TRANSFORMER-LIFE-MANAGEMENT
CONFERENCE

Continuous condition monitoring and protection of high voltage transformers by

Dr. Jörn Peuser
B2 electronic

Continuous condition monitoring and protection of high voltage transformers by

b2 electronic GmbH
High Voltage

Continuous condition monitoring and protection of high voltage transformers by direct sensor monitoring of oil aging

Dr. rer. nat. Jörn Peuser, Dr.-Ing. Manfred R. Mauntz

TLM 2015 – 27. / 28. October 2015 – Dubai

Content

1. Transformer oil and Motivation
2. Basic sensor concept and physical principle
3. Self-learning, adaptive temperature compensation
4. Online measurement and interpretation
5. Applications

Continuous condition monitoring and protection of high voltage transformers by

Transformer oils / insulating oils

Mineral oil based transformer oils:

- classical, unadditivated transformer oils
- Oils with Inhibitors, e.g. good oxidation stability

Synthetic transformer oils:

- Silicon oil
- synthetic ester

Transformer oils / insulating oils

- higher dielectric strength against possible voltage breakthroughs, and more compact
- prevent corrosion,
- remove heat by convection and
- protect the insulation and
- contribute to noise reduction.

High dielectric strength → Voltage breakthroughs

Mineral oil (ε = 2.2), polarities of cellulose (ε = 5.1) → most water in the cellulose

Esters (ε = 3.3) have significantly higher water dissolving power due to their molecular polar structure than mineral oil

→ Mineral oil: 44 ppm H_2O at 20 ° C
→ Ester: 2700 ppm H_2O at 20 ° C

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Transformer oils / insulating oils

To do so we need:

- an excellent resistance to aging
- a low dissipation factor tan δ
- very good cold flow ability
- good corrosion protection properties

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The 4 important measurements - online

- Temperature 24/7
- The loss angle tan δ 24/7
- The water in insulating oils 24/7
- Breakdown voltage of the insulating oils 24/7

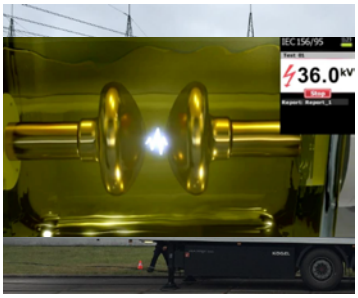

Figure source: b2 electronic GmbH . Riedstraße 1 . 6833 Klaus . Vorarlberg/Österreich, 2014

BA60, BA75,
BA80, BA100

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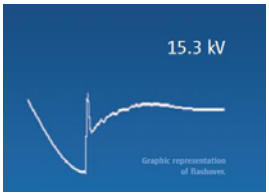
One important measurement - BDV

<5µs - Ultra fast switch-off time

Highest level of RFI/EMC Shielding and rugged metal design!



Glas vessel – recommended by standard

Low weight and very compact design

Comprehensive test reports

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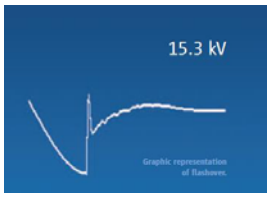

Glas vessel – recommended by standard

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Comprehensive test reports

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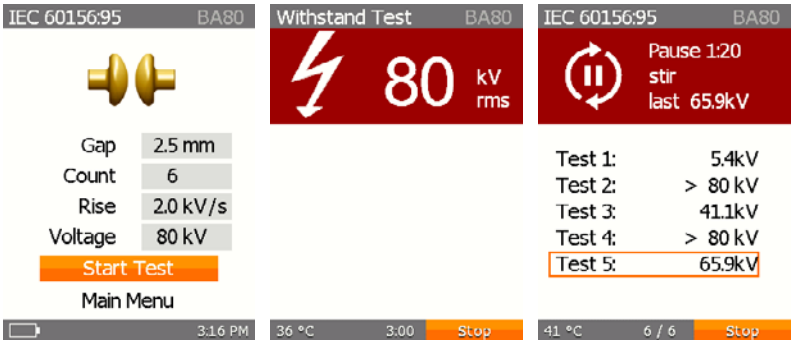
BA

Portable Breakdown Analyzer

Very bright - colour display



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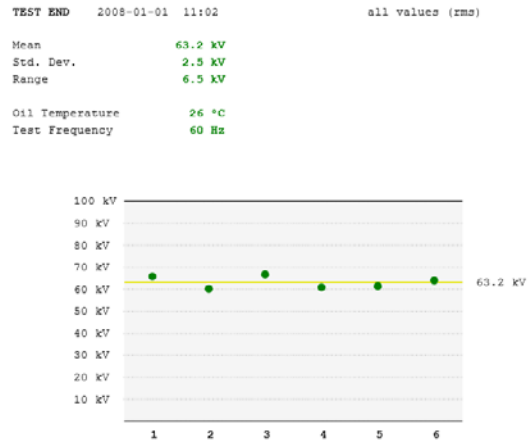
Comprehensive test reports



- Print-out (not BA60) - internal printer
- PDF -, Text - and XML-file
- Printout also from external printer (via PC)

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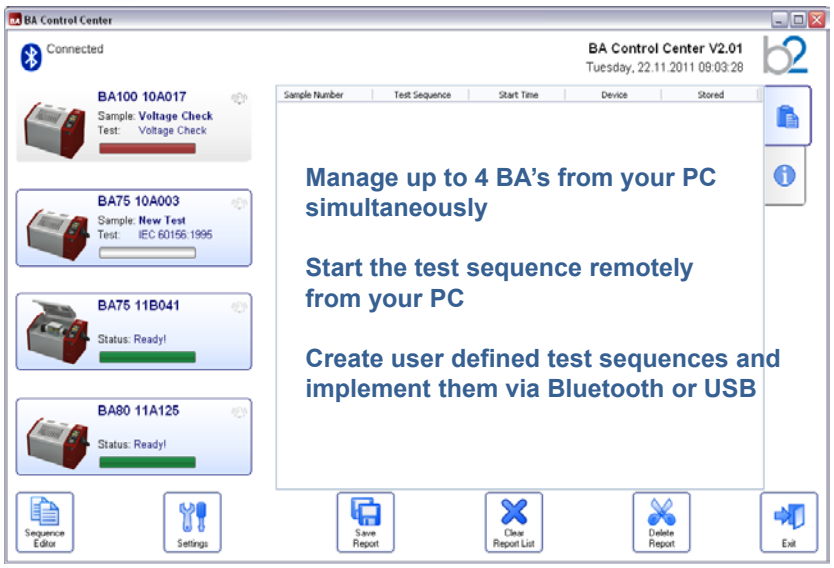
PC Software „BA Control Center



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BA

Portable Breakdown Analyzer

- Bluetooth
- USB
- Printer (not BA60)
- Mains supply
- Battery (not BA60)
- 12V
- Comprehensive accessoires

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Transformer oil ages over time

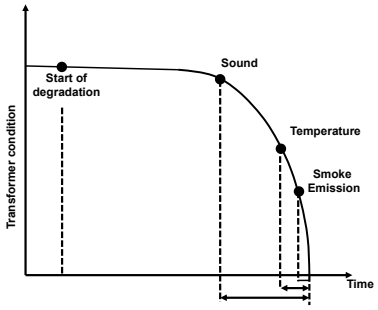
The process of degradation and products of contamination in the oil change the conductivity in insulating oils:

- contamination during the assembly
- formed acids
- aldehydes and peroxides

This results in the formation of sludge

Sludge:

- attacks the cellulose insulation
- inhibits oil flow
- traps heat inside the transformer



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Continuous condition monitoring and protection of high voltage transformers by

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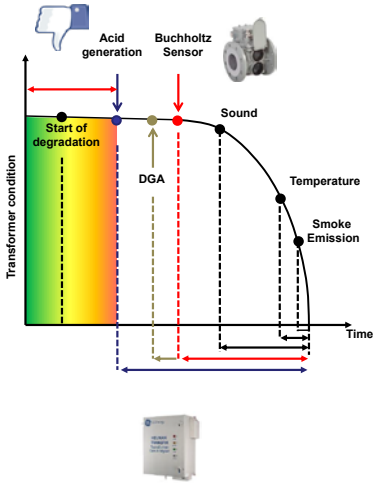

No detection!

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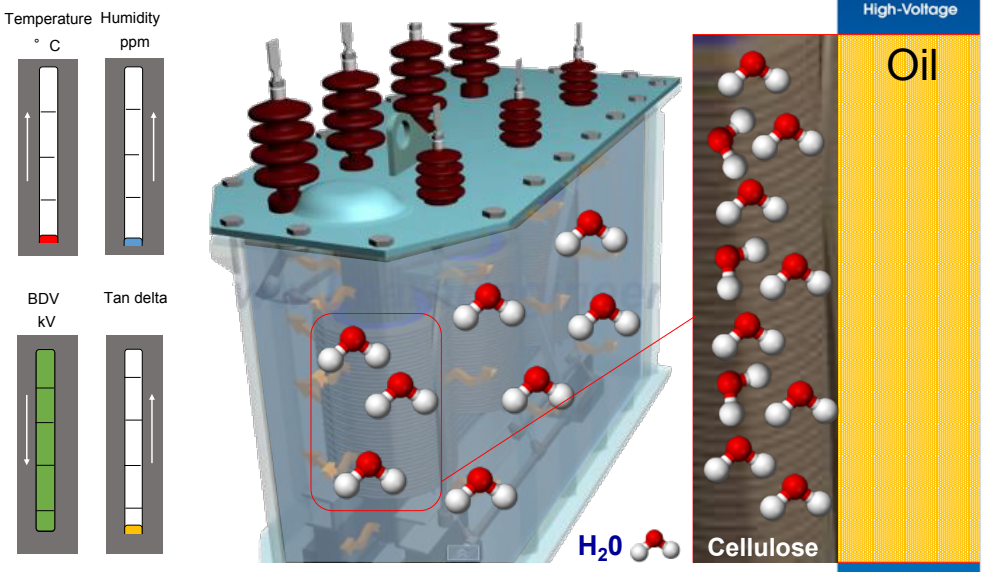
Model humidity in HV transformaters



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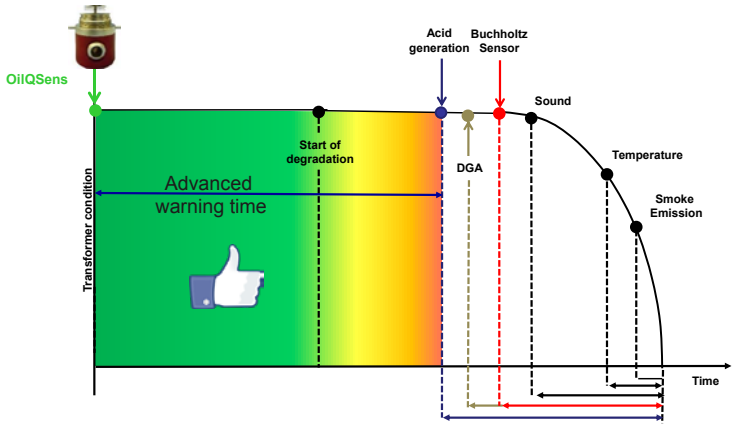
Transformer oil ages over time



OilQSens® provides an advanced warning time!

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Measurements and Calculations

- **Measurements:**
  - electrical conductivity κ
  - relative permittivity ε_r
  - temperature T

- **Calculations:**
  - Dissipation factor tan δ by electrical conductivity κ and relative permittivity ε_r
  - Breakthrough voltage by electrical conductivity κ and relative permittivity ε_r
  - Humidity estimation by relative permittivity ε_r
  - Temperature compensation of all measured values

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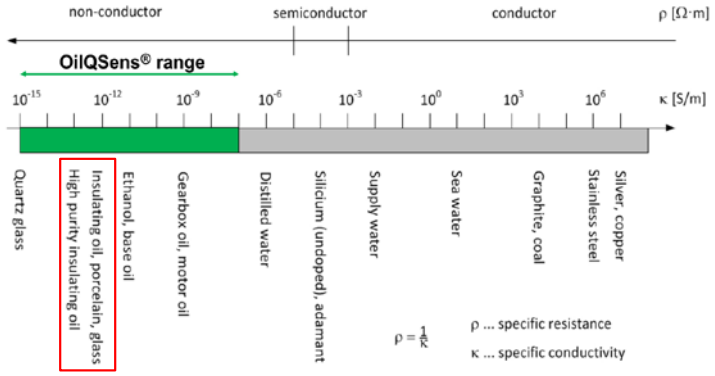
OilQSens® sensitivity: electrical conductivity κ



OilQSens® combines an excellent high sensitivity with low noise and a broad detection range!

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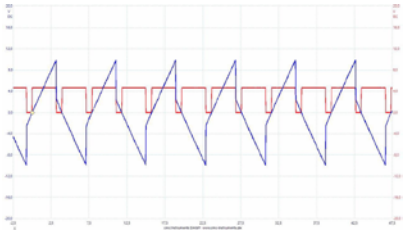
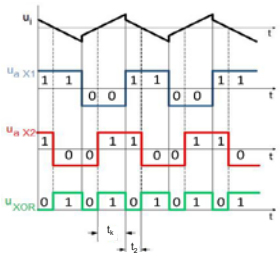
OilQSens® basic sensor concept



$$\kappa = \frac{R_1}{R_2} \cdot \frac{l}{A} \cdot \frac{C}{t_\kappa} = \frac{const.}{t_\kappa}$$

$$\varepsilon_r = (t_\kappa - t_2) \cdot \frac{\kappa}{2\varepsilon_0}$$

$$u_i = \frac{-1}{R_x C_I} \int_0^T u_A(t)\,dt$$



A direct measurement of AC observables (RC circuit) is inaccurate: Oil has a very high resistance R (several GW), and a very low capacity C which leads to high uncertainties, errors and a low resolution, which is necessary to follow the effects in oil.

OilQSens® approach: κ and ε_r are determined by a precise time measurement with a very high accuracy and repeatability based on an integrating measurement technique with a high time/bandwidth product.

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Loss factor tan δ, rel. humidity

Loss factor tan δ out of electrical conductivity κ and permittivity ε_r,
with dielectric constant ε_0, angular frequency $\omega = 2\pi f$

loss factor tan δ : $\tan\delta = \frac{\kappa}{\varepsilon_r \varepsilon_0 \omega}$ ⟶ $\tan\delta_{TC} = \frac{\kappa_{TC}}{\omega\, \varepsilon_0 \varepsilon_{rTC}}$

relative humidity rH: $\mathrm{rH} = a_0 \cdot \varepsilon_r + b_0$ ⟶ $\mathrm{rH}_{TC} = a_{0TC} \cdot \varepsilon_{rTC} + b_{0TC}$

TC -> temperature compensated

TC: Standard 90°C or …. °C?

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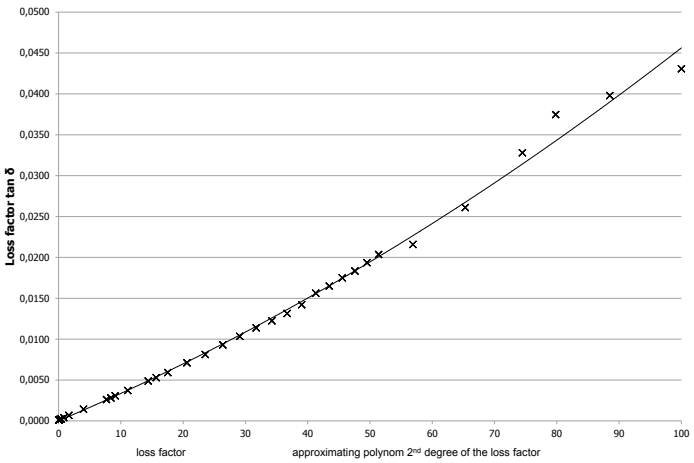
Loss factor tan δ as a function of the proportion of aged oil



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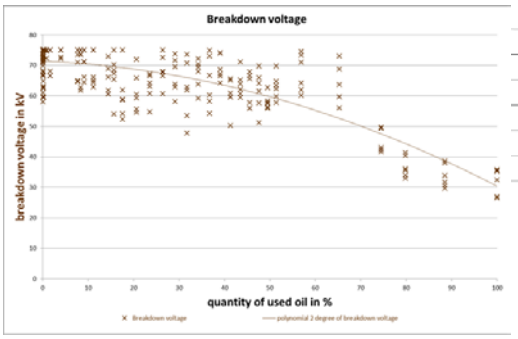
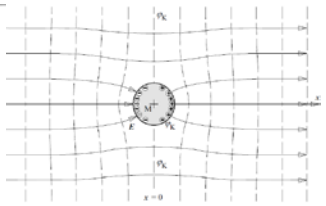
Breakdown voltage and conductivity as a function of the mixing ratio of new and used transformer oils





Field strength increase up to a factor of 3

Source: *Küchler, A.: Hochspannungstechnik, Grundlagen – Technologie – Anwendungen, VDI-Verlag, Düsseldorf, 3. Auflage, 2009*

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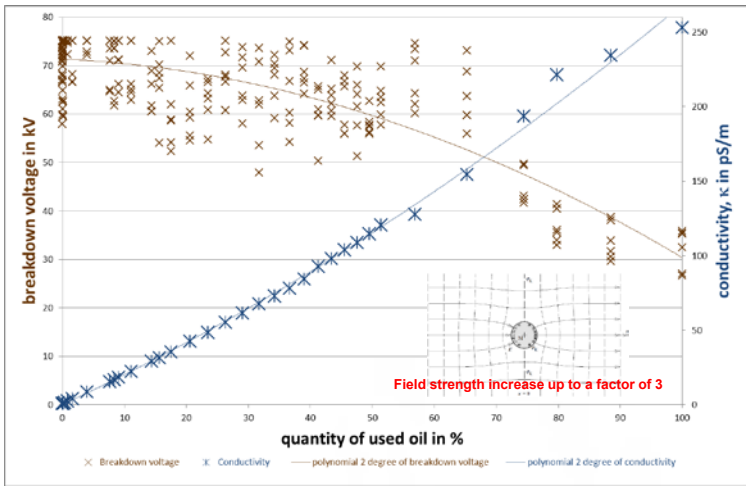
Breakdown voltage and conductivity as a function of the mixing ratio of new and used transformer oils



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Measured transformer oils

Oil name	Conductivity κ [pS/m]	Permittivity ε_r
Meguin J10	0,8817	2,199572
Trafolube 1	1,5126	2,161324
Trafolube 2	1,7033	2,176118
Starke & Sohn 1	0,1056	2,173823
Starke & Sohn 2	0,0542	2,170717

Even down to very low conductivities, they can be measured with a very high precision.

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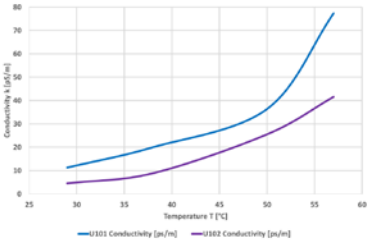
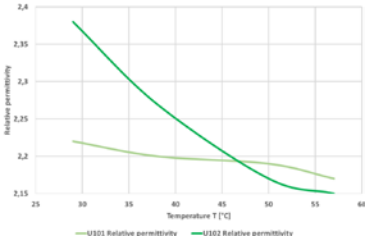
Temperature dependency of κ and ε_r

Increase of temperature results in



increase of the **conductivity κ**

decrease of the **relative permittivity ε_r**



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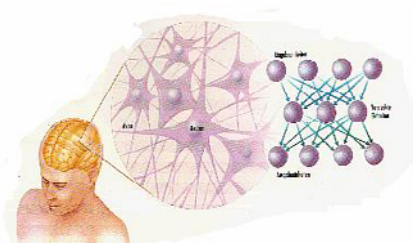
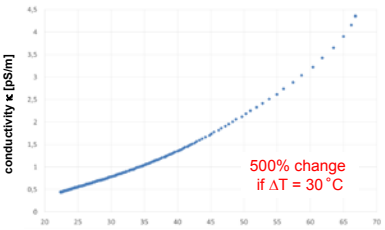
Adaptive temperature compensation of κ and ε_r based on neuronal network

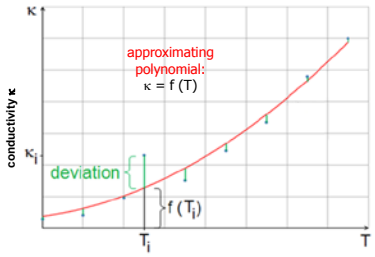




approximating polynomial:

$$\kappa = \kappa_{T0} + a\Delta T + b\Delta T^2 + c\Delta T^3$$

*Gaussian least squares method with risk function



Source: U. Lämmel: WI Projekt – Neuronale Netze, University of Technology, Business and Design, Wismar 2010

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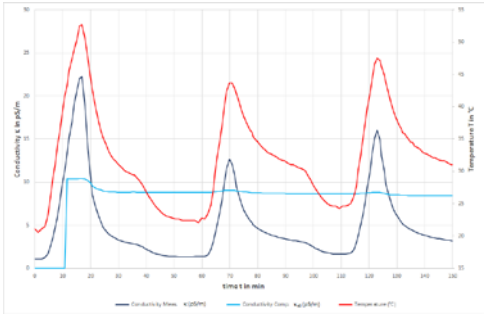
The measured values – after temperature compensation

….. the conductivity κ of the oil increases with temperature. The type of pollution and its temperature dependence cannot be assumed to be known ….

Here we see how efficient the self-learning adaptive temperature compensation algorithm is working ….



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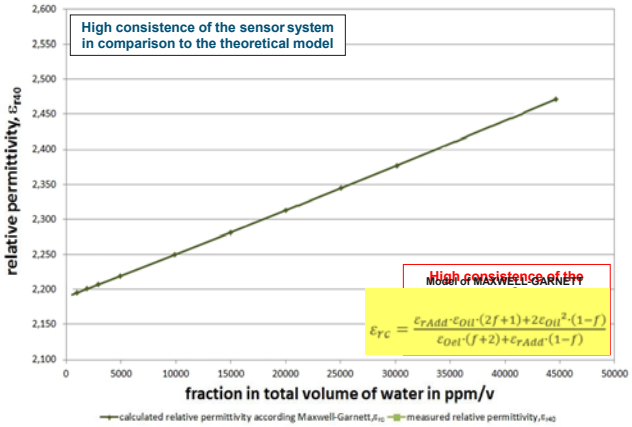
Course of the measured dielectric permittivity ε_{rTC} with the calculated dielectric permittivity ε_{rC}



Source: Maxwell-Garnett, J.: Effective medium models for the optical properties of inhomogeneous media, Philosophical Transactions of the Royal Society of London, Vol. 203, 1904

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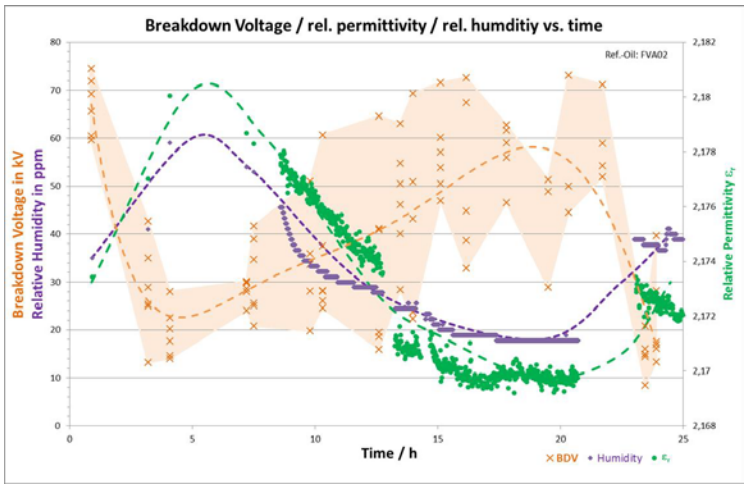
BDV, permittivity and moisture vs. time



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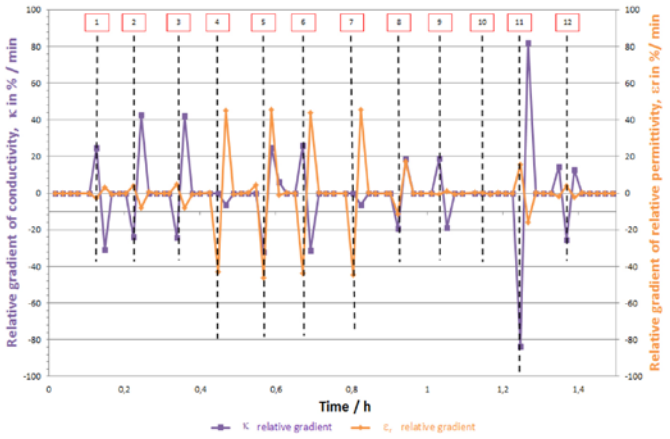
Simulation of partial discharge in transformers



#	BDV [kV]
1	89,8
2	67,8
3	72,3
4	82,5
5	89,0
6	84,3
7	80,8
8	80,9
9	87,1
10	92,8
11	75,3
12	89,3

1 – 12 BDV measurement

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Application example:

Monitoring of an oil regeneration plant

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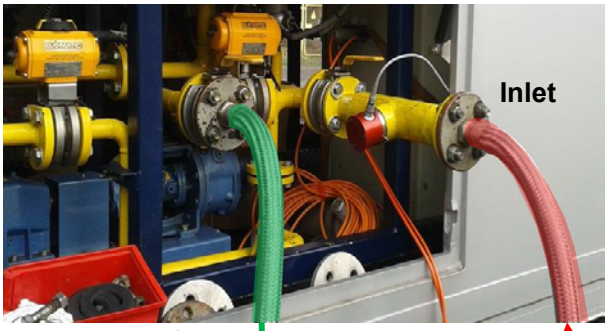
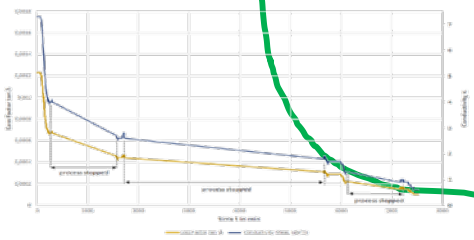
Application: oil regeneration plant



Filtration

Vacuum drying



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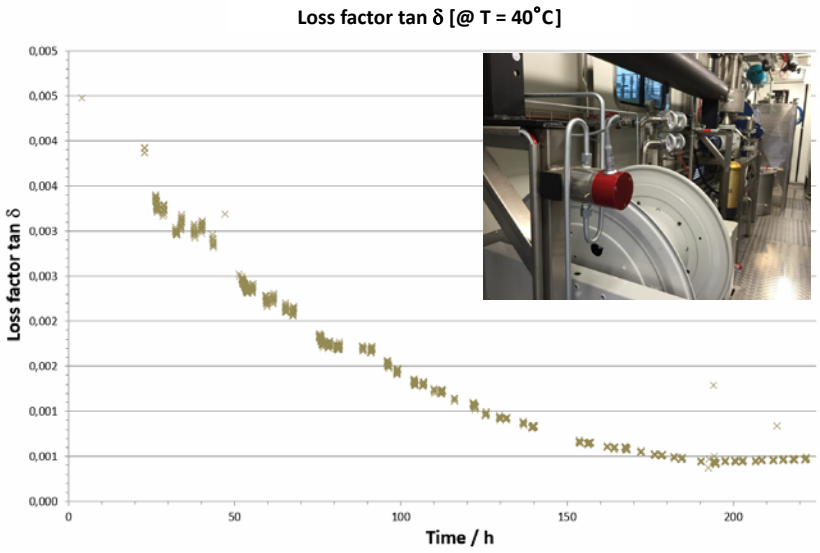
Loss factor tan δ and conductivity κ vs. time



Loss factor tan δ: $\tan\delta = \frac{\kappa}{\varepsilon_r \varepsilon_0 \omega}$

Measured @ 40° C
Compensated @ 90° C
Laboratory @ 90° C

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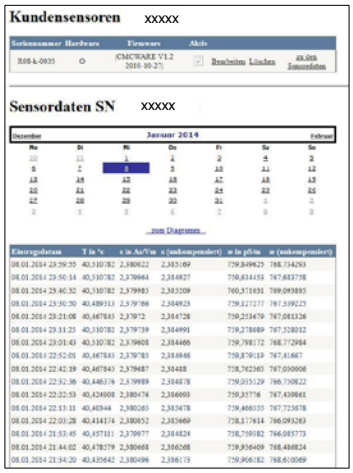
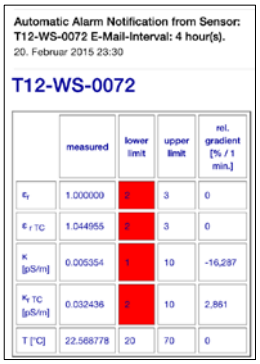
Server – Interface via Internet Browser / E-Mail



Automatic email notification (incl. graphs):



Overview interfaces

Serial (RS232):
9-pin SUB-D

Network (LAN / WLAN):
Ethernet / IEEE 802.11 b/g with
IEEE 802.11i encryption

Optional communication:
RS232/USB Adapter,
RS232/Profibus

Software:
WSens®/SW

Web based decentralized Conditioning Monitoring System:
Measuring signal transmission to web server,
Data query / presentation via Web browser

Continuous condition monitoring and protection of high voltage transformers by

Conclusion and outlook

- **Online measurement 24/7 of the**
  - loss angle tan δ
  - breakdown voltage
  - water in insulating oils

- **Remote monitoring of HV transformers 24/7**

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