Challenges in continuous monitoring of transformer insulation

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Wojciech Koltunowicz is with OMICRON Energy Solutions GmbH, Berlin, Germany, where he is involved in monitoring of HV equipment, leading group of Experts in Diagnostics and Monitoring Services. From 1987 to 2007 he was with CESI, Italy, where he was mainly involved in HV testing and diagnostics of HV equipment.

He received M.Sc., PhD and Dr.habil. degrees in electrical engineering from the Warsaw University of Technology in 1980, 1985 and 2004, respectively.

He is secretary of CIGRE Advisory Group D1.03 “Insulating Gases”, WG D1.25 and D1.37. He is member of CIGRE AG D1.02 “High Voltage and High Current Test and Measuring Technique and Diagnostic” and WG D1.51. He is also member of IEC TC42 WG14. He is author of dozens of international reports.

Challenges in continuous monitoring of transformer insulation

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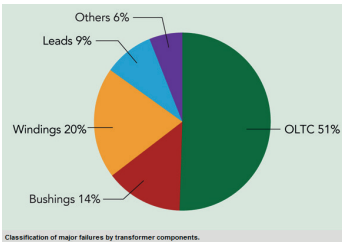
Challenges in continuous monitoring of transformer insulation

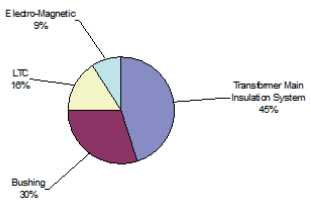
Laurentiu-Viorel BADICU
OMICRON Energy Solutions GmbH, Berlin, Germany

Failure statistics of power transformers

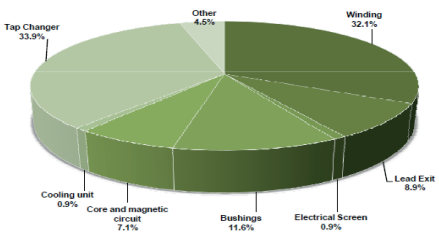


Patrick Picher, Hydro-Québec IREQ, and Claude Rajotte, Condition Monitoring of Aging Transformers, Hydro-Québec TransÉnergie T&D World Magazine

Relative Annual Transformer Failure Risk
No Maintenance



John E. Skog, Business Case for Transformer On-line Monitoring EPRI Diagnostic Conference July 2006



S. Tenbohlen, F. Vahidi, P.Mueller, J. Gebauer, M. Krueger, Zuverlässigkeitsbewertung von Leistungstransformatoren, Stuttgarter Hochspannungssymposium, 2012

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Challenges in continuous monitoring of transformer insulation

Content

> Absolute measurements of bushing capacitance and dissipation factor

> Reduction/rejection of high level interferences and sensitive PD detection

> Case study 1: Large distribution transformer (66/22 kV)

> Case study 2: Power transformer (230/115 kV)

Case study 1: Large distribution transformer 66/22 kV

Winchelsea substation, Victoria, Australia

Challenges in continuous monitoring of transformer insulation

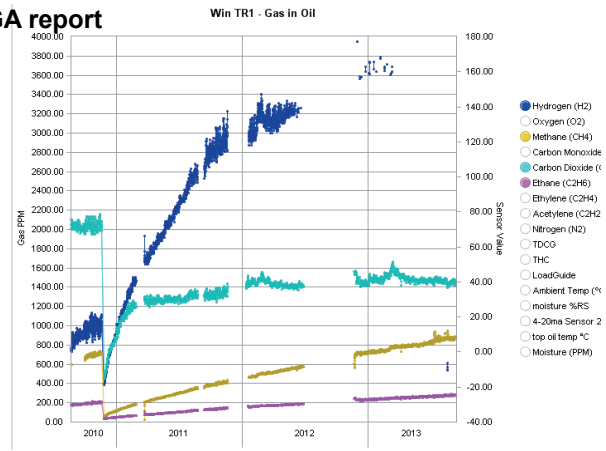
Case study 1: Large distribution transformer

Background

- Distribution transformer: 5/7MVA ONAN/ONAF 66/22kV, OIP bushing
- Constructed in **1998**, no indications of any problem
- Relocated in **2007**, not heavily loaded
- **Feb. 2010** annual DGA indicated 5400 ppm of H_2
- In **2010** the oil was refurbished and on-line DGA monitoring was installed
- High concentration of H_2 remained

Case study 1: Large distribution transformer

On-line DGA report



- **H_2 and CH_4** steady increase → oil decomposition under ongoing PD
- **CH_4 and C_2H_6** → extreme overheating of the mineral oil and adjacent metals
- Low concentration of **CO** → no paper insulated parts involved

Challenges in continuous monitoring of transformer insulation

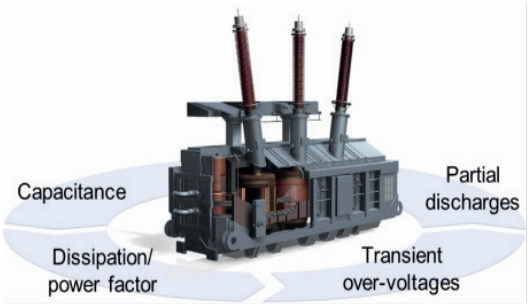
Case study 1: Large distribution transformer

Lab DGA analysis

Gas Analysis	08/03/2013	ppm/day	
Sample No	6838085		
Fluid Temp C	41		
Hydrogen (H2)	4300	88.68	Very High ++
Methane (CH4)	600	4.47	High +
Ethane (C2H6)	220	1.32	Abnormal +
Ethylene (C2H4)	1	0.03	
Acetylene (C2H2)	<1	0.00	
Carbon Monoxide (CO)	150	1.82	
Carbon Dioxide (CO2)	1200	6.05	
Oxygen (O2)	880		
Nitrogen (N2)	22000		
TDCG (ppm)	5271	96.32	High ++
Equivalent TCG (%)	25.46		
Total Gas (%)	29351.000		
CO2/CO	8.00		
O2/N2	0.04		
Equipment Condition	4		

Case study 1: Large distribution transformer

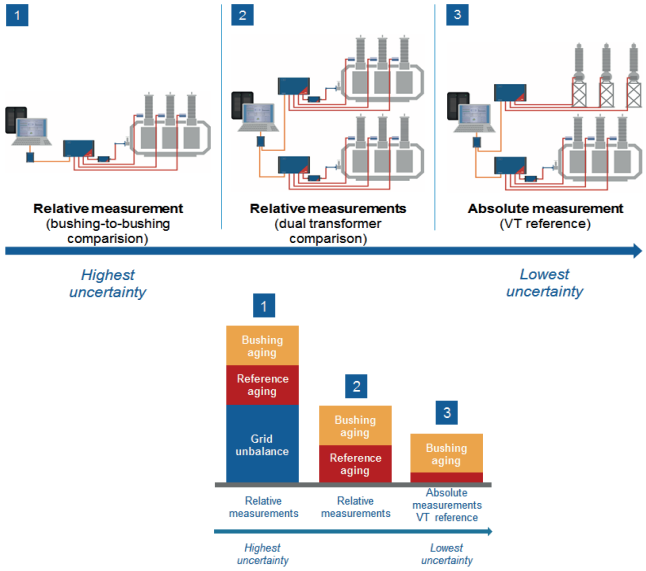
Parameters continuously monitored



Challenges in continuous monitoring of transformer insulation

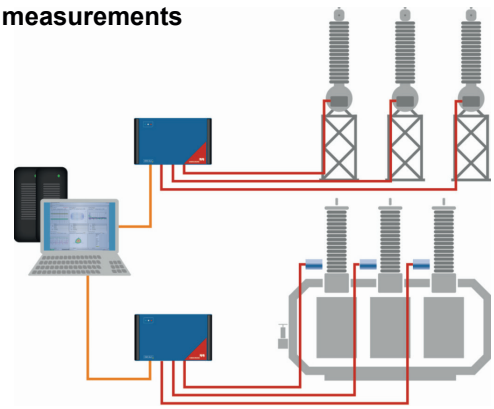
Case study 1: Large distribution transformer

Absolute and relative C/DF measurements



Case study 1: Large distribution transformer

Absolute C/DF measurements



- Daily changes of the system voltages do not affect the sensitivity
- Highest sensitivity is achieved
- A group of instrument transformers has to be available nearby the transformer

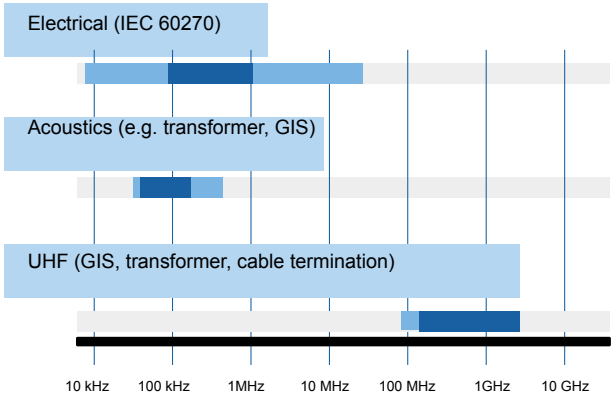
Challenges in continuous monitoring of transformer insulation

Case study 1: Large distribution transformer

PD detection methods

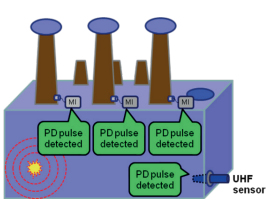
Electrical:
Conventional (according to IEC60270)
HF/VHF/UHF

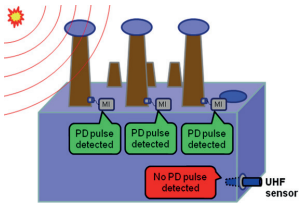
Nonelectrical:
Acoustic
Optical
Chemical

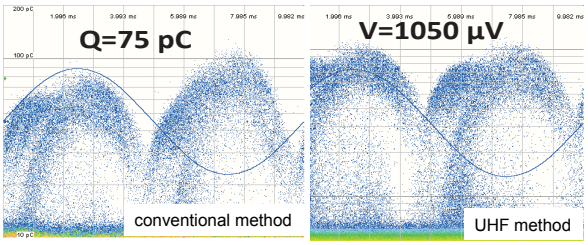


Case study 1: Large distribution transformer

PD Measurements with Conventional and UHF Method





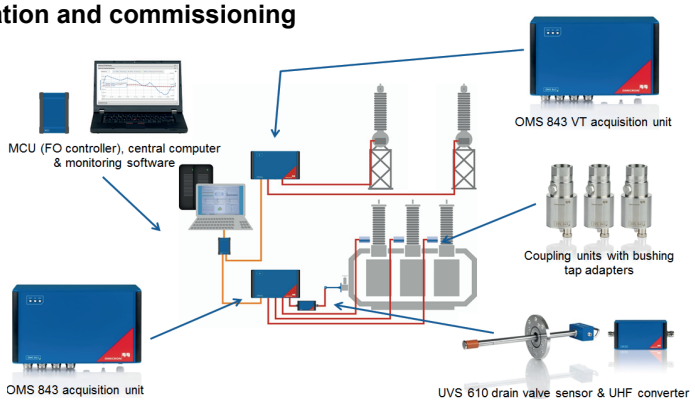


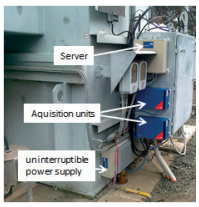
Example of PRPD pattern for PD defect.

Challenges in continuous monitoring of transformer insulation

Case study 1: Large distribution transformer

Installation and commissioning





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Monitoring System Components

Bushing tap adapters and coupling units

- Synchronously captures signals for
  - Capacitance, DF/PF
  - Transient over-voltages
  - Partial discharge
- Multiple redundant high-voltage protections
- Built-in temperature sensor
  - For temperature compensation of measured values
- IP66, -40°C...+90°C ambient temperature

Coupling unit with bushing tap adapter

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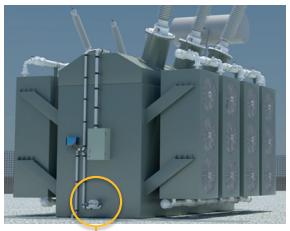
Challenges in continuous monitoring of transformer insulation

Monitoring System Components

UHF sensor

- UHF sensor detect PD signals inside the transformer tank
- Sensor (antenna) is connected to signal converter
- Sensor is mounted at oil drain valve (or at hatch)



Drain valve sensor & converter

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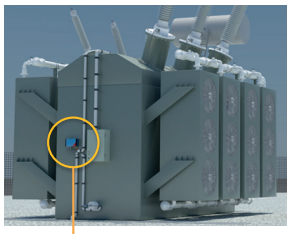
Monitoring System Components

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, -33°C...+55°C ambient temp.



Acquisition unit

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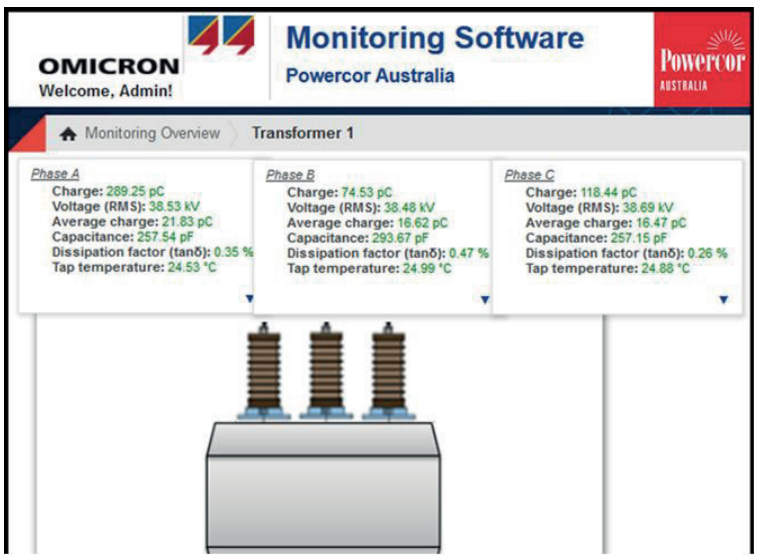
Challenges in continuous monitoring of transformer insulation

Monitoring System Components

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:
  - Operator:
    - 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

Monitoring Software - GUI



Challenges in continuous monitoring of transformer insulation

Commissioning

Standards and recommendations regarding DF

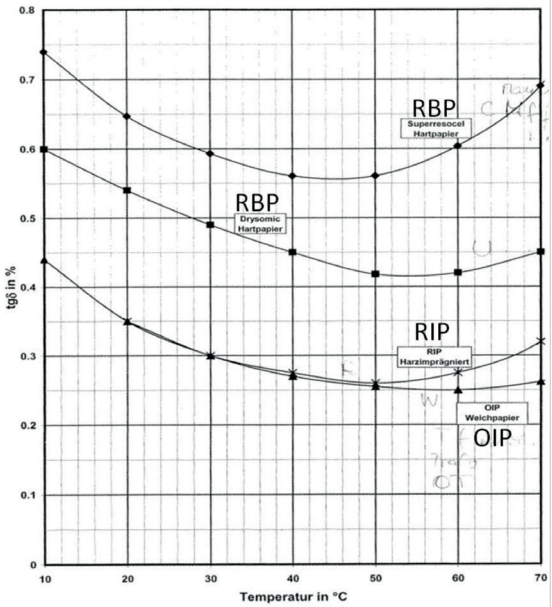
Type	RIP	OIP	RBP
Main insulation	Resin impregnated paper	Oil impregnated paper	Resin bonded paper
DF / tan delta (20°C, IEC60137)	< 0.7 %	< 0.7 %	< 1.5 %
PF cos phi (20°C, IEEE C57.19.01)	< 0.85 %	< 0.5 %	< 2 %
Typical new values	0.3-0.4 %	0.2-0.4 %	0.5-0.6 %
PD (IEC60137) at U_m 1.5 U_m /√3 1.05 U_m /√3	< 10 pC < 5 pC < 5 pC	< 10 pC < 5 pC < 5 pC	 < 300 pC

Analysis of the results

Temperature correction of DF

$$tan\delta\downarrow 20° = c\downarrow Mat\,(\vartheta) * tan\delta\downarrow B$$

where:
- ϑ is the bushing temperature
- c_{Mat} is a correction factor depending on the insulation system of the bushing (OIP, RIP, RBP-Drysomic and RBP-Superresocel)



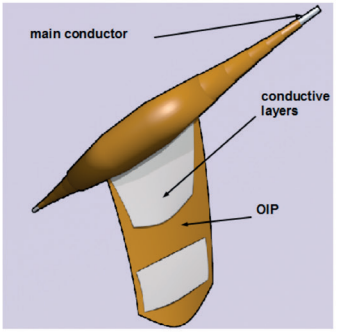
Temperature dependence of the dissipation factor [Karl Frey, Micafil]

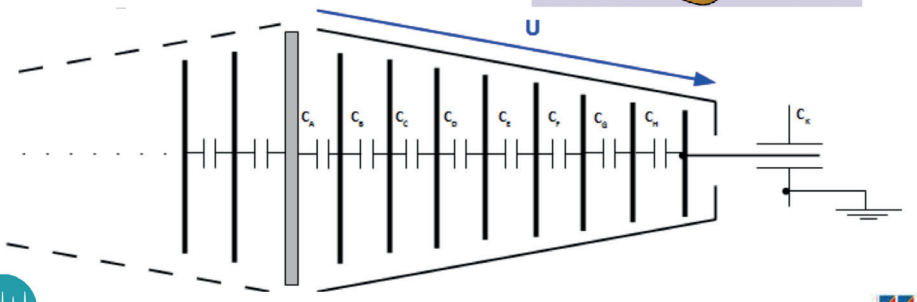
Challenges in continuous monitoring of transformer insulation

Analysis of the results

Capacitive bushing design

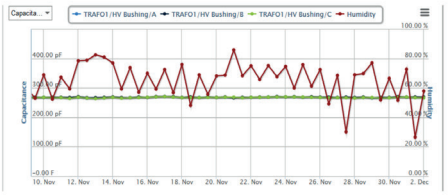
Voltage [kV]	No. of layers	% change
123	14	7.1
245	30	3.3
420	40	2.5
550	55	1.8

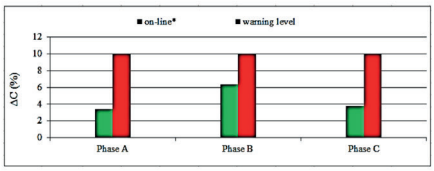


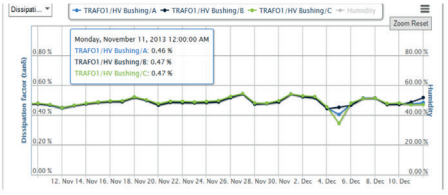


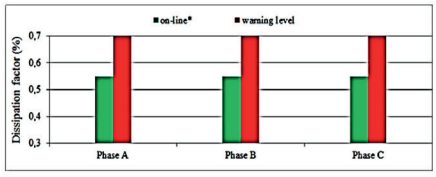
Analysis of the results

Absolute values of capacitance and DF





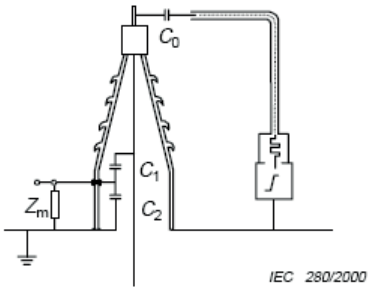




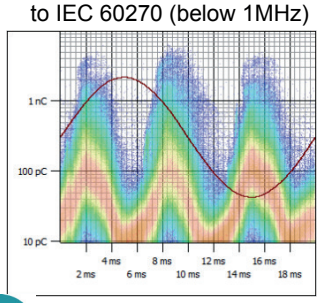
Challenges in continuous monitoring of transformer insulation

Analysis of the results

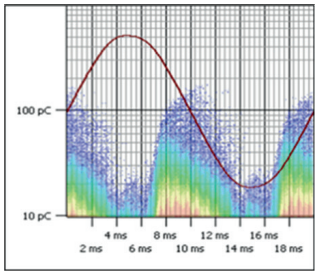
Conventional PD measurements



measuring frequency according to IEC 60270 (below 1MHz)



measuring frequency outside IEC 60270 recommendation (@ 3MHz)



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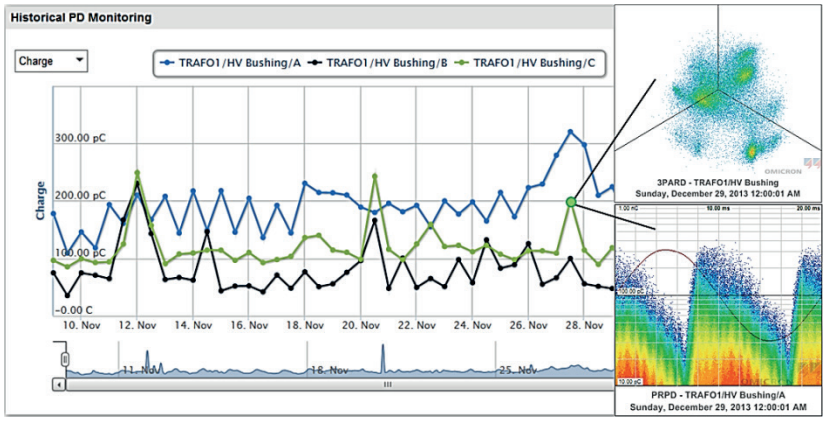
Analysis of the results

Partial discharges analysis using the conventional method



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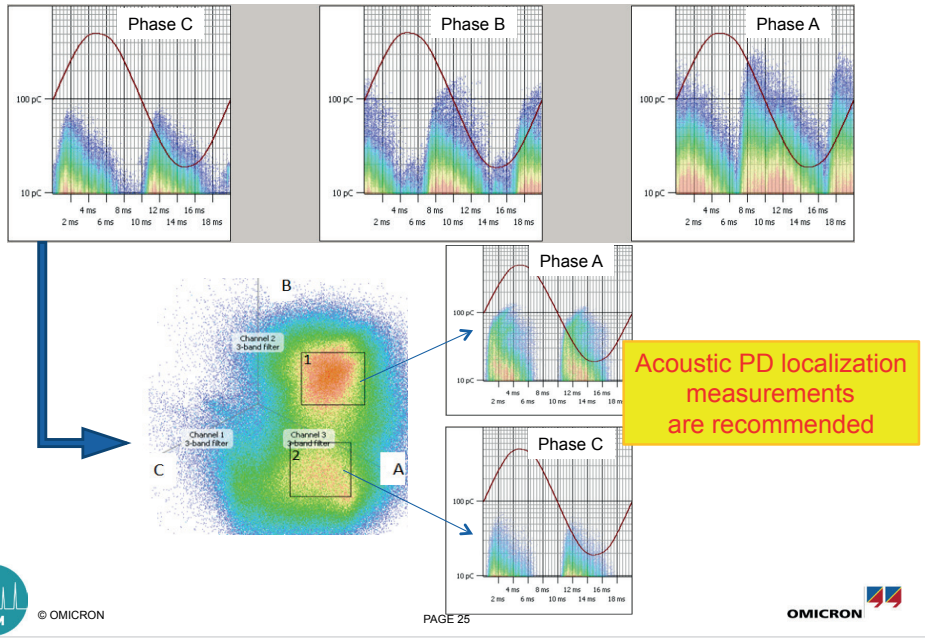
Challenges in continuous monitoring of transformer insulation

Analysis of the results

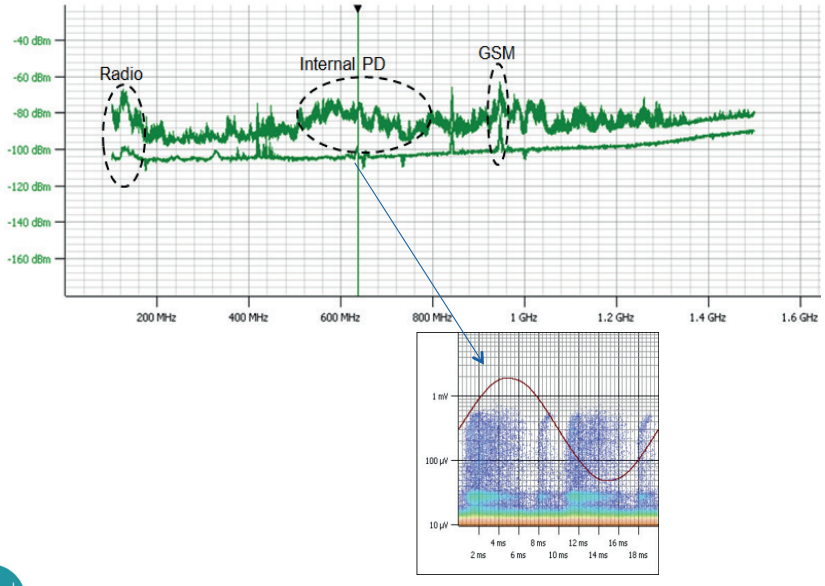
Partial discharges analysis – electrical method



PAGE 25

Analysis of the results

Partial discharges analysis – UHF method

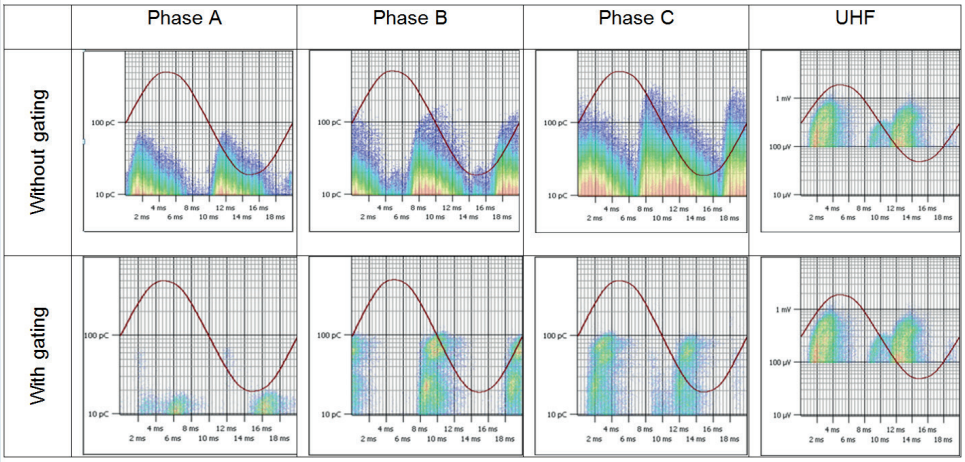


PAGE 26

Challenges in continuous monitoring of transformer insulation

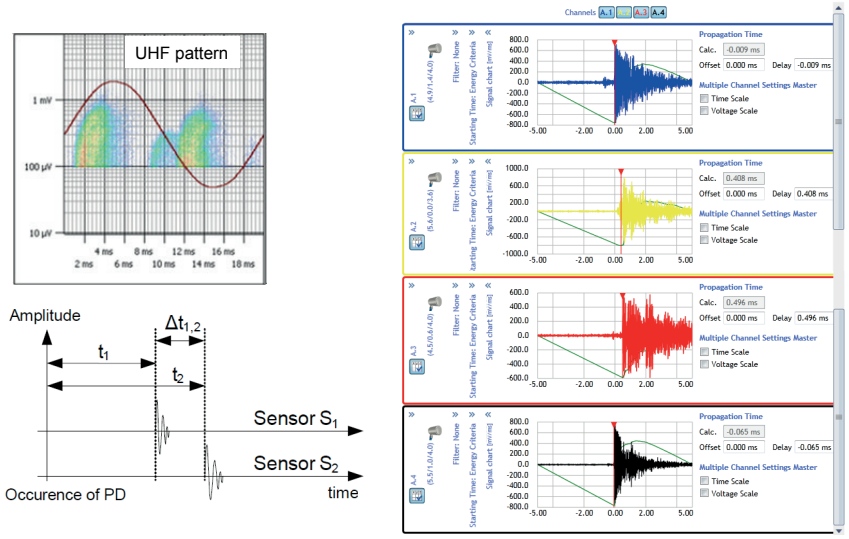
Analysis of the results

Rejection of disturbances by UHF gating



Analysis of the results

Acoustic measurements triggered by the UHF signal

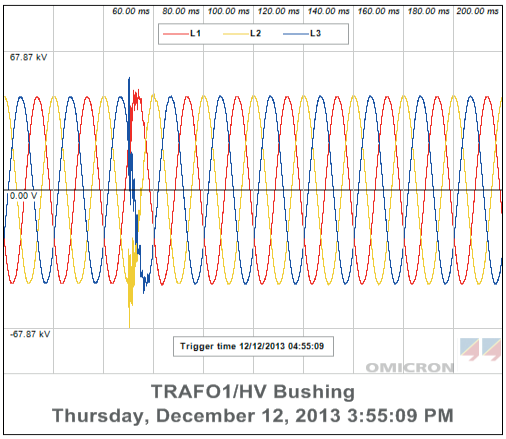


Challenges in continuous monitoring of transformer insulation

Analysis of the results

Transient Over-voltages

20 transient over-voltages were recorded → highest amplitude 1.77 p.u.



TRAFO1/HV Bushing
Thursday, December 12, 2013 3:55:09 PM

Case study 2: Power transformer 230/115 kV

Challenges in continuous monitoring of transformer insulation

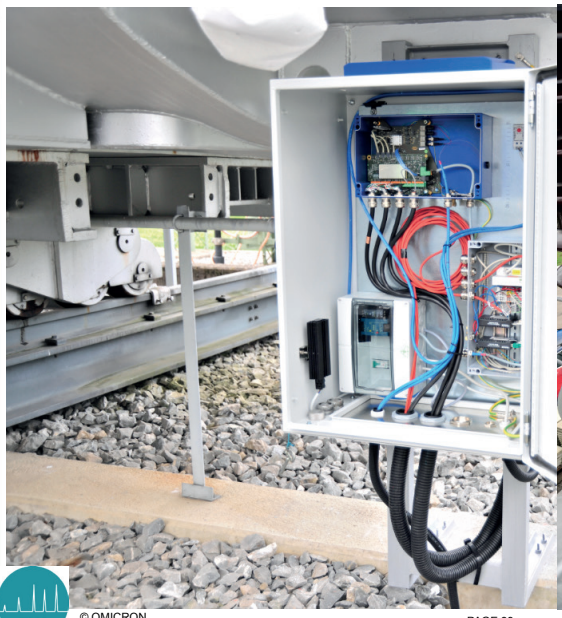
Case study 2: Power transformer 230/115 kV

Background

- 130/130/100 MVA – 230/115/48 kV – 1973
- monitoring system installed on 230 kV side in 2013
- bushing of **phase A** was replaced in 2010
- RBP bushings
- absolute measurements of C/DF are performed
- reference signal taken from VTs
- continuous increase in H_2 concentration from March 2014 to June 2014

Case study 2: Power transformer 230/115 kV

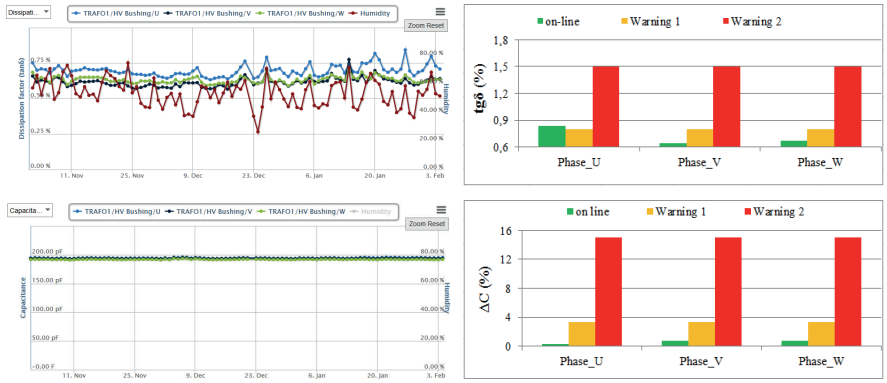
Monitoring system installation



Challenges in continuous monitoring of transformer insulation

Case study 2: Power transformer 230/115 kV

Absolute values of capacitance and DF



Capacitance variation and dissipation factor limits for RBP bushings

U_N [kV]	tan δ [%]	Δ C [%]
123	2.0	20
245	1.5	15
420	1.0	10

S. Tenbohlen et al.: "Enhanced Diagnosis of Power Transformers using On- and Off-line Methods: Results, Examples and Future Trends", *CIGRE Session 2000*, paper 12-204, Paris, 2000.

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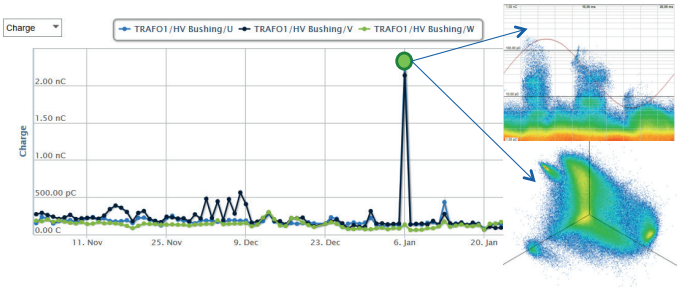
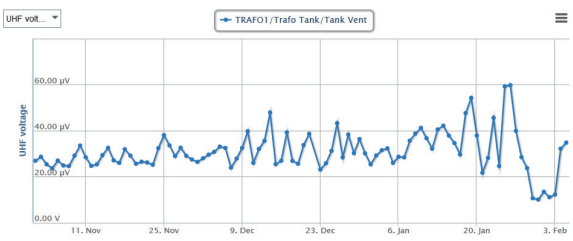
Case study 2: Power transformer 230/115 kV

PD trend from electrical method



PD trend from UHF method



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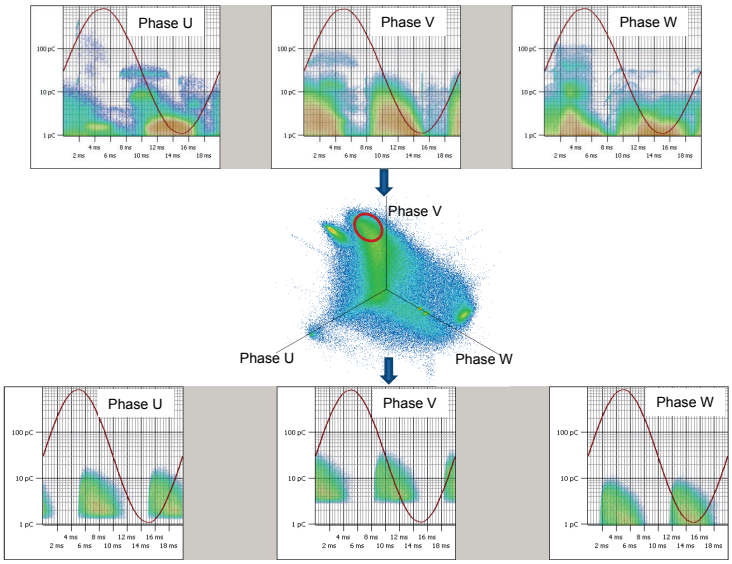
Challenges in continuous monitoring of transformer insulation

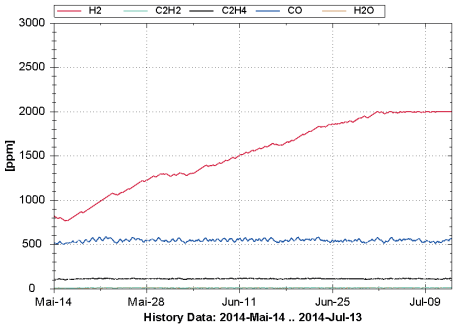
Case study 2: Power transformer 230/115 kV

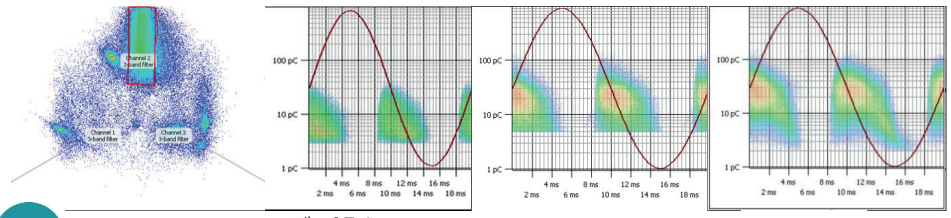
Partial discharges analysis – electrical method – February 2014



Case study 2: Power transformer 230/115 kV

PD – DGA correlation





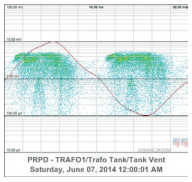
5th of February 16th of April 25th of June

Challenges in continuous monitoring of transformer insulation

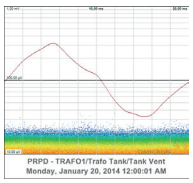
Case study 2: Power transformer 230/115 kV

Partial discharges analysis – UHF method

550 MHz



1,2 GHz



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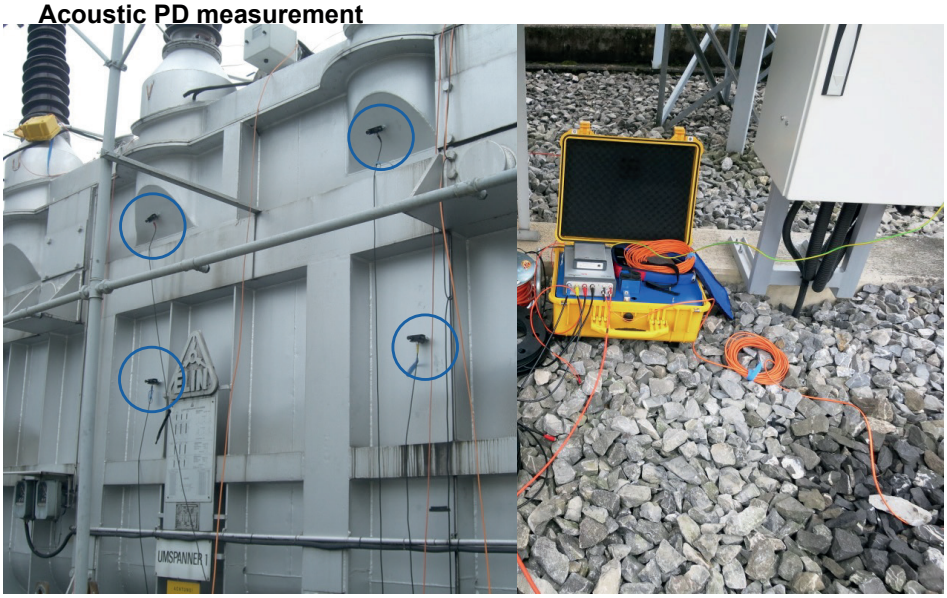
Case study 2: Power transformer 230/115 kV

Acoustic PD measurement



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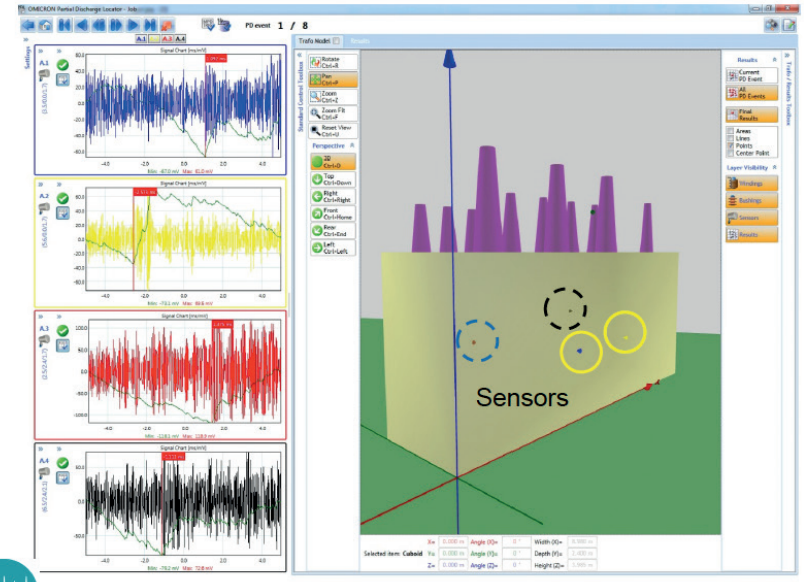
Challenges in continuous monitoring of transformer insulation

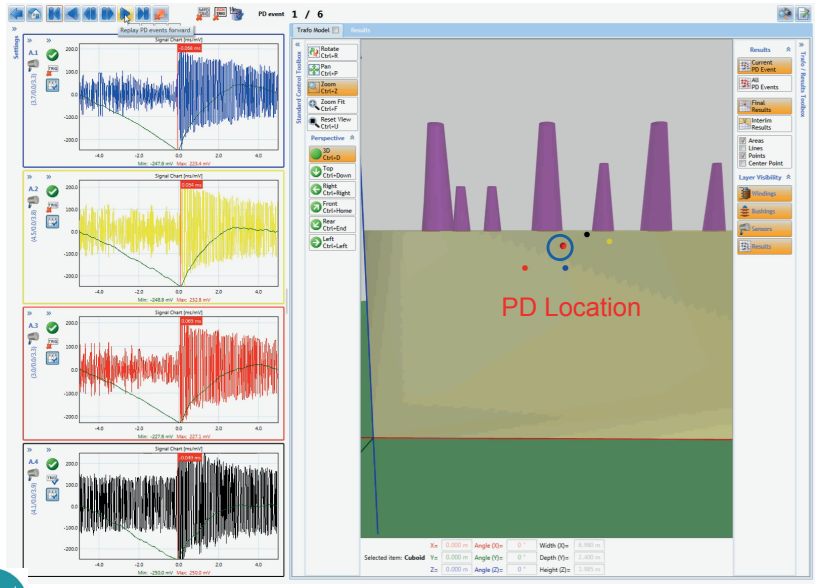
Acoustic PD measurement

1st sensor position



Acoustic PD measurement

2nd sensor position



Challenges in continuous monitoring of transformer insulation

Case study 2: Internal inspection

41

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Case study 2: Internal inspection

42

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Challenges in continuous monitoring of transformer insulation

Conclusions

The monitoring system provider needs to overcome a lot of challenges to achieve:

- **High accuracy of C and DF monitoring values**

It can be achieved by performing absolute measurements with reference signal taken from VTs.

- **High sensitivity of PD measurement:**

Combining of conventional and UHF PD detection methods.

Using advanced SW features – multi-channel and multi-spectral technique for multiple PD source separation and noise elimination.

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Thank you very much for your attention!

19 Oktober 2014