Transformer Bushing Monitoring

Detect Bushing and Insulation Defects Before they Can Cause a Failure

Peak Measure Transformer Seminar
Wilsonville OR

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Theory

Supplementary bushing monitoring is vital

> Bushing failures contribute significantly to failure statistics of power transformers

> With dissolved gas analysis (DGA), only by-products of insulation degradation inside the tank can be detected – not at the bushings

Cigre A2.37 Transformer Failure Statistics
Failure Locations of Substation Transformers >100 kV

Source: No. 261 – April 2012 ELECTRA
Transformer monitoring focused on dielectric health

Monitors critical defect indicators

> Bushing monitoring: Capacitance and dissipation/power factor (DF/PF)
  > The classic bushing aging indicators
  > Online measurement with lab accuracy

> Partial discharge (PD) in bushings and transformer
  > Early detection of defects
  > Advanced PD noise suppression and UHF gating

> HV transients monitoring
  > Transients are detected directly at the bushings where disturbances occur
Theory

**Bushing defects and their indicators**

> Partial breakdowns
  > Capacitance
  > Partial discharges

> Voids, cracks
  > Capacitance
  > Partial discharges

> Aging by-products, moisture
  > Dissipation/power factor

Bush with capacitive layers and tap electrode on flange
Theory

Capacitance and dissipation/power factor

> Critical indicators of partial breakdowns, cracks, aging and moisture in bushings

> With online monitoring, these indicators are measured under real load conditions

> Continuous information about insulation status allows early corrective action

> Reliable and accurate measurement results enable comparison with acknowledged standards
Standards

Offline bushing tests

> Capacitance:
  > Cigre working group A2.34: *Guide for transformer maintenance* presents capacity changes when one control field layer is short-circuited

> Dissipation/power factor:
  > Acceptance level depends on bushing design

<table>
<thead>
<tr>
<th>Voltage [kV]</th>
<th>No. of layers</th>
<th>Capacitance change in %</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>

Voltage class and change of capacitance for condenser type bushings
[Source: Cigre working group A2.34]
Where Can I Get the Reference from?

- Off-line test: Reference from HQ capacitor
- On-line test: Reference?
Relative C/DF Measurement

> Sum of the bushing currents
  > Three phase vectors are added up
> Bushing-to-bushing comparison
  > Vectors of bushings in same phase are compared
Methods

Relative C, DF/PF measurement

> Changes in grid unbalance (phase shifts) can have a misleading impact on online C, DF/PF measurements when the sum-of-current approach or a bushing-to-bushing comparison is used to determine the values.

Example of changes of the sum vector of the 3 phases of a transformer within 2 days.
Systematic error 0.65 %
plus instrument inaccuracy 0.5 %
→ Capacitance?
→ DF impossible!

[OIP, R, P]

[typ: 0.25, typ: 0.35]

[P. Picher “Integration of New Transformer Monitoring Technologies ...”
TechCon Asia-Pacific 2011]
Methods

Measurement configuration options

1. Relative measurement (bushing-to-bushing)

2. Dual transformer comparison

3. Absolute measurement (VT reference)

Highest uncertainty

Lowest uncertainty
Methods

Reducing measurement uncertainty

> Grid unbalance impacts are minimized with the use of a 2\textsuperscript{nd} transformer for comparison or a VT as reference

> Using a VT as reference, the smallest uncertainty is achieved
Methods

Benefits of highly accurate C, DF/PF measurement

> Enables the application of standards for offline measurement via:
  > Excellent accuracy comparable to offline tests
  > Implemented temperature compensation of measured values
  > Long-term stability of measurement

![Graph showing temperature dependence of dissipation factor](image)

Capacitance and DF measurement over 1.75 years, and alarm levels:
- 478 pF warning
- 467 ± 2 pF measurement
- 0.7 % IEC warning
- 0.27 ± 0.05 % measurement

[Source: Karl Frey, Micafil]
Theory

Partial Discharge Analysis

> The majority of transformer failures are caused by problems within the windings

> DGA can be used to identify fault types

> On-Line PD is used to verify the severity of the fault as well as identify type of PD.

> Follow up with acoustic localization

Cigre A2.37 Transformer Failure Statistics
Failure Locations of Substation Transformers >100 kV

- Tap changer: 26%
- Other: 1%
- Winding: 45%
- Core and magnetic circuit: 3%
- Bushings: 17%
- Isolation: 1%
- Lead exit: 7%

Source: No. 261 – April 2012 ELECTRA

Electrical treeing on coil blocking insulation – evidence of partial discharge activity
Methods

Partial discharge (PD) detection

> PD detection is the early indicator of defects in dielectric insulation

> In typical field environments of transformers, electrical PD detection suffers from a high noise level
  > Originated from outside the transformer, like corona

> Monitor PD at the bushing taps and inside the transformer tank, using a UHF sensor
  > The sensor inside the tank is not affected by outside noise

> Synchronous multi-channel recording enables UHF gating
  > Using the UHF signals to distinguish between PD events inside and outside the transformer at the bushing tap sensors

> Further advanced noise suppression technologies are available:
  > 3-Phase Amplitude Relation Diagram (3PARD)
PD Activity over 4 Days

Graph showing PD activity over 4 days with data points for Q in nC and t in dd:hh:min. The graph includes three lines labeled L1, L2, and L3.
Fighting PD Noise: UHF Gating

- Corona
- EM Field
- Conduction
- Electr. PD
- Internal PD
- UHF PD
- EM Field

Diagram showing the relationship between Corona, EM Field, Conduction, Electr. PD, and Internal PD.
Combination of the Methods

IEC PD Measurement

UHF PD Measurement

MPD 600 1.4:
Q_{IEC} 2.140 nC

Corrected IEC PD Measurement

MPD 600 1.4:
Q_{IEC} 266.7 pC
3PARD: PD Discrimination by Amplitude

[Diagram with labels for EM Field, Current, Corona, Internal PD, and MPD1, MPD2, MPD3.]
3PARD and Back Transformation
On-Line Application of 3PARD
Methods

PD denoising and source separation

PD diagrams of 3 phases without separation

Measurements related to each other in a 3PARD diagram

Separated PD activity: located in phase C
Methods

Recording of transient over-voltages

> Detection directly at bushings
  > Where the dielectric stress occurs

> Recording of full signal shape at all 3 phases

> Supports IEEE compliant export format (COMTRADE C37.111-1999)

Different examples of transients recorded at bushings of a power transformer
Benefits

Condition monitoring to extend transformer life

> Continuous assessment of insulation state
  > Early detection prevents failures

> Absolute C, DF/PF monitoring ensures lab accuracy in the field

> Advanced noise suppression for reliable PD source detection

> Complete HV transient waveform recording for effective impact assessment

MONTRANO system components for continuous monitoring of transformer dielectric health
Benefits

Actionable data to plan corrective action early

> Web-based data access
  > Fast and easy system status overview
  > Detailed trend data
  > Easily adaptable charts and diagrams
  > Configurable warnings and alerts

> Detailed trend data for modern transformer health management
System configuration

Customized and extendable system

> One or more transformers can be monitored
> Optional communication with SCADA system
> Fiber-optic communication from acquisition units to central computer
  > Undisturbed communication
  > Galvanic isolation
  > Up to 4 km (2.48 miles) distance
System configuration

1 Relative C, DF/PF measurement

MCU (FO controller), central computer & monitoring software

Coupling units with bushing tap adapters

OMS 843 acquisition unit

UVS 610 drain valve sensor & UHF converter

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2 System configuration

2 Dual transformer comparison

- MCU (FO controller), central computer & monitoring software
- OMS 843 acquisition unit
- Coupling units with bushing tap adapters
- UVS 610 drain valve sensor & UHF converter
- OMS 843 acquisition unit

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System configuration

3 Absolute measurement with VT reference

OMS 843 VT acquisition unit

Coupling units with bushing tap adapters

OMS 843 acquisition unit

MCU (FO controller), central computer & monitoring software

UVS 610 drain valve sensor & UHF converter
Hardware components

1. Bushing tap adapters
2. UHF sensors
3. OMS 843 acquisition unit
4. Reference acquisition unit
5. Fibre optic communication
6. Central computer and software
Hardware components

Bushing tap adapters and coupling units

> Synchronously captures signals for
  > Capacitance, dissipation/power factor
  > Transient over-voltages
  > Partial discharge (PD)

> Robust, modular design for different types of bushings
  > Standardized coupling unit
  > Customizable tap adapter

> Multiple redundant high-voltage protections

> Built-in temperature sensor
  > For temperature compensation of measured values

> IP65, -40°C...+90°C (-40°F...+194°F) ambient temperature
Hardware components

UHF sensor

> UHF sensor detects PD signals inside the transformer tank

> Consists of sensor (antenna) and signal converter

> Mounting at drain valve or hatch
  > Customizable flange adapters optional

UVS 610 drain valve sensor & UHF converter
Hardware components

OMS 843 – Transformer acquisition unit

> 4-channel, simultaneous acquisition of data from the bushing tap adapters and UHF sensor

> Advanced signal processing for capacitance, DF/PF, transient over-voltages and PD calculation

> 10 analog inputs for additional measurements
  > Humidity
  > Ambient temperature
  > Optional measurements, e.g. oil pressure

> Fiber-optic communication to central computer

> IP65 enclosure, -30°C...+55°C (-27.4°F...+131°F) ambient temperature
Hardware components

OMS 843 VT – Reference acquisition unit

> Acquisition unit for the reference signal for capacitance, DF/PF measurement from a set of voltage transformers (1...3 phases)

> Provides reference signal for absolute capacitance and DF/PF measurement

> Fiber-optic communication
  > Undistorted signal transmission ensures high-precision measurement
  > Galvanic insulation

> System accuracy (at 50/60 Hz, including VT)
  > Capacitance: ± 2pF + dyn. VT error
  > DF/PF: 0.05% + dyn. VT error
Hardware components

**MCU monitoring control unit**

> Fiber optic bus controller

> Transmitter between acquisition units and central computer

> 3-channel fiber-optic communication

> USB connection to computer

> Integrated in enclosure of central computer or in separate housing for outdoor mounting
Software

Central computer and monitoring software

> State-of-the art database system for long-term data storage and retrieval

> Web-based data access & visualization

> Different user roles/logins:
  > Operators:
    > Overview of full system setup
    > View all data with free configurable charts and diagrams
    > Confirm warnings and alarms
  > Administrator: As operator, plus
    > Configuration of all monitoring parameters
    > Set and change warning and alarm rules
Software

Warnings and alarms

> Defined threshold settings for alarm notifications

> Real-time display of current alarm level

> View of events that triggered an alarm

> Alarm confirmation by operators
   > Confirmed alarms change color or
   > Are taken out of viewing window (optional settings)

> All alarm data saved
Software

Data visualization

> Configurable trend charts show data for each monitored parameter
> Tooltip pop-up for easy accessible detailed information of each data point
> All data records and corresponding charts can be exported
MONTRANO – Transformer Monitoring System

> Continuous assessment of insulation state
> Absolute C, DF/PF monitoring ensures lab accuracy in the field
> Advanced noise suppression for reliable PD source detection
> Complete HV transient waveform recording for effective impact assessment
> Web-based data access for fast and easy data & system status overview
> Detailed trend data for modern transformer health management

Thank you for your attention.