



TRANSFORMER-LIFE-MANAGEMENT
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Material Testing with VLF on Transformers

Jürgen Jakober
b2 High Voltage





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Material Testing with VLF on Transformers

**Continuous Condition Monitoring
of Insulation Oils
in HV Transformers**

OilQSens®

TLM Conference
Bangkok Nov. 2017
Mr. Juergen Jakober
b2 electronic GmbH

Content:
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cmc Instruments GmbH



Jürgen Jakober
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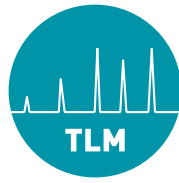
**b2 electronic GmbH
is an Austrian based company in
the field of high voltage test
equipment**

Mr. Jürgen Jakober
Sales Director



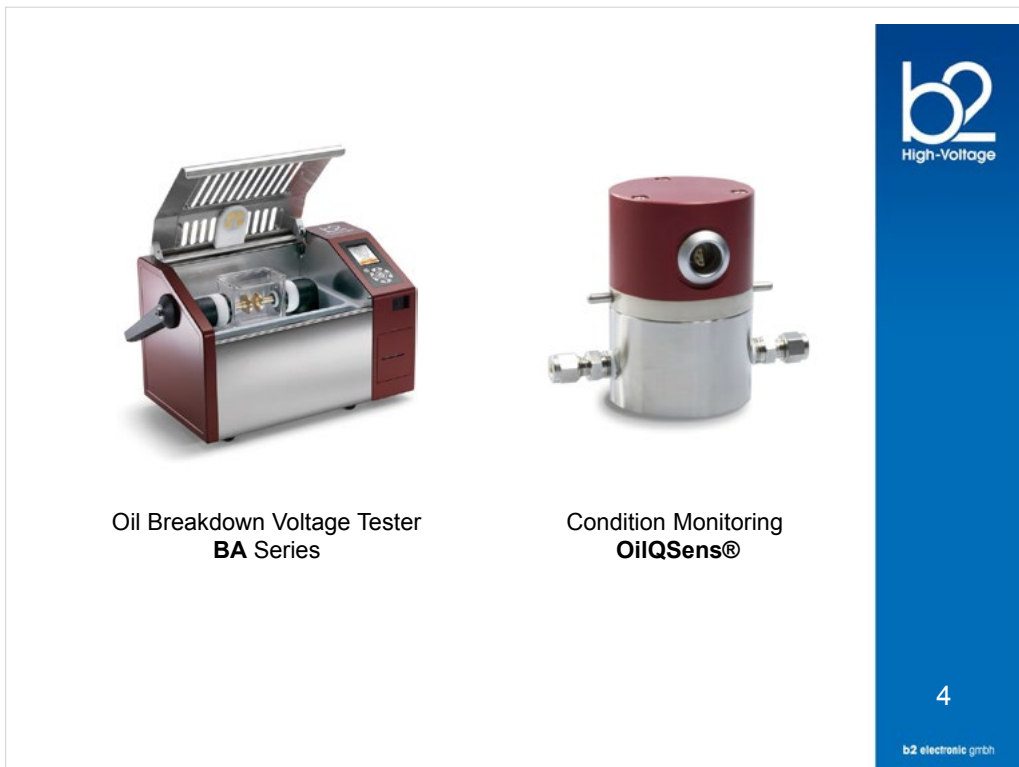
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Material Testing with VLF on Transformers



Oil Breakdown Voltage Tester
BA Series

Condition Monitoring
OilQSens®



Material Testing with VLF on Transformers

Content

1. Transformer oil: mineral or synthetic based
2. Existing measurement techniques
3. Basic sensor concept and physical principle
4. Self-learning, adaptive temperature compensation
5. Online measurement and interpretation
6. Applications



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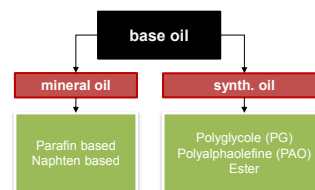
Transformer oils

Mineral oil based transformer oils :

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

Synthetic transformer oils :

- Silicon oil
- synthetic ester



Why using synthetic transformer oils (Esters)?

- Higher thermal stability → Transformers smaller and more compact
- Mineral oil ($\epsilon = 2.2$); polarities of cellulose ($\epsilon = 5.1$) → most water in the cellulose
- Esters ($\epsilon = 3.3$) have a significantly higher water dissolving power due to their molecular polar structure than mineral oil

→ Mineral oil: 44 ppm H₂O at 20 ° C
→ Ester: 2700 ppm H₂O at 20 ° C



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Transformer oils

We need :

- a low dissipation factor $\tan \delta$
- a high breakdown voltage
- an excellent resistance to aging
- very good cold flow ability
- good corrosion protection properties



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Insufficient maintenance



Disaster waiting to happen!

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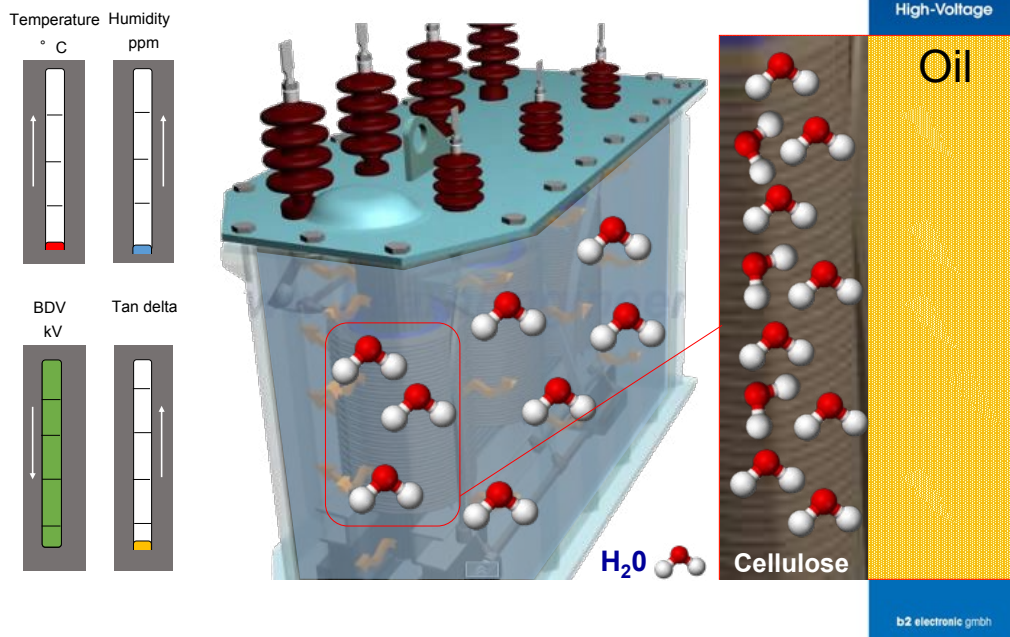
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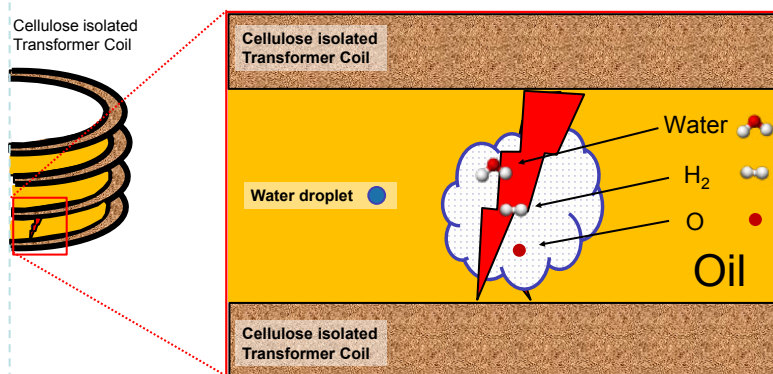
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Model humidity in HV transformers

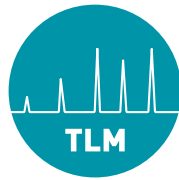


Model humidity in HV transformers



→ Water reduces the dielectrical strength (breakdown voltage) of the oil.

- Which can result in a discharge
- rises the temperature locally and evaporates the water
- Due to the gas bubble (containing a mix of H₂O, H₂, O), the dielectrical strength is lowered further.
- H₂ gets solved into the transformer oil.



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The Water Hazard

Where does the water come from?

New transformers:

- Improper or inadequate drying
- Improper installation
- Inadequate drying of new oil.

In service units:

- Leaks
- defective breathers
- Maintenance
- ageing of insulation



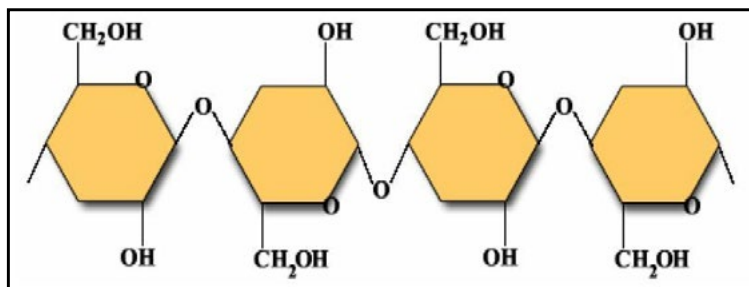
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Solid insulation degradation

The solid insulation in a transformer, paper, pressboard, wood etc. are cellulose.



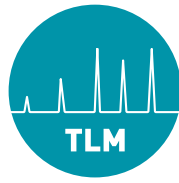
The Cellulose molecule consists of a "chain" of Glucose rings. As the cellulose ages, it polymerises - It loses rings and becomes weaker - the amount of deterioration is known as the Degree of Polymerisation.



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Photo macrograph (250 x) of new Kraft Paper

Fibres clear and undamaged

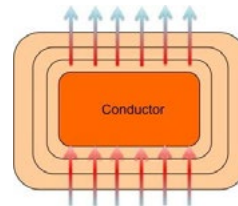


Acidity level of oil 0.03mgKOH/gm

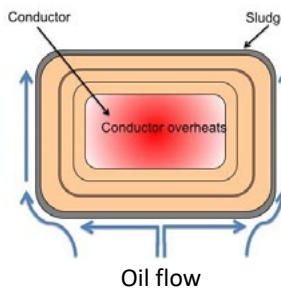
From aged transformer. Surface coated.



Acidity level of oil 0.3mgKOH/gm



Oil flow through the windings, passes through the paper insulation, cooling the conductor and removing heat.



Once sludge forms in and on the paper insulation it forms a barrier preventing the fluid from penetrating the paper insulation and removing heat from the conductor. At the same time the sludge attacks the paper insulation accelerating deterioration.

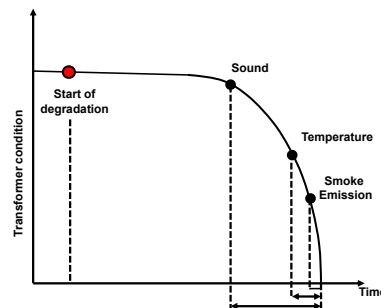


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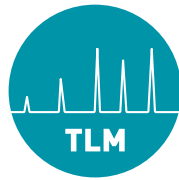
The problem

Existing techniques start working after the gas formation → after damage is done



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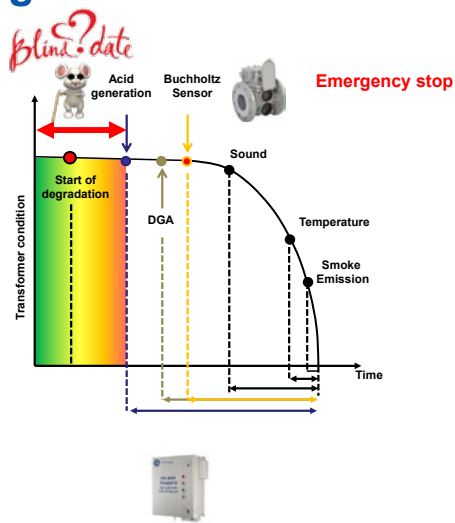
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Transformer oil ages over time

Existing techniques start working
after the gas formation →
after damage is done



←→ No detection!



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Ions, DGA, Buchholtz



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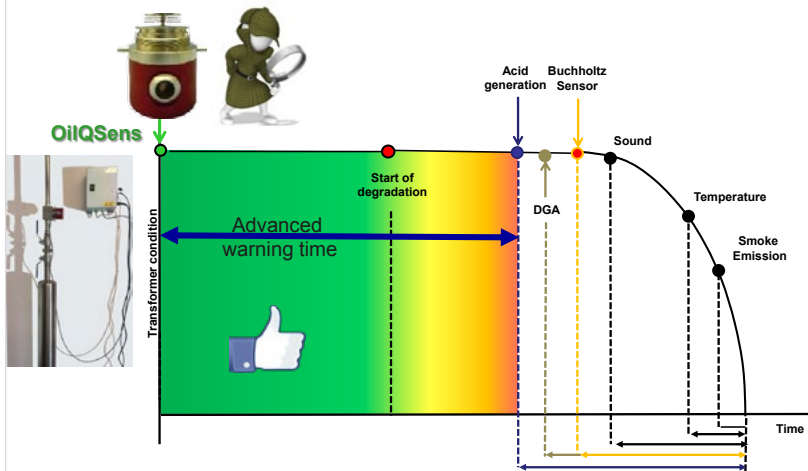
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OilQSens® provides an advanced warning time



- OilQSens® can help to identify the critical units of the transformer fleet
- SmartSentry® can help to keep the transformer fleet in a healthy condition



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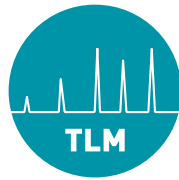
Comparison online:
OilQSens®, Water, tan delta, break down voltage

Detection	OilQSens®	Moisture meter	Tan delta meter
Water Activity (estimated)	✓	✓	✗
Tan delta (calculated)	✓	✗	✗
Break down voltage (estimated)	✓	✗	✗
Conductivity & relative permittivity (measured)	✓	✗	✗
Damage prevention	✓	✗	✗



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Measurements and Calculations

Values of interest:

- Dissipation factor $\tan \delta^*$
- Breakthrough voltage **estimation and trending**
- Humidity **estimation and trending**

Source values:

- electrical conductivity κ
- relative permittivity ϵ_r
- temperature T
- Temperature compensation of all measured values



- o Highest precision due to innovative measurement method.
- o Adaptive temperature compensation algorithm is running in the background.
- o Highly encrypted data transfer to server.

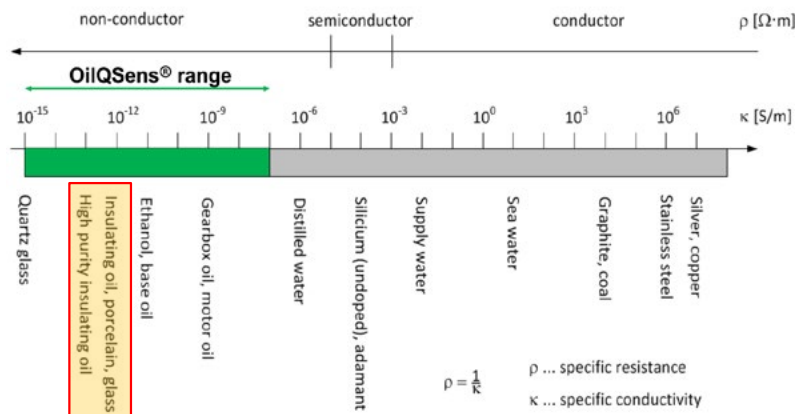
$$(*) \tan \delta = \frac{\kappa}{\epsilon_r \epsilon_0 \omega}$$

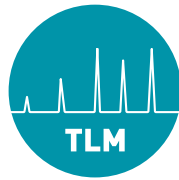
ϵ_0 = dielectric constant
 $\omega = 2\pi f$ = angular frequency



Sensitivity: electrical conductivity κ

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

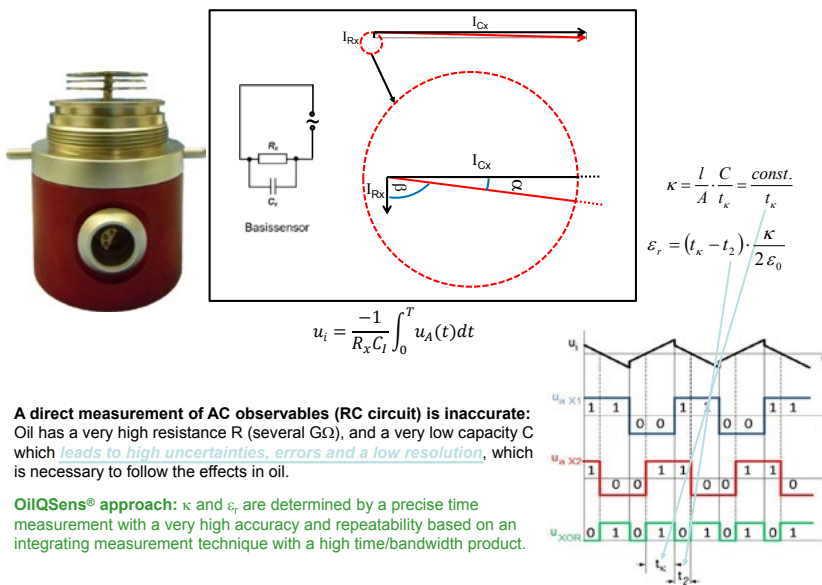




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Basic sensor concept



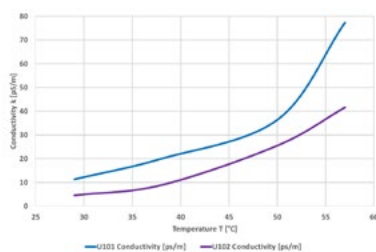
A direct measurement of AC observables (RC circuit) is inaccurate: Oil has a very high resistance R (several GΩ), and a very low capacity C which leads to high uncertainties, errors and a low resolution, which is necessary to follow the effects in oil.

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.



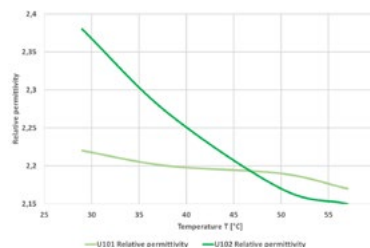
Temperature dependency of κ and ε_r

Increase of temperature results in



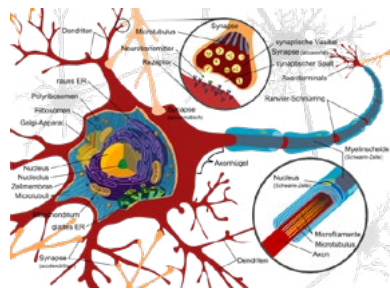
increase of the conductivity κ

decrease of the relative permittivity ε_r



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Adaptive temperature compensation of κ and ϵ_r based on neuronal network

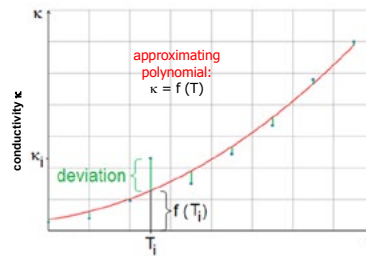
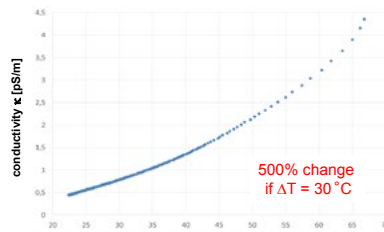


approximating polynomial:

$$\kappa = \kappa_{T_0} + a\Delta T + b\Delta T^2 + c\Delta T^3$$

$$R = \sum_{i=1}^N ((\kappa_i - \kappa_{T_0} - a\Delta T_i - b\Delta T_i^2 - c\Delta T_i^3) \cdot e^{-\Delta T_i / \ln(2)})^2$$

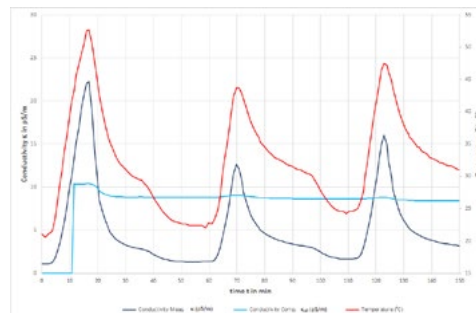
*Gaussian least squares method with risk function



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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Without adaptive temperature compensation of κ and ϵ_r ...



... no reliable statement is possible!

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Laboratory measurements

Loss factor tan delta

*Comparison with 3rd party device
of different transformer oils*

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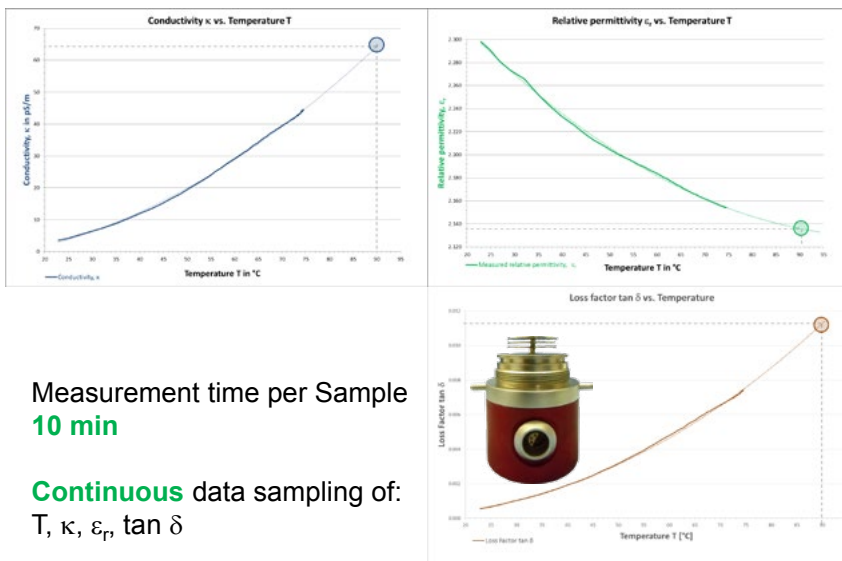
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Loss factor tan delta - OilQSens®



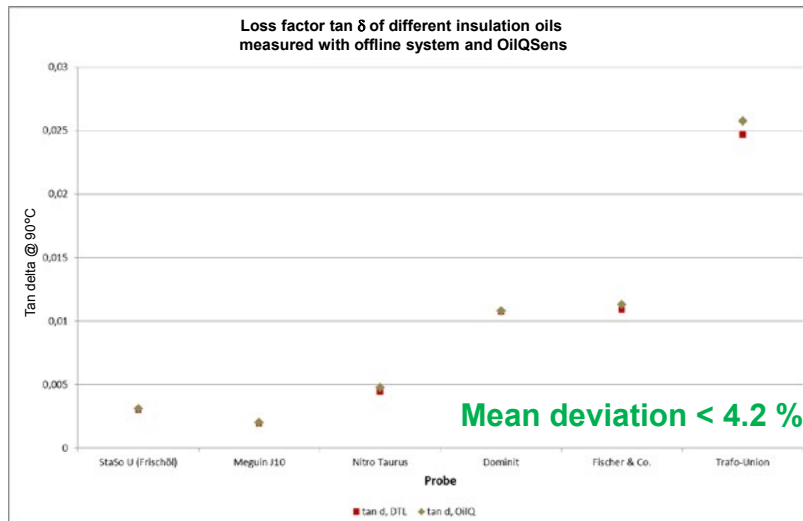
Measurement time per Sample
10 min

Continuous data sampling of:
T, κ , ϵ_r , tan δ

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Loss factor tan delta - Comparison



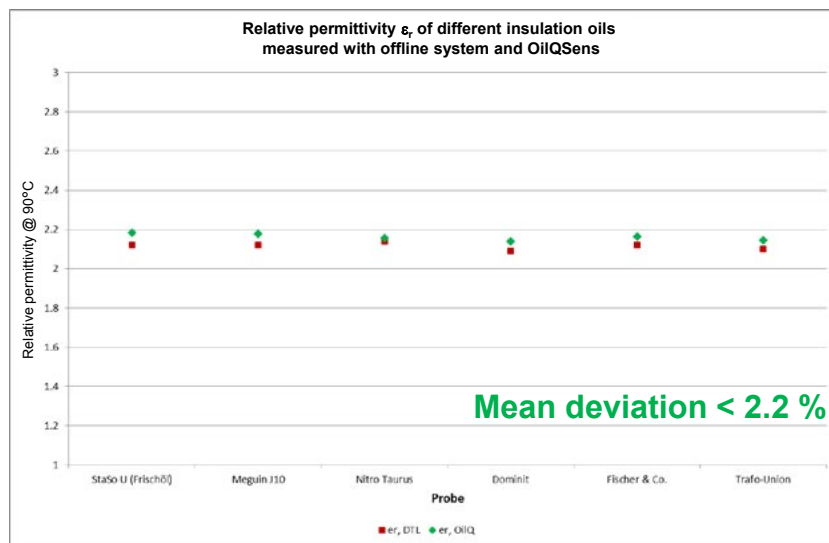
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Relative permittivity - Comparison



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Application Examples



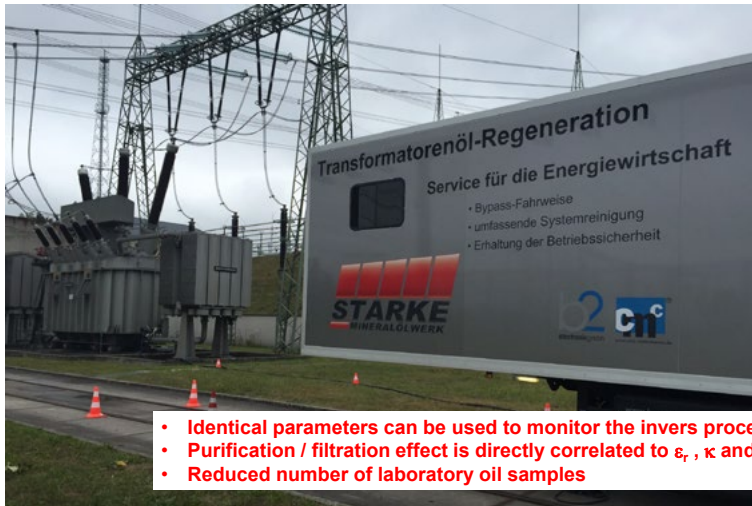
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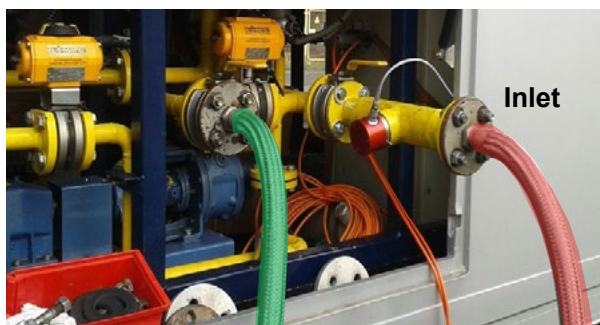
OilQSens® provides online process control in oil regeneration plants



- Identical parameters can be used to monitor the invers process:
- Purification / filtration effect is directly correlated to ϵ_r , κ and $\tan \delta$
- Reduced number of laboratory oil samples

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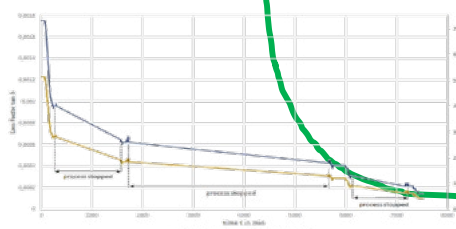
Application: oil regeneration plant



filtration
purification
vacuum drying

Purification / filtration effect is directly correlated to ϵ_r , κ and $\tan \delta$

Reduced number of laboratory oil samples



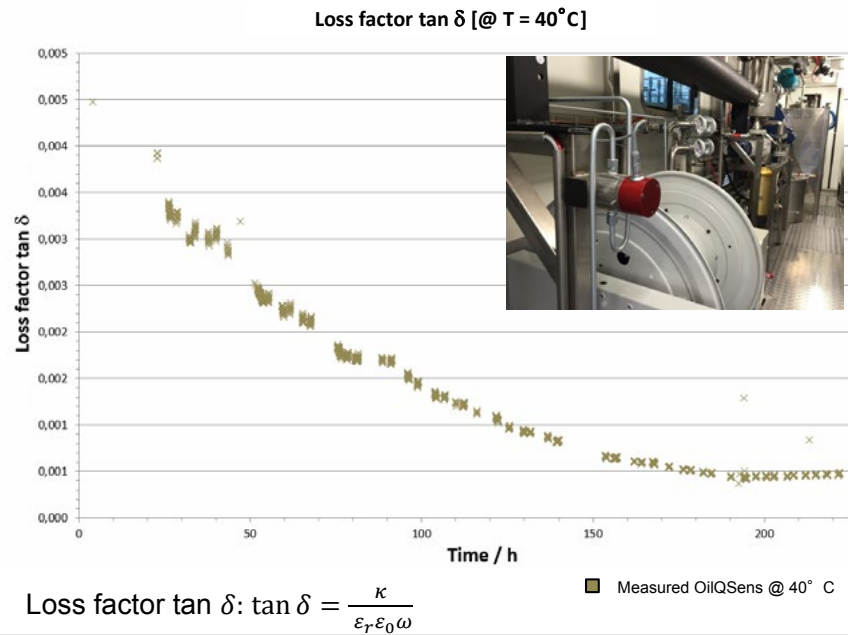
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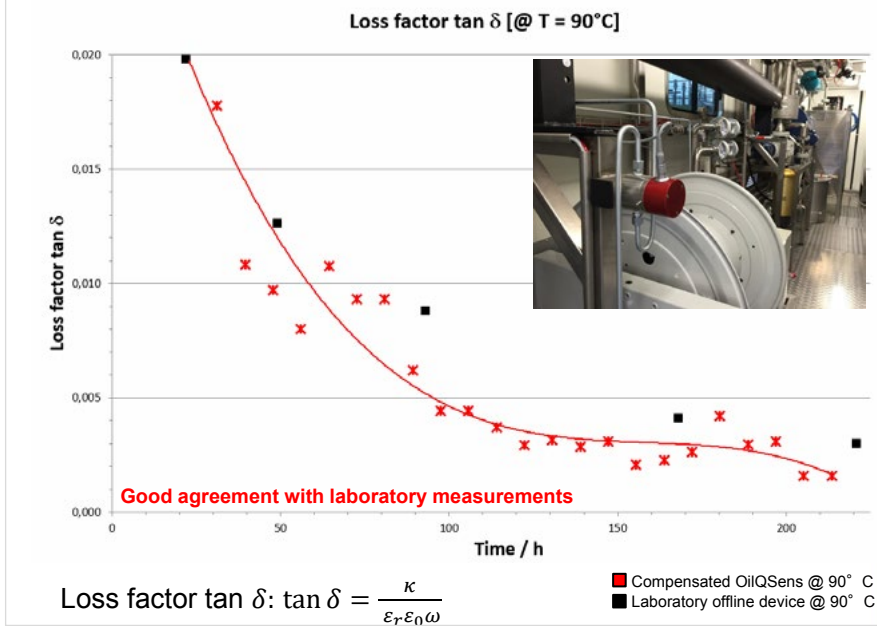
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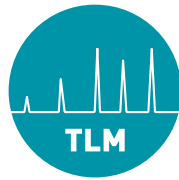
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Loss factor $\tan \delta$ vs. time



Loss factor $\tan \delta$ vs. time





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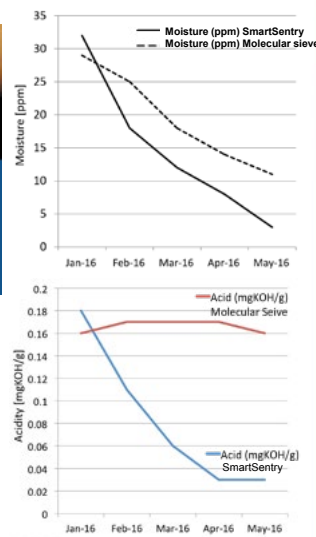
Online Regeneration & Oil Condition Monitoring High Voltage Transformer Protection



- Non intrusive – uses the transformer convection flow
- Simple to install
- Removes moisture
- Removes acids
- Removes dissolved sludge
- Removes DBDS

Online oil condition measurement

Permanent purification & dehydration **24 / 7 / 365**



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Key technology – Adsorbents.

Low cost, online, oil conditioning unit.

It offers a improvement over conventional oil regeneration and recovery systems.

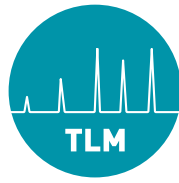
Ideal system to fit to new transformers to prevent moisture build up.

It can also be used on older transformers to restore the insulation.

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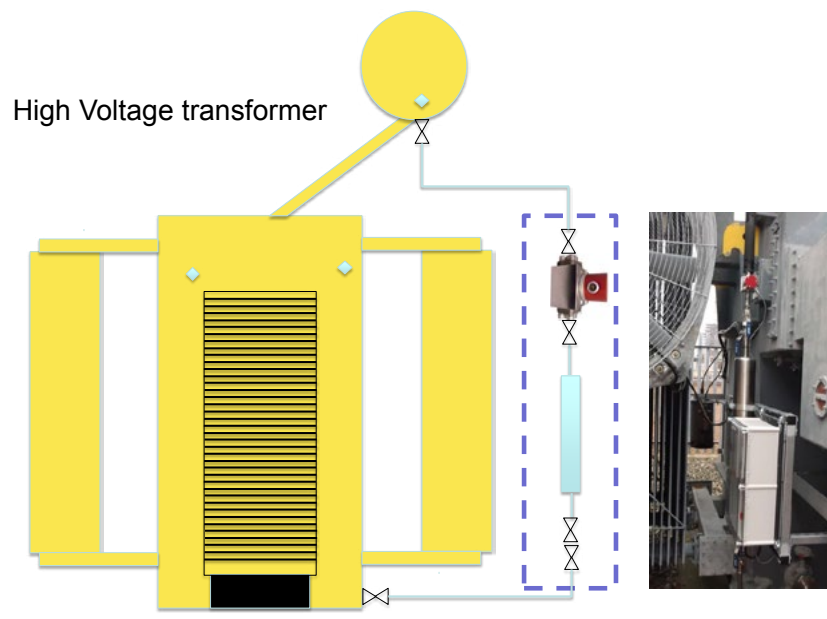
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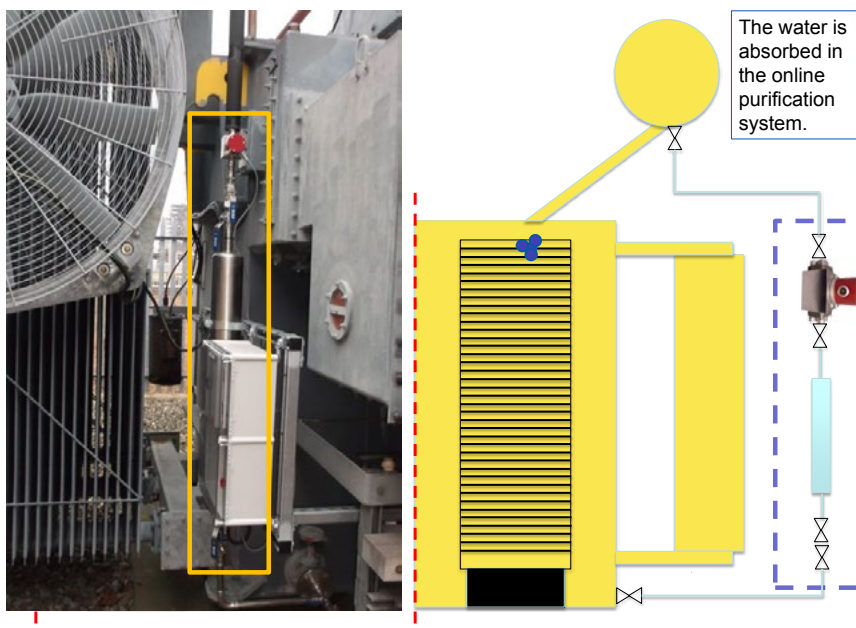
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Fitment and flow



Advantage of an on online purification system with oil monitoring





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Installations



Fitted to a 30 MVA

Passive, no pump required.

Controls:

- Moisture
- Acids
- Dissolved sludge

Holds up to ~10kg of water, acids, etc.

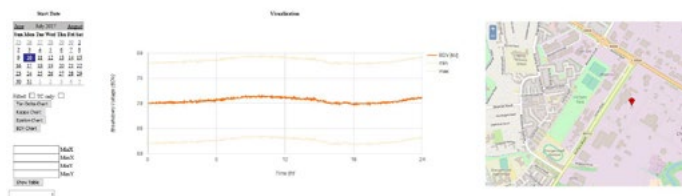
Economical & long life and can be recycled.

Maintains oil in peak condition

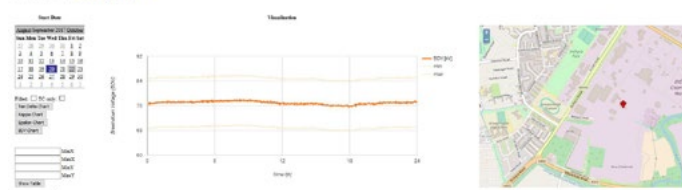


**CMS Server-Interface via Internet Browser
REMOTE ACCESS 24 / 7**

Sensordata SN V11-OQ-0118



Sensordata SN V11-OQ-0119

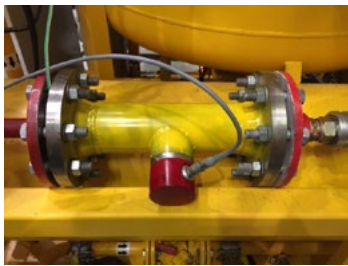




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Thanks for your attention! Questions?



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