTS OF A WORLDWIDE TRANSFORMER RELIABILITY SURVEY" CIGRE SC A2 COLLOQUIUM 2015, Shanghai
Transformer Oil-Oil Bushings
Transformer Oil-Gas Bushings

<table>
<thead>
<tr>
<th>EKTG</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Transformer Bushing (Oil–Gas)</td>
</tr>
<tr>
<td>Voltage Range</td>
<td>52 kV–1000 kV</td>
</tr>
<tr>
<td>Current Range</td>
<td>Up to 4000 A</td>
</tr>
<tr>
<td>Design</td>
<td>RIP condenser core</td>
</tr>
</tbody>
</table>

Source: HSP Germany
LV Bushings of GSU Transformers

Technical Data:

\[ U_r = 36 \text{ kV} \]

\[ I_r = 17 \text{ kA} \]
Outdoor GIS-Air Bushings

400kV GIS Substation, Vorarlberger Illwerke, Buers Austria

Source: HSP Germany
Wall Bushings
# Generator Bushings

<table>
<thead>
<tr>
<th>EMH/EKMI</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Generator Bushing (Air–Air)</td>
</tr>
<tr>
<td>Voltage Range</td>
<td>12 kV–36 kV</td>
</tr>
<tr>
<td>Current Range</td>
<td>Up to 36000 A</td>
</tr>
<tr>
<td>Design</td>
<td>RIP condenser core</td>
</tr>
</tbody>
</table>

![EMH and EKMI bushings](image)
Insulation Systems of High Voltage Bushings

RBP Resin Bonded Paper

RIP Resin Impregnated Paper

OIP Oil Impregnated Paper
# Insulation Systems of High Voltage Bushings

<table>
<thead>
<tr>
<th>Recommended measures</th>
<th>Time schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual check – leakage and mechanical damage</td>
<td>In case of maintenance work</td>
</tr>
<tr>
<td>Measurement of capacitance and dielectric dissipation factor</td>
<td>- after installation as reference for later measurements (fingerprint)</td>
</tr>
<tr>
<td></td>
<td>- 10 years after commissioning</td>
</tr>
<tr>
<td></td>
<td>- dependend on results after each 5 years (uncritical values) or shorter</td>
</tr>
</tbody>
</table>

Source: B. Heil (HSP Troisdorf, Germany), „Diagnose und Bewertung von Durchführungen“, OMICRON AWT Germany 2010
## Share of Products

<table>
<thead>
<tr>
<th>Product</th>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OIP</td>
<td>65-70%</td>
<td>Oil Impregnated Paper</td>
</tr>
<tr>
<td>RBP</td>
<td>(gering)</td>
<td>Resin Bonded Paper</td>
</tr>
<tr>
<td>RIP</td>
<td>30%-35%</td>
<td>Resin Impregnated Paper</td>
</tr>
<tr>
<td>Neu RIS</td>
<td>0%</td>
<td>Resin Impregnated Synthetics</td>
</tr>
</tbody>
</table>

Source: MICAFIL
Resin Impregnated Synthetics (RIS)

- Craped paper is replaced by a open synthetic textile
- Textile can be impregnated with a filled resin with high viscosity (filler = Aluminiumoxide or Siliciumoxide)
- Filled resin systems are proven to be reliable for use in HV applications for several 10 years
- Improved thermal conductivity and mechanical strength
- No long drying period needed
- Reduced manufacturing time and costs
- **Available up to 170kV today**

Source: MICAFIL
High Voltage AC Test in the Factory
Lower Part in a Oil Filled Vessel

Source: MICAFIL
Capacitive Bushings (1)

$E_{\text{max}} =$ high

without capacitive layers

$E_{\text{max}} =$ smaller

with capacitive layers

Earthing Cap
Capacitive Bushings (2)

Aluminium foil
Paper
Aluminium foil
Conductor

Aluminium foils with equal areas
Capacitive Bushings (3)

Current at the Measurement Tap

50Hz $\rightarrow I_C = U \omega C = 10 \ldots 100mA$

$BIL \ 1.2\mu\text{s} \rightarrow I_C = C \frac{dU}{dt} = 200A$
Capacitive Bushing of a 123kV CT
Measuring and Voltage Tap

**Fig. 4:** Power Factor Tap
1. Closing and grounding cap
2. Measurement electrode
3. Insulation tap
4. Gasket
5. Tap flange
6. Bushing flange
7. Last layer

**Fig. 5:** Voltage Tap
1. Closing and grounding cap
2. Measurement electrode
3. Insulation tap
4. Gasket
5. Filling plug
6. Bushing flange
7. Connection to internal layer
8. Tap external housing

Source: Passoni & Villa
Bushing Measuring Tap
Measuring Taps

ABB

MICAFIL
Measuring Taps
Measuring Taps
Arcing at the Measurement Tap

Source: Norbert Koch „Diagnoseverfahren an Hochspannungsdurchführungen aus Herstellersicht“, Diagnoseverfahren an Schaltanlagen und Transformatoren, HdT Essen 2013
Partly Burned Measurement Tap of a 245kV-RIP Busing

Source: Hubert Goebel GmbH
Partly Burned Measurement Tap of a 400kV-OIP Busing

Source: Hubert Goebel GmbH
## Diagnostic Methods

<table>
<thead>
<tr>
<th>Type of Fault</th>
<th>Diagnostic Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>OIP 5  RBP 5  RIP 5</td>
</tr>
<tr>
<td>Ageing</td>
<td>OIP 4  RBP 4  RIP 4</td>
</tr>
<tr>
<td>Contact problems and high impedance faults between layers</td>
<td>OIP 5  RBP 5  RIP 5</td>
</tr>
<tr>
<td>Shorted grading layers</td>
<td>OIP 5  RBP 5  RIP 5</td>
</tr>
<tr>
<td>Leakage</td>
<td>OIP 5  RBP 5  RIP 5</td>
</tr>
<tr>
<td>Partial discharges</td>
<td>OIP 5  RBP 5  RIP 5</td>
</tr>
</tbody>
</table>

### General
- **Type of Fault**: Moisture, Ageing, Contact problems and high impedance faults between layers, Shorted grading layers, Leakage, Partial discharges
- **Diagnostic Technique**: OIP, RBP, RIP

### Visual Inspection
- **Type of Fault**: Moisture, Ageing, Contact problems and high impedance faults between layers, Shorted grading layers, Leakage, Partial discharges
- **Diagnostic Technique**: OIP, RBP, RIP

### Thermography
- **Type of Fault**: Moisture, Ageing, Contact problems and high impedance faults between layers, Shorted grading layers, Leakage, Partial discharges
- **Diagnostic Technique**: OIP, RBP, RIP

### Electrical Basic
- **Type of Fault**: Capacitance
- **Diagnostic Technique**: OIP, RBP, RIP

### Capacitance
- **Type of Fault**: DF/PF
- **Diagnostic Technique**: OIP, RBP, RIP

### Electrical Advanced
- **Type of Fault**: Dielectric Response with FDS / PDC
- **Diagnostic Technique**: OIP, RBP, RIP

### Partial discharge measurement
- **Type of Fault**: Dissolved gas analysis, Moisture in oil
- **Diagnostic Technique**: OIP, RBP, RIP

### Oil
- **Type of Fault**: DF/PF, Conductivity of oil (IEC 61620), Particles in oil, Analysis of Furanic components, Test for corrosive Sulfur
- **Diagnostic Technique**: OIP, RBP, RIP

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1=very good, 2=good 3=fair 4=poor 5=not applicable
*big leakages can be detected with hot collar test  **DF/PF from 2-12kV
Fig. 13. Measurement indicating poor current path between bushing inner and outer terminal.
C-Tan δ Progression of a Bushing

C Tan-Delta Progression of a 220 kV RBP (Hard Paper) Bushing
Year of Manufacturing 1961, horizontal mounted, oil filled

- Date of Measurement
- Tan Delta x 10^-3
- Change of Capacitance %

Source: RWE

Source: Volker Seitz: „Vorbeugende Instandhaltung an Leistungstransformatoren“, OMICRON Anwendertagung 2003, Friedrichshafen
Bushing Fault

Source: Volker Seitz: „Vorbeugende Instandhaltung an Leistungstransformatoren“, OMICRON Anwendertagung 2003, Friedrichshafen
Fault Mechanisms and Diagnosis

- Partial breakdowns
  - Measurement of capacitance
  - TanDelta measurement
  - PD measurement

- Voids, cracks
  - Measurement of capacitance (RBP)
  - PD measurement

- Contact problems on measurement taps
  - Tan Delta voltage sweep (tip-up test)

- Ageing, moisture
  - Dielectric response measurements
  - TanDelta

<table>
<thead>
<tr>
<th>Voltage [kV]</th>
<th>No. of layers</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>123</td>
<td>14</td>
<td>7.1</td>
</tr>
<tr>
<td>245</td>
<td>30</td>
<td>3.3</td>
</tr>
<tr>
<td>420</td>
<td>40</td>
<td>2.5</td>
</tr>
<tr>
<td>550</td>
<td>55</td>
<td>1.8</td>
</tr>
</tbody>
</table>
Definitions of Dielectric Losses

Dielectric losses are caused by

- Conductive losses
- Polarization losses
- Partial discharges

DF: \( \tan \delta = \frac{|I_{RP}|}{|I_{CP}|} = \frac{1}{R_p \cdot \omega \cdot C_P} \)

PF: \( \cos \varphi = \frac{|I_{RP}|}{|I_{tot}|} \)

DF: \( \tan \delta = \frac{U_R}{U_C} = R_s \cdot \omega \cdot C_s \)

PF: \( \cos \varphi = \frac{U_R}{U_{tot}} \)
### Standards

<table>
<thead>
<tr>
<th>Type</th>
<th>RIP</th>
<th>OIP</th>
<th>RBP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main insulation</td>
<td>Resin impregnated paper</td>
<td>Oil impregnated paper</td>
<td>Resin bonded paper</td>
</tr>
<tr>
<td>DF / tan delta (20°C, IEC60137)</td>
<td>&lt; 0.7 %</td>
<td>&lt; 0.7 %</td>
<td>&lt; 1.5 %</td>
</tr>
<tr>
<td>PF cos phi (20°C, IEEE C57.19.01)</td>
<td>&lt; 0.85 %</td>
<td>&lt; 0.5 %</td>
<td>&lt; 2 %</td>
</tr>
<tr>
<td>Typical new values</td>
<td>0.3-0.4 %</td>
<td>0.2-0.4 %</td>
<td>0.5-0.6 %</td>
</tr>
<tr>
<td>PD (IEC60137) at $U_m$</td>
<td>&lt; 10 pC</td>
<td>&lt; 10 pC</td>
<td>&lt; 300 pC</td>
</tr>
<tr>
<td>1.5 $U_m / \sqrt{3}$</td>
<td>&lt; 5 pC</td>
<td>&lt; 5 pC</td>
<td></td>
</tr>
<tr>
<td>1.05 $U_m / \sqrt{3}$</td>
<td>&lt; 5 pC</td>
<td>&lt; 5 pC</td>
<td></td>
</tr>
</tbody>
</table>
### Table 40: Indicative DF/PF Limit Values for Condenser Bushings

<table>
<thead>
<tr>
<th></th>
<th>RIP Resin impregnated</th>
<th>OIP Oil impregnated</th>
<th>RBP Resin bonded paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>new</td>
<td>new</td>
<td>new</td>
</tr>
<tr>
<td>15Hz</td>
<td>&lt;0.6%</td>
<td>&lt;0.5%</td>
<td>&lt;0.7%</td>
</tr>
<tr>
<td>50/60Hz</td>
<td>&lt;0.5%</td>
<td>&lt;0.4%</td>
<td>&lt;0.6%</td>
</tr>
<tr>
<td>400Hz</td>
<td>&lt;0.6%</td>
<td>&lt;0.5%</td>
<td>&lt;0.7%</td>
</tr>
</tbody>
</table>

At 20°C
RBP - Bushings

- Not free of cavities – Partial Discharges possible also at rated voltage

- Higher dielectric losses can feed to thermal instability

- RPB has cavities and cracks in the paper which are normally filled with the surrounding oil

- Increase of capacitance

- After a longer storage period this oil is running out. The PD level is increasing and the capacitance is getting smaller
RBP – Bushings Cracks in the Insulation
Measurement on 220kV RBP Bushings (1971)
TanDelta 15-400Hz

DF (f) A, B, C

Frequency (Hz)

0.0 Hz  50.0 Hz  100.0 Hz  150.0 Hz  200.0 Hz  250.0 Hz  300.0 Hz  350.0 Hz  400.0 Hz  450.0 Hz

Percentage

0.0 %  0.2 %  0.4 %  0.6 %  0.8 %  1.0 %  1.2 %

Legend:
- A
- B
- C
RBP Bushing Oil-Filled Cracks
Oil Ingress by Capillare Effect
RBP Bushing 123kV (1963)

Influence of Moisture
Micafil UTXF 24 (Drysomic) RBP Bushings

A, B, N humid after wrong storage
C dried
Micafil UTXF 24 RBP Bushings
A, B, N never used, wrongly stored, C dried

DF (f) A, B, C, N

- A
- B
- C
- N

Dried and humid conditions are indicated in the graph.
Micafil UTXF 24 FDS Messung
RBP Bushing 123kV
RBP Bushing 123kV

PF (f) A, B, C

- A
- B
- C

0.0Hz, 50.0Hz, 100.0Hz, 150.0Hz, 200.0Hz, 250.0Hz, 300.0Hz, 350.0Hz, 400.0Hz, 450.0Hz
RBP Bushing 123kV

Bushing has to be exchanged

defective contact on the measuring tap or
defective connection between the innermost layer and the HV conductor or
partial breakdown between layers
Measurement Tap O.K.
Innermost Layer was not Properly Connected to the HV Conductor.
123kV RBP Bushing
Dissipation Factor Measurement

![Graph showing dissipation factor measurement over different frequencies for A, B, and C.]

- **DF (f) A, B, C**
- Frequency ranges from 0.0 Hz to 450.0 Hz.
- Dissipation factor ranges from 0.0% to 8.0%.
- Different symbols and colors represent A, B, and C.

**Legend:**
- **A** (blue line with square markers)
- **B** (red line with triangle markers)
- **C** (yellow line with circle markers)
Measurement of the Removed Bushing
Measurement of the Removed Bushing

DF (f)

0,0%  2,0%  4,0%  6,0%  8,0%  10,0%  12,0%  14,0%  16,0%
0,0Hz  50,0Hz  100,0Hz  150,0Hz  200,0Hz  250,0Hz  300,0Hz  350,0Hz  400,0Hz  450,0Hz

C1
Faulty Contact on a Head Connection
245kV RBP Bushing

Source: Hubert Goebel GmbH
Faulty Contact on a Head Connection
245kV RBP Bushing

Source: Hubert Goebel GmbH
OIP Bushings

- Paper of the OIP bushings ages particularly at high temperatures
- Through aging the dielectric losses will increase -> this increases the power factor
- Temperature dependent aging decomposes the Paper and produces additional water -> this accelerates the aging
OIP Bushings Winding Machine

Source: Trench Brochure „OIP Transformer Outdoor Bushings“
Assessment of 50/60Hz C-Tanδ Results (OIP)

Source: Proposal from OMICRON, GÖBEL and HSP for the Cigre Working Group A2.43 „Reliability of HV Bushings“
Tan δ Dependency on the Temperature

Relative tanδ as function of temperature

C-Tan $\delta$ Dependency on the Temperature

Limits für Measurement Results

a) Capacity:
Voltage Level / Change of Capacitance

$\geq 245$ kV  2.3 %
$\geq 362$ kV  1.7 %
$\geq 420$ kV  1.5 %
$\geq 550$ kV  1.3 %
$> 550$ kV  0.8 %

b) tan delta

*Normal values are between 0.2 % and 0.4 %*

The Temperature Influence can be neglected between 20°C bis 70°C.

*Values between 0.4 % and 0.5 %: $\rightarrow$ Contact HSP*

*Values > 0.55 % can be an indicator for an internal problem and should be investigated by a DGA*

Source: HSP Manual
Breakdown in a OIP Bushing
OIP Bushing Fault

Source: Hubert Goebel GmbH
OIP Bushing Fault

Source: Hubert Goebel GmbH
OIP Bushing
at the Sharp Edge of the Foil

Source: Hubert Goebel GmbH
OIP Bushing

Source: Hubert Goebel GmbH
33kV OIP Bushings

New bushings

Removed bushings

C-Tan-Delta Meas.
Tan Delta (T) at 50Hz (OIP DF)

Source: ABB, Bushing diagnostics and conditioning
Tan Delta (f) at 30°C (33kV OIP DF)

![Graph showing Tan Delta (f) A, B, C]
123kV OIP Bushings $\text{TanDelta} = f(U)$
123kV OIP Bushings TanDelta = f(f)
123kV OIP DF Corroded Measuring Tap
Ageing of RIP Bushings

- Partial breakdowns between capacitive layers are rather seldom
- Decrease of the power factor with increasing test voltage can be an indicator for partial breakdowns
- Also defective connections of the measurement layer to the test tap or of the innermost layer to the high voltage conductor may be the reason for a decrease of the power factor with increasing test voltage
- Increase of the capacitance after a partial breakdown between two layers:

\[ C_{\text{new}} = C_{\text{old}} \times \frac{n}{(n-1)} \]

\( n \) = number of layers approx. 4-7 kV per layer
RIP Bushings
RIP Bushing
Partial Breakdown on a RIP Bushing

Source: B. Heil, „Diagnose und Bewertung von Durchführungen“, OMICRON AWT Germany 2010
Closed Grading Foils
Better design for Very Fast Transients (VFT)
Breakdown in Oil Causes a Flash-Over in the Earth Lead
due to Fast Transient Earth Currents
Breakdown in Oil Causes a Flash-Over in the Earth Lead
due to Fast Transient Earth Currents
Measurement on a 420kV Bushing
Measurement of the Capacitance and the Dielectric Dissipation Factor on C1
Measurement of the Capacitance and the Dielectric Dissipation Factor on C1

**UST**

<table>
<thead>
<tr>
<th>U PRÜF [V]</th>
<th>I PRÜF [A]</th>
<th>C [F]</th>
<th>VF [%] gemessen</th>
</tr>
</thead>
<tbody>
<tr>
<td>10001,00</td>
<td>1,21E-03</td>
<td><strong>3,852E-10</strong></td>
<td>4,0732</td>
</tr>
</tbody>
</table>

**GST**

<table>
<thead>
<tr>
<th>U PRÜF [V]</th>
<th>I PRÜF [A]</th>
<th>C [F]</th>
<th>VF [%] gemessen</th>
</tr>
</thead>
<tbody>
<tr>
<td>10000,00</td>
<td>2,13E-03</td>
<td><strong>6,784E-10</strong></td>
<td>4,0387</td>
</tr>
</tbody>
</table>
Measurement of the Capacitance and the Dielectric Dissipation Factor on C1

![Graph showing DF (V) and DF (f)]
Insulation Resistance Measuring Tap against Flange

782 Ohm
Partial Discharge Measurement
Inception Voltage below 20kV
Partial Discharges > 2nC at 45 kV
PD Location
Measuring Tap
Measuring Tap
Cutted Bushing
Burned Contact Spring

50Hz: \( I = U \omega C \approx 37 \text{ mA} \)

VFT: \( I = C \frac{du}{dt} > 100 \text{A} \)
Relative Tan δ Dependency on the Temperature

Relative tanδ as function of temperature

5.4 Electrical measurements

Measurements on bushings require experience with measuring equipment, test set up and the interpretation of measurement results. This is for some part due to the relatively small capacitance values, which are corrupted by the ambient influence of the environment alone. The measurement of the dielectric dissipation factor can be influenced by the voltage feed on the GIS-side by humidity, weather etc.

5.5 Measuring procedures

Mainly the measuring procedures differ by the coupling of the measuring signal. In case of so-called “not grounded” measurements the test voltage is applied to the conductor of the bushing and the measuring signal is taken at the test tap of the bushing.

The “grounded” measuring procedure is applied, if the bushing which has to be measured does not have a test tap. This is not applicable for the bushing type EKTG.

The devices required for the measurement are usually equipped specifically for the measurement of bushings. The measurement methods are described in comprehensive manuals.

5.6 Equipment

Measuring equipment is available from several manufacturers. Data can be found in the internet or enquired at HSP.

5.7 Limits

For the measurement the influence of the ambient temperature has to be taken into consideration. In the diagram on the left side for C and tan delta the variation through temperature is shown. (Fig.24).

For the material RIP, resin impregnated paper there are limit values for the deviation of the capacitance and the dielectric dissipation factor with relation to the “new value”. This value is reliably deducted from the reference measurement described under 4.4.

In case the deviations are larger than mentioned in the table below, HSP has to be contacted in any case. When there are very large deviations the bushing may have to be taken out of operation.

<table>
<thead>
<tr>
<th>Voltage level</th>
<th>C Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 123 kV</td>
<td>10 %</td>
</tr>
<tr>
<td>≥ 123 kV</td>
<td>5 %</td>
</tr>
<tr>
<td>≥ 245 kV</td>
<td>3 %</td>
</tr>
<tr>
<td>≥ 420 kV</td>
<td>1 %</td>
</tr>
<tr>
<td>Guide value tan delta</td>
<td>0.004 – 0.006</td>
</tr>
</tbody>
</table>

Source: HSP Operation Instruction BAL EKTG03e
220kV RIP Bushing, Stored Outside
220kV RIP Bushing, Stored Outside
Influence of Humidity –
for 123kV Bushings with Silicone Coated Composite Insulators
Mounted Horizontally
Influence of Humidity –
for 123kV Bushings with Silicone Coated Composite Insulators Mounted Horizontally
Influence of Humidity
for 123kV Bushings with Silicone Coated Composite Insulators Mounted Horizontally

Bushings with moss and outer humidity

Bushings cleaned, measured at dry weather
Measurement with Guard

Leakage current is bypassing the meter
Measurement With High Humidity With and Without Guard
Measurement With High Humidity With and Without Guard

![Graph showing measurement with and without guard at different frequencies. The graph compares Ohne Ableitung (tan) and Mit Ableitung (tan). The without guard line shows a steeper decrease in percentage compared to the with guard line.](image-url)
Moisture in RBP and RIP Bushings

• The oil side of RBP and RIP bushings doesn't need a housing

• Cellulose near to the surface can absorb water, if bushings are not stored properly

• Incoming water, also from the ambient air reduces the dielectric strength – this causes an increase of the dielectric dissipation factor
Water in RBP and RIP Bushings

Drying of RBP and RIP bushings is limited.

RIP wet

RIP dry
Measurement of the Dielectric Response with FDS und PDC

Combination of PDC und FDS reduces measurement time
Combined FDS-PDC Measurement on a RIP Bushing
FDS Results on RIP, RBP and OIP Bushings

![Graph showing results on RIP, RBP, and OIP bushings](image-url)
FDS/PDC on a RIP Bushing at Different Temperatures

Source: G. Kopp, „Measurement of the dielectric response on HV bushings“
FDS/PDC with Dry and Wet Surface

Source: G. Kopp, "Measurement of the dielectric response on HV bushings"
Drying of a 145kV RBP Bushing
TanDelta Measurement
Drying of a 145kV RBP Bushing

Drying:
1200h at 90°C / 200°F

1. Measurement before drying
2. Measurement after drying
High Voltage Test with PD Measurement
PD Measurement - Phase Resolved Pattern @ 157kV

Gamut

Intensity [PDs/s]

MPD540 1.1:

- Q_{IEC} = 789.8 \text{ pC}
- Q_{Peak} = 2.688 \text{ nC}
- Q_{Avg} = 966.0 \text{ pC}

n = 68.36 \text{ kPDs/s}
I_{Dis} = 1.926 \text{ \mu C/s}
P_{Dis} = 267.1 \text{ mW}
D = 358.0 \text{ aC}^2/\text{s}
Separation of PD Sources in 3CFRD

3CFRD = 3 Center Frequency Relation Diagram

A(500kHz) > A(2MHz) > A(8MHz)
PD Measurement Cluster 3

- **500 kHz**
  - 338.9 pC
  - 2.265 nC
  - 449.8 pC
  - 118.2 nC/s
  - 19.25 mW
  - 46.95 nC²/s

- **2.8 MHz**
  - 502.8 PDs/s

- **8 MHz**
  - 592.8 PDs/s

**Graphs**

- FFT of PD input
  - 2 MHz/div
  - 10 dBm/div
<table>
<thead>
<tr>
<th>Indication</th>
<th>RBP</th>
<th>OIP</th>
<th>RIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>increase of capacitance</td>
<td>oil in cracks or partial breakdowns</td>
<td>partial breakdowns</td>
<td>partial breakdowns</td>
</tr>
<tr>
<td>high dissipation factor</td>
<td>partial breakdowns; insulator surface wet or dirty (clean the insulator); ageing of the inner insulation; water in the inner insulation;</td>
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</tr>
<tr>
<td>dissipation factor is decreasing with increasing voltage</td>
<td>bad potential connections; partial breakdowns</td>
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<tr>
<td>dissipation factor is strongly increasing with increasing temperature</td>
<td>high moisture in the insulation; high degree of ageing</td>
<td>high moisture in the insulation; high degree of ageing</td>
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</tr>
<tr>
<td>partial discharges</td>
<td>normal, if constant</td>
<td>Discharges produce gasses; Errosion of the cellulose; production of x-wax</td>
<td>partial breakdowns; cracks or voids after electrical or mechanical stress;</td>
</tr>
</tbody>
</table>
michael.krueger@omicron.at

Questions and Remarks?