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Dubai
22. – 23.Oktober 2013

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About the Conference

TLM goes global

Transformer Life Management 2013 – ME 22. – 23.Oktober 2013

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The exit from nuclear energy in Europe and the increasing importance of alternatively based forms of energy generation like wind power and photovoltaic sources lead to new challenges and modes of operating the networks and their equipment. In parallel the age of the devices and their transmission demands continuously exceed.

With these new conditions also the challenges for transformers enlarge. The question is how to deal with the tasks resulting thereof, thus to continuously ascertain the stability and operability of the devices. The TLM - 2013 symposium wants to help operators, asset managers, constructors, engineers and scientists in taking action to these disputes.

To develop efficient and sustainable maintenance strategies the operators of transformers need reliable condition diagnoses and appraisals, thus to improve the actual condition of the equipment.

An overlook on the actually available methods and on new developments and trends will be the topics of the lectures. Here the entire classical and the new procedures for diagnosis, the possibilities of a monitoring and the application of the tests as well as the processing of the gathered information will be discussed.

Due to this, substantial decisions on the operability and required measures can be taken, thus to optimize or even extend the residual lifetime of transformers.
Audience
The symposium is directed to engineers, physicians, chemists, constructors and to qualified technicians and craftsmen of manufactures and operators of transformers, to developers and interested persons from universities and research institutions and asset managers.

Lecture topics:

- Power Supply in future times
- Service and maintenance strategies
- Operation under economical aspects
- Lifetime Prolongation of the equipment
- Asset Management / Fleet Management
- Transformer repair at the enterprise and on site
- Monitoring of transformers and auxiliaries
- Condition analysis / classical and new forms of diagnosis
- High Voltage tests on and off site
- Research in insulations, Insulating Liquids and the aging of material

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Conference Program

Tuesday 22.10.2013

11^{00}	Check-in with welcome snack and distribution of the conference papers
12^{15}-12^{45}	Welcome and Introduction in the symposium topics by Chairman **Prof. Dr.-Ing. Hossein Borsi, University of Hannover**
12^{45}-13^{15}	Challenges and Solutions for the Networks of the Future Key Speaker
13^{15}-13^{45}	Topics of IEC 60296 **Nils Herlenius, ERGON Europe**
13^{45}-14^{15}	Oil Diagnosis on practical examples - How / What / Why **Peter Werle, ABB Transformer Service**
14^{15}-15^{15}	Coffee Break, Visit the Exhibition
15^{15}-15^{45}	Fleet Management – spending your service budget on the right assets **Laurent Allard, Ralf Schneider, ABB Power Products**
15^{45}-16^{15}	Loss Measurement on Power Transformers **Dan Keller, Highvolt Germany**
16^{15}-16^{45}	Top Solutions for Transformer Life Time Extension **Klaus Olbricht, EMB Germany**
16^{45}-17^{15}	The benefits of inhibited transformer oils using gas to liquid based technology **Joerg Friedel, Shell Technology Centre Hamburg**
19^{00}	Dinner - Social Event

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Conference Program

Wednesday 23.10.2013

9^{00}-9^{30}	Welcome and Introduction in the conference topics by Chairman **Prof. Dr.-Ing Hossein Borsi**
9^{30}-10^{00}	Estimating moisture in Power Transformers **Mohammad Tariq, Megger**
10^{00}-10^{30}	Drying of Transformers in the Field with Vaporphase, low frequency, or oil spray process **Christoph Morlo, Meier-Prozesstechnik Germany**
10^{30}-11^{00}	**Coffee Break, Visit the Exhibition**
11^{00}-11^{30}	Appraisal of Transformers using Gas-Monitoring Systems **Fabio Scattigio, Terna Italy**
11^{30}-12^{00}	Condition based (Re-)Investment planning **Georg Daemisch, DTC-Daemisch Transformer Consult**
11^{30}-12^{00}	Properties behind effective Transformer Oil Cooling **Hendrik Cosemans, Nynas AB Middle East**
12^{00}-12^{30}	Acoustic and electrical methods combined for localizing partial discharge in power transformer **Stefan M. Hoek, Omicron Austria**
12^{30}-13^{00}	Oilregeneration, positive Solutions **Milan Rybensky, Filtervac**
13^{00}-13^{30}	On –site Power Transformer demagnetization **Girish Narayana, Haefely Switzerland**
13^{30}-14^{30}	Trends and Opportunities of Transformer Monitoring **Tayyar Egeli, Weidmann Electrical Technology AG**
14^{30}-15^{30}	Conclusion and discussion - End of Conference - Lunchbuffet

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Topics of IEC 60296

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Nils Herlenius was born in Sweden. He has a MSc. Chemical Engineering from Royal Technical University (KTH) in Stockholm and an Executive MBA from the University of Strathclyde in Glasgow. He is a well known speaker and adviser at many utilities and OEMS with nearly 20 years in the transformer oil business. Active member of both CIGRE and IEC, author of technical papers and reviewing author for IEEE. He is currently Technical & Marketing Director for Ergon Europe MEA Inc. He is also a passionate musician and a private pilot.

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New IEC 60296 (ed. 4)

From a Transformer Oil Manufacturer's Perspective

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ABSTRACT

This paper highlights some of the major updates in the new IEC 60296 (ed. 4, published in 2012), "Fluids for electrotechnical applications – Unused mineral transformer oils for transformers and switchgear" [1], and some of the considerations a transformer oil manufacturer needs to take in order to fully meet the new IEC 60296 standard.

1. INTRODUCTION

The IEC 60296 (ed. 4) published in February 2012 replaces the IEC 60296 (ed.3) from 2003 [2]. Since 2003, various findings made an update of the IEC 60296 necessary. Few of them mentioned below:

In 2005, Doble conducted testing for presence of corrosive sulphur in some 500 un-used transformer oils. The tests showed that more than 40 percent of the oils were corrosive as per ASTM 1275A [3] which was the existing test method for corrosive sulphur.

In 2006, the laboratory of Sea Marconi Technologies and the Italian utility Terna, together with Italian and US Universities, identified a single compound, suspected to been added to the oil as an antioxidant, in declared un-inhibited transformer oils [4].

In 2009 Cigre published a report on the copper corrosion problem "Copper sulphide in transformer insulation" [5] and IEC published the new corrosive test method IEC 62535 [6], complimenting the already existing corrosive tests DIN 51353 [7] and ASTM 1275B [8].

In 2010 Cigre started the new working group A2-40, "Copper sulphide long-term mitigation and risk assessment" [9], and IEC initiated work to establish an official IEC method of detecting Dibenzyl Disulfide [10]. Professor Kapila from the University of Missouri – Rolla presented at the My Transfo 2010 the detection of an undeclared metal deactivator in transformer oils in his presentation *"Rapid and Specific Determination of Additives, Contaminants and By-products in Transformer Mineral Oils with Electrospray – Mass Spectrometry and Tandem Mass Spectrometry"* [11]

In 2011, the Belgian laboratory Laborelec [15] presented a paper on its discovery of an undeclared metal deactivator in transformer oils.

2. Major change of IEC 60296 (ed. 4) versus IEC 60296 (ed. 3)

- New interpretation of "un-inhibited" and "inhibited" transformer oil
- Metal passivators / deactivators
- Dibenzyl disulfide
- Other additives
- Corrosive sulfur test

2.1 New interpretation of "un-inhibited" and "inhibited" transformer oil

In the previous IEC 60296 (ed. 3) inhibitors improving the oxidation stability of the transformer oil were strictly limited to those described in the IEC 60666 "Detection and

Topics of IEC 60296

determination of specified additives in mineral transformer oils" [13]. No other additives improving the result the oxidation stability were allowed as per the IEC 60296 (ed. 3). If any of the antioxidant of the IEC 60666 were added, the oil should have been declared as either "trace inhibited" or "inhibited" transformer oil depending on the amount of inhibitor used.

In the new IEC 60296 (ed.4), the definition of "un-inhibited" and "inhibited" transformer oils is only linked to the antioxidants of the IEC 60666. As before, if any of the antioxidant described in the IEC 60666 are added - the transformer oil should be declared as either "trace inhibited" or "inhibited". Furthermore, in the new IEC 60296 (ed. 4) any additives may be used, including those which as per IEC 60296 definition are defined as an antioxidants. The choice of antioxidants is no longer limited to those described in the IEC 60666.

As a consequence, the transformer oil manufacture can add any antioxidant additive that is not described in the IEC 60666 and declare the oil as "un-inhibited", even though the transformer oil contains a synthetic antioxidant.

2.2 Metal Deactivators

The discovery of metal deactivators in some transformer oils on the market [11 and 12] raised concerns. These types of additives could hide potentially corrosive oil and give so called "false negative" results on corrosion tests. These additives additionally sabotage the oxidation test and do not give a fully representative result of the oxidation test, though the known metal deactivators are consumed quickly in service. The use of such additives without declaration and agreement with the buyer of the transformer oil – is a violation of both the previous IEC 60296 (ed. 3) and the new IEC 60296 (ed.4).

Chemical literature classifies metal deactivators into two major groups as per their functioning mechanism, which either can be of chelant or of passivating type [19]. The new IEC 60296 (ed. 4) describes both *"metal deactivators"* and *"metal passivators"* as examples of *"antioxidant additive"*, but it is important to note that the IEC 60666 can only detects metal passivators, i.e. not metal deactivator of the chelant type.

As per the new IEC 60296 (ed.4) the oil shall be tested for "metal passivator additives of IEC 60666". Some of the other metal deactivators found declared or un-declared in transformer oils and that is not described in the IEC 60666, can be detected by independent laboratories such as: Sea Marconi [14] and Laborelec [15].

2.3 Dibenzyl Disulfide Detection

Method for detection of dibenzyl disulfide as per IEC 62535 [6] is added as a compulsory requirement. For more information regarding this additive, see: [4], [16] and [17].

2.4 Other Additives

Known by few and used by even less, in the previous IEC 60296 (ed.3), article 5.4C gave the buyer an option to request the supplier to declare all additives in the oil. In the new IEC 60296 (ed.4) all additives shall be declared.

An transformer oil that fully complies with the new IEC 60296 (ed.4) shall include the following information on additives in the Product Data Sheet (PDS):

- Antioxidant additives, as per the IEC 60666
- Metal Passivators, as per the IEC 60666
- Dibenzyl disulfide as per the IEC 62535
- Other Additives – shall be declared

It is important to note that as per the new IEC 60296 (ed.4), if any additives are added that improve the oxidation stability, i.e. not only those described in the IEC 60666, the transformer oil shall be subject to the 500 hours oxidation test as per IEC 61125 C [18]. Example: any oil containing a metal deactivator, passivating or chelant type.

2.5 Corrosive Sulfur Test

Additionally to the corrosive sulphur test DIN 51353, the IEC 62535 [6] test on "potentially corrosive sulphur" is included in the new IEC 60296 (ed. 4). An informative annex has also been added with information on "potentially corrosive sulfur". The annex includes useful information on how to "detect corrosive sulphur compounds in oil containing a metal passivator additive (declared or suspected)," [1]

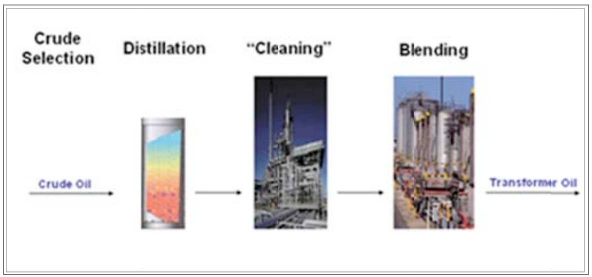
3. Manufacturing of Transformer Oil Meeting the IEC 60296 (ed.4)

For a mineral transformer oil to meet the new IEC 60296 (ed.4) standard: crude oil selection and correct oil fractionation by distillation are important to meet the requested viscosity at 40 and -30 degree Celsius (ISO 3104), sufficient amount of polycyclic aromatic compounds must be removed in order to pass the health requirements (IP 346), corrosive sulphur has to be removed in order to pass the "not corrosive" requirements tested as per IEC 62535 and DIN 51353. As per the IEC 60296 (ed. 4), the transformer oil shall meet more than 20 requirements.

To manufacture mineral naphthenic transformer oil that meets the IEC 60296 (ed.4), there are basically four steps as illustrated in picture 1: Crude oil selection, Distillation, Cleaning and Blending. Paraffinic transformer oil additionally needs to undergo a dewaxing process.

3.1 Crude Oil Selection

A typical misunderstanding is that the corrosive behavior of the oil is dependent on the origin of the crude oil. There are several sources of good quality naphthenic crude oil, appropriate for premium transformer oil production, with very different total sulphur content, such a North Sea crude with approximately 0,5 weight percent sulphur and Venezuelan crude with approximately 2,7 weight percent sulphur. But there is no link between transformer oils that are corrosive, i.e. do not pass the corrosive tests of IEC 62535 and the DIN 51353, and the origin of the crude oil. Instead oil found to be corrosive have originated from both low sulphur containing crude to high sulphur level crude oils. So the total sulphur content of a crude oil is not an indicator if the finished transformer oil will be corrosive or not.



Picture 1: Typical Transformer Manufacturing Process.

3.2 Distillation

The distillation of the crude oil is a process where the oil is being separated into different fractions depending on the boiling temperatures. The light fractions, i.e. the gases, distills at a temperature of less than 40 degrees Celsius (<105°F), while the heaviest fractions, i.e. asphalt, would distill at approximately 700 degrees Celsius (1290°F) and above. A typical cut for transformer oil is similar to light gasoil or diesel, i.e. typical 300–370 degrees Celsius (572–698°F).

Table 1 contains the boiling points of certain sulphur compounds. The distillation process generally excludes the lower molecular weight compounds from the transformer oil distillate and it is only the higher molecular weight molecules, such as the substituted dibenzothiophene compounds, that are present in the oil after the distillation process. In the case of benzothiophene or dibenzothiophene compounds, there are substituted hydrocarbon groups attached to the carbons on the base ring structure. As the molecular weight of the molecule increases the boiling point will increase above what is listed in the table. However, the base benzothiophene chemistry is retained.

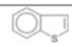
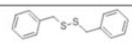
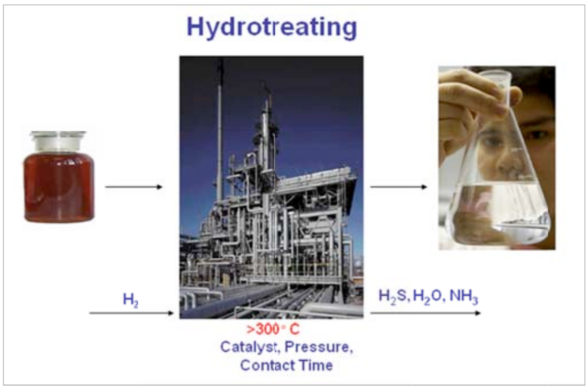
Compound		Boiling Point	Boiling Point
Thiophene		83 °C	183°F
Diethylsulfide	$(C_2H_5)_2S$	92 °C	198°F
Thiophenol		169°C	336°F
Benzothiophene		221°C	430°F
Dibenzyl-disulfide		270°C	518°F
Dibenzothiophene		332°C	630°F

Table 1: Boiling Point for certain sulphur compound. Source: Ergon and Albermarle

3.3 Cleaning by means of Hydrotreatment

The transformer oil distillate is not acceptable as transformer oil as it will not pass the IEC 60296 (ed.4) requirements. The distillate stock still contains sulphur compounds that are corrosive at typical conditions found in a transformer in service and the oxidation stability of the distillate is not sufficient and would not pass the oxidation test IEC 61125 C [18] required as per the IEC 60296 (ed.4).

There are several methods used for cleaning the transformer oil distillate but most commonly, used by the major transformer oil manufacturers, is hydrotreatment (also sometimes called hydrofinishing or hydroprocessing). Hydrotreatment (see picture 2) is a process where unstable molecules such as those containing oxygen, nitrogen, sulphur, and metals are removed and olefins and aromatics are saturated. By removing these unstable molecules and saturating the carbon-carbon double bonds, we are eliminating the risk of getting an oil that is dangerous for health (by removing the polycyclic aromatic compounds) and eliminating the possibility of adverse reactions that could happen under the typical operating conditions found in a transformer. During the hydro-treatment process the oil is exposed to high pressure, approximately 2000 PSIG (~140 bar), high temperature up to 385 degrees Celsius (725°F), plenty of hydrogen to feed chemical reactions and a nickel-molybdenum or cobalt-molybdenum catalyst tailor made for removal of reactive compounds.



Picture 2: Cleaning the Transformer Oil Distillate by Hydrotreating

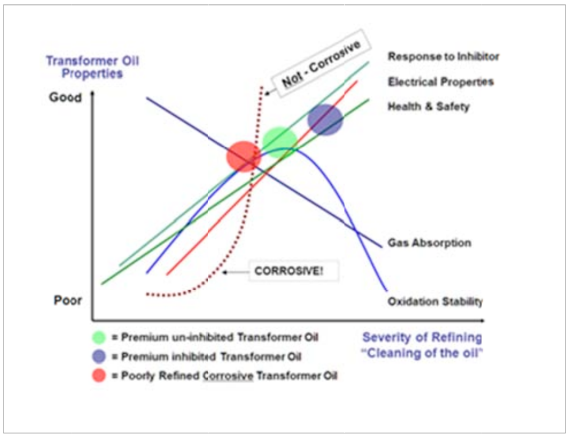
The severe conditions found in the hydro treatment process, you will never find in a transformer even under the most severe conditions, see table 2, and the sulphur containing compounds that would survive the hydrotreatment process and end up in the finished transformer oil are very few (typically 25-150 ppm), stable and non-corrosive, i.e. they easily pass the DIN 51353 and the IEC 62535 required by the new IEC 60296 (ed.4).

Parameter	Hydrotreating Process	Power Transformer
Pressure	261 KPA 1800 PSIG	10 - 100 KPA 1,5 - 15 PSIG
Temperature	316° - 385°C 600°-725°F	Typical ~75°C / 167°F
Hydrogen	~95% by volume	ppm by volume
Catalyst	Ni-MO or Co-MO	Copper

Table 2: Typical values for hydrotreating process versus a power transformer

Picture 3 illustrates the balance of various parameters the transformer manufacturer needs to take into consideration when producing transformer oil meeting the IEC 60296 (ed.4). As seen from the picture 3: all parameters, with the exception of gassing tendency and oxidation stability, are improved by a more severe refining, i.e. more severe hydro treatment / cleaning of the oil. With more severe cleaning, the ability of the oil to absorb gasses decreases due to the reduction of aromatic carbons. There is an optimum point where maximum oxidation stability is achieved by keeping enough stable sulfur and nitrogen compounds in the oil.

The optimum point of maximum oxidation stability is of crucial importance when manufacturing an un-inhibited transformer oil meeting the IEC 60296 (ed.4), i.e. an oil that will pass the 164 hours oxidation stability test as per IEC 61125 C [18] without the use of additives such as peroxide decomposers, metal passivators and deactivators that all have an impact on the oxidation test.



Picture 3: Cleaning the Transformer Oil Distillate by Hydrotreating

3.4 Blending

The blending can be either adding different streams of the refining process or adding additives such as the ones described by IEC 60666 for a trace or inhibited type transformer oil. As described in 3.4 "Other Additives", the new IEC 60296 (ed.4) open up for the use of any additives, including additives not described in the IEC 60666, that improves the oxidation stability - as long as they are declared in the product data sheet and certificates of compliance.

4. Conclusions and Recommendations

There are major changes in the new IEC 60296 (ed. 4) from 2012 compared to previous IEC 60296 (ed. 3) from 2003. The new interpretation of un-inhibited and inhibited transformer oils puts more focus on the use of additives in transformer liquids.

To secure premium quality, it is important that users of transformer liquids request that the supplier fully meet the new IEC 60296 (ed.4) – including the full declaration of additives in the Product Data Sheet (PDS).

This paper highlights some of the major changes in the new IEC 60296 (ed.4) but it is not a substitute for the new IEC 60296 (ed.4). It is therefore highly recommended that the user downloads the latest IEC 60296 from the IEC.

Topics of IEC 60296

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Nils Herlenius was born in Sweden. He has a MSc. Chemical Engineering from Royal Technical University (KTH) in Stockholm and an Executive MBA from the University of Strathclyde in Glasgow. He is a well-known speaker and adviser at many utilities and OEMS with nearly 20 years in the transformer oil business. Active member of both CIGRE and IEC, author of technical papers and reviewing author for IEEE. He is currently Technical & Marketing Director for Ergon Europe MEA Inc. He is also a passionate musician and a private pilot.

Jimmy M. Rasco was born in the United States. served as Manager of Technical Service for Ergon Refining, Inc, Vicksburg Refinery responsible for the Laboratory and Technical Services for 15 years. Jimmy also served as Vice President-Product Services, Ergon Refining, Inc responsible for quality and development of naphthenic and paraffinic base oils. Jimmy has worked in petroleum refining for 38 years in the area of Quality Control and Technical support. He currently has global responsibility for base oil technology for both paraffinic and naphthenic products. He has a BS degree in Chemistry from Alcorn State University.

Edward Casserly was born in the United States. He has a B.A. in Chemistry from the University of St. Thomas in Houston, Texas and a Ph.D. in Organic Chemistry from Rice University in Houston. He has been involved in R&D and technical support for specialty petroleum products for over 28 years. He has co-authored 18 scientific publications and is co-inventor on 7 US patents. He is currently Director – Refinery R&D for Ergon Refining.

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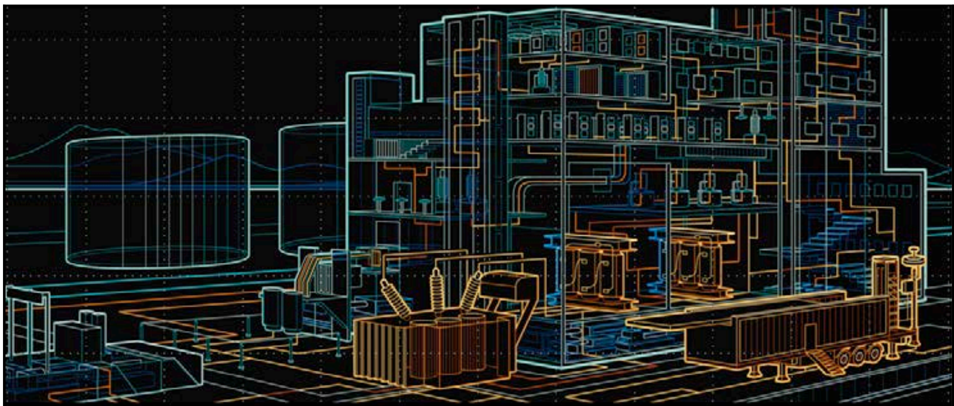
Oil Diagnosis on practical examples - How / What / Why

Peter Werle, ABB Transformer Service

Dr.-Ing. Peter Werle has studied Electrical Engineering at the University of Hannover, where he afterwards received his Dr.-Ing. degree at the Schering-Institute for High Voltage Technique and Engineering.

Since 2003 he is with ABB AG, Transformer Service in Halle, Germany, where he has hold different national and international positions. Since 2010 he is the general manager of the Transformer Service Workshop in Halle with more than 200 employees. He is member of VDE, IEEE, DKE K 182 insulation liquids and CIGRÉ as liason officer A2 - IEC TC 10 and active in different working Groups. He is the author or co-author of more than 100 publications and owner of more than 20 patents in Asset Management, Diagnostic Methods, Monitoring and High Voltage Testing.

Oil Diagnosis on practical examples - How / What / Why



Dr. Peter Werle, ABB AG – Business Unit Transformers, Transformer Service Center Halle, Germany

Transformer Life Management 2013 – ME

Oil Diagnosis on Practical Examples

Agenda

- Introduction
  - Oil tests
  - Methods of condition assessment
- Case studies: Oil tests and real cases
- Conclusions

Oil Diagnosis on practical examples - How / What / Why

Oil tests

- Reasons for oil testing:
  - „Easy“ method to evaluate the condition of essential components of transformers
  - Oil samples can be taken during operation („on line method“)
- Different oil test groups:
  - SOT: Investigation of the properties of the insulation fluid
  - DGA: Investigation of the dissolved gases
  - FURAN Analyses: Investigation of the properties of the solid insulation
  - …

SOT: **S**tandard **O**il **T**est

- Breakdown voltage
- Clarity / Particles
- Dielectr. dissip. factor
- Acidity
- Moisture content
- Interfacial tension
- Inhibitor content
- Corrosive sulfur
- PCB content
- …

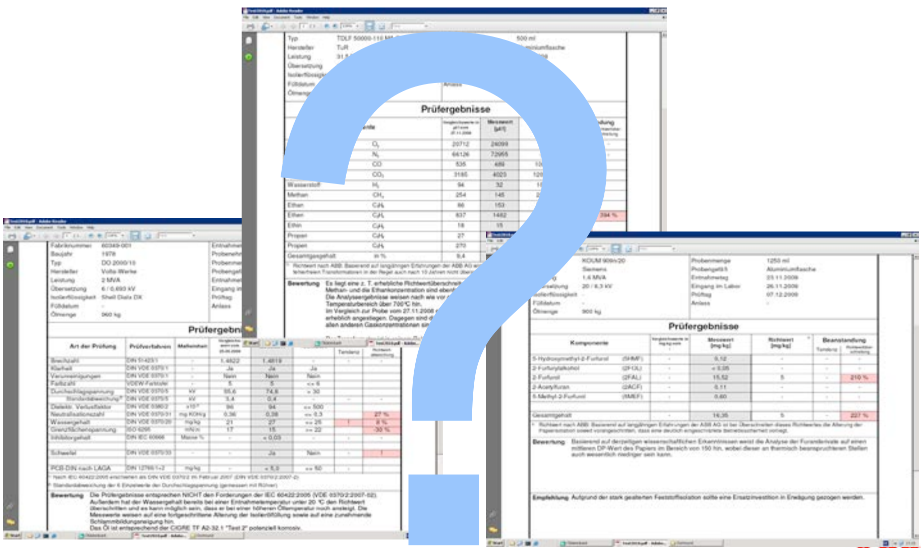
Oil Diagnosis on practical examples - How / What / Why

DGA: **D**issolved **G**as **A**nalysis

- Reasons for gases
  - Total gas content
  - Ambient gases
  - Operation of the transformer
  - Oxidation processes
- Typically analysed gases:

Oxygen	O2	Nitrogen	N2
Carbon Monoxide	CO	Carbon Dioxide	CO2
Hydrogen	H2		
Methane	CH4		
Ethane	C2H6		
Ethene	C2H4	Ethine	C2H2
Propane	C3H8	Propene	C3H6

How? What? Why?



Oil Diagnosis on practical examples - How / What / Why

Electrical measurements

Method	Object	Online	Offline
Resistance measurements	Detection of breaks and/or bad contacts for all taps		•
Insulation resistance measurements	Estimation of insulation condition, indication on wet insulation		•
Transmission ratio measurements (TTR)	Detection of winding- or layer short circuits and interruptions		•
FRA (Frequency Response Analysis)	Detection of winding short circuits and coil deformations		•
Dissipation Factor Measurements (tanδ)	Estimation of insulation condition / Aging		•
FDS (Frequency Domain Spectroscopy)	Determination of humidity of the paper insulation material (AC method)		•
PDC (Polarization Depolarization Current)	Determination of humidity of the paper insulation material (DC method)		•
PD measurements	Detection of week spots inside the insulation system	•	
Visual Inspection	Detection of leakages, pollution, other problems,	•	•
Infra Red Scan	Detection of hot spots and hot , source of heat	•	
UV-Camera	Detection of corona impulses	•	

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Oil Diagnosis on practical examples - How / What / Why

Example 1
Network Connection Transformer

Oil Diagnosis on practical examples - How / What / Why

Example 1
Description and Background

- Technical data of the transformer:

	Rated value
Voltage	110 / 20 / 10 kV
Year of manufacturing	1991
Power	31,5 MVA

- Network connecting transformer in Germany
- History:
  - Maintenance actions have been performed regularly
  - Last action: Exchange of the main valve at the bottom of the transformer

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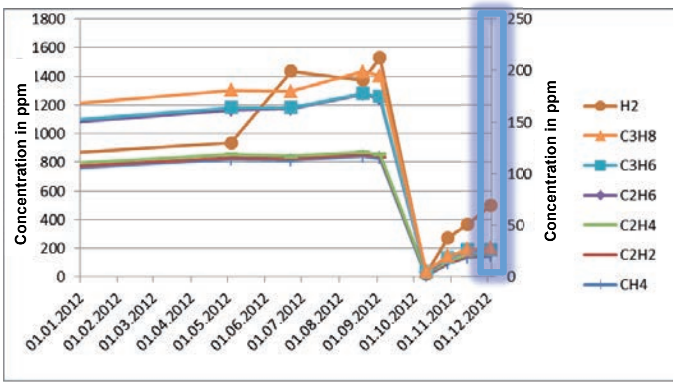
Example 1
DGA Trend

- Time frame 01/2012 – 12/2012



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Oil Diagnosis on practical examples - How / What / Why

Example 1
Results of the SOT (12/2012)

Test	Result
Breakdown voltage	71,5 kV
Dielectr. dissip. factor	8,5 ‰
Acidity	<0,03 $mg_{KOH}/g_{Öl}$
Moisture content	4,4 mg/kg
Interfacial tension	29,3 mN/m

- No abnormalities

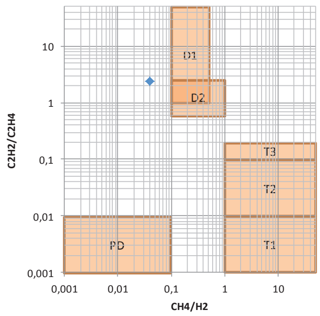
Example 1
Results of the DGA (12/2012)

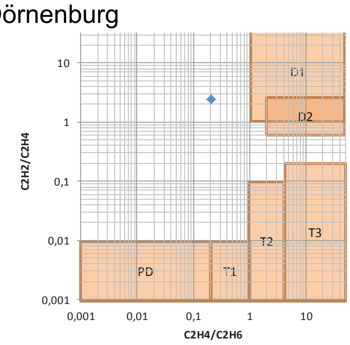
DGA	Gas concentration [ppm]
H_2 [ppm]	501
O_2 [ppm]	17556
N_2 [ppm]	40018
CO_2 [ppm]	243
CO [ppm]	17
CH_4 [ppm]	20
C_2H_6 [ppm]	3
C_2H_4 [ppm]	1
C_2H_2 [ppm]	2
C_3H_8 [ppm]	1
C_3H_6 [ppm]	1
Total Gas Content [%]	5,8

Oil Diagnosis on practical examples - How / What / Why

Example 1
Evaluation of the DGA

- Value H_2 of above the limit
- Kay gas for PD
- IEC 60599 Quotients:
  - C2H2/C2H4: 2,4; CH4/H2: 0,04; C2H4/C2H6: 0,21
  - Quotients close to PD (see table 2, IEC 60599)
- Graphical evaluation acc. to Dörnenburg



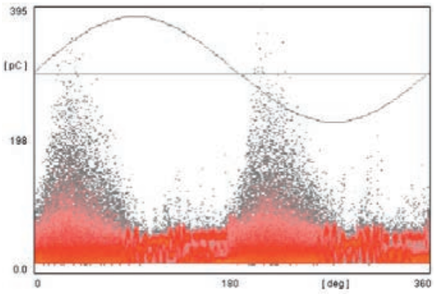


Example 1
Further measurements

Measurement	Result
PD measurement with induced voltage	PD was measured, no localization possible
Transmission ratio	No abnormalities
Winding resistances	No abnormalities
Insulation test	No abnormalities
FRA	No abnormalities
FDS	No abnormalities

Oil Diagnosis on practical examples - How / What / Why

Example 1
Further measurements (PD)



PD Pattern: Non-conduction material (cavity) without any contact to metallic electrode

Example 1
What was the problem?

- Transformer was sent to ABB´s transformer service center
- A vacuum was applied to the transformer in a vacuum chamber
- Oil was filled under vacuum
- HV test in test field, no PD were measured anymore

Oil Diagnosis on practical examples - How / What / Why

Example 2
Industrial Transformer

Oil Diagnosis on practical examples - How / What / Why

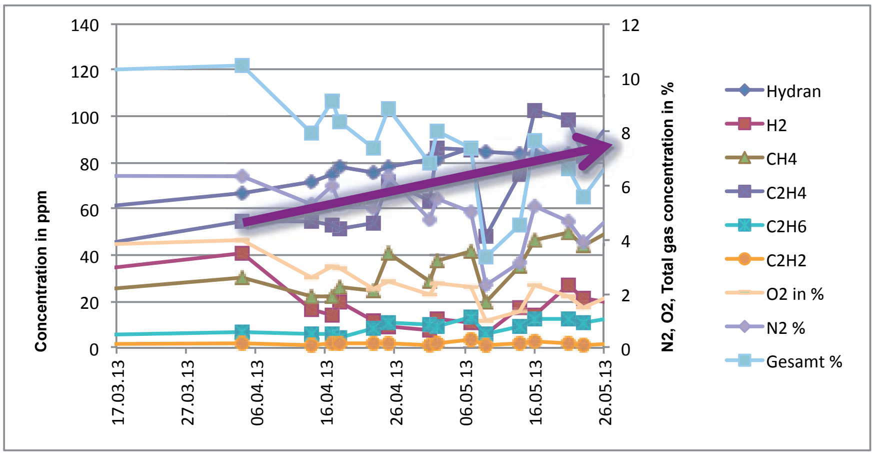
Example 2
Description and Background

- Technical data of the transformer:

	Rated value
Voltage	33 / 1.2 - 0.55 kV
Year of manufacturing	2012
Power	132 - 55 MVA

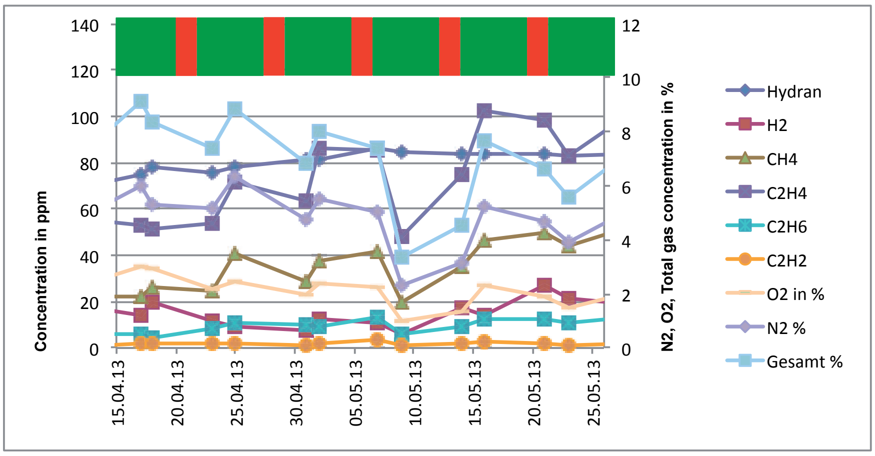
- History:
  - Increase of gas concentration was detected by a Hydran sensor
  - Recommendation by customer consultants: weekly DGA

Example 2
Trend of the DGA



Oil Diagnosis on practical examples - How / What / Why

Example 2
DGA Trend, zoom with operation profile of the transformer



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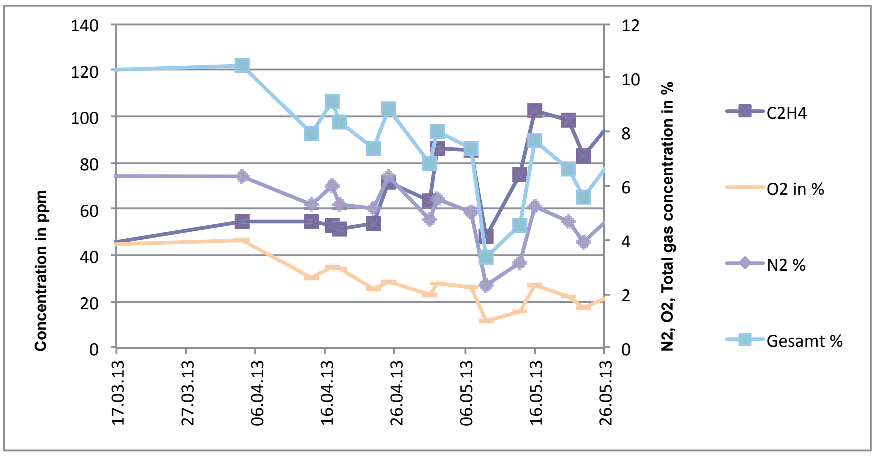
Example 2
DGA Trend, zoom



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Oil Diagnosis on practical examples - How / What / Why

Example 2
Results of the SOT(07/2013)

Test	Result
Breakdown Voltage	74 kV
Dielectric dissip. factor	0,9 ‰
Acidity	<0,03 $mg_{KOH}/g_{Öl}$
Moisture content	3,8 mg/kg
Interfacial Tension	39,8 mN/m

- No abnormalities

Example 2
Results of the DGA (07/2013)

Test	Result
H_2 [ppm]	10
O_2 [ppm]	28354
N_2 [ppm]	64150
CO_2 [ppm]	502
CO [ppm]	64
CH_4 [ppm]	35
C_2H_6 [ppm]	6
C_2H_4 [ppm]	57
C_2H_2 [ppm]	1
C_3H_8 [ppm]	2
C_3H_6 [ppm]	20
Total Gas Content [%]	9,6

Oil Diagnosis on practical examples - How / What / Why

Example 2
Evaluation of the DGA

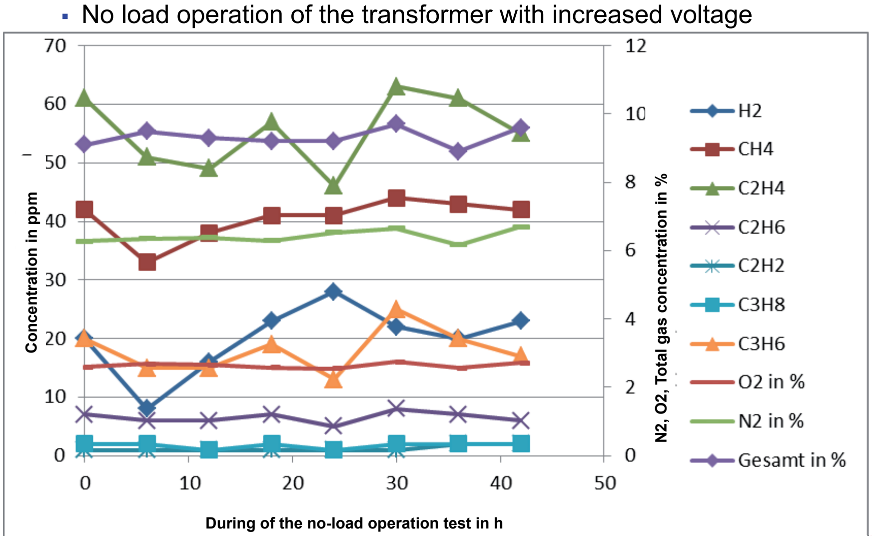
- No gas limit was exceeded

- On site performed electrical measurements:

Measurement	Result
Transmission ratio	No abnormality
Winding resistances	No abnormality
Insulation resistances	No abnormality

Example 2
DGA during no-load operation

- No load operation of the transformer with increased voltage



Oil Diagnosis on practical examples - How / What / Why

Example 2
Further electrical measurements

Messungen	Ergebnis
Transmission ratio	No abnormality
Winding resistances	No abnormality
Insulation resistances	No abnormality
Tanδ	No abnormality

Example 2
Is there a problem?

- No gas limits were exceeded
- No indication of any problems in the main connection were found
- No gas increase during no load operations were found
- Strong changes of O_2, and N_2 concentration which are expected to be stable (DGA provided by the customer)

Oil Diagnosis on practical examples - How / What / Why

Example 3
Shunt Reactor

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Oil Diagnosis on practical examples - How / What / Why

Example 3
Description and Background

- Technical data of the shunt reactor

	Rated value
Voltage	120 kV
Year of manufacturing	1979
Power	60 MVAr

- History:
  - Abnormal DGA results in 2012

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Example 3
Results of the SOT (07/2012)

Test	Result
Breakdown voltage	71 kV
Dielectric dissip. factor	2,4 ‰
Acidity	<0,03 $mg_{KOH}/g_{Öl}$
Moisture content	8,8 mg/kg
Interfacial Tension	39,1 mN/m

- No abnormalities

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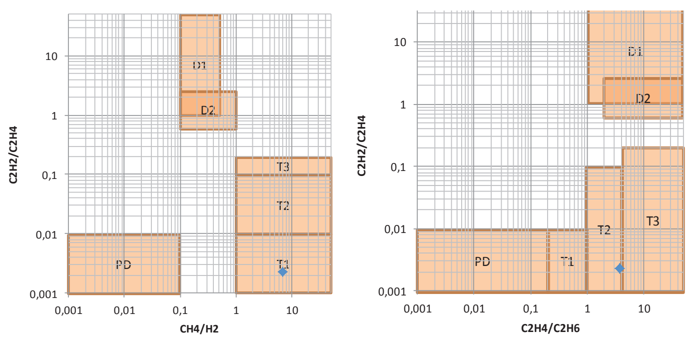
Oil Diagnosis on practical examples - How / What / Why

Example 3
Results of the DGA (07/2012)

Test	Result
H_2 [ppm]	60
O_2 [ppm]	19460
N_2 [ppm]	54872
CO_2 [ppm]	5229
CO [ppm]	769
CH_4 [ppm]	406
C_2H_6 [ppm]	116
C_2H_4 [ppm]	439
C_2H_2 [ppm]	1
C_3H_8 [ppm]	16
C_3H_6 [ppm]	177
Total Gas Content [%]	8,1

Example 3
Evaluation of the DGA

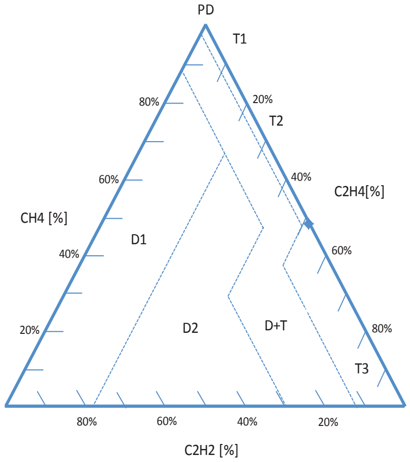
- Limit was exceeded at methane and ethene concentrations
- IEC 60599 Quotients:
  - C2H2/C2H4: 0,0; CH4/H2: 6,8; C2H4/C2H6: 3,8
  - Indication: Thermal fault between 300°C and 700°C
- Graphical interpretation acc. to Dörnenburg



Oil Diagnosis on practical examples - How / What / Why

Example 3
Evaluation of the DGA

- Duval triangle



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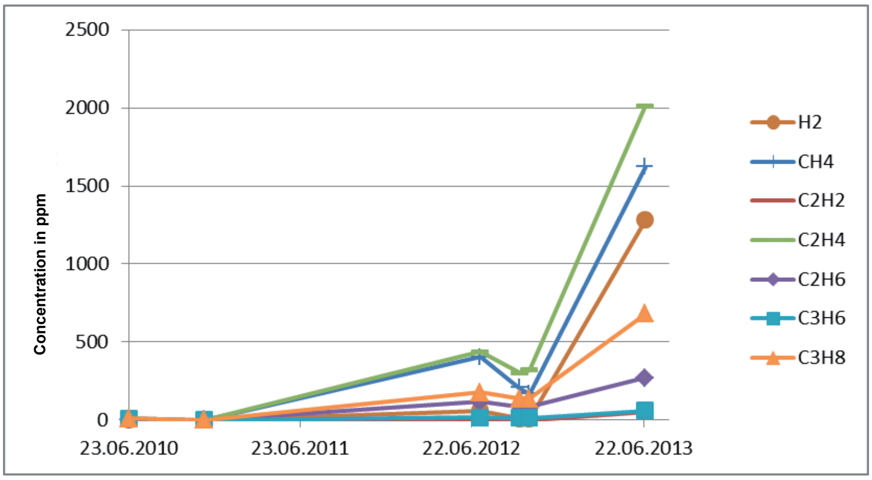
Beispiel 2
Evaluation of the DGA: DGA Trend



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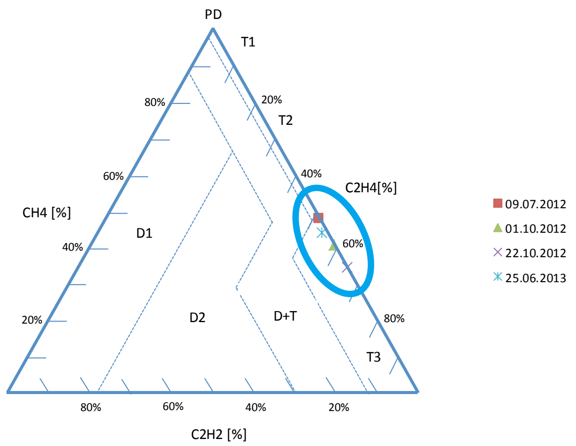
Oil Diagnosis on practical examples - How / What / Why

Example 3
Evaluation of the DGA

- Trend in Duval triangle



Example 3
What was the problem?

- HV test in Transformer Service Center
- PD at nominal voltage
- Visual inspection of the active part:
  - Hot spot at the core

Oil Diagnosis on practical examples - How / What / Why

Conclusion

- Oil tests (SOT, DGA)
  - Can be done online, low afford to be sent
  - Possibility to get indication for failures even in an early state
  - Plausibility of all analysis and test results must be checked carefully
- Additional methods can be applied for clarification

Integral view at all proberties of an transformer must be taken into consideration

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Oil Diagnosis on practical examples - How / What / Why

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Fleet Management – spending your service budget on the right assets

Laurent Allard, Ralf Schneider
ABB Power Products

Mr Laurent Allard, Diagnostic & Monitoring Engineer for Power Transformer.

Laurent joined ABB in 2007 and has worked for 6 years as a diagnostic and monitoring engineer on power transformers (PT) in the field: commissioning of PT, Standard Electrical Tests & Advanced diagnostics on PT, Low Frequency Heating Dryings (LFH), Condition assessments of PT. He then became in 2012 Engineering Solutions Sales Manager for PT. He is also at the head of "On-load Tap Changer (OLTC) Vibration Diagnostic Project" which is now a strong tool used for OLTC diagnostic on PT. Laurent is based in Geneva, Switzerland.

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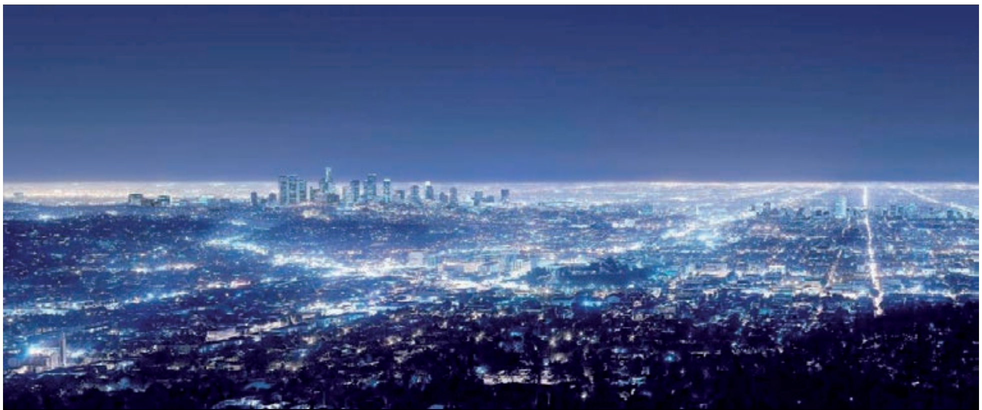
Fleet Management – spending your service budget on the right assets

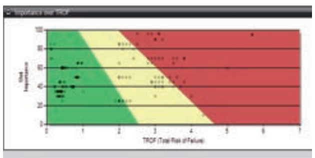


Laurent Allard, ABB Sécheron SA, Switzerland
Transformer Life Management 2013 – Dubai – October 22th & 23th, 2013

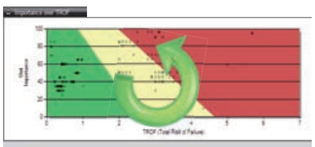
Fleet Management – Spending your service budget on the right assets

Content

- Mature Transformer Management Program (MTMP)



- Dynamic Transformer Management Program (DTMP)



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Fleet Management – spending your service budget on the right assets

Challenge – Need for higher reliability?
Mature Transformer Management Program (MTMP™)

Optimize investments: Maintain / Repair / Replace
- Which units present the highest risks in my fleet ?
- Which unit to maintain or repair in priority ?
- Should I maintain, repair or repair by a new unit ?

Solution: MTMP™
- Evaluate condition, remaining life time, risk of failure
- Define actions to mitigate the risks
- Modular analysis with 3 steps on a fleet on specific units
  - Fleet screening, Advance survey, Expert assessment

Benefits
- Provide more visibility and “predictability” to asset managers
  - Decide on preventive maintenance actions
  - Plan investments - invest in the right units

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MTMP™ - Output of a level 2 assessment survey
Power producer: Example of action plan to mitigate risk

Visual Inspection, Advanced Diagnostics, Design Review (if available)

Issues/Condition

UNIT #	Mechanical	Electrical	Thermal	Accessories	Overall score	ACTIONS
	Winding	Arcing	Heating		95	Visual inspection and repair in factory/rewinding
	Tank			OLTC heating	80	Repair on site and OLTC overhaul
			Aged oil	Bushing	70	Oil regeneration / filtration and advanced diagnosis / change HV bushing
		Arcing		Thermometer	50	Exchange TopOil – thermometer / on line monitoring of DGA
				Silicagel	40	Exchange silicagel
					25	Standard maintenance actions and controls
					15	Standard maintenance actions and controls / 10% overload capabilities
					10	Standard maintenence actions and controls / 15% overload capabilities

Score: 0: good condition
100: bad condition

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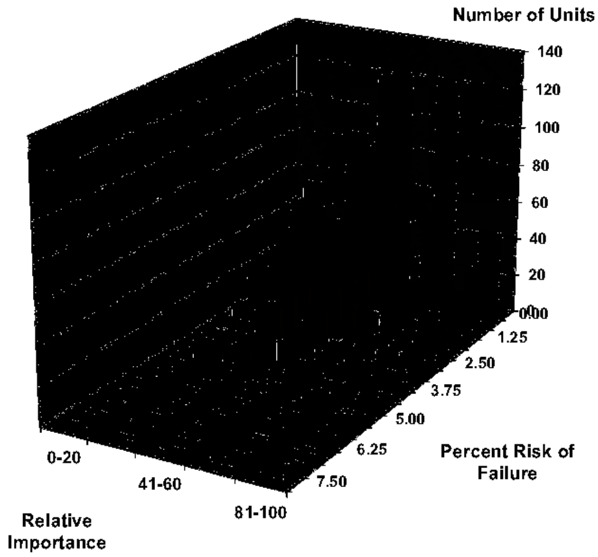
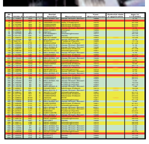
Fleet Management – spending your service budget on the right assets

Transformer Risk Assessment
Population Overview using ABB MTMProgram™



MTMP™ - Success story
Utility, USA



Customer need

- Increase reliability
- Plan investments for 10 coming years

ABB response

- Assessment of the condition of the fleet (MTMP survey)
- Evaluate risks of failure on 128 transformers
- Prioritize actions to optimize maintenance budget of 1'280 kUSD

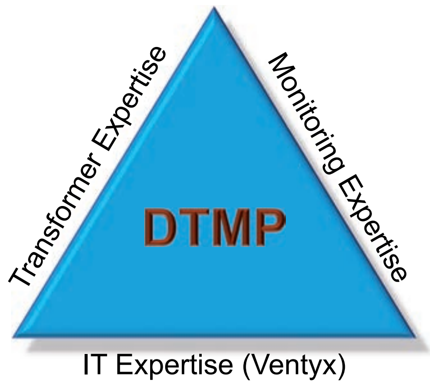
Customer benefits

- Maintenance budget reduced by 24%
- Budget now spent on the right units contributing to a higher overall reliability
  - 11 risky units: budget increased from 9% to 25%
  - 47 medium risks: budget increased from 37% to 45%
  - 70 low risks: budget decreased from 54% to 30%

Fleet Management – spending your service budget on the right assets

DTMP (Dynamic Transformer Management Program) is based on 10 Years of working with MTMP

- ✓ With the recent increase of monitoring sensors, there is a need to move to a dynamic/real-time approach
- ✓ MTMP → snapshot of the fleet health,
- ✓ DTMP → dynamic, constantly-updated view



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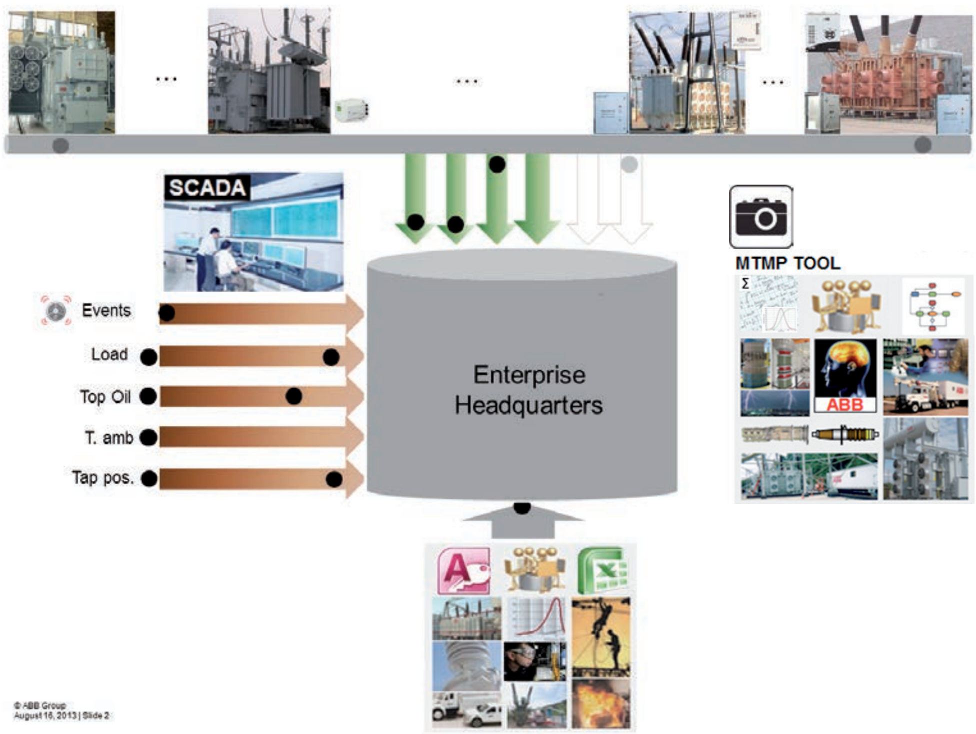

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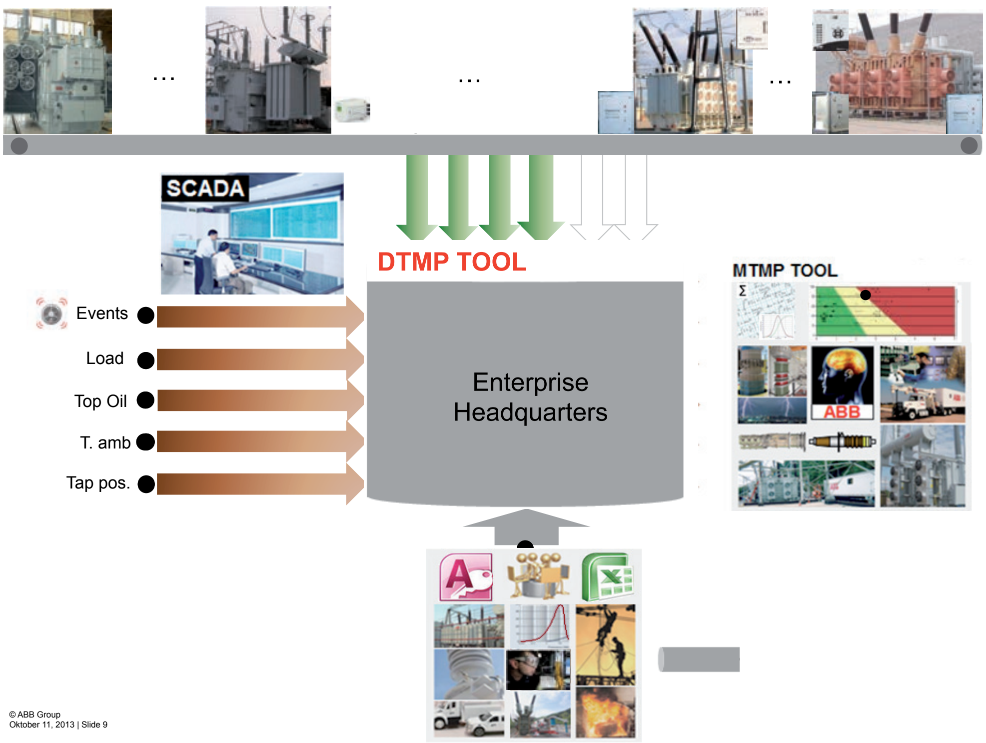

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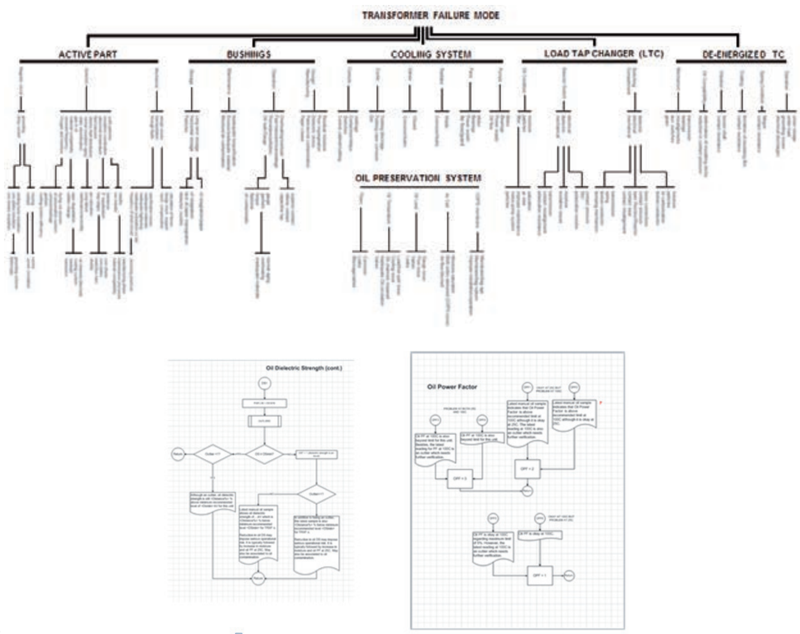
Development Background - Algorithms



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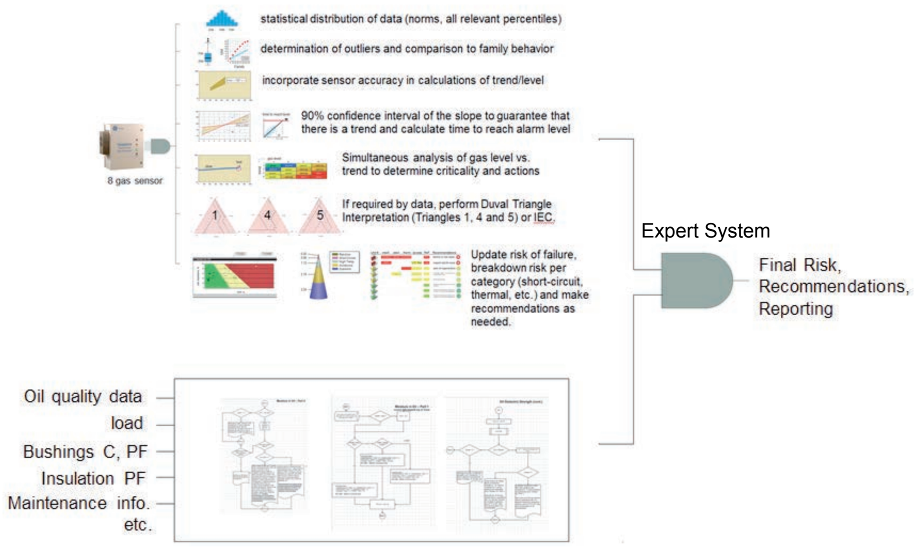
Continuous calculation, multiple parameters



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DTMP
Application: Ventyx Focal Point

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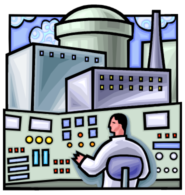
Fleet Management – spending your service budget on the right assets

DTMP
Résumé



- ✓ After the baseline is created by MTMP, DTMP will automatically pull all monitored information into its database
- ✓ Manual data input (as annual DGA, Furans, electrical testings…)
- ✓ Maximizes the investments as condition assessment, monitoring equipments…
- ✓ ABB & non ABB Transformers
- ✓ Number of transformers unlimited
- ✓ Customized solutions depending on data available
- ✓ Transformer Risk of Failure updated daily - Assessments performed multiple times per hour to identify trends and probabilities
- ✓ Messages and warnings issued if a potential problem exists
- ✓ As more data becomes available, the automated assessment gets even better

→ Helps you to pinpoint units that need maintenance, to avoid failure, and allow you to spend your service budget on the right assets

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Fleet Management – spending your service budget on the right assets

Dan Keller, Highvolt Germany

Dan Keller studied and graduated from University of Cooperative Education (Bautzen) with a Dipl.-Ing. (BA) in electrical engineering.

He joined the HIGHVOLT Prüftechnik Dresden GmbH control department in 2009 as a design engineer. Since 2011 he works as Area Sales Manager and is responsible for U.A.E., Kuwait, Qatar, Bahrain, Egypt, Poland, Czech Republic and Italy.

HIGH VOLT

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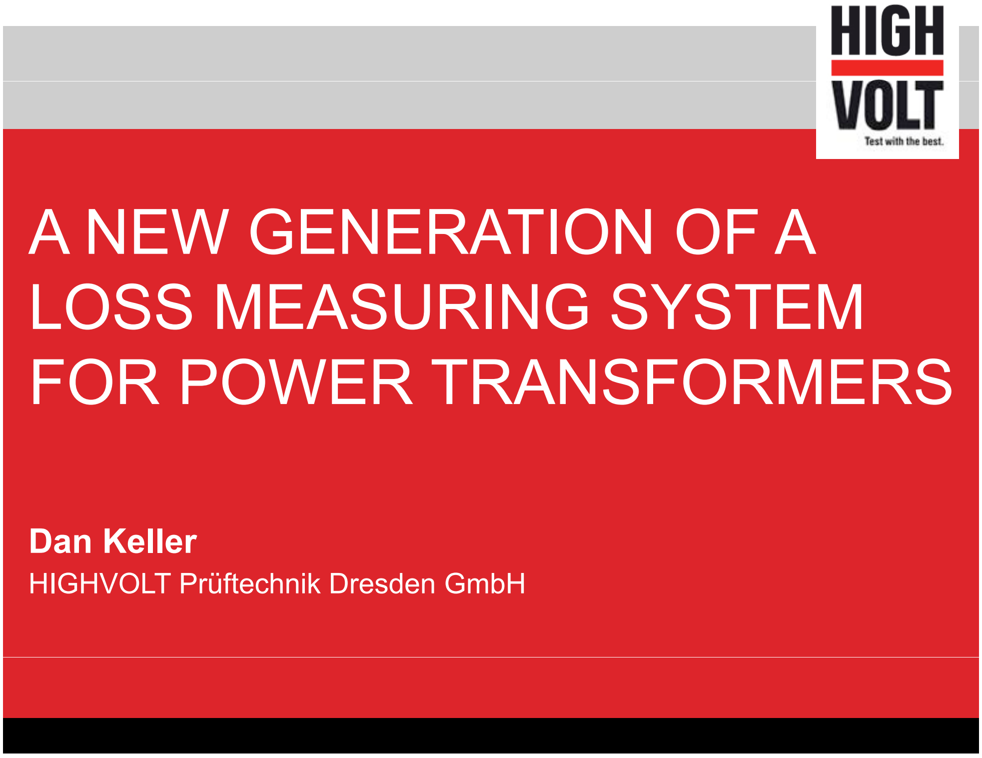

Fleet Management – spending your service budget on the right assets

Content

HIGH VOLT

- Information about HIGHVOLT
- Introduction to loss measurements
- Test set-up of loss measurement devices
- Comparison of different solutions
- Mobile Loss Measurement Calibration
- Summary

24.07.2013 A New Generation of a Loss Measuring System for Power Transformers 2

Test Systems for HV Transformers

HIGH VOLT

Factory test systems

On-site test systems

24.07.2013 A New Generation of a Loss Measuring System for Power Transformers 6

Fleet Management – spending your service budget on the right assets

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HIGH VOLT

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Introduction to Loss Measurements

HIGH VOLT

- Tests are carried out to show that equipment under test meets customer requirements and specifications
- Tests are part of quality assurance
- Routine tests are carried out with every individual product, type test are carried out with a representative sample
- IEC and IEEE standards for transformer test require the determination of load loss and no-load loss as routine tests
- Test equipment for loss measurements is established and well known
- There is a new device for loss measurements by HIGHVOLT

Fleet Management – spending your service budget on the right assets

No-Load Loss Measurement of Transformer

HIGH VOLT

- **Purpose:**
  - during life-time a transformer consumes a considerable amount of energy due to losses in iron and in windings
  - the losses have to be guaranteed by the manufacturer, a correct value is very important
- **Standards:**
  - IEC 60076-1:2011, clause: 10.1: "General requirement for routine, type and special tests", clause 10.5: "Measurement of no-load loss and current"
  - IEC 60076-8:1997, clause: 10: "Guide to the measurement of losses in power transformers"
  - IEEE Std C57.12.90-1999, clause: 8: "No-load losses and excitation current"

24.07.2013 A New Generation of a Loss Measuring System for Power Transformers 9

Load Loss Measurement of Transformer

HIGH VOLT

- **Purpose:**
  - during life-time a transformer consumes a considerable amount of energy due to losses in windings and in iron
  - information about losses is important for safe operation and lost resources
  - the losses have to be guaranteed by the manufacturer, a correct value is very important
- **Standards:**
  - IEC 60076-1:2011, clause 10.1: "General requirement for routine, type and special tests", clause 10.4: "Measurement of short-circuit impedance and load loss"
  - IEC 60076-8:1997, clause: 10: "Guide to the measurement of losses in power transformers"
  - IEEE Std C57.12.90-1999, clause 9: "Load losses and impedance voltage"

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Fleet Management – spending your service budget on the right assets

Content

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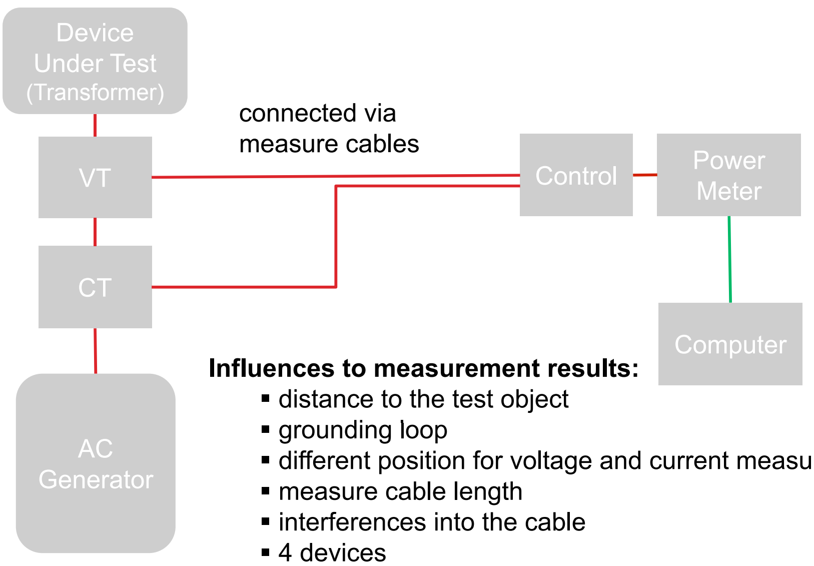
Typical Test Set-up of Loss Measurement Devices (Single Phase)

HIGH VOLT



Influences to measurement results:

- distance to the test object
- grounding loop
- different position for voltage and current measuring
- measure cable length
- interferences into the cable
- 4 devices

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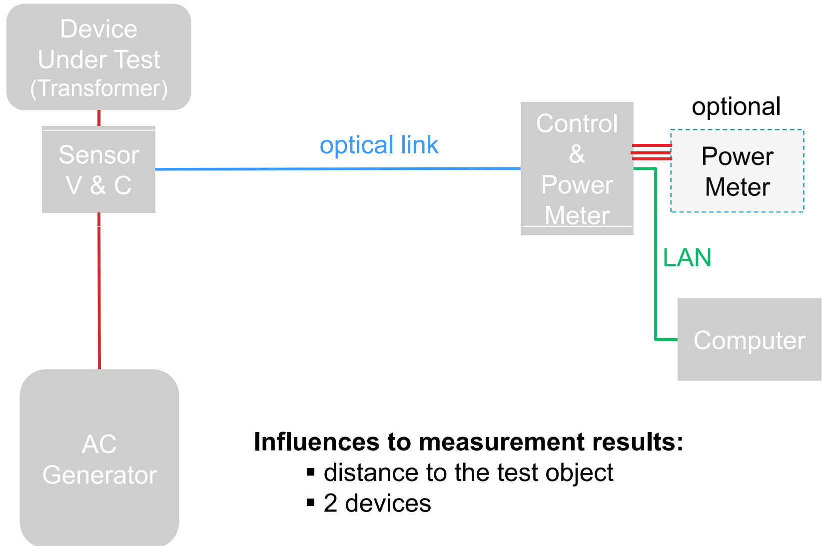
Fleet Management – spending your service budget on the right assets

Test Set-up of New Loss Measurement Devices (Single Phase)

HIGH VOLT



Influences to measurement results:
- distance to the test object
- 2 devices

LiMOS 2000/100 or 4000/200 by HIGHVOLT

Loss Measurement Device

HIGH VOLT

Fleet Management – spending your service budget on the right assets

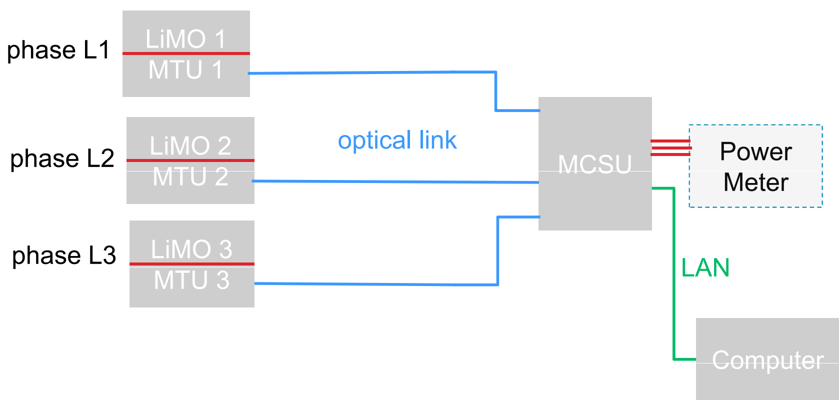
3 Phase Loss Measurement Device - LiMOS

HIGH VOLT

SIMPLIFIED SKETCH

sensors + electronic
(current /voltage)

control & power meter



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LiMO - Sensor Principle

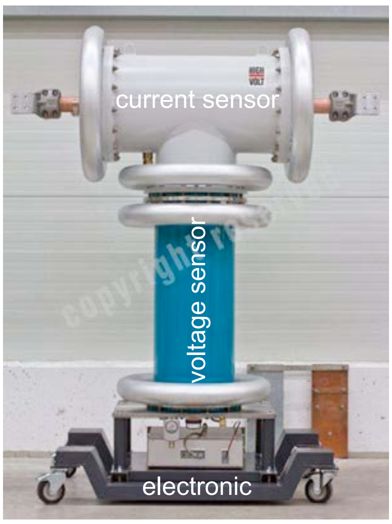
Loss Measurement Device

HIGH VOLT

LiMO (sensors)
- inductive current sensor
- capacitive voltage sensor

LiMO-MTU (electronic)
- amplifier
- analog digital converter
- reference voltage
- controller
- interface
- self test

MTU = Measuring and Transmission Unit



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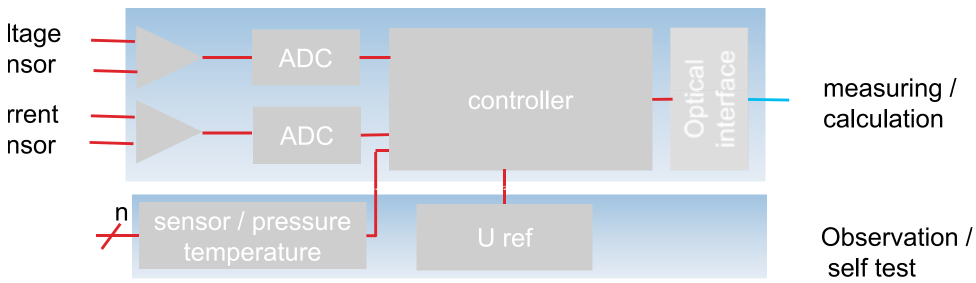
LiMO – MTU Sensor Electronic

Loss Measurement Device

SIMPLIFIED SKETCH



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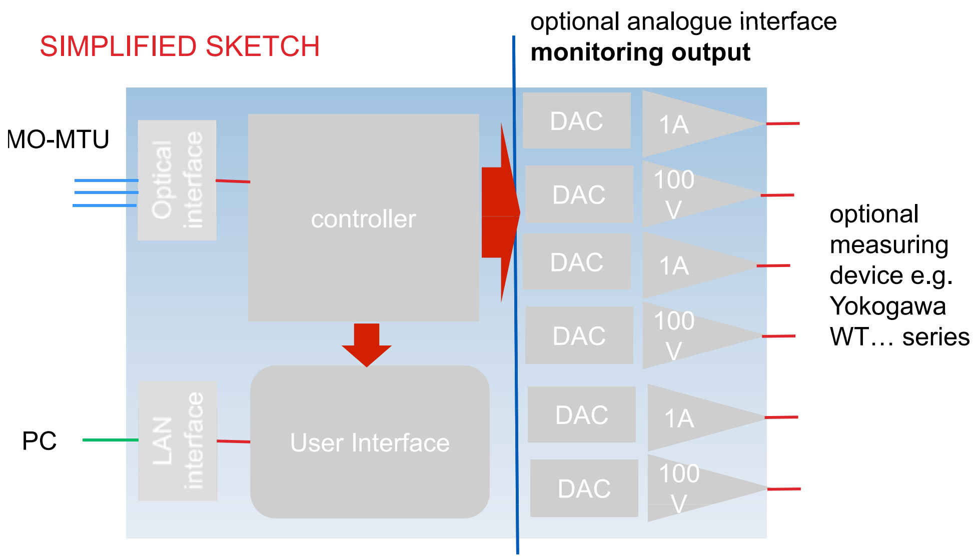
LiMO – MCSU Evaluation Electronic

Loss Measurement Device

SIMPLIFIED SKETCH



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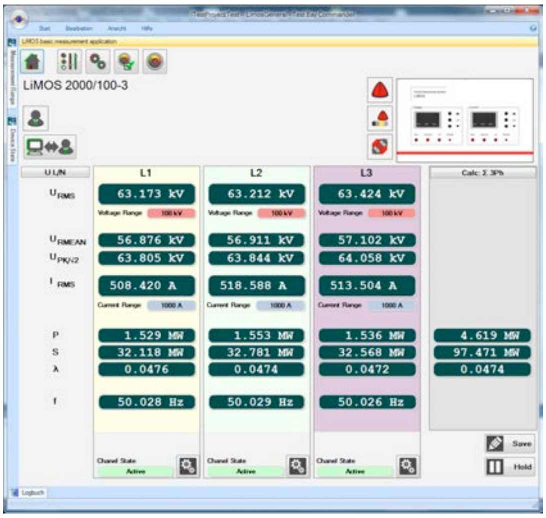
iMOS - Software

Loss Measurement Device

HIGH VOLT

Features:

- device operation control incl. measurement range control and status messages
- processing and visualization of measured values
- capable of multi channel data processing if used with multi phase systems



LiMOS 2000/100 Technical Data and Accuracy

Loss Measurement Device

HIGH VOLT

Voltage Measurement:
Primary voltage kV 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100
Accuracy class % 0.08

Current Measurement:
Primary current A 1, 2, 5, 10, 20, 50, 100, 200, 500, 1000, 2000
Accuracy class % 0.08

Power Measurement:

Power factor	Accuracy
cos φ = 1	0.11 %
cos φ = 0.1	0.13 %
cos φ = 0.05	0.19 %
cos φ = 0.01	0.87 %
cos φ = 0.008	1.10 %

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Content

- Information about HIGHVOLT
- Introduction to loss measurements
- Test set-up of loss measurement devices
- Comparison of different solutions
- Mobile Loss Measurement Calibration
- Summary

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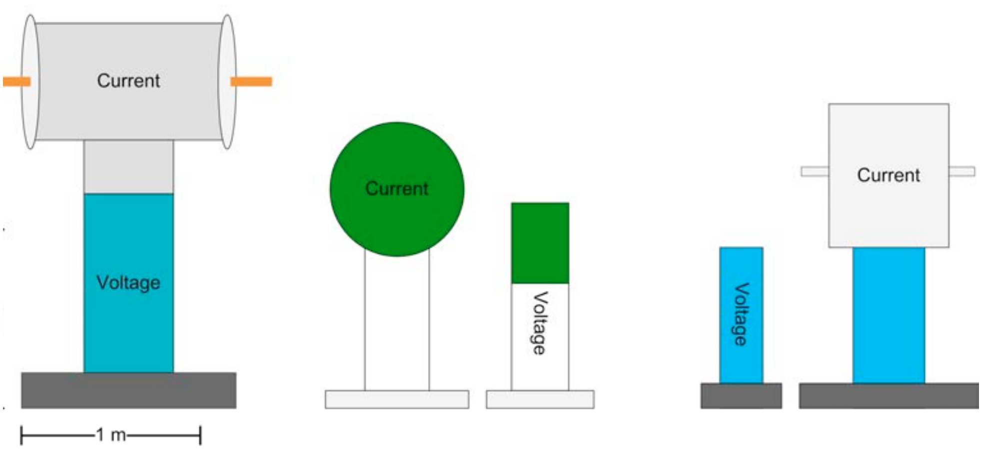
Comparison of Different Solutions
HV Components - Size per Phase

SIMPLIFIED SKETCH

A) LiMOS B) C)



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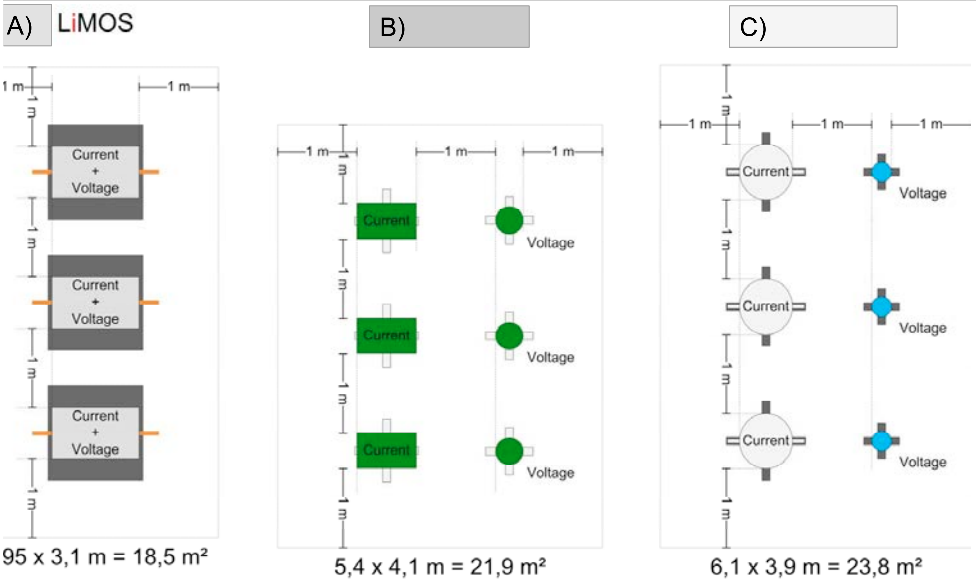
Comparison of Different Solutions HV Components - Layout

HIGH VOLT



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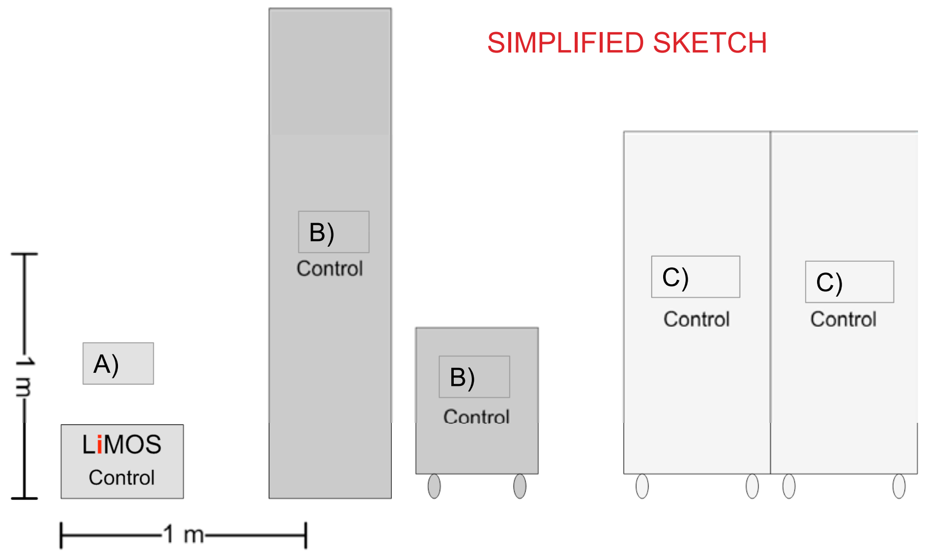
Comparison of Different Solutions Sizes of Control Units for 3 Phases

HIGH VOLT



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Comparison of Different Solutions
Control and Measurement

HIGH VOLT

A) HIGHVOLT LiMOS 2000-100	B) 2000A/100kV Competitor	C) 2000A/100kV Competitor
0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100 kV manual or auto-range	0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100 kV	1, 2, 5, 10, 20, 50, 100 kV
1, 2, 5, 10, 20, 50, 100, 200, 500, 1000, 2000 A manual or auto-range	1, 2, 5, 10, 20, 50, 100, 200, 500, 1000, 2000 A	one CT range 2000 : 1 current measurement ranges of the wattmeter's: 5, 2, 1, 0.5, 0.2, 0.1, 0.05, 0.02, 0.01, 0.005 A
Included iMOS Software (optional additional Yokogawa WT3000)	Fluke Norma 5000 or Yokogawa WT3000	3 wattmeters by MI

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LiMOS 2000/100 by HIGHVOLT
At a glance

HIGH VOLT

- Ethernet optical link to connect the measuring system to a HIGHVOLT test system
  - ➔ supports automatic control
  - ➔ is easy to handle
  - ➔ allows automatic safety procedures, e.g. emergency off in case of over temperature or over pressure
  - ➔ reduces influences of cable impedances, interferences or noise on measured values substantially

- One HV device for current and voltage
  - ➔ saves space
  - ➔ is easy to connect
  - ➔ is easy to calibrate

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Fleet Management – spending your service budget on the right assets

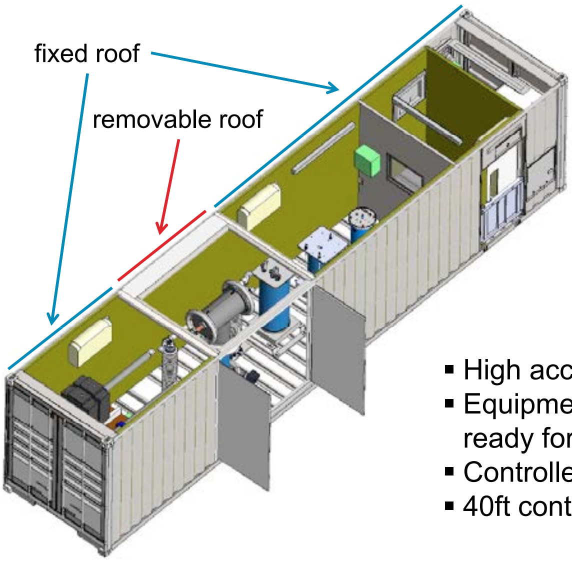
Content

HIGH VOLT

- Information about HIGHVOLT
- Introduction to loss measurements
- Test set-up of loss measurement devices
- Comparison of different solutions
- Mobile Loss Measurement Calibration
- Summary

LiMOS – calibration (Service from HIGHVOLT)

HIGH VOLT



- High accuracy
- Equipment completely installed and ready for operation within 2h
- Controlled environmental conditions
- 40ft container for road transport

Fleet Management – spending your service budget on the right assets

Content

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SUMMARY

- Common standards require the determination of losses
- HIGHVOLT introduced a new device that can measure power, voltage and current with high accuracy and little space requirements
- Physical quantities are measured close to the sensor and transmitted via optical link
- Measured values can be handed out digital or analog
- The device can be traceably calibrated against national standards for power directly in addition to voltage and current
- Procedures in test bays can be considerably simplified due to remote measurement range control of sensors
- Appropriate software for automatic device control and test
- If designed as multi channel device with relevant data processing it can be used in multi-phase systems

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HIGH VOLT

YOUR COMMENTS AND QUESTIONS

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HIGH VOLT

APPENDIX

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Fleet Management – spending your service budget on the right assets

Mobile Loss Measurement Calibration Laboratory

HIGH VOLT

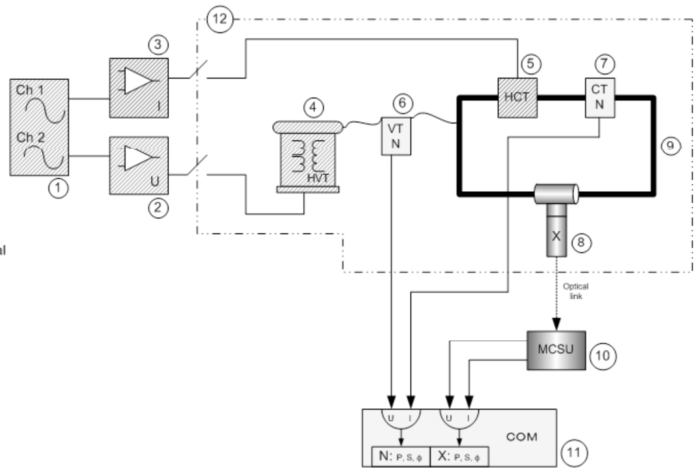
LOSS MEASURMENT

1 Arbitrary waveform generator
2 Amplifier for voltage channel
3 Amplifier for current channel
4 High-voltage transformer
5 High-current transformer
6 Standard voltage transformer
7 Standard current transformer
8 System to be inspected, type LiMOS
9 High current loop on high voltage potential
10 Analog output signal generator for 8
11 Power comparator
12 High-voltage test circuit

Power Generation: 100 kV and 2000 A

Reference Standards

Test Object



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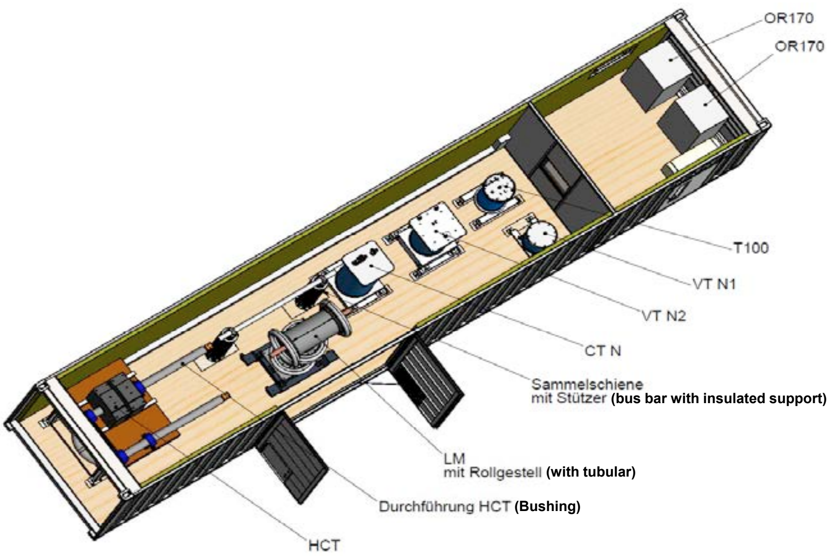
Mobile Loss Measurement Calibration Test Field

HIGH VOLT



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Results from the calibration of the mobile loss calibration test field

HIGH VOLT

PERFORMED BY SP (SWEDISH NATIONAL LABORATORY)

SP
KALIBRERINGSBEVIS
utfärdat av riksmätplats 01
CALIBRATION CERTIFICATE issued by a Swedish National Laboratory
Contact person: Allan Bergman, Measurement Technology, +46 10 516 54 98, allan.bergman@sp.se
Date: 2013-01-09
Reference: MTePX28712-K01 Rev.1
Page: 1 (6)
RMP 01

Quantity	Expanded uncertainty range	
	from	to
active power at 50 Hz	± 0.011 %	± 0.03 %
active power at 60 Hz	± 0.011 %	± 0.019 %
voltage at 50 Hz	± 0.011 %	± 0.014 %
voltage at 60 Hz	± 0.011 %	± 0.013 %
current at 50 Hz	± 0.021 %	± 0.03 %
current at 60 Hz	± 0.021 %	± 0.03 %

for active power	**0.036 %**
for RMS-value of voltage	**0.023 %**
for RMS-value of current	**0.033 %**

LiMOS Calibration

HIGH VOLT

Calibration Certificate K 1255

HIGH VOLT
page 1 of 18

Calibration object:	Channel 1 of the power measurement system Type: LiMOS 2000/100-3 Serial no.: 905613 consisting of - LiMO Type: 2000/100 Serial no.: P0181000-7 - LiMO-MTU Typ: 2000/100 Serial no.: MTU12-52476242-1 - LiMO-MCSU Typ: A 2000/100-3 Serial no.: MCSU12-52476242 Channel: 1
Manufacturer:	HIGHVOLT Prüftechnik Dresden GmbH
Customer:	
HIGHVOLT oder no.:	
Place of calibration:	Highvolt Prüftechnik Dresden GmbH
Date of calibration:	2012-10-29
Issue date of calibration certificate:	2012-12-04
Atmospheric conditions:	Temperature: 24.3 °C, rel. humidity: 50.2 %
Register No.:	K 1255

TLM

TRANSFORMER-LIFE-MANAGEMENT
CONFERENCE

Top Solutions for Transformer Life Time Extension

Klaus Olbricht, EMB Germany

New methods for subsequent hermetic sealing of transformers

By Dipl.-Ing. K. Olbricht

Transformers are often the most expensive equipment for power supply companies, and they are products to be planned on a longterm basis.
Both the financial and organizational risks rise the longer the transformer has been in operation. Potential failures as well as the very long delivery times, sometimes several years, cause great problems for power supply companies and industrial customers.

Figure 1: Power transformer

In Europe alone 60% of the installed transformers have been in operation for more than 25 years now although the service life under normal service conditions is only 25 to 30 years. It is therefore essential that reliable operation of the installed equipment is ensured in future as well.

Due to varying service temperatures during operation an extra volume must be provided to allow the oil to expand. This function is normally provided by the transformer's conservator connected with the transformer tank via a pipe and with the atmosphere via a pipe.

The service life of transformers, in particular power transformers with oil-paper insulation, is determined by the service life of cellulose in paper and in pressboard particles. Ageing and decomposition of the transformer cellulose affect both its electrical and mechanical strength. An increased water content of solid insulation material causes significant disadvantages for transformer operation, in particular in components subject to high electric load. Moisture reduces the mechanic and electric strength of insulating materials and accelerates the ageing process and partial discharge intensity.

Apart from moisture oxygen is another catalyst accelerating ageing of the active insulation.

The impact of oxygen on ageing of oil can be suppressed by inhibitors. Accelerated decomposition of cellulose begins with advanced thermal decomposition and, hence - depending on load - with increasing age. Therefore, subsequent hermetic sealing in open-type transformers can prolong the service life of even older units and, in addition, is an effective solution when a leaking hermetic sealing has to be replaced or repaired.

The state of the art offers a number of solutions preventing or significantly slowing down the penetration of atmospheric oxygen and water in the transformer, thus slowing down its ageing process caused by oxidation.

Hermetically sealed transformer

The hermetically sealed transformer was developed to prevent oil from getting into contact with oxygen and water. The transformer tank that does neither have a conservator nor an air cushion is sealed. This design has been used for distribution transformers only and more recently also for medium-power transformers. The tank and the radiators must be able to accommodate thermal expansion of oil as an expandable medium. Hermetically sealed transformers require low maintenance.

Figure 2: Hermetically sealed transformer

Nitrogen cushion

A nitrogen cushion preventing the penetration of atmospheric oxygen and water in the oil filling is formed in the conservator above the oil level.

Hydro-type compensator

Another method to prevent the oil from getting into contact with water and oxygen is the use of a hydro-type compensator in the conservator. Although this technical concept performs the tasks of hermetic sealing, its practical implementation has caused technical problems including higher costs, regular inspection of the rubber sack for tightness, longterm reliability of the membrane, difficult determination of oil level and inconveniencies with oil handling.

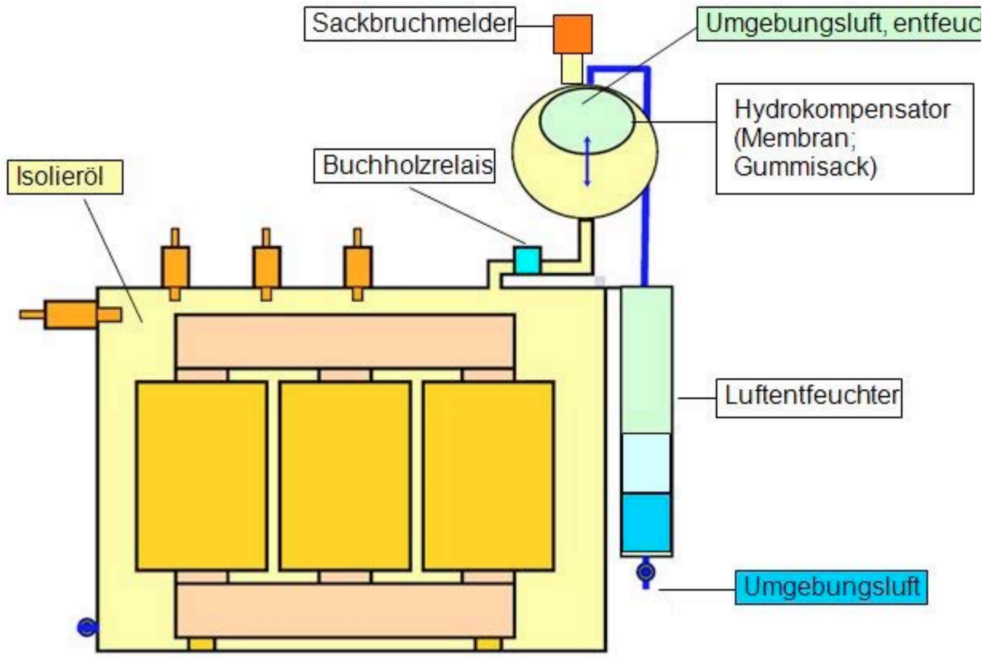

Figure 3: Transformer with hydro-type compensator

Sackbruchmelder	Air cell failure relay
Isolieröl	Insulating oil
Buchholzrelais	Buchholz relay
Umgebungsluft, entfeuchtet	Ambient air, dehumidified
Hydrokompensator (Membrane; Gummisack)	Hydro-type compensator (membrane; rubber sack)
Luftentfeuchter	Air dehumidifier
Umgebungsluft	Ambient air

Top Solutions for Transformer Life Time Extension

There exists another option for hermetically sealing a transformer or subsequent hermetic sealing.
This is a universal solution suitable for all transformers and eliminating the disadvantages of the other methods.

This solution is the **breather buffer box G3B.**

Figure 4: Fermentation lock

The breather buffer box operates on the principle of the fermentation lock known from wine making.
The gas in the conservator that expands with increasing temperature pushes the oil level in the external cylinder of the box downwards and, in parallel, in the internal cylinder upwards.
During cooling down the atmospheric pressure pushes the oil into the opposite direction.

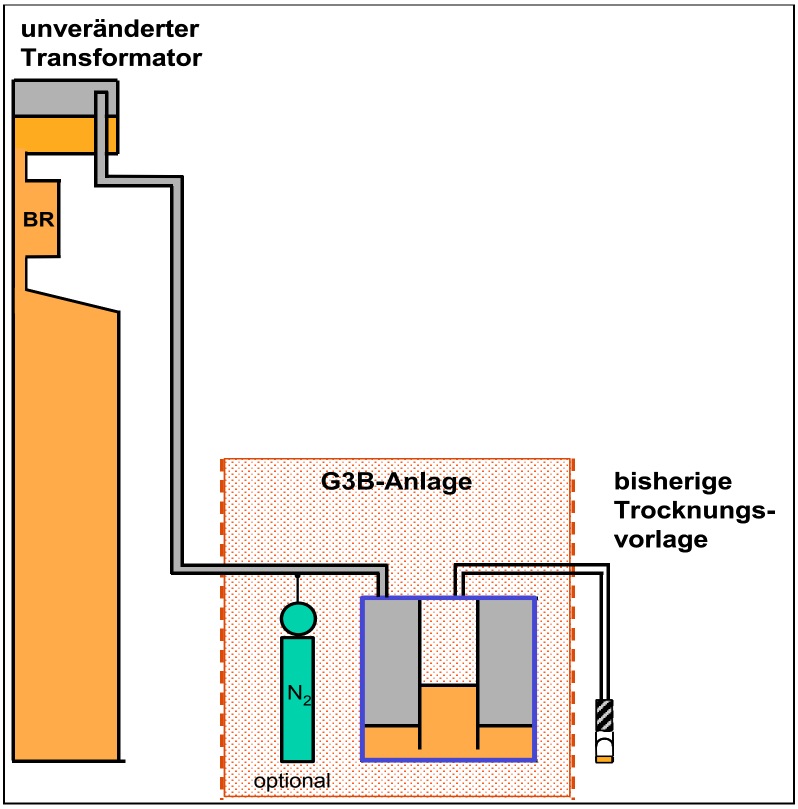

Figure 5: Principal scheme of the breather buffer box

unveränderter Transformator	Unchanged transformer
BR	Buchholz relay
G3B-Anlage	G3B unit
bisherige Trocknungsvorlage	Desiccant used until now
optional	optional

Construction of a breather buffer box unit

The G3B unit consists of a cylindrical box integrated in the breathing line of the transformer upstream of the moisture absorber. Optionally a nitrogen pressure gas bottle can be integrated.
The box is provided with a bottomless inner cylinder and is partly filled with oil as a service medium for pressure variation and diffusion barrier supported by a floating aluminium disk. The box cannot be locked and has two natural end positions for the oil level differences which serve to compensate the 30°C difference of the tank oil temperature. Under these conditions the oxygen-reduced air in the gas chamber of the conservator is separated in the cylinder box from the dry ambient air. If the atmospheric pressure in the conservator is exceeded by 40 mbar (maximum oil level in the internal cylinder), gas is released into the atmosphere. If pressure falls below the atmospheric pressure by 20 mbar (minimum oil level in the internal cylinder), either dry ambient air (subsequent natural hermetic sealing) or nitrogen from the pressure gas bottle is supplied (subsequent N2-aided hermetic sealing).

The boxes are available in different sizes:
G3B-1 for an oil weight in the transformer up to 1 t
G3B-2 for an oil weight in the transformer up to 2 t
G3B-5 for an oil weight in the transformer up to 5 t

Installation

G3B units are of modular construction including the oil sump of the transformer. Up to three cylindrical boxes can be placed one above the other, or the boxes can be arranged as twin columns connected in parallel and installed in the oil sump. The nitrogen pressure gas bottle is placed in a gas cabinet outside the oil sump. The unit is filled with a defined oil quantity. The subsequent hermetic sealing process can be accelerated by flushing the conservator with nitrogen during installation.

Figure 6: G3B unit with weatherproof lining

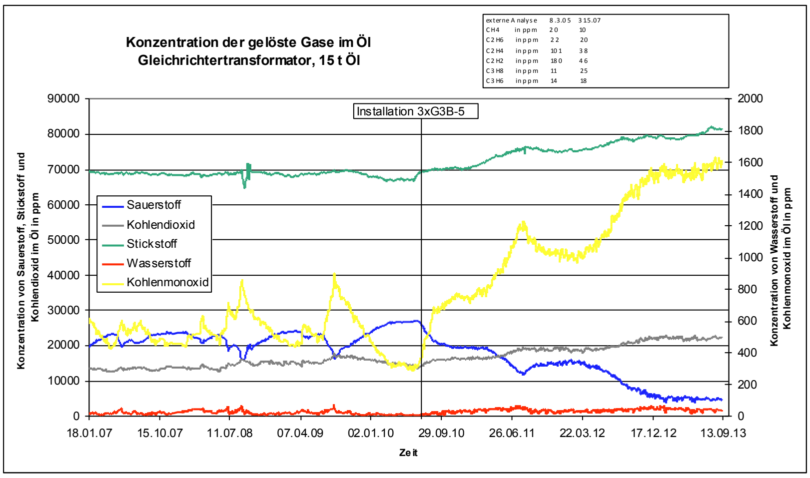

Figure 7: Development of the gas balance for subsequent natural hermetic sealing

Konzentration der gelösten Gase im Öl	Concentration of dissolved gases in oil
Gleichrichtertransformator, 15 (45) t Öl	Rectifier transformer, 15 (45) t oil
Installation 3xG3B-5 (3 x G3B-5/N_2)	Installation 3xG3B-5 (3 x G3B-5/N_2)
Konzentration von Sauerstoff, Stickstoff und Kohlendioxid im Öl in ppm	Concentration of oxygen, nitrogen and carbon dioxide in oil in ppm
Sauerstoff	Oxygen
Kohlendioxid	Carbon dioxide
Stickstoff	Nitrogen
Wasserstoff	Hydrogen
Kohlenmonoxid	Carbon monoxide
Zeit	Time
Konzentration von Wasserstoff und Kohlenmonoxid im Öl in ppm	Concentration of hydrogen and carbon monoxide in oil in ppm
externe Analyse	External analysis

Figure 8: G3B unit with nitrogen supply

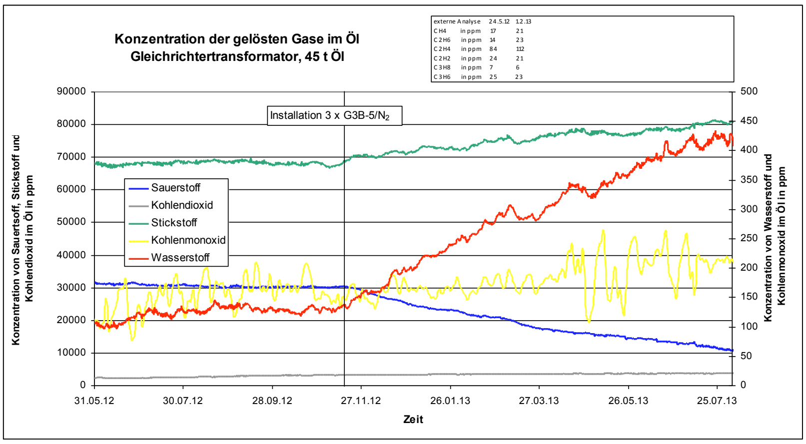

Figure 9: Development of the gas balance for subsequent N2-aided hermetic sealing

Konzentration der gelösten Gase im Öl Gleichrichtertransformator, 15 (45) t Öl	Concentration of dissolved gases in oil Rectifier transformer, 15 (45) t oil
Installation 3xG3B-5 (3 x G3B-5/N_2)	Installation 3xG3B-5 (3 x G3B-5/N_2)
Konzentration von Sauerstoff, Stickstoff und Kohlendioxid im Öl in ppm	Concentration of oxygen, nitrogen and carbon dioxide in oil in ppm
Sauerstoff	Oxygen
Kohlendioxid	Carbon dioxide
Stickstoff	Nitrogen
Wasserstoff	Hydrogen
Kohlenmonoxid	Carbon monoxide
Zeit	Time
Konzentration von Wasserstoff und Kohlenmonoxid im Öl in ppm	Concentration of hydrogen and carbon monoxide in oil in ppm
externe Analyse	External analysis

Figure 10: G3B for smaller power transformers

Advantages

- Maintenance-free sealing system.
    - Decrease of oxygen concentration in the active component.
    - Prevention of water penetration from outside.
- Ensuring the gas collection function of the Buchholz relay.
- Modular construction to adapt to oil volume and service temperature.
- Installation in existing and new transformers possible.
- Suitable for off-load switches.
- Easy installation.
- Long service life.
- No interference with the oil system of the transformer.

Additional options

- Monitoring of oxygen, moisture and hydrogen in the gas chamber possible.
- Active drying of gas chamber possible with regenerable external dryer
- Nitrogen supply during resaturation.

The breather buffer box was developed by Gatron in Greifswald.

It is manufactured by Eisenwerk Bassum Werk Peenemünde.

The box is distributed and installed by EMB GmbH in Barleben near Magdeburg.

Elektromotoren und Gerätebeau Barleben GmbH (EMB) was founded in 1992 in the framework of the privatization of East German companies after the reunification of the two German states.
Transformer protection relays have been manufactured in Barleben for more than 60 years now.

The patented monitoring device developed in 1921 by the German engineer Max Buchholz as a combined flow and gas collection relay has proved to be an inevitable unit for transformer protection.
Nothing has been changed to date to the principal construction and mode of operation.

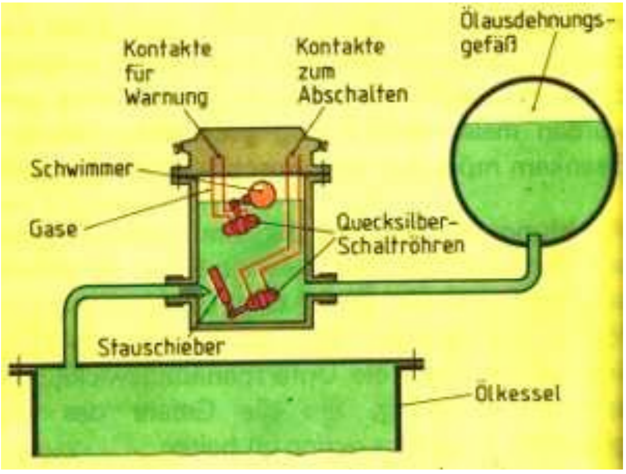

Figure 11: Principal construction of the Buchholz relay

Kontakte für Warnung	Alarm contacts
Schwimmer	Float
Gase	Gases
Stauschieber	Damper
Kontakte zum Abschalten	Disconnection contacts
Ölausdehnungsgefäß	Oil conservator
Quecksilberschaltröhren	Mercury contact tubes
Ölkessel	Oil tank

The principal construction shown in Figure 11 originates from the 50ies of the past century. In addition to mercury contact tubes, magnet contact tubes or microswitches are used today. The lower switching system is normally provided with a float as well.

Due to its relatively simple construction, ease of operation, high reliability, freedom from maintenance and very long life, the Buchholz relay has proved to be for several decades now one of the most important protective devices of the transformer worldwide.
The information which can be derived from the fault gas (composition, quantity, when produced) is significant for the early detection of transformer malfunction and may prevent subsequent damage when gathered in due time.

The function of the Buchholz relay in its usual form is a purely mechanical one and does not allow the detection of gas accumulation. Longterm, low-energy faults produce low gas quantities over a longer period whilst energy-rich faults produce large gas quantities within a short period. The Buchholz relay is unable to recognize this difference as it does not provide adequate information about when gas was generated or over what period of time it was accumulated. Therefore, the existing risk can be estimated only roughly. As the generation of a signal requires a very large gas volume, at the time of the release of the signal the basic fault may already have reached an advanced stage. The chemical analysis of the collected gases carried out in order to identify the fault, can be falsified by old gases contained or a long retention time.

The intention now was to develop a Buchholz relay with geometrical dimensions just slightly different from those of a standard unit, but able to detect even small gas quantities and show the generation of gas over time. The result is the Buchholz relay of NM series.

Figure 12: EMB Buchholz relay of NM series

The sensor is integrated in the Buchholz relay. It allows analogue measurement of gas volumes between 30 cm^3 and 300 cm^3. The original function of the relay is not affected by the measuring device. The necessary electronic devices are accommodated in the terminal box of the Buchholz relay.

The normal function of the Buchholz relay is supplemented by a capacitive level sensor. The measurement range is 30 cm^3 to 300 cm^3. Measurements beyond this range are theoretically possible, however, because of response of the upper switching system they are not relevant. Analogue level measurements are performed continuously so that the gas generation over time and the dissolution of gas during extended retention periods are recorded as well. The supply voltage of the sensor is 24 volts. This voltage is available on the control box or control cabinet of the transformer.
Plug-in connection is in the terminal box of the relay. The Buchholz relay of NM series is suitable for outdoor installation.

By developing the Buchholz relay of NM series EMB succeeded in overcoming the disadvantages of the standard Buchholz relay, namely lack of signalization and representation of the generation of gas over time.

Buchholz relays of the NM series are components perfectly suitable as monitoring systems of transformers.

Buchholz relays of the NM series are, however, also suitable for separate applications where they offer optimum sensing and evaluation options for monitoring and protecting transformers.

The benefits of inhibited transformer oils using gas to liquid based technology

Joerg Friedel,
Shell Technology Centre Hamburg

Joerg Friedel has a PhD degree in chemistry from the University of Halle in Germany. He joined Shell in 1995. His current role is a Global Product Application Specialist for Transformer and Hyper-compressor Oils. He is responsible for technical contacts to global customers, ensuring that products meets market requirements and acceptance. He is a member of IEC and CIGRÉ.

He has a wide experience of lubricants applications, including base oils and their use in finish lubricants, and in chemical products.

The benefits of inhibited transformer oils using gas to liquid based technology

The benefits of inhibited transformer oils using gas to liquid based technology

DEFINITIONS AND CAUTIONARY NOTE

The companies in which Royal Dutch Shell plc directly and indirectly owns investments are separate entities. In this presentation "Shell", "Shell group" and "Royal Dutch Shell" are sometimes used for convenience where references are made to Royal Dutch Shell plc and its subsidiaries in general. Likewise, the words "we", "us" and "our" are also used to refer to subsidiaries in general or to those who work for them. These expressions are also used where no useful purpose is served by identifying the particular company or companies. "Subsidiaries", "Shell subsidiaries" and "Shell companies" as used in this presentation refer to companies over which Royal Dutch Shell plc either directly or indirectly has control. Companies over which Shell has joint control are generally referred to "joint ventures" and companies over which Shell has significant influence but neither control nor joint control are referred to as "associates". In this presentation, joint ventures and associates may also be referred to as "equity-accounted investments". The term "Shell interest" is used for convenience to indicate the direct and/or indirect (for example, through our 23% shareholding in Woodside Petroleum Ltd.) ownership interest held by Shell in a venture, partnership or company, after exclusion of all third-party interest.

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The benefits of inhibited transformer oils using gas to liquid based technology

AGENDA

1. Benefits of using inhibited versus uninhibited transformer oils
2. Base Oils for transformer oil production
3. Shell Diala S4 ZX-I – inhibited transformer oil using GtL base fluid
   - Resistance to ageing & degradation in service
   - Cooling – thermal properties, fluidity
   - Ease of use – miscibility/compatibility with other oils
4. Conclusions – benefits of GTL based inhibited transformer oils over conventional products

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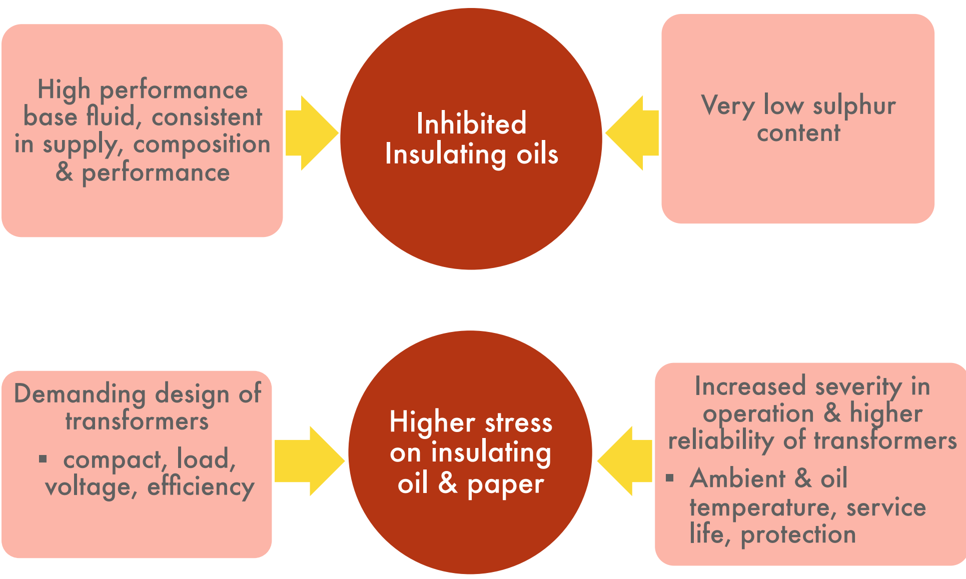
BASE FLUIDS – CHANGE AND CHALLANGE



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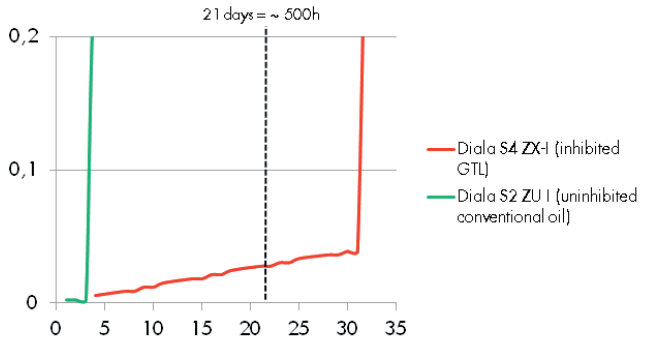
RESISTANCE TO DEGRADATION - INHIBITED GTL VERSUS CONVENTIONAL UNINHIBITED OIL

IEC 61125C = The induction period is reached when the volatile acidity significantly exceeds 0.1 mg KOH/g



- Inhibited oils show predictable & best resistance to degradation
- Monitoring antioxidant concentration gives indication of oil condition before significant quantities of acids are developed (and potentially attack the paper)

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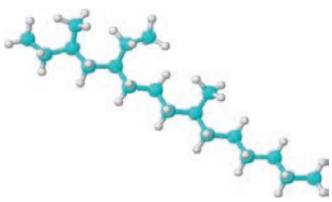
BASE OILS USED FOR MANUFACURING OF TRANSFORMER OILS

1. Naphthenic base oil – degree of raffination depends on crude, and inhibitior
2. Paraffinic base oil – usually highly refined and inhibited

3. GTL base oil, primarily iso-paraffinic, no impurities, excellent antioxidant response, narrow molecular distribution



GtL base oil is produced in Qatar JV plant from Natural Gas using the Fischer-Tropsch Process

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RESISTANCE TO DEGRADATION - INHIBITED GTL VERSUS CONVENTIONAL INHIBITED OIL

	Limits IEC 60296	IEC 60296 – sect 7.1 Higher oxid stab & low sulphur	Inhibited Shell Diala S3 ZX-I	Inhibited Shell Diala S4 ZX-I (GTL)
Oxidation Stability IEC 61125 C	164/500 hours	500 hours	500 hours	500 hours
Total acidity, mgKOH/g	max 1.2	max 0.3	0.02	0.02
Sludge, % weight	max 0.8	max 0.05	0.01	<0.01
Dielectric dissipation factor (DDF) at 90 °C	max 0.5	Max 0.05	0.009	0.001

- GTL inhibited oils – exceptional resistance to degradation.

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POTENTIAL IMPROVEMENTS OVER CURRENTLY USED TRANSFORMER OILS

- Increased oxidation stability
- Improved cooling properties
- Oil should not promote corrosion – sulphur content should be minimized
- High flash point

Easy changeover and continued practice from currently used transformer oils:

- Dissolved Gas Analysis (DGA) for monitoring the transformer condition can be used.
- Comparable compatibility with construction materials (sealings, varnish)
- Comparable interaction with paper insulation (e.g. water solubility)
- Miscibility with current used transformer oils

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RESISTANCE TO DEGRADATION - INHIBITED GTL VERSUS CONVENTIONAL INHIBITED OIL

IEC 61125 C extended oxidation stability test

- Test run for standard 500 hrs, when inhibitor content reduced to approx 50 % of initial value, antioxidant was topped up to initial level (refer to IEC 60422), later inhibitor topping up regularly. Test run for approx 2180 hrs (> 4X usual duration)

Shell Diala S4 ZX-I (GTL)

Acidity (mgKOH/g) **0.18**

Sludge <0.01 % wt

Oil loss **0** % wt

Shell Diala S3 ZX-I

Acidity (mgKOH/g) **0.96**

Sludge <0.01 % wt

Oil loss **24** % wt

- Extended resistance to degradation in normal service & when re-inhibited.

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RESISTANCE TO AGEING & DEGRADATION – CORROSIVE SULPHUR

Property	Units	Method	IEC 60296 Table 2 + section 7.1	Shell Diala S4 ZX-I	Shell Diala S3 ZX-I
Total Sulphur content	mg/kg	ASTM D 5185	Section 7.1 limit Max 500	<1	<40
Corrosive Sulphur		DIN 51353	Not corrosive	Not corrosive	Not corrosive
Corrosive Sulphur		IEC 62535	Not corrosive	Not corrosive	Not corrosive
Corrosive Sulphur		ASTM D 1275 B	-	Not corrosive	Not corrosive

- Essentially zero sulphur minimises risk of oil based corrosive sulphur failures.

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COOLING PROPERTIES OF OIL IN TRANSFORMER

Modeling of oil cooling in transformer can be undertaken from a knowledge of oil properties at different temperatures, such as:

- Viscosity
- Specific heat capacity
- Thermal conductivity
- Density
- Thermal coefficient of expansion

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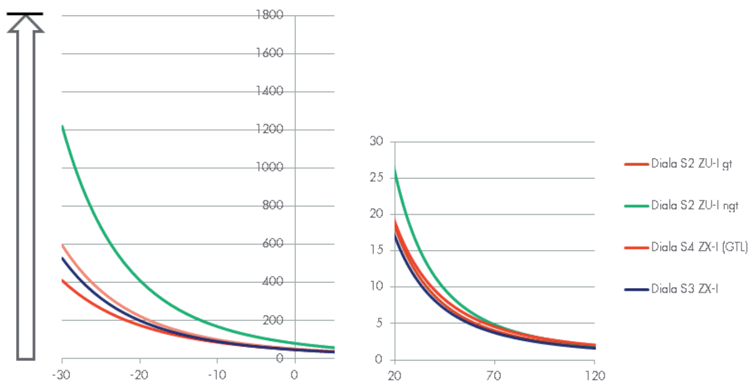
COOLING – VISCOSITY (FLUIDITY)

Shell Diala typical viscosity (cSt) versus temperature (°C)



- Good fluidity across broad temperature range, especially low temperatures down to -30 °C, facilitate a safe low temperature start.
- Comparable viscosity to conventional oils at higher temperatures.

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TLM

TRANSFORMER-LIFE-MANAGEMENT
CONFERENCE

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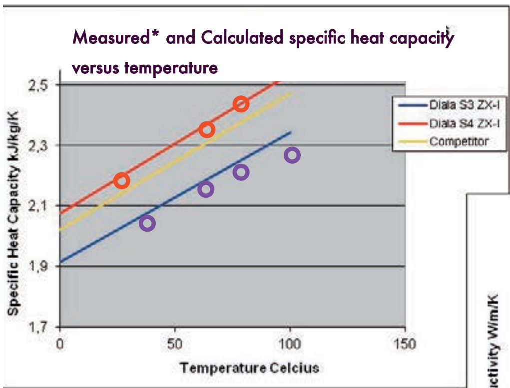
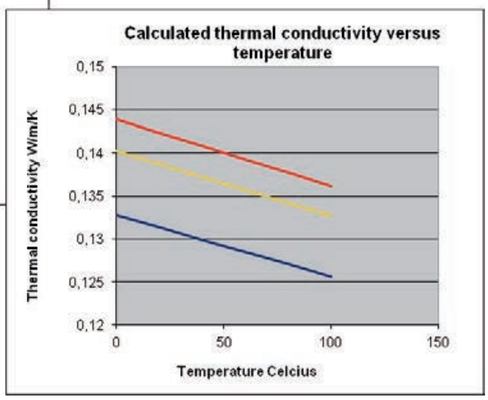
COOLING - THERMAL PROPERTIES (APPROXIMATE)

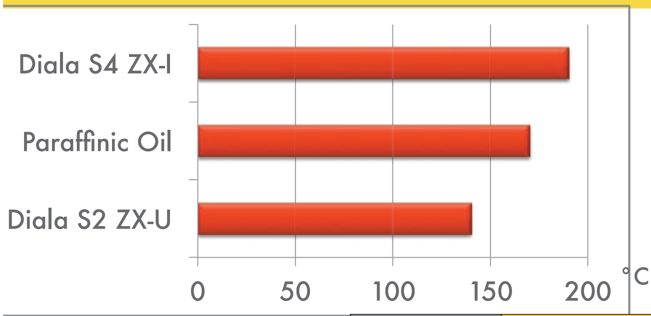


*measured by ASTM E 1269 mod.



- Density app. 9 % lower compared to naphthenic transformer oils

COMPARISON FLASH POINT COC AND EVAPORATION LOSS



Evaporation loss	ASTM D 972 22h at 107 °C	ASTM D 5800 1 h 250 °C
Naphthenic Oil	26%	100%
Diala S4 ZX-I	0,75%	40%

- Significantly higher flash point and reduced volatility provides additional safety.

The benefits of inhibited transformer oils using gas to liquid based technology

STRAY GASSING RESULTS WITH SHELL DIALA S4 ZX-I VS. SHELL DIALA S3

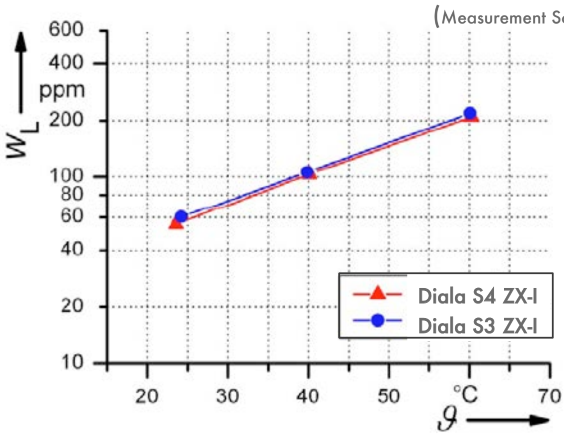
Stray Gassing Results ASTM D 7150
164 hrs at 120 °C , 30 min air stripped before test [ppm v/v]

	Diala S4 ZX-I	Diala S3 ZX-I
Hydrogen	40	54
Carbon Monoxide	249	229
Carbon Dioxide	304	176
Methane	5	2
Ethan	16	< 1
Ethylene	4	< 1
Acetylene	< 1	< 1

- DGA experience from currently used transformer oils might be transferred to Diala S4 ZX-I

WATER SATURATION VS. TEMPERATURE

(Measurement Schering Institute, Vaisala Humicap MM 70)



- No significant difference in water solubility to conventional transformer oils.

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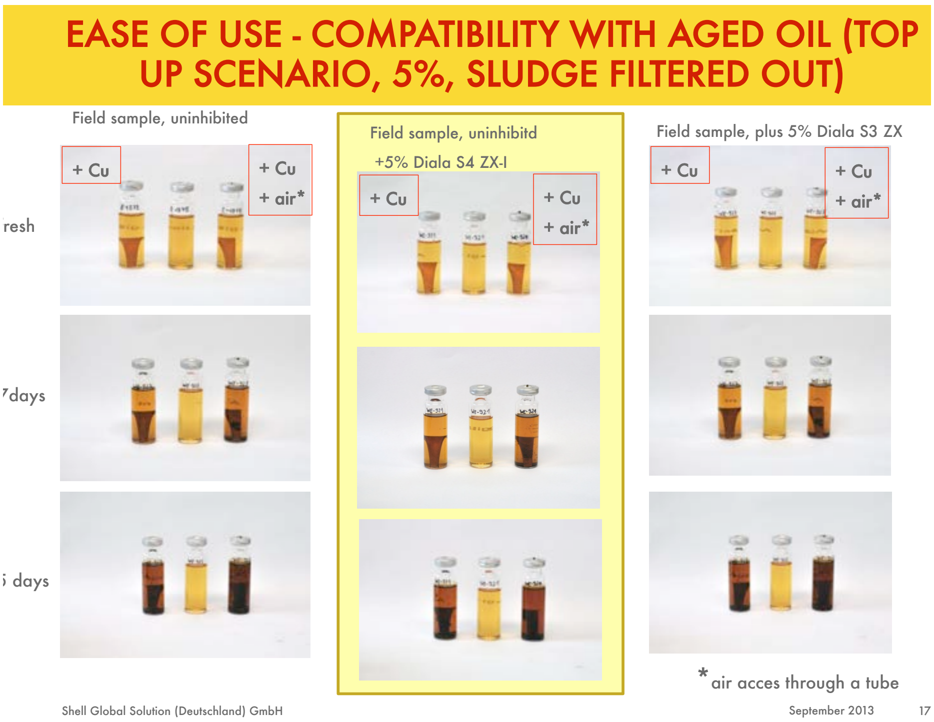

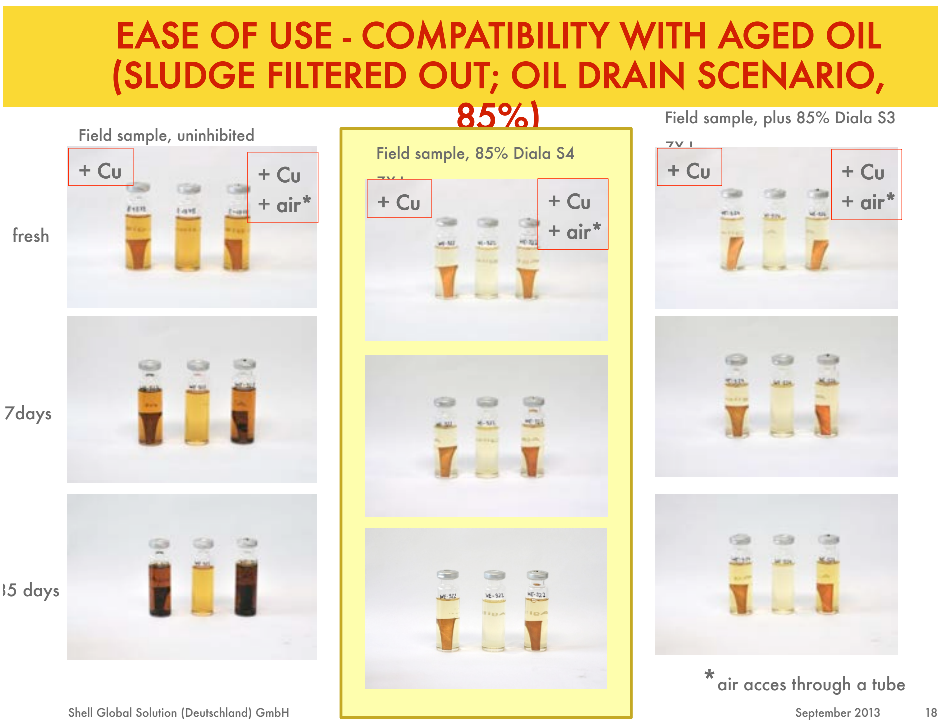

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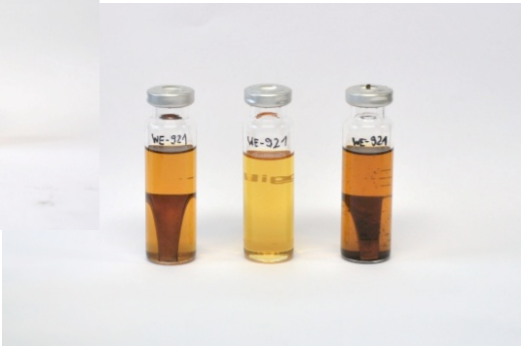
EASE OF USE - COMPATIBILITY/MISCIBILITY CONCLUSIONS



- No miscibility, compatibility, solvency issues found.
  GTL based transformer oils can be used alongside traditional oils.
  Top-up performance even better than Diala S3 ZX-I.

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COMPATIBILITY WITH SEALING ELASTOMERS

	Type	Hardness change Shore A	Weight change %	Volume change %
NBR	ANT 6800	-2 (68/66)	+ 0,33	+ 1,43
FPM	S 161/19-69	0 (76/76)	+ 0,2	+ 0,26
MFQ	A-SK 65-16	0 (62/62)	+ 0,23	+ 0,29

- No sealing compatibility issues, GtL fluids are compatible with typical sealants and components used in transformers.

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The benefits of inhibited transformer oils using gas to liquid based technology

CONCLUSIONS – BENEFITS OF INHIBITED TRANSFORMER OILS BASED ON GTL

- Diala S4 ZX-I meets & exceeds IEC 60296:Ed 4 2012 highest oxidation stability, low sulphur specification.
- Exceptional resistance to ageing & degradation.
- Modeling predicts good to superior cooling in service .
- Essentially zero sulphur minimises risks due to corrosive sulphur.
- Safety benefits due to higher flash point and lower volatility.
- Easy to use with other oils, no miscibility/compatibility/solvency issues found.
- Praxis experiences with conventional products can be used.
- Product being evaluated & approved by OEMs & utilities, a rising number have confirmed acceptance and approved, and the product is being successful used in transformers.

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Estimating moisture in Power Transformers

Mohammad Tariq, Megger

Mohammad Tariq was born 1983 and graduated from University Of Bahrain with distinction on 2005 and joined Megger in early 2006. Currently he is a senior applications engineer with Megger in the field of advanced electrical protection, cable fault location and diagnostics and transformer diagnostics. He was involved in development of relay protection testing software modules and authored several papers , technical notes and application guides.

Megger.

Estimating moisture in Power Transformers

- How to Estimate and What to Do

Matz Ohlen, Megger Sweden

Abstract— **Modern technology and developments in signal acquisition and analysis techniques have provided new tools for transformer diagnostics. Of particular interest are dielectric response measurements where insulation properties of oil-paper systems can be investigated. Dielectric Frequency Response, DFR (also known as Frequency Domain Spectroscopy, FDS), was introduced more than 15 years ago and has been thoroughly evaluated in a number of research projects and field tests with good results. DFR data in combination with mathematical modeling of the oil-paper insulation is proven as an excellent tool for moisture assessment. The dryness of the oil-paper insulation systems in power transformers is a key factor in both their short and long term reliability since moisture has deleterious effects on dielectric integrity and insulation ageing rates. This paper gives a background to moisture issues in transformers, where it comes from, how it can be measured, how it can be addressed and how this can be used for decisions on maintenance and/or replacement.**

Keywords – moisture, power transformers, dielectric frequency response; DFR; frequency domain spectroscopy; FDS; power factor; dissipation factor

I. INTRODUCTION

With an aging power component population, today's electrical utility industry faces a tough challenge as failures and consequent repair and revenue loss may inflict major costs. Transformers have become one of the most mission critical components in the electrical grid. The need for reliable diagnostic methods drives the world's leading experts to evaluate new technologies that improve reliability and optimize the use of the power network.

The condition of the insulation is an essential aspect for the operational reliability of electrical power transformers, generators, cables and other high voltage equipment. Transformers with high moisture content have a higher aging rate and can not without risk sustain higher loads.

On the other hand it is also very important to identify "good" units in the aging population of equipment. Adding just a few operating years to the expected end-of-life for a transformer means substantial cost savings for the power company.

II. MOISTURE IN TRANSFORMERS

The insulation system of power transformers consists of oil and cellulose. Both materials generally change their dielectric properties during the life of the transformer and among factors contributing mostly to the degradation of transformer insulation moisture plays an important role. Presence of water in solid part of the insulation, even in small concentrations, increases its aging rate, lowers the admissible hot spot temperature and increases the risk of bubble formation. In addition, moisture reduces the dielectric strength of transformer oil as well as the inception level of partial discharge activity [1].

A. Where is the water?

When discussing moisture in transformers it is important to understand where the water resides. Consider the following example (typical values for a 300 MVA service aged power transformer at 50°C):

- The insulation in a power transformer consists of oil impregnated cellulose and oil.
- 60 tons of oil with water content of 20 ppm = 1.2 liter
- 10 tons of cellulose with 3% water content = 300 liter
- Almost all water is in the cellulose!

During normal operation at different loads and temperatures the water moves back and forth between oil and cellulose. Sometimes the water content in the oil is doubled, 40 ppm/2.4 liter. However the moisture in the cellulose remains almost the same, 299 liter. The average moisture content in the solid insulation is very constant!

B. Moisture accelerates aging

Aging of the cellulose insulation is directly related to the moisture content. Figure 1 describes life expectancy for the insulation at various temperatures and moisture content [3]. At 90°C, cellulose with 1% moisture has a life expectancy of about 12 years. At 3% moisture the life expectancy is only 3 years!

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Estimating moisture in Power Transformers

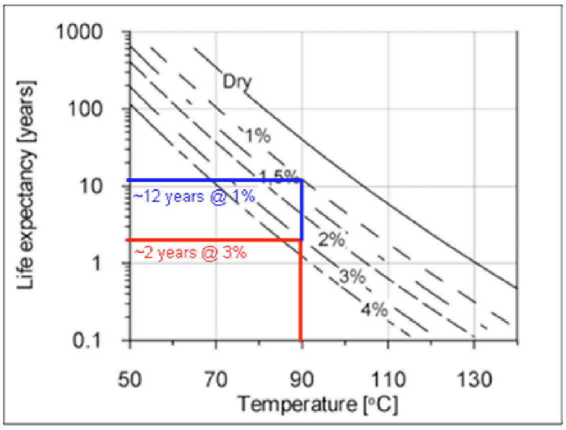

Figure 1. Life expectancy for cellulose at different temperature and moisture content [3]

C. Moisture limits the loading capability

A rise in temperature, especially at thick insulation layers, causes evaporation of adsorbed water with a high vapor and gas pressure within the inner layers of paper. This pressure may become high enough to create formation of vapor-filled cavities (bubbles) on the insulation surface with subsequent decrease of the dielectric strength [2].

Figure 2 describes limitation of load conditions due to moisture content [4].

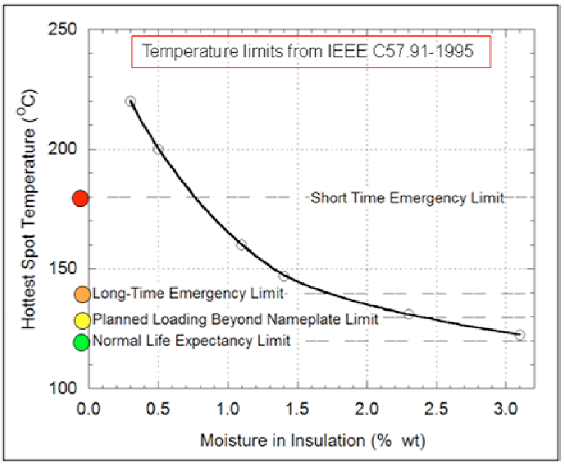

Figure 2. Recommended maximum loading limits (IEEE) as function of moisture [4]

D. Where does the water come from?

Transformers are dried during the manufacturing process until measurements or standard practices would yield a moisture content in the cellulosic insulation of less than 0.5% to 1.0% depending upon purchaser's and manufacturer's requirements. After the initial drying, the moisture content of the insulation system will continually increase. There are three sources of excessive water in transformer insulation [2]:

- Residual moisture in the "thick structural components" not removed during the factory dry-out or moistening of the insulation surface during assembly
- Ingress from the atmosphere (breathing during load cycles, site erection and/or maintenance/repair processes)
- Aging (decomposition) of cellulose and oil.

1) Residual moisture

Excessive residual moisture can remain in some bulky insulating components, particularly in wood and plastic or resin-impregnated materials, which need much longer drying times in comparison to paper and pressboard. Typically, these are supports for leads, support structures in the load tap changer (LTC), support insulation for the neutral coils of the winding, cylinders, core support insulation, etc.

Different insulation materials require different drying durations. The drying time is roughly inversely proportional to insulation thickness in square. However the structure of material is an important factor as well, e.g. pressboard featuring a high density requires longer drying time than low density pressboard. [2].

New transformers are generally dried to a moisture content < 1%. When drying larger transformers, the residual moisture may be as low as about 0.3%.

2) Ingress from the atmosphere

The main source of the buildup of water in transformers is the atmosphere and there are several mechanisms and occasions for moisture ingress.

- Exposure to humid air during site installation
- Leaking gaskets and faulty water traps may expose the inside of the transformer to moisture humid air
- Exposure to humid air during maintenance

3) Decomposition of cellulose

The aging of cellulosic materials leads to molecular chain scission and the formation of byproducts including water and furanic compounds.

Figure 3 describes several studies on how moisture is produced as a function of number of chain scissions. After five chain scissions a paper starting at a degree of polymerization of 1200 has ended up with a DP of 200 [2] (curves should only be considered as indicators on the order of magnitude of the water producing effect).

Typical increase of moisture in a transformer can be in the order of 0.05 – 0.2%/year pending design [2, 5]

Estimating moisture in Power Transformers

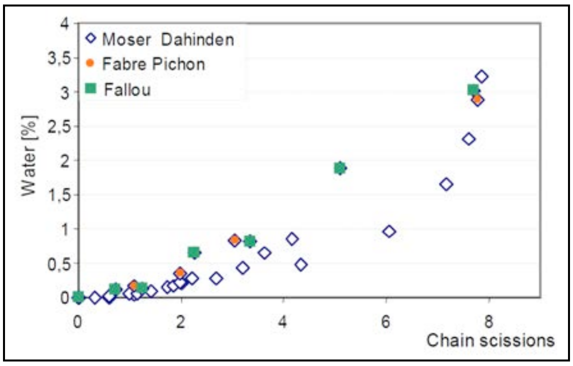

Figure 3. Produced water as a function of number of chain scissions [2]

III. Standards and Recommendations for Moisture

International standards and guides give some recommendations for moisture assessment. As an example IEEE C57.106-2002 recommended the following approximate percent by weight of water in solid insulation.

- < 69 kV, 3% maximum
- > 69 - < 230 kV, 2% maximum
- 230 kV and greater 1.25% maximum

Other standards and guides only give a classification of the moisture content. Figure 4 depicts moisture categories according to some standards and practices.

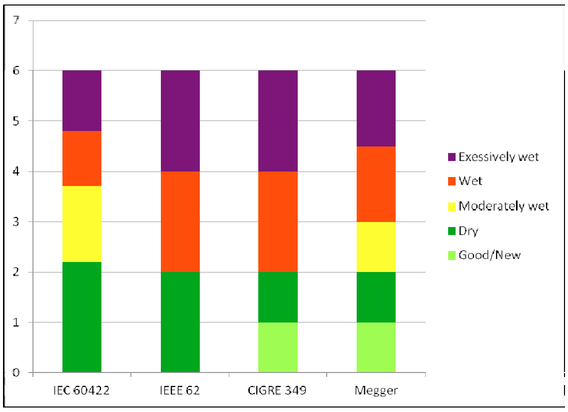

Figure 4. Moisture assessment examples

IV. Moisture Measurements

There are several methods available to measure the moisture content in the solid insulation of the transformer.

Direct method

- Take paper sample from transformer and measure moisture content using Karl Fisher titration

Indirect methods

- Moisture in oil
  - Absolute values
  - Relative saturation
- Power frequency tan delta/power factor measurements
- Dielectric response measurements
  - Return Voltage Measurement (RVM) – DC method
  - Polarization-Depolarization Current measurements (PDC) – DC method
  - Dielectric Frequency Response measurements (DFR/FDS) – AC method

A. Direct method – KFT on paper samples

Karl Fischer titration allows for determining trace amounts of water in a sample using volumetric or coulometric titration. Its principle is to add a reagent (titre iodine) to a solution containing an unknown mass of water until all water reacts with the reagent. From the amount of reagent the mass of water can be calculated.

Several factors may affect the results of KFT analyses, e.g.:

- There is always ingress of moisture from the atmosphere during sampling, transportation and sample preparation. This happens particularly during paper sampling from open transformers
- Cellulose binds water with chemical bonds of different strengths. It is uncertain whether the thermal energy supplied releases all the water.
- Heating temperature and time certainly changes the released water.

To investigate the effect of these influences and to evaluate the discrepancies that may result from KFT analyses, a round robin test (RRT) was carried out among seven laboratories from four European countries [1]. It concentrated on analyzing the water content in paper relative to weight and the water content in oil relative to weight in three oil and paper samples according to the respective laboratory’s standard procedures. The obtained results revealed an unsatisfactory comparability between the laboratories, as shown below in Figure 5.

As seen in the figure the results show large variations. For sample A, containing little water, the comparability was worst. Moisture estimates varied between 1.0% and 2.0%.

Another issue for direct measurements of moisture in cellulose is the uneven distribution of moisture. In the “REDIATOOL” project [8], samples were taken from different parts of a transformer and analyzed for moisture. Results are presented in Figure 6. As seen in the figure the moisture distribution is very uneven between different parts and locations. To get a “true” result from KFT analysis of paper it is important to take many samples and average the results.

Estimating moisture in Power Transformers

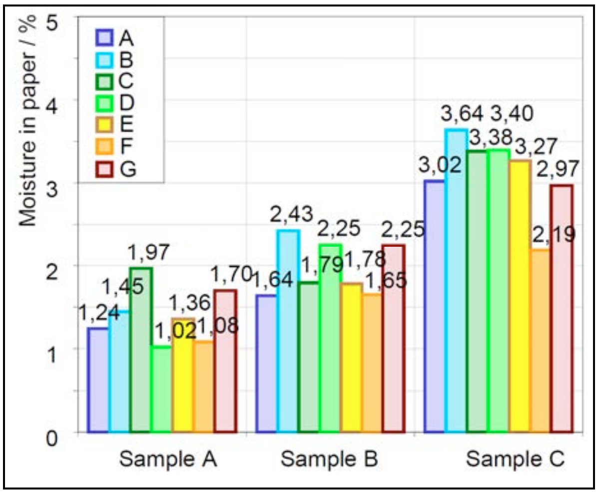

Figure 5. Moisture content in paper in % relative to weight as measured by seven laboratories [1].

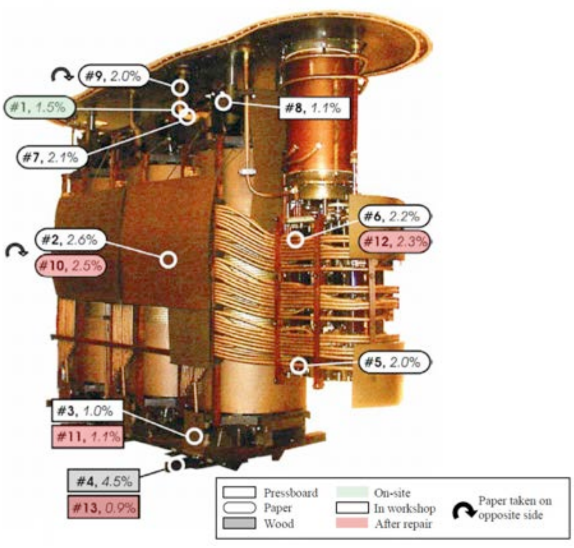

Figure 6. Moisture content estimated by means of KFT in samples of transformer solid insulation at different locations and sampling events [8]

Water content determination by means of dielectric response or other indirect methods is often calibrated by comparing them with evaluations based on KFT. However, as shown above, KFT results also suffer from a poor comparability between different laboratories. The user must therefore be aware of this fact, and understand that a deviation in the comparison does not necessarily point out weaknesses of the evaluated methods.

B. Moisture in oil

Measuring moisture levels in oil is probably the most common method for moisture assessment. Many operators of power transformers apply equilibrium diagrams to derive the moisture by weight (%) in cellulose from the moisture by weight in oil (ppm). This approach consists of three steps:

1. Sampling of oil under service conditions
2. Measurement of water content by Karl Fischer Titration
3. Deriving moisture content in paper via equilibrium charts .

The procedure is affected by substantial errors, e.g:

- Sampling, transportation to laboratory and moisture measurement via KFT causes unpredictable errors.
- Equilibrium diagrams are only valid under equilibrium conditions (depending on temperature established after days/months).
- A steep gradient in the low moisture region (dry insulations or low temperatures) complicates reading.
- The user obtains scattered results using different equilibrium charts.
- Equilibrium depends on moisture adsorption capacity of solid insulation and oil.

The influence of sampling, transportation and laboratory analysis has been evaluated in a round robin test carried out among seven laboratories [1]. The obtained results also here revealed an unsatisfactory comparability between the laboratories, as shown below in Figure 7.

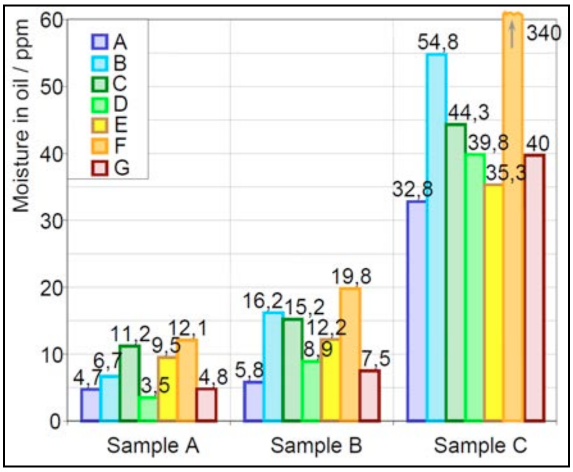

Figure 7. Moisture content in oil in ppm relative to weight as measuredby the laboratories [1]

For the drier samples A and B only a trend was recognizable; the results varied from 3.5 to 12.1 ppm for sample A and from 5.8 to 19.8 ppm for sample B. Systematic differences were obvious. It has to be mentioned that for the dry oils, the results also varied within one single laboratory and a standard deviation of 20% is not unusual.

The amount of water in the oil is used to derive moisture content in paper by using equilibrium charts. Several charts are available, below figure 8 shows "Oomen". Note the steep gradient the low moisture region that severely complicates reading.

Estimating moisture in Power Transformers

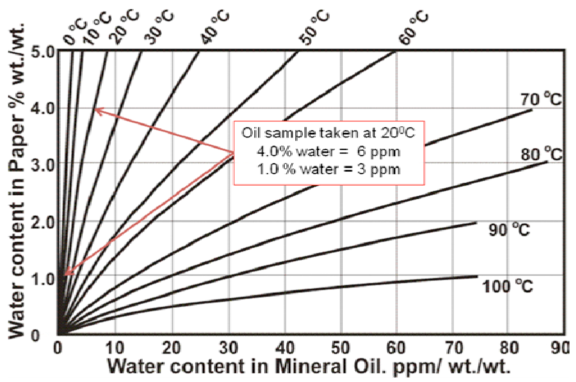

Figure 8. Equilibrium chart for moisture content in paper versus water content in oil at various temperatures.

One step to improve the method of using equilibrium diagrams is to use the *relative saturation* in oil (%) or *water activity* instead of the moisture by weight (ppm). In case direct measurements are performed with a probe mounted directly on the transformer this method removes the issues with sampling and transportation. Furthermore the moisture absorption capacity is less temperature dependent and oil aging and its influence on moisture saturation level becomes negligible, since it is already included into relative saturation [2]. However the method is still pending equilibrium and charts are pending material.

C. *Power frequency tan delta/power factor measurements*

Tan delta/Power factor measured at power frequency (50/60 Hz) shows the combined dissipation factor coming from losses in oil and cellulose. It is known that the measurement cannot discriminate a dry transformer with service aged oil from a wet transformer with new oil and the method is relatively insensitive to moisture levels < 2%.

Figure 9 describes the relation between power frequency tan delta values and moisture levels for a new and service-aged typical core-form transformer. At 0.3% power factor (20°C), the moisture may be from 0.5% to about 2% pending the condition of the oil.

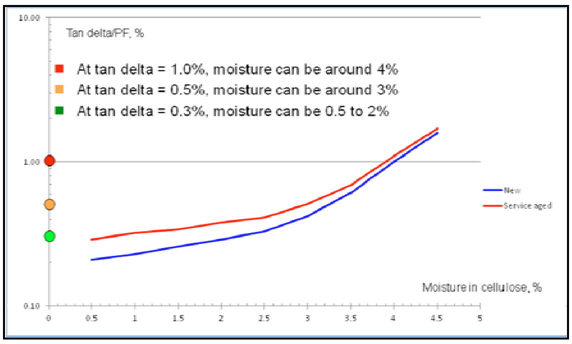

Figure 9. Tan delta (% @ 20C) vs moisture (%) for a new and service-aged typical core-form transformer

Furthermore it is also well-known that the standard tan delta temperature correction factors/tables (TCF) given in standards and many instrument manufacturers user manuals/recommendations, are incorrect for the individual transformer [9]. This adds an additional source of inaccuracy to the method.

D. *Dielectric response measurements*

Dielectric response measurements can be performed in time (DC) or frequency (AC) domain. The most common measurement techniques/methods are:

DC methods – Time domain

- Return Voltage Measurement (RVM); Voltage vs time
- Polarization-Depolarization Current Measurement (PDC); Current vs time

AC method – Frequency domain

- Dielectric Frequency Response Measurements (DFR/FDS); Capacitance and dissipation factor vs frequency

The different methods have been thoroughly investigated in several tests and experiments [7]. The dielectric response methods RVM, PDC and DFR/FDS where used to analyze the moisture content for different arrangements of insulation geometry at different temperatures by the corresponding software programs. Results were compared to KFT analysis.

The results of RVM analysis differed strongly, although the moisture content of paper was constant during all the measurements. Dependences on the oil conductivity as well as on the temperature and the insulation geometry appeared. Hence the RVM software used could not evaluate moisture in oil-paper-insulation systems well since the interpretation scheme used was inaccurate without taking into account the geometry and oil parameters.

Results of PDC analysis showed much smaller influence of insulation geometry and weaker temperature dependence. These influences were already compensated by the interpretation software used. With increasing oil conductivity the evaluated moisture content increased, although in reality it remained constant. Nevertheless, the simulation results were close to the level evaluated by Karl Fischer titration.

The DFR/FDS analysis provided the best compensation for insulation geometry. At the same time, the paper seemed to become drier with increasing temperature. This actually happens in reality because of moisture diffusing out of the paper, but not to indicated extent. The observed tendency rather reveals imperfect compensation for temperature variations. Similarly as for the other methods, an increased oil conductivity results in a slight increased of the estimated moisture content. For more details please see [7]

1) *Dielectric Frequency Response Measurements*

The first field instrument for DFR/FDS measurements of transformers, bushings and cables was introduced 1995 [9]. Since then numerous evaluation of the technology has been performed and as an example, several international projects/reports define dielectric response measurements together with insulation modeling as the preferred method for

Estimating moisture in Power Transformers

measuring moisture content of the cellulose insulation in power transformers [1], [6], [7].

In DFR tests, capacitance and dissipation/power factor is measured. The measurement principle and setup is very similar to traditional 50/60 Hz testing with the difference that a lower measurement voltage is used (200 Vpeak) and instead of measuring at line frequency 50/60 Hz, insulation properties are measured over a frequency range, typically from 1 kHz down to 1 mHz.

The results are presented as capacitance and tan delta/power factor versus frequency. Measurement setup is shown in Fig 10 and typical DFR results from measurement on transformers in different conditions in Fig 11.

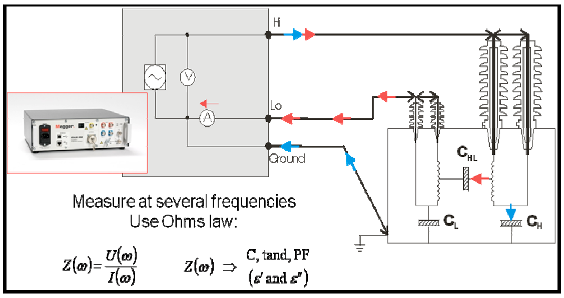

Figure 10. DFR/FDS test setup

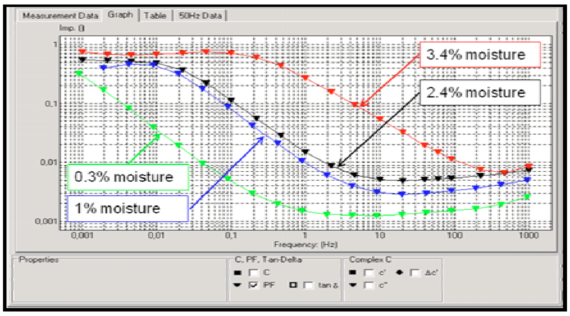

Figure 11. DFR measurements on four different transformers at different temperatures with moisture content ranging from 0.3% to 3.4%

a) Moisture Assessment

The method of using DFR for determining moisture content in the oil-paper insulation inside an oil-immersed power transformer has been described in detail in several papers and articles elsewhere [1], [6], [7], [10] and is only briefly summarized in this paper.

The dissipation factor for an oil/cellulose insulation plotted against frequency shows a typical inverted S-shaped curve. With increasing temperature the curve shifts towards higher frequencies. Moisture influences mainly the low and the high frequency areas. The middle section of the curve with the steep gradient reflects oil conductivity. Fig 12 describes parameter influence on the reference curve.

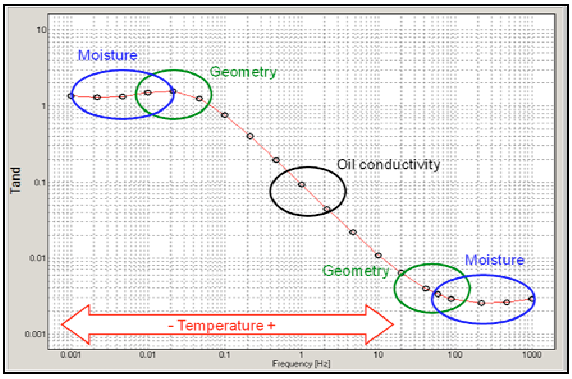

Figure 12. Parameters that effects the dissipation factor at various frequencies

Using DFR for moisture determination is based on a comparison of the transformers dielectric response to a modeled dielectric response (reference curve). A matching algorithm synthesizes a modeled dielectric response and delivers a reference curve that reflects the measured transformer. Results are displayed as moisture content along with the temperature corrected power frequency tan delta and oil conductivity. Only the insulation temperature (top oil temperature and/or winding temperature) needs to be entered as a fixed parameter. Figure 13 depicts results after insulation analysis/assessment.

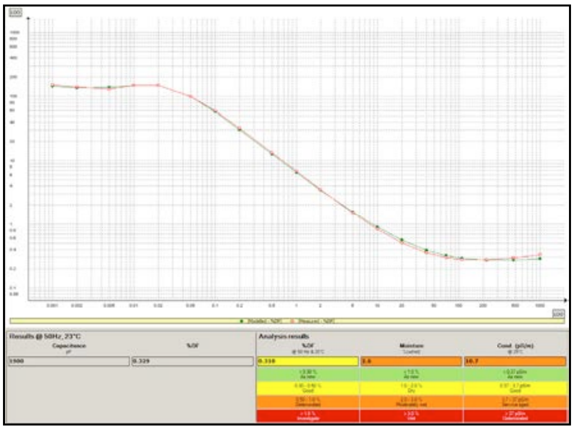

Figure 13. DFR insulation analysis/assessment

2) Comparing DC and AC techniques/methods

DC and AC measurements can be performed at low or high voltage and it is also possible to combine techniques by mathematically convert time domain data to frequency domain data and vice versa [11]. When selecting a suitable method for field measurements it is important to consider how sensitive the instrument is to substation interference.

A summary is presented in Table I. AC methods are generally more robust in high-interference conditions. DC methods and in particular low voltage DC measurements are very sensitive to DC interference from e.g. corona. The interference will add to the measured polarization current which the analysis SW will interpret as increased moisture in the insulation.

TABLE I. NOISE SENSITIVITY FOR DIFFERENT DIELECTRIC RESPONSE MEASUREMENT METHODS

Interference signals	**DFR Measurement Technologies**		
	Low Voltage DC	Low Voltage AC	High Voltage AC
AC (50/60Hz + harmonics)	Sensitive	Not sensitive	Not sensitive
DC/VLF	Very sensitive	Sensitive	Not sensitive

V. Transformer Drying

Transformer drying is an important maintenance action in today's aging transformer fleet and several reports and publications describe the issues related to drying [11], [12], [13] (it is not the intention of this paper to cover details on the different processes, the interested reader is recommended to study the references).

The different methods for drying can be summarized as follows:

Two major techniques are used:

- Drying the insulation by drying the oil – Field
- Drying the insulation with heat and vacuum – Field and factory

Drying the oil can be performed with:

- Molecular sieves
- Cellulose filters
- Cold traps
- Combined oil regeneration and degassing

Drying the insulation can be performed with:

- Vacuum and heat
- Pulsation drying through oil circulation
- Hot oil spray drying
- Low frequency heating
- Vapour phase drying

All methods can remove water out of the transformer insulation. However the efficiencies in the different techniques vary to a very large extent. See Figures 14 and 15 describing water extraction capacity and the time needed for drying a 400 MVA transformer with 14 ton insulation from 3% down to 1.5% moisture.

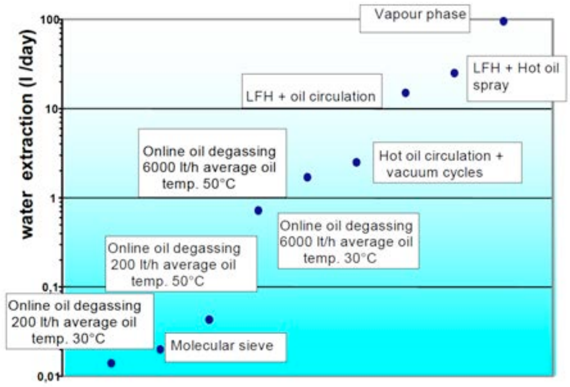

Figure 14. Drying velocity from 3% down to 1,5 % average humidity

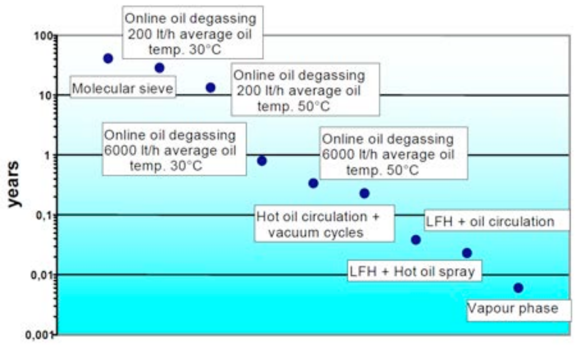

Figure 15. Drying time to dry a 400 MVA transformer with 14 ton insulation from 3% down to 1,5 % average humidity [13]

VI. Field Experinces

A. Maintenance based on water in oil analysis

TABLE II. MOISTURE IN SOLID INSULATION BASED ON WATER IN OIL ANALYSIS COMPARED TO DFR ANALYSIS

Transformer	**Type**	**% moisture in insulation (from oil analysis)**	**% moisture in insulation (from DFR)**	**Oil Cond (pS/m)**
1	Core	**2.5**	0.9	0.38
2	Core	**1.8**	0.9	0.49
3	Core	**1.4**	0.9	0.41
4	Core	**2.8**	0.7	1.3
5	Shell	*Not available*	**1.2**	**1.5**
6	Core	**3.5**	**2**	**3.0**
7	Shell	**3.3**	1	0.30

Estimating moisture in Power Transformers

A utility had selected seven transformers for oil regeneration and drying. The decision was based on water in oil measurements. Before processing the service company suggested DFR measurements to verify status before treatment [14].

Tables II show results from oil tests and DFR measurements. Out of the seven transformers selected only 1 or 2 needed treatment! This is an example of how water in oil analysis tend to overestimate moisture in solid insulation

B. On-line oil regeneration and drying

In this example a 30+ year distribution transformer was selected for oil regeneration and drying. Transformer and process information:

- 25 MVA manufactured 1972
- 17 days of hot oil circulation with clay filtering (Fuller's earth)
- PF down from 0.4% to 0.3%
- Moisture in cellulose not significantly reduced. 3% before drying and 2.7% after drying
- Degraded oil significantly improved. Conductivity before regeneration 12.0 pS/m and 1.6 pS/m after filtering

DFR measurements before-after treatment is presented in Figure 16.

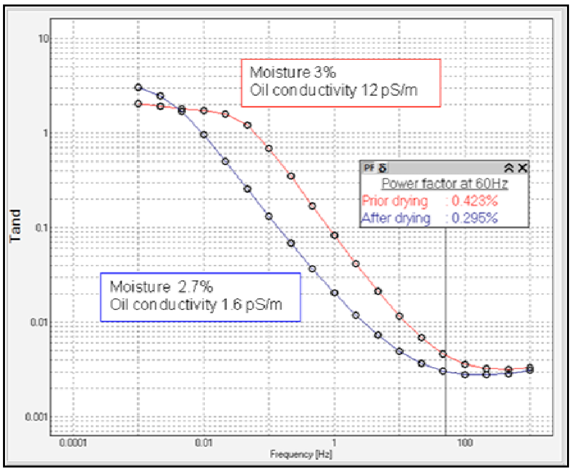

Figure 16. DFR measurements before-after oil regeneration and drying of a 25 MVA transformer [15]

VII. Summary and Conclusions

- Moisture is one of the the worst enemies of the transformer!
    - Limits the loading capability
    - Accelerates the aging process
    - Decreases dielectric strength
- The water/moisture in a transformer resides in the solid insulation, not in the oil
- Dielectric Frequency Response Measurement is a great technique for moisture assessment as it can measure:
    - Moisture content in the cellulose insulation
    - Conductivity/dissipation factor of the insulating oil accurately corrected to 25°C reference temperature
    - Power frequency tan delta/power factor, accurately temperature corrected to 20°C reference temperature
- Drying a power transformer can take from days to years pending drying process and technology

VIII. References

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Drying of Transformers in the Field with Vaporphase, low frequency, or oil spray process

Mr. Matthias Bommel, Meier Prozesstechnik GmbH

- working at MEIER since 2009
- supporting the sales team worldwide
- Product Specialist Transformer Drying Technology

Mr. Tobias Ladermann, Meier Prozesstechnik GmbH

- working at MEIER for 9 years
- specialized in (Vacuum-/ Pressure-)
- Impregnation Technology and Vacuum Drying
- specialized in Sales over the past 4 years
- responsible for Sales in the Middle East Area

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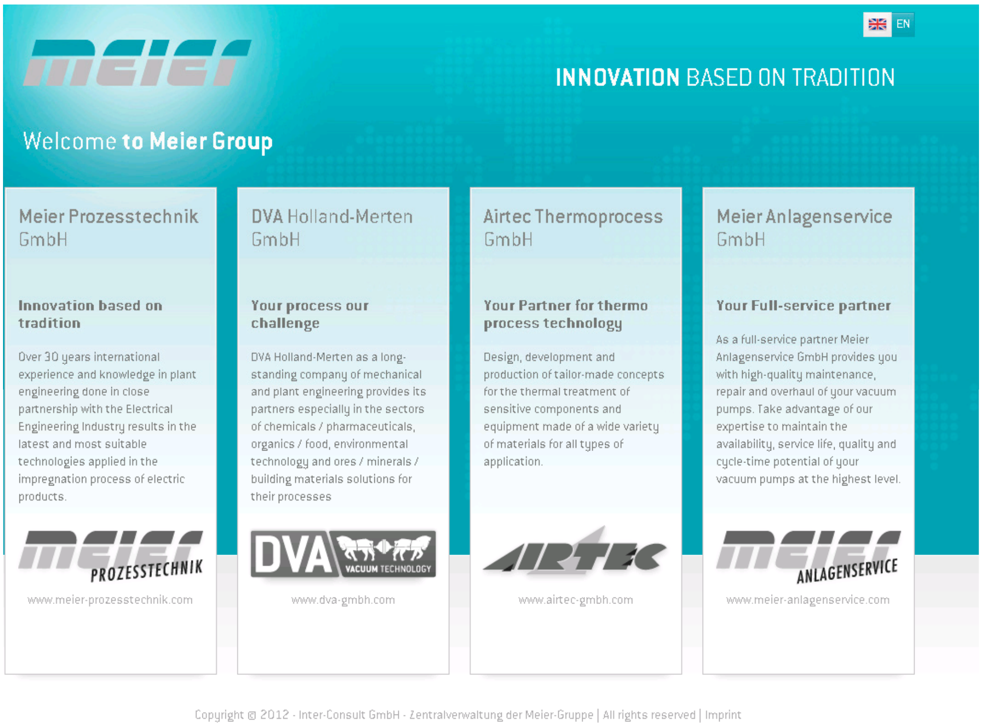
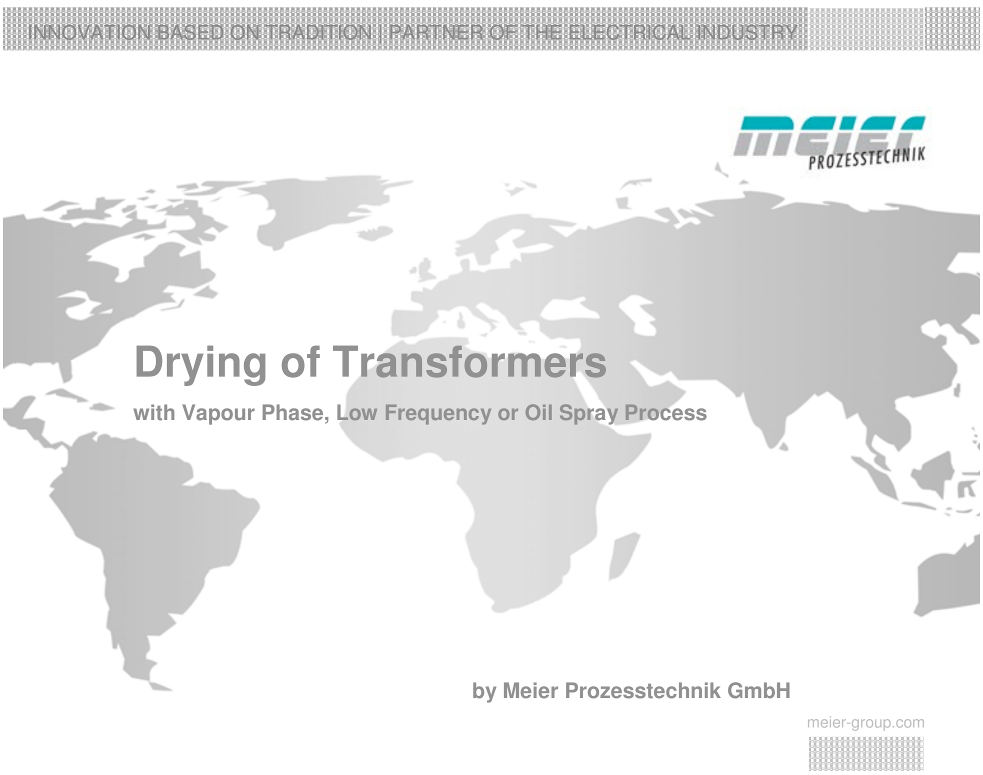
Drying of Transformers in the Field with Vaporphase, low frequency, or oil spray process





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About Meier Prozesstechnik GmbH

- located in Bocholt, Germany
- owned by Mr. Aloys Meier himself
- about 100 employees, about 250 within the Meier-Group
- more than 30 years of international experience
- system solutions for the electrical industry
- close partnership to the electrical industry
- tailor-designed systems to customers needs – made in Germany

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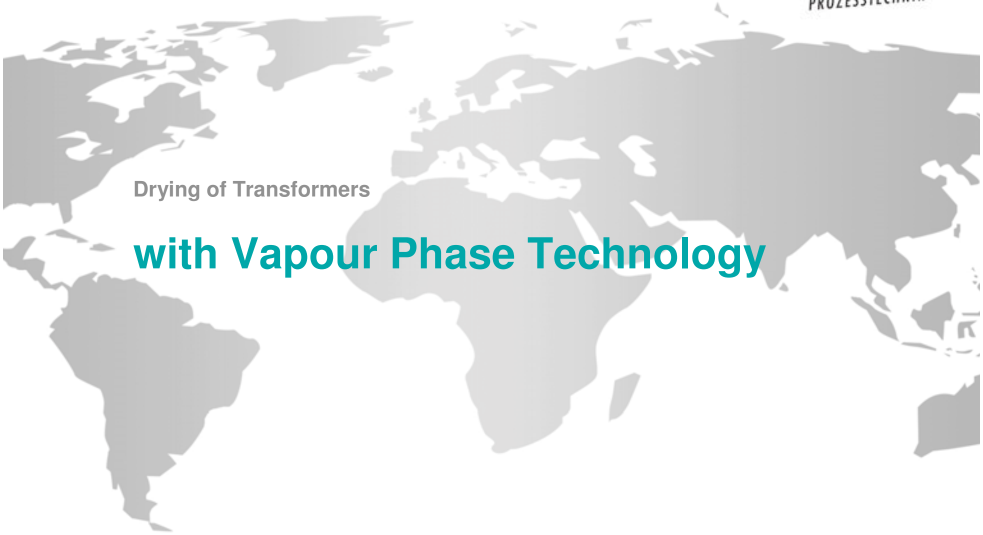

Drying of Transformers

with Vapour Phase Technology

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Drying of Transformers in the Field with Vaporphase, low frequency, or oil spray process

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Advantages of Vapour Phase Drying Technology

- Most efficient method for power transformers from 100 MVA up to the top range
- Energy saving due to shorter and more efficient drying method
- Less depolymerisation of insulation paper due to drying under vacuum
- Cleaning of the active part from old transformer oil during heating up and drying
- Less residual moisture in the insulation - compared to conventional drying (<0,3%)

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Difficulty of Vapour Phase Drying Technology

Due to the supplied solvent vapour (kerosine), dangerous situations may occur

Solution

Safety measures for plants operating with explosive media are available and minimize the risks. Meier Prozesstechnik has been developing and using these safety measures for years.

Official Certificate from DEKRA

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Features of Vapour Phase Equipment, example given:

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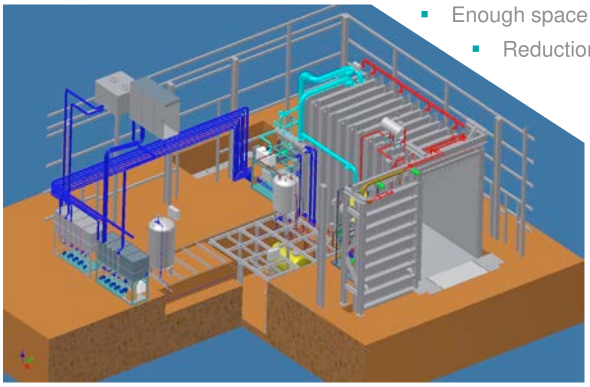
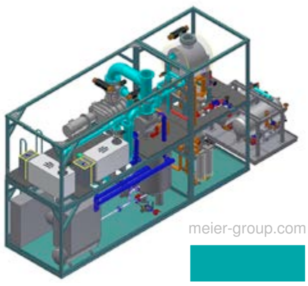
- New Design approved
- Completely preassembled
- Only small pit necessary
- Enough space for maintenance
- Reduction of installation time





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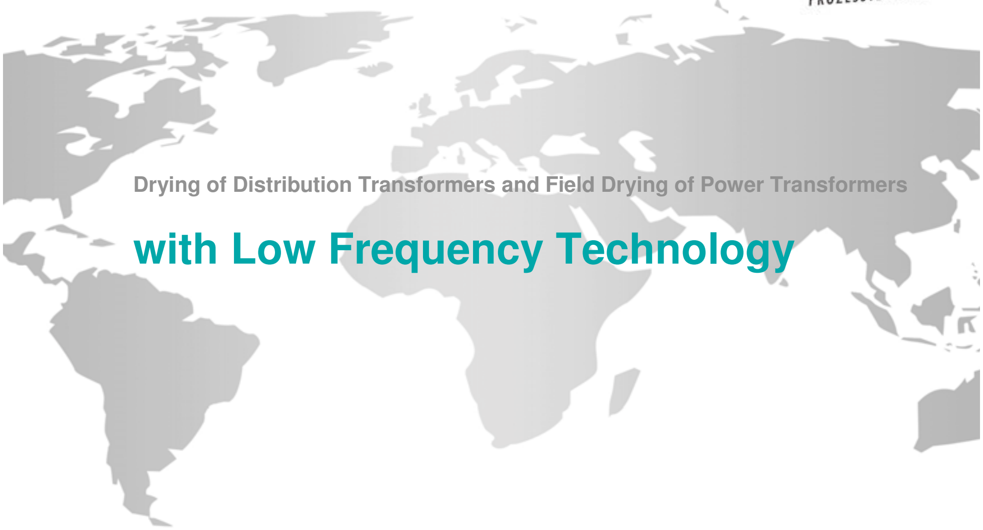

Drying of Distribution Transformers and Field Drying of Power Transformers

with Low Frequency Technology

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Drying of Transformers in the Field with Vaporphase, low frequency, or oil spray process

INNOVATION BASED ON TRADITION | PARTNER OF THE ELECTRICAL INDUSTRY

Advantages of Low Frequency Drying Technology

meier PROZESSTECHNIK

- Most effective drying method for distribution transformers up to 2,5 MVA
- Energy saving due to heating up windings and insulation material only
- Short process time and with this, workshop place saving
- Less depolymerisation of insulation paper
  (due to drying and filling under vacuum, without aeration)
- Clean process
- Applicable for drying of power transformers in the field

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INNOVATION BASED ON TRADITION | PARTNER OF THE ELECTRICAL INDUSTRY

Features of Low Frequency Equipment

meier PROZESSTECHNIK

- Tailor-designed autoclaves
- Regulation of oil filling speed
  - corresponding pipelines will be emptied automatically after filling
- Quick-Connectors (for copper bus bars and LF cables)
- Control of the dryness is done with a pressure rising test
- Provision of preheated dry air from the compressed air supply
  - to prevent corrosion on the core and the transformer housing
- Winding-temperature is calculated from the measured resistance of the winding
- Integration of a DC-measurement in addition to the AC-Measurement system:
  - for checking the AC measurement
  - characterised by high quality and accuracy
  - comparable with the measurement system of a testing field
- Manually, semi- or fully automic process possible
- Quality Management System to record all process steps

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Drying of Transformers in the Field with Vaporphase, low frequency, or oil spray process

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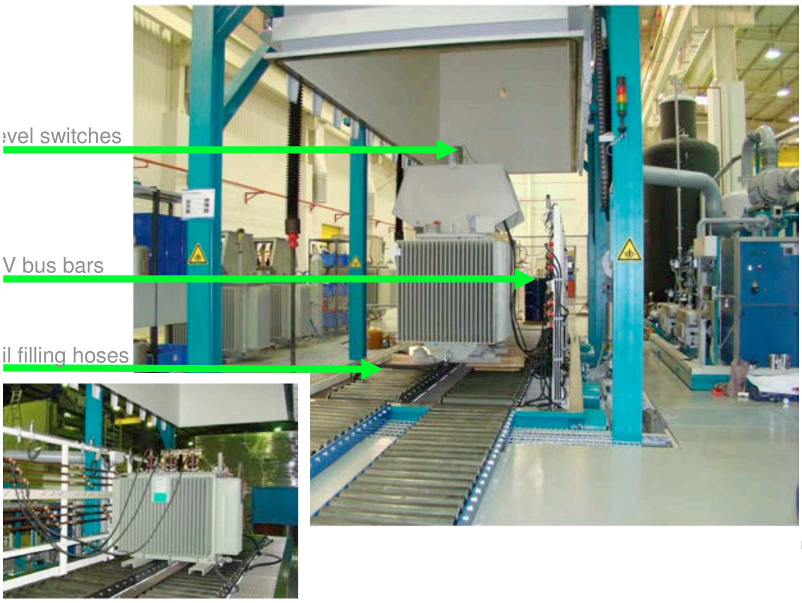
Features of Low Frequency Equipment, example given:



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Low Frequency Equipment

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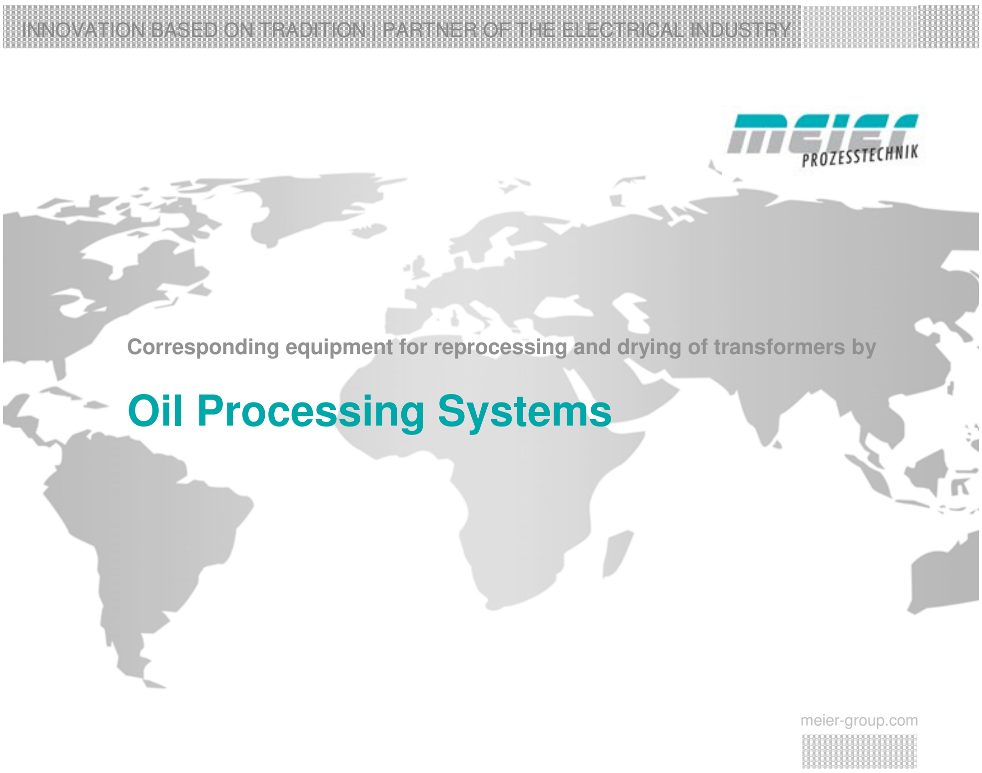

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Drying of Transformers in the Field with Vaporphase, low frequency, or oil spray process

Appraisal of Transformers using Gas-Monitoring Systems

Fabio Scatiggio,
Trasmissione Elettricità Rete Nazionale S.p.A

Fabio Scatiggio was born in Venezia, Italy, in 1957. He is with Terna Rete Italia where he is in charge as Chemical Laboratory Manager.
He is the Italian representative in many IEC TC 10 and CIGRE A2&D1 working groups. Mr. Scatiggio has published many papers on transformers diagnosis by DGA and on problems related with presence of corrosive sulphur in oil.

Mr. Scatiggio received the "IEC Award 1906" in 2008 and was awarded as "CIGRE Distinguished Member" in 2012.

Terna

Appraisal of Transformers using Gas-Monitoring Systems

Appraisal of Transformers using Gas-Monitoring Systems

Fabio Scatiggio

Liquid Insulation

In 1887 first use of oil for transformer insulation by Westinghouse, as alternative to air and bitumen impregnated paper

Insulating fluids serve 3 main function:

- To remove the heat generated by load and no-load losses
- To insulate electrically, also in combination with solid materials
- To lubricate moving parts

To transport by-products used for diagnostic (DGA, furans, acids, methanol, water, etc.)

Appraisal of Transformers using Gas-Monitoring Systems

Dissolved Gas Analysis (DGA)

Under electrical, thermal and oxidative stress oil and paper degraded generating many by-products. Some of them are gases.

Quantity of gas is depending by total energy amount, type of gas is depending by energy density.

Some gases are dissolved in oil:

Degassed Trafos ⇒ 0.2% in volume (2000 ppm)

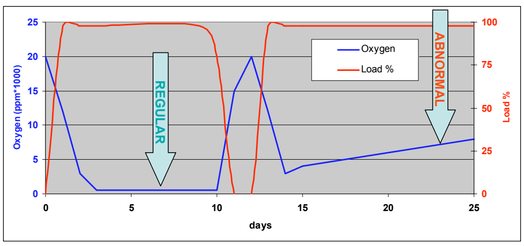
In service Trafos ⇒ 4 – 10% in volume (40.000 ÷ 100.000 ppm)

Dissolved Gas Analysis (DGA)

Dissolved gas in oil are mainly (90-95%) composed of Nitrogen and Oxygen coming from atmosphere, with smaller amounts of carbon oxides and hydrocarbons.

Nitrogen is inert. It doesn't react and increases time by time.

Oxygen is consumed due to oxidative reactions.



Appraisal of Transformers using Gas-Monitoring Systems

Dissolved Gas Analysis (DGA)

Gas	Formula	Origin	Solubility in oil (% vol)	Ostwald Constant	
				at 20 °C	at 50 °C
Nitrogen	N_2	Atmosphere	9	0.09	0.09
Oxygen	O_2	atmosphere	16	0.17	0.17
Carbon monoxide	CO	Cellulose/oil	9	0.12	0.12
Carbon dioxide	CO_2	Cellulose/oil	120	1.08	1.00
Hydrogen	H_2	Oil	7	0.05	0.05
Methane	CH_4	Oil	30	0.43	0.40
Ethane	C_2H_6	Oil	380	2.40	1.80
Ethylene	C_2H_4	Oil	280	1.70	1.40
Acetylene	C_2H_2	Oil	400	1.20	0.90

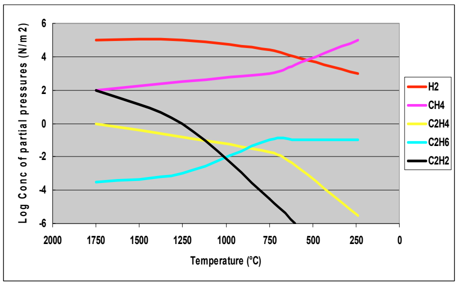
Dissolved Gas Analysis (DGA)

Cellulose forms carbon oxides (CO and CO_2) and minor amounts of H_2 and CH_4.
Oil decomposition becomes from rupture of C-H and C-C links, then secondary reactions create hydrocarbons and carbon oxides and sometimes carbon black.

Halstead's thermodynamic model:

- Hydrogen generation is almost independent by temperature.
- Acetylene generation starts above 1000°C.

Only theoretical since it is based on unrealistic isothermal equilibrium



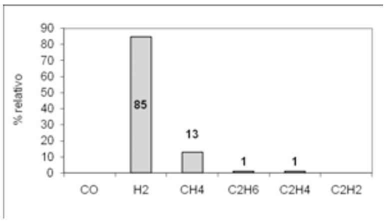
Appraisal of Transformers using Gas-Monitoring Systems

Dissolved Gas Analysis (DGA)
Partial discharge

An electric discharge that only partially bridges the insulations between conductors. Typically: 1 eV (electronic bombing).

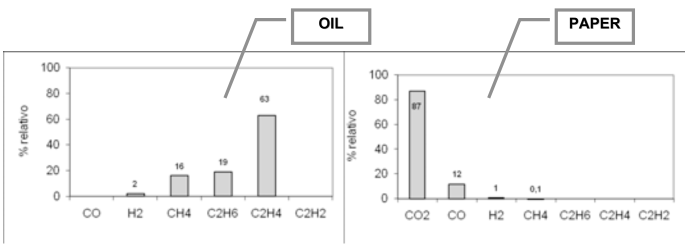
Discharge in oil ⇒ partial discharge (corona) ⇒ H_2, C_2H_6, CH_4 and solid paraffin.

Discharge in cellulose ⇒ high density partial discharge with paper perforation ⇒ C_2H_2.



Dissolved Gas Analysis (DGA)
Local overheating

Hot spots typically at 300 – 450°C sometimes > 1000°C.
< 450°C ⇒ CH_4 and H_2
> 450°C ⇒ C_2H_4 and CH_4
> 800°C ⇒ C_2H_4 only
> 1000°C ⇒ C_2H_2 also



Appraisal of Transformers using Gas-Monitoring Systems

Dissolved Gas Analysis (DGA)

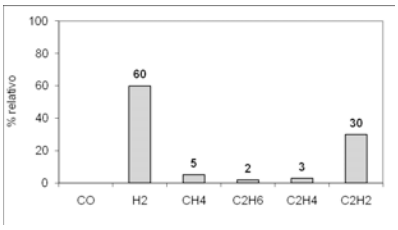
Arcing

A discharge that bridges the insulations between conductors with temperatures in range 1000 – 1300 °C.

Intermittent discharge with low current circulation (sparking), ⇒ H2 and C2H6.

Continuous discharge of short time duration with high current circulation, ⇒ H2 and C2H2 (arcing).

0.025 ml gas / Joule

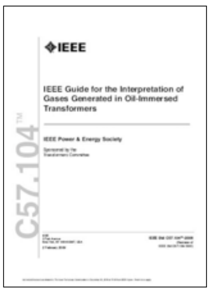


DGA Interpretation

Every single gas and its relationship with the other gases should be taken in account.

Specific Guidelines were developed and published:

- IEC 60599
- IEEE StsC57.104



Appraisal of Transformers using Gas-Monitoring Systems

Faults

Classified as:

Partial discharges

Electrical defects

- Low energy density (sparking)
- High energy density (arcing)

Thermal defects

- Local overheating at low temperature
- Local overheating at medium temperature
- Local overheating at high temperature

Interpretation Schemes

Key gas: Dickinson, Potthoff, LCIE

Ratios: Doernemburg, Rogers, IEC 60599, IEEE Std C57.104

Graphical: Shank, tri-linear, Duval, Okubo & Tsukioka.

Appraisal of Transformers using Gas-Monitoring Systems

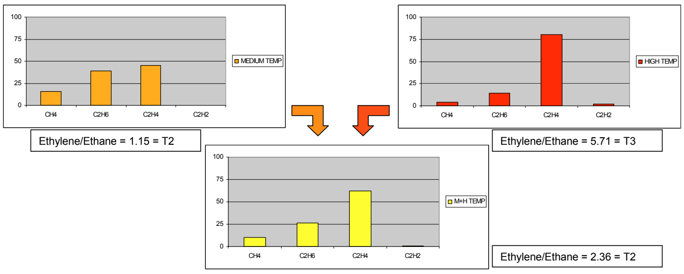
Interpretation Schemes

They are not conflicting.

They can be used together, for diagnostic fine tuning.

No one is able to classify all the potential gas compositions.

Interpretation is hard for evolving faults or contemporaneous faults.



Interpretation Schemes

Key gases:

Hydrogen ⇒ Partial discharge (PD)

Hydrogen & Hydrocarbons ⇒ Overheating (in oil)

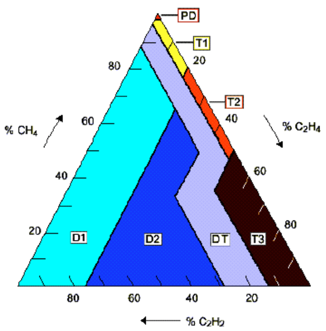
Acetylene ⇒ Arcing

Carbon Oxide ⇒ Overheating (in paper)

Remark: these gases are always present

Appraisal of Transformers using Gas-Monitoring Systems

Graphic criteria
Duval's Triangle N°1



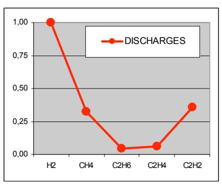
PD: partial discharges

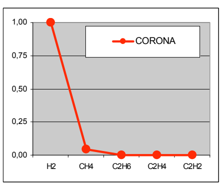
T1: thermal <300°C
T2: thermal 300 – 700°C
T3: thermal >700°C

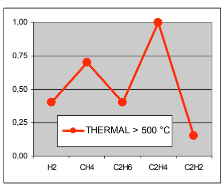
D1: low energy discharges
D2: high energy discharges

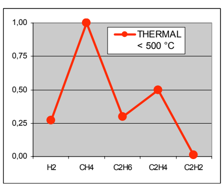
DT: thermal & electric fault (mix)

Graphic criteria
Okubo e Tsukioka









In ordinate axis (y) normalized concentrations are displayed.

In abscissa axis (x) gases in the following sequence H2, CH4, C2H6, C2H4, C2H2.

One shape → One defect

Appraisal of Transformers using Gas-Monitoring Systems

Criteria based on gas ratio

$\frac{CH_4}{H_2}$ **PD assessment**;

$\frac{C_2H_2}{C_2H_4}$ **Arcing;**

$\frac{C_2H_2}{C_2H_6}$ **Discharges of high intensity;**

$\frac{C_2H_4}{C_2H_6}$ **Oil overheating>500C;**

$\frac{CO_2}{CO}$ **Cellulose overheating;**

$\frac{C_2H_2}{H_2}$ **Oil contamination from diverter switch of LTC;**

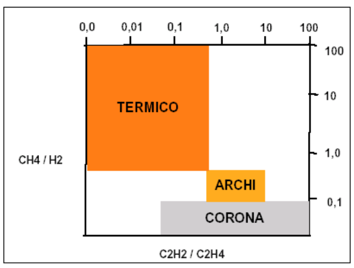
$\frac{N_2}{O_2}$ **Consumption of oxygen; sealing;**

Empirical equation used for estimating hot spot temperature

Hot spot (°C) = 322 log (C_2H_4/C_2H_6) + 525.

Doernemburg ratios

In 1967 Doernemburg (Brown-Boveri) proposed the first criteria based on gas ratio



Appraisal of Transformers using Gas-Monitoring Systems

Rogers ratios

Ad the end of 70's Rogers (CEGB) considered 4 gas ratios, and the values of the ratios are considered to fall into only 2 classes (0 if <1, and 1 if >1).

There are consequently 16 possible combinations of which nine are found to be associated with specific fault types.

It is still today, also with Doernemburg ratio, used in IEC 60599 and IEEE Std C57.104.

Rogers ratios

CH_4 / H_2	C_2H_6 / CH_4	C_2H_4 / C_2H_6	C_2H_2 / C_2H_4	Diagnosis
0	0	0	0	Only if CH_4 / H_2 = 0.1 PD, otherwise OK
0	0	0	1	Flash-over
0	0	1	0	Conductor overheating
0	0	1	1	Arc with power – persistent sparking
0	1	0	0	Overheating 250 ÷ 300°C
0	1	0	1	Tap changer, selector
0	1	1	0	- - -
0	1	1	1	- - -
1	0	0	0	Overheating < 150°C
1	0	1	0	- - -
1	0	1	1	Circulating current - bad contacts
1	0	1	1	- - -
1	1	0	0	Overheating 200 ÷ 300°C
1	1	0	1	- - -
1	1	1	0	- - -
1	1	1	1	- - -

Appraisal of Transformers using Gas-Monitoring Systems

Guide IEEE Std C57.104

Developed in 1978 in USA by ANSI and IEEE and revisited in 1991

4 level conditions to classify the transformers risk, depending by TDGC and gas concentrations:

- Condition 1: satisfactory condition, if any individual gas exceed the level should prompt additional investigations.
- Condition 2: abnormal situation, if any individual gas exceed the level should prompt additional investigations. Evaluate trend.
- Condition 3: high decomposition condition, if any individual gas exceed the level should prompt additional investigations. Immediate action for evaluate trend. Fault(s) probably present.
- Condition 4: excessive decomposition condition. Continued operation could result in failure.

Guide IEEE Std C57.104

	Dissolved gas in ppm							
	H_2	CH_4	C_2H_2	C_2H_4	C_2H_6	CO	CO_2	Σ combustible gas (TDGC)
1	100	120	35	50	65	350	2500	720
2	101- 700	121-400	36-50	51-100	66-100	351-570	2501-4000	721-1920
3	701-1800	401-1000	51-80	101-200	101-150	571-1400	4001-10000	1921-4630
4	> 1800	> 1000	> 80	> 200	> 150	> 1400	> 10000	> 4630

Total Dissolved Combustible Gases = TDGC = hydrogen + methane + acetylene + ethylene + ethane + carbon oxide

Appraisal of Transformers using Gas-Monitoring Systems

Guide IEEE Std C57.104

Condition	TDGC (ppm)	TDGC rate (ppm/day)	Sampling frequency	Action
4	> 4630	> 30	daily	Consider removal from service Advise manufacturer
		10 – 30	daily	
		< 10	weekly	Exercise with extreme caution Analyze for individual gases Determine load dependence Plan outage
3	1921-4630	> 30	weekly	
		10 – 30	weekly	
		< 10	monthly	
2	721-1920	> 30	monthly	Exercise with caution Analyze for individual gases Determine load dependence
		10 – 30	monthly	
		< 10	quarterly	
1	720	> 30	monthly	
		10 – 30	quarterly	Regular
		< 10	annual	

Guide IEC 60599

Published in 1978 as 599, it uses 3 gases ratio (C2H2/C2H4, CH4/H2 e C2H4/C2H6) with a 3 digit code in range 0÷2 (ex. 102 means: low energy discharge).
In 1999 it was fully revisited (now 60599), 3 digit codes were replaced by numerical values of ratios. Typical values and alarm values were included.

Case	Typical fault	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6
PD	Partial discharge	Non significant	< 0.1	< 0.2
D1	Low energy discharges	> 1	0.1 – 0.5	> 1
D2	High energy discharges	0.6 – 2.5	0.1 – 1	> 2
T1	Thermal fault < 300°C	Non significant	> 1	< 1
T2	Thermal fault 300 – 700 °C	< 0.1	> 1	1 – 4
T3	Thermal fault > 700°C	< 0.2	> 1	> 4

Appraisal of Transformers using Gas-Monitoring Systems

Guide IEC 60599

Typical values 90%

	DGA in ppm (v)						
	H_2	CO	CO_2	CH_4	C_2H_6	C_2H_4	C_2H_2
TR without OLTC	60-150	540-900	5100-13000	40-110	50-90	60-280	3-50
TR with OLTC	75-150	400-850	5300-12000	35-130	50-70	110-250	80-270
Furnace TR	200	800	6000	150	150	200	- - -
Distribution TR	100	200	5000	50	50	50	5
Bushings	140	1000	400	40	70	30	2
TV	70-1000	- - -	- - -	- - -	- - -	20-30	4-16
TA	6-300	250-1100	800-4000	11-120	7-130	3-40	1-5
Cables	150-500	40-100	220-500	5-30	10-25	3-20	2-10

Guide IEC 60599

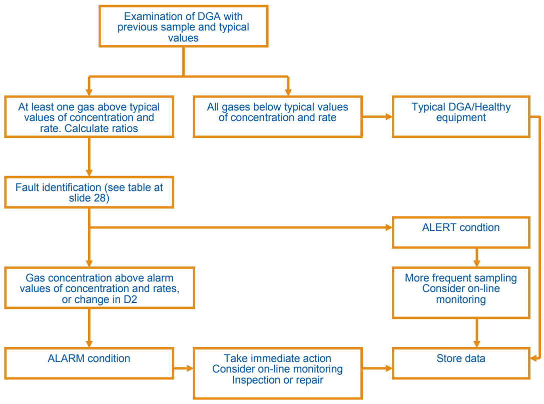
Additionally others ratio are proposed:

- CO_2/CO ratio for solid insulation evaluation (range 7±4)
- O_2/N_2 ratio for atmospheric system evaluation (membrane rupture). Low ratios related to excessive oxygen consumption and consequent degradation of solid insulation.
- C_2H_2/H_2 ratio; values > 2 ÷ 3 are considered as an indicator of OLTC trans-contamination.

Appraisal of Transformers using Gas-Monitoring Systems

Guide IEC 60599

Flow chart



IEC 61181

Factory Test

Specific for Heat Run Test (Temperature-Rise).

similar to IEEE Std C57.130

Typical values at 90%, in ppm/h					
Type	H_2	C_n	H_2+C_n	CO	CO_2
Core-type	0,1 – 1,3	0,04 – 0,3	0,1 – 1,6	0,4 - 2	5 - 18
Shell-type				4	
Special cases	1,7	0,5	2,2	5	20

H_2+Cn	N° of cases	N° of cases involved in faults or defects
< 0,5	215	1
0,5 - 1	36	1
1 - 2	21	4
2 - 5	12	4
5 - 10	4	2
> 10	3	3

Appraisal of Transformers using Gas-Monitoring Systems

IEC 61181
Factory Test

TERNA's specification - Max amounts for heat run test (I=1,1 In):

- $C_2H_2 \leq 0,3$ ppm
- $H_2 + CH_4 + C_2H_6 \leq 2$ ppm/h
- $CO \leq 5$ ppm/h
- $CO_2 \leq 20$ ppm/h
- $C_2H_4 / C_2H_6 < 1$

Limitations

To create a baseline.
DGA's guidelines should be used by expert and skilled technicians.
Presence and type of gas depends by:

- Equipment type (location, transformer type, etc.)
- Liquid type (nature, saturation and solubility)
- Preservation system (open, close, sealed) and circulating system (natural, forced, driven)
- Fault temperature
- Solid materials in contact with oil (Kraft or upgraded paper, Nomex, etc.)
- Sampling (syringes, etc.) and measuring techniques (extraction, detectors).

Must be used only if gas concentrations are notably grater than detection limits.

… interpretation of their significance is, at this time, not a science but an art subject to variability

(from IEEE Std C57.104-2008, page 1)

Appraisal of Transformers using Gas-Monitoring Systems

History cases

1) Atmospheric gases

TRANSMISSION TRANSFORMER 1 – 250 MVA – with membrane				
Date	Total gases	Nitrogen	Oxygen	Water
16/03/00	8,81	6,32	0,15	3
05/07/00	11,7	9,23	0,17	4
21/09/01	14,6	11,8	0,37	4
27/05/02	12,8	10,4	0,10	6
24/11/03	19,5	15,2	0,32	3
09/12/04	16,7	13,0	0,11	4

TRANSMISSION TRANSFORMER 2 - Sister Unit – 250 MVA – with broken membrane				
Date	Total gases	Nitrogen	Oxygen	Water
04/11/99	22,3	21,3	0,30	4
04/03/00	70,3	66,8	0,98	2
24/05/01	79,5	76,5	0,72	4
17/07/02	92,1	85,9	0,32	4
09/12/04	98,1	90,6	0,29	5
03/01/05	9.4	7.9	0.30	REPARED

Transformer Life Management 2013 – ME
Appraisal of Transformers using Gas-Monitoring Systems

History cases

1) Atmospheric gases

TRANSMISSION TRANSFORMER– 63 MVA – without membrane				
Date	Total gases	Nitrogen	Oxygen	Water
12/06/02	5,30	4,61	0,46	3
29/12/02	89,5	65,6	22,0	3
22/09/03	82,6	72,0	8,59	6
14/10/03	77,7	70,5	4,03	5
07/05/04	98,3	71,4	23,8	3
15/11/04	97,9	75,7	18,4	2

Appraisal of Transformers using Gas-Monitoring Systems

History cases

2) PD

TRANSMISSION TRANSFORMER - 40 MVA								
Date	H_2	CH_4	C_2H_4	C_2H_6	C_2H_2	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6
29/08/1984	31	10	0	5	0	0,00	0,32	0,00
27/10/1985	136	28	1	13	0	0,00	0,21	0,00
27/11/1986	145	37	1	18	0	0,00	0,26	0,00
10/11/1987	200	47	0	25	1	N.A.	0,24	0,00
28/09/1988	290	65	2	34	0	0,00	0,22	0,00
05/07/1989	190	108	4	79	0	0,00	0,57	0,00
10/09/1991	130	123	4	99	0	0,00	0,95	0,00
MAINTENANCE								
29/09/2004	66	204	7	211	0	0,00	3,09	0,00

History cases

3) Fake PD

STEP-UP TRANSFORMER - 33 MVA								
Date	H_2	CH_4	C_2H_4	C_2H_6	C_2H_2	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6
12/09/2003	19	7	4	16	0	0,00	0,37	0,25
20/10/2003	83	32	9	67	0	0,00	0,39	0,13
23/12/2004	569	14	9	97	0	0,00	0,02	0,09
17/02/2005	103	9	8	63	0	0,00	0,09	0,13
21/04/2005	76	6	7	53	0	0,00	0,08	0,13

STRAY GASS

Appraisal of Transformers using Gas-Monitoring Systems

History cases

4) Local overheating (hot spots) I

TRANSMISSION TRANSFORMER – 150 MVA									
Date	H_2	CH_4	C_2H_4	C_2H_6	C_2H_2	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6	
29/09/1997	737	1320	1610	251	40	0,02	1,79	6,41	
09/03/1998	785	1900	2320	369	54	0,02	2,42	6,29	
09/03/1999	1160	3290	3900	640	58	0,01	2,84	6,09	
17/03/2000	1353	4916	5850	1033	74	0,01	3,63	5,66	
30/10/2000	14	264	308	30	13	0,04	18,86	10,27	DEG
17/03/2001	1029	2137	2807	371	84	0,03	2,08	7,57	
25/02/2002	1537	4432	6366	815	61	0,01	2,88	7,81	
10/02/2003	27	29	57	50	6	0,11	1,07	1,14	DEG
21/12/2004	1549	4174	5574	767	89	0,02	2,69	7,27	

DEFECT INTO CORE, IN SERVICE, ON-LINE MONITORED,
PERIODICALLY DEGASSED TO PREVENT BUBBLING

History cases

4) Local overheating (hot spots) II

STEP-UP TRANSFORMER – 2.5 MVA									
Date	H_2	CH_4	C_2H_4	C_2H_6	C_2H_2	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6	
22/03/05	59000	17000	25000	6000	168	0.01	0.42	4.16	
06/04/05	9	17	17	3	0	0	1.89	5.16	REP.
18/04/05	19	41	48	7	1	0.02	2.16	6.85	

Appraisal of Transformers using Gas-Monitoring Systems

History cases

4) Local overheating (hot spots) III

STEP-UP TRANSFORMER – 153 MVA									
Date	H_2	CH_4	C_2H_4	C_2H_6	C_2H_2	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6	
20/01/01	69	14	4	3	17	4.25	0.20	**1.33**	
21/01/03	318	36	18	6	120	6.67	0.11	**3.00**	
10/02/03	262	37	16	5	150	9.38	0.14	**3.2**	LOWER LOAD
22/0/03	310	51	36	7	168	4.66	0.16	**5.14**	
28/06/04	345	63	46	9	193	4.19	0.18	**5.11**	
14/11/04	458	74	56	9	253	4.51	0.16	**6.22**	

Fault hypothesis (in increasing order of probability):

- PD bushing/connector
- OLTC contamination
- Core's iron "cold" discharges

History cases

5) OLTC trans-contamination – False arching

TRANSMISSION TRANSFORMER – 63 MVA									
Date	H_2	CH_4	C_2H_4	C_2H_6	C_2H_2	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6	
11/07/02	85	40	38	28	159	**4.18**	0.47	1.36	
11/03/03	166	65	131	41	234	**1.78**	0.39	3.20	
11/02/04	234	109	332	79	269	**0.81**	0.47	4.20	MANT+ TREAT
13/10/04	88	26	72	25	122	**1.69**	0.29	2.88	

Appraisal of Transformers using Gas-Monitoring Systems

History cases

6) High Energy Discharges (arching)

TRANSMISSION TRANSFORMER – 400 MVA										
Date	H_2	CH_4	C_2H_4	C_2H_6	C_2H_2	CO	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6	
30/11/83	11	89	4	5	0	120	0	0.09	0.80	
26/08/94	10	119	4	7	1	220	0.25	0.08	0.57	
21/03/95	36	125	15	13	8	270	0.03	0.53	1.15	
31/05/95	261	181	76	302	113	370	1.48	0.69	0.25	Buchholz trip
31/05/95	33%	2%	0.29%	0.21%	0.85%	19%	-	-	-	
	16500	8600	2200	5040	10200	22800	-	-	-	if at equil.

Short circuit between coils and windings displacement

History cases

7) Evolving faults

CORONA

TRANSMISSION TRANSFORMER – 250 MVA										
Date	H_2	CH_4	C_2H_4	C_2H_6	C_2H_2	CO	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6	
15/07/02	5	3	2	0	0	31	0	0.60	-	FACTORY TEST
30/12/02	47	26	7	7	0	39	0	0.59	1.00	SERVICE START
26/11/03	198	43	32	21	0	74	0	0.22	1.52	
08/03/04	315	57	42	27	0	91	0	0.18	1.55	
07/06/04	1322	1187	1195	278	8	122	0	0.89	4.30	
24/06/01	2201	2715	2940	732	15	133	0	1.24	4.02	

HOT SPOT

Appraisal of Transformers using Gas-Monitoring Systems

Dissolved Gas in Oil Analysis (DGA)

4 Steps:

- Sampling
- Gas extraction from oil by Töppler's pump or mercury-free pump (TOGA), by stripping or by head-space
- Analysis by GC (in according with IEC and IEEE) or by PAS (not in according with IEC and IEEE)
- Interpretation

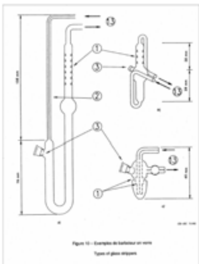
Gas extraction or separation

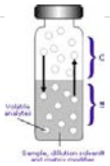
1. Total by mercury Töppler's pump or mercury-free pump.
2. Partial by mercury Töppler's pump or mercury-free pump.
3. Stripping, by the carrier gas (Argon, etc) bubbling itself through a small volume of the oil.
4. Head Space, a glass small vial is partially filled with oil (~ 1\3) and pressurized with carrier gas (~ 2\3). Oil is heated and shacked and a few amount of gases moves from oil to carrier.

To draw attention: except 1) for every single gas partition coefficients oil/gas MUST BE KNOWN.

Appraisal of Transformers using Gas-Monitoring Systems

Gas extraction or separation





$$C_L = C_G\left(K + {V_G}/{V_L}\right)$$

$$K = {C_L}\Big/\left(C_G - \frac{V_G}{V_L}\right)$$

Table 2: Head-space partition coefficients

	Example of naphthenic oil	Example of paraffinic oil
Density	0.864	0.849
H2	0.074	0.036
O2	0.17	0.18
N2	0.11	0.12
CH4	0.44	0.37
CO	0.12	0.073
CO2	1.02	0.64
C2H2	0.93	0.89
C2H4	1.47	1.27
C2H6	2.09	1.73
C3H6	5.04	4.36
C3H8	5.37	4.72
C4H6	10.10	

Gas extraction or separation

IEC 60567 (§ 7.5.1)

WARNING : THIS METHOD *(Head Space)* WILL PROVIDE REPRODUCIBLE RESULTS ONLY IF ALL THE OPERATION AND CALIBRATION PARAMETERS ARE PRECISELY CONTROLLED, OTHERWISE SIGNIFICANT ERRORS MAY OCCUR.

The following parameters are of particular importance: total volume of vials, volume of oil, tightness of septa, temperature, dilution with argon and actual pressure in the vials after each step of the procedure. The same exact parameters should always be used, for field samples, gas standards and oil standards.

OPERATION AND QUALITY CONTROL BY HIGHLY SKILLED PERSONNEL IS RECOMMENDED.

Appraisal of Transformers using Gas-Monitoring Systems

Total vs. HS vs. Transportable

	Total + GC	Head Space + GC	Transportable
Gas extraction system	Töpler pump or automatic (TOGA)	Head space	HS + Stripping
Gases (supply)	Ar, aria, H2	Ar, aria, H2	ambient ari
Columns	2 (typically)	2 (typically)	None
Detectors	2 (TCD + FID)	2 (TCD + FID)	PAS (IR + acoustic)
Use	Laboratory	Laboratory	On field
Target	Chemists	Chemists	Trained people
Automatic	Yes	Yes	No
Calibration	Gas (cylinder)	Gas (cylinder) + Oil (prepared)	Gas (cylinder) + Oil (prepared)
Partition coefficients	Free	Need	Need
IEC, IEEE	Yes	Yes	No

Lab vs. On-Line

	Laboratory Equipment	On – Line (8 gas GC based)	On – Line (8 gas PAS based)
Gas extraction system	Manual or automatic total degassing	Membrane + HS	Membrane + HS
Gases (supplies)	Ar, Air, H_2	He	Ambient air
Columns	2	2	None
Detectors	2 (TCD + FID)	TCD	PAS + FC
Gases detected	all	all (but N2 calculated)	all (but N2 calculated)
Sensibility	Excellent	Suitable	Suitable
Repeatability	Good	Excellent	Excellent
Reproducibility	Good	Poor	Poor
Time constant	Depend by sampling	Every 2 - 8 h.	Every 4 - 8 h.
Trafos controlled #	No limits	1	1 max. 2
Target	Chemists	Trained people	Trained people
Use	Laboratory	On-line	On-line

Appraisal of Transformers using Gas-Monitoring Systems

Thanks for your attention

Condition based (Re-)Investment planning

Georg Daemisch,
DTC-Daemisch Transformer Consult

Education

M.Sc.Electrical Power Engineering-Karlsruhe-Germany

Professional Career

- DTC (Daemisch Transformer Consult) specialized in consulting for transformers and executing On-Line treatment of transformers and life time assessments – 2005 until now
- Owner and managing director of DIDEE GmbH (Daemisch Industriedienstleistungen GmbH) and – 1992 until now
- Independent – 1991
- Ginsbury Electronic – 1988
- Sales Engineer for southern Europe in MR (Maschinenfabrik Reinhausen) in Regensburg/Germany for OLTC's – 1985
- Sales Engineer for big power transformers in BBC Mannheim (ABB) for Latin America, Near East and other areas – 1978
- Sales Engineer for small and middle sized transformers in TRAFO UNION (Siemens/AEG) – 1975

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07/13

TLM 2013 Dubai

Dipl.-Ing. Georg Daemisch

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1. Introduction:

Even if the condition based maintenance is up to now not really introduced as the only acceptable option for the maintenance philosophy at power transformers we must now go the next step forward, using the knowledge of the condition of our assets to plan and co-ordinate the (re-) investment of one of our most important key asset:

The Transformer

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2. Introduction:

Very often, if we discuss with the users we find out that the classical preventive maintenance idea is already alive with the result, that due to

Unnecessary treatments finally unnecessary failures are produced.

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2. Introduction:

This is understandable, because in many cases the maintenance groups feel the pressure to do something in order to prove their necessity and to have in case of failure the answer, that there was done something and the failure cannot happened by lack of correct maintenance.

Nevertheless remains:

If the data do not indicate any corrective action:

DO NOTHING!

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3. Condition assessment:

Doubtless remains as the biggest challenge to understand the actual condition of a transformer.

There are offered nowadays a number of measurement systems and processes, which promise to give the user every all necessary data for evaluating the actual condition of his transformer.

Nevertheless data alone tell you :

Nothing

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3. Condition assessment:

1. The first step is to evaluate the data in a critical way in order to discriminate the reliable data from the wrong ones.
2. Based on the reliable data may be decided, if more measurements are necessary or not.
3. Having sufficient and reliable data a diagnosis can be elaborated.
4. Based on the diagnosis a action plan may be worked out, based on the complete technical and financial environment.

Health care planning

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4. Sampling and measurements:

Looking in some enquiries it seems, that the customers like to have the contractor coming with a complete truck of measurement systems, shutting the transformer down with the target to have now all possible information.

But makes this really sense?

Our experience tells a simpler story:

- Having a comprehensive DGA and oil quality history
- Making a well based reference sampling with reliable state of art equipment.

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4. Sampling and measurements:

The reference sampling should go together with a visual control of the transformers, also with a deeper discussion with the personnel in order to understand the individual condition in the plant and naturally the transformers there!

Based on such facts the first condition assessment can be finalized. Based on this further investigation may be made or in case the data are sufficient a final report can be delivered.

Needed is the expertise to transfer Data to diagnosis and from Diagnosis to adequate action

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5. Report and results:

The reference sampling should go together with a visual control of the transformers, also with a deeper discussion with the personnel in order to understand the individual condition in the plant and naturally the transformers there!

Based on such facts the first condition assessment can be finalized. Based on this further investigation may be made or in case the data are sufficient a final report can be delivered.

What must this report contain?

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5. Report and results:

1. **Actual health condition**
2. **Actual ageing condition (remaining substance)**
3. **Load capability assessment**
4. **Risk assessment**
   - **Technical risk**
   - **Financial risk**
5. **Possible (necessary) actions**

Based on the impact of item 4 determining the necessary actions in a

Health care plan

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6. The risk environment:

A Technical

- ageing condition
- failure mode
- load capability
- remaining life time under actual condition
- failure probability

B Financial

- financial consequences of a failure
- loss of asset
- loss of production
- collateral losses
- failure probability

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6. Technical versus Financial considerations:

A general problem in the whole story is that mostly there is not made a assessment of the technical risk in view of the financial considerations.

A highly endangered transformer in a certain application may remain acceptable and in service, since the consequences of a possible fault may be controllable and it would be economic to use the remaining substance to the highest extent.

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6. Technical versus Financial considerations:

On the other hand a much less critical transformer in a key application needs a complete different view, because its fault has tremendous financial implications.

Also using load tolerant transformers in high load condition areas, even with higher total losses is finally a more economic solution, as using less tolerant units with lower losses, because in the latter case the total life time costs are intolerantly high.

Result: It is a must to understand the technical and the financial background in order to optimize the

complete Population life cycle costs

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7. Specification:

The first condition, which must be considered, before the transformer is even ordered, is the correct specification. Today this paper must be much more stringent, than ever before, in order not to leave doors open for cheap and not adequate design and to get really comparable offers.

The required specification must cover:
- Correct temperature rise
- Correct temperature profile
- Adequate and technically sense making cooling systems
- Limits of Oxygen consumption
- Correct auxiliaries (for example sampling devices)

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8. Monitoring:

To understand and control the condition a more or less close monitoring must be implemented. What is close enough? The span reaches from regular (in a 3 – 24 month cycle) sampling and controlling to complex On-line monitoring up to On-line GC systems.

In which extent the monitoring should be done depends on the individual case. Nevertheless the data stream of monitoring systems must be canalized in order to have a use of it. Otherwise the data and therefore the monitoring is wasted money

Monitoring solves no problem and is not maintenance

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9. Treatments:

Based on the monitoring data certain actions should be implemented. To keep the transformer working certain maintenance procedures are on the market:

- Oil purification (treatment)
- Regeneration
- On-line conditioning

Oil purification does not fix real problems, like excess of water or gas. It is a simple cosmetical measure
Regeneration (reclamation) addresses oil ageing problems and is not a “wonder medicine” and is applied typically once in a transformer life
On-Line conditioning is the process to maintain the substance

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10. Examples:

The following examples show certain typical cases for investment or not investment, depending of the complete technical/financial environment.

- In the industrial plant a break down of 1 unit is tolerable, because of sufficient redundancy and spare available.
- Similar in the power plant for the start up transformer, but NOT for the substation auxiliary supply.
- Using the load tolerant older transformers with higher losses in the high load centers and the less tolerant low loss transformers in the low load condition means save life cycle optimization.
- In power plants is the "shut down" time the crucial point

Examples:

Example 1 Aluminium smelter plant in Germany

Background:

- The plant is now over 40 years old and under the condition of the high energy costs the decision to keep it running or to stop is always a short term issue.
- The plant delivers high quality products, which will be preferably used in the neighbouring rolling plant.
- The whole plant is highly aged including the transformer population, which was also badly maintained till about the 90th of the last century.
- On the other hand to much investment under the above mentioned conditions was not acceptable.

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Examples:

Example 1 Aluminium smelter plant in Germany

Solution:
- Starting a correct monitoring program with regular oil and DGA tests.
- Based on this developing of a health care planning for the population.
- Investment in the necessary equipment for improving and preservation of the transformers.
- After achieving correct technical conditions of the transformer population by using the adequate technologies i.e. On-Line conditioners, reclamation etc. developing of a long term re-investment plan for that population.

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Examples:

Example 1 Aluminium smelter plant in Germany

Long term re-investment:

The population consists of three generations:
- The first installation about 40 years
- The second stage about 30 years
- The first reinvested units installed at 2000

The intensive condition assessment shows, that all three generations converge with their EOL prevision to about the same time in the next 5-10 years. (including the “new” generation)

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Examples:

Example 1 Aluminium smelter plant in Germany

In 2008 two new units a 35 MVA and a 20 MVA were delivered and two of the old units were sent to the factory for refurbishment.

At least the 35 MVA type has proven a very stable and long term tolerant design. For this reason a refurbishment seemed justified, even if the cost would be not much less or even equal to a new unit.

The assessment of the dismantled unit proved this point of view.

In the case of the 20 MVA unit the condition of the core sheets was so bad, that a refurbishment for this type made not really sense.

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Examples:

Example 1 Aluminium smelter plant in Germany

Long term aspect and planning:

In order to minimize the re-investment without reducing the reliability of the production the following policy was determined:

Since there is a 3 of 4 unit arrangement it is tolerable that 1 unit of the 4 units fails as far a replacement is available. The already working preservation programs are continued

So for every transformer type a spare is available, that a fast replacement of a failed unit is possible. So it is possible to use all units in their full life time cycle till the final EOL condition.

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Examples:

Example 2 Combined heat and power plant

Background:

A 2x 120 MVA CHP power plant 50 years old was planned to be shut down in the year 2012. So at a first step in 2006 the transformer population GSU, and auxiliary transformers were assessed and a health care planning defined in order to reach the planned shut down in a reliable way. Necessary treatments, like reclamation and using On-Line conditioners and On-Line monitoring were implemented.

2008 was decided to extend the life time of the plant to the year 2020. To cope with this situation a new planning was necessary.

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Examples:

Example 2 Combined heat and power plant

The new extended life time cycle needed a new assessment of the main transformers GSU, station auxiliaries and start up transformers. It now could not fully be assured, that all transformers could really reach the new target.

The possible options were assessed and evaluated:
Option 1 purchase completely new transformers
Option 2 try to survive with the existing transformers
Option 3 purchase only two new transformers (1 station auxiliary, 1 Start up). There was also a used GSU transformer, which could be adopted for that plant in good condition.

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Examples:

Example 2 Combined heat and power plant

Solution:
The option 3 was selected for the following reasons:
Purchasing new transformers was not only from the cost side not acceptable, also the risk of new transformers was not really improving the reliability.
To survive with the existing ones Option 2 was also not a acceptable reliable version.

Option 3 finally fulfilled all necessary requirements of reliable service on the one hand and minimized costs and risk at highest score of reliability.

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Examples:

Example 3 Transformer population of a rural utility

Background:

This utility positioned in a rural area has a transformer population with transformers up to 35 years. In order to understand the condition and be able to plan on middle and long term, there was awarded a first contract to DTC for the 20 oldest units up to 35 years age.

Later on for 20 units 15-30 years old.

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Examples:

Example 3 Transformer population of a rural utility 110/20kV 35/40 MVA

Result:

The first batch of older transformer had the surprising result, that these transformers were nearly in a "new condition" The reason for that is 1. the transformers are low loaded and the temperature exceeds seldom 50 C and 2. these transformers were of a good old highly tolerant design.

The second batch also showed, that the younger transformers of "modern" design were much weaker and presented under the same load and temperature condition indications of ageing.

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Examples:

Example 3 Transformer population of a rural utility 110/20kV 35/40 MVA
Final recommendations and new challenge:

In this case under the actual conditions no replacement or re-investment is necessary

A new challenge is now a load increase at certain places due to new renewable energy systems mainly wind parks.

Here was developed as new service a load capability study for transformers in order to select for these increased load the most tolerant units, since it was obvious, that different transformers of different design will not react in the same way on increased load. Another way to make best use of the investment assets.

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Case studies Health care planning

Example 4 Condition and Planning

The auxiliary transformers in a power plant must be assessed and a health care planning has to be proposed

PLant1	Condition	Measure	Priority	tecn. Risk	fin. Risk	Invest 2013 in T€	Invest 2014 in T€	Invest 2015 in T€	Invest 2016 in T€	Invest 2017 in T€
N 0BBT01	normal	O	5	6	2			20		
N 0BBT02	normal	O	5	6	2			20		
P 0BBT01	reduced	O;W	1	4	2	20				
P 0BBT02	Normal	O	5	6	2			20		
Y 3BCT70	Partially warm	O; W; R	1	2	5	32,5; 25			20	
Y 3BCT80	Partially warm reduced	O; W; R	1	2	5	32,5; 25			20	
Invest/ Jahr						135		60	40	

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Case studies Health care planning

Example 5

Recommended measure and risk

Scenario 1

Action : **NONE**

Result and Risk: GT2 and GT3 fast declining, GT3 and GT4 could result in breakdwon

Cost 0 , **Risk very high**

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Example 5

Recommended measure and risk

Scenario 2

Action : Reclamation and Re-inhibiting at GT2 and GT3, also re-positioning of Hydran M2

Result and Risk: limited collateral damaged

Costs low (< 200k €), Risk remains high, better controllable

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Example 5

Recommended measure and risk

Scenario 3

Action: Reclamation and Re-inhibiting at GT2 and GT3, also re-positioning of Hydran M2, work with online monitoring device, and prepare a spare transformer

Result and Risk: minimized

Costs high (~6 Million €) , Risk minimized

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10. Examples:

The examples show very clear the difference between technical and financial risk. Since the substation supply is integrated in the generator bus bar a failure means a shut down of the plant of at least 1 week.
For the start up transformers with the higher technical risk the financial risk and therefore the priority is much lower, because in case of failure alternative power sources are available without shut down.
Last example shows the result of a TPM (Transformer Population Management) study for a power plant in Indonesia. The purchase of a spare transformer remains the most favorable solution!

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11. Summary:

Saving money means to spend it in a intelligent and fact based way.

Means:

Gaining the data in a reliable way, using these data to transfer them to facts (Expertise!) and finally

Decision, well based on true facts implementing the necessary processes, investing the necessary money for the

most technical reliable and economically optimized solution

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Properties behind effective Transformer Oil Cooling

Hendrik Cosemans, General Manager Nynas Dubai

As a Belgian national, where 3 official languages are part of the national structure, Hendrik is adding English and Spanish to his language portfolio. And very basics of Arabic, but he would like to improve these skills.

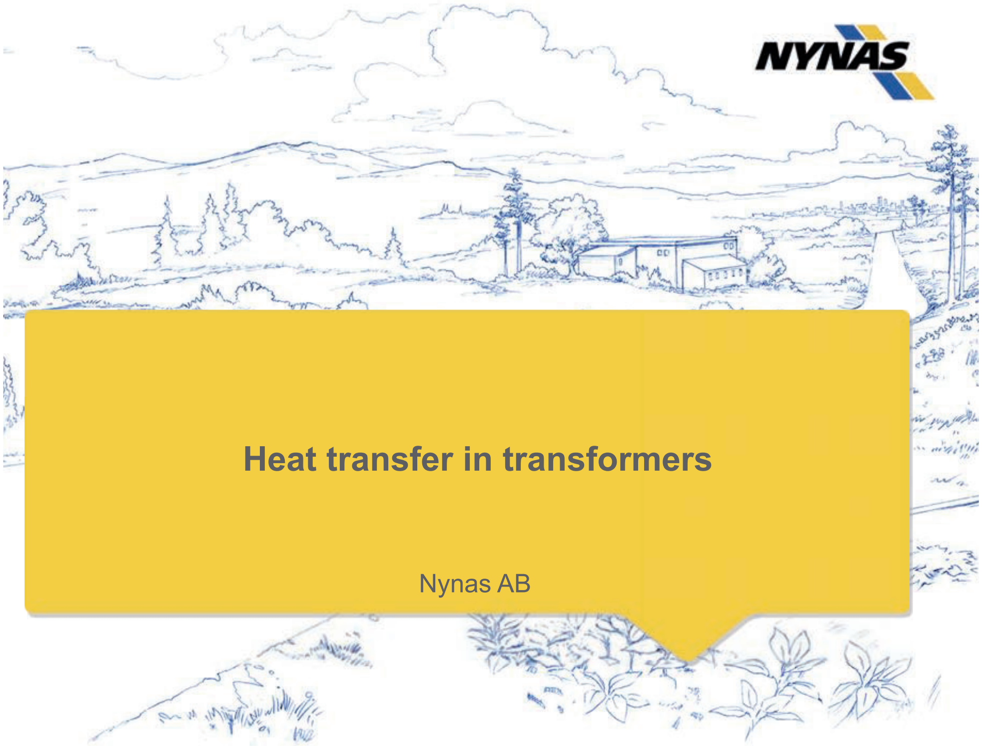
Trained as a Business Engineer he has travelled the world, both in his studies and work experience. Barcelona, Belfast and Dubai have little secrets for him. He moved from Linde Gas to Nynas in 2007.

Being active in the field of sales or purchasing, the commercial surroundings are where he thrives best. The international business scene was swapped for Dubai's iconic landscape since 2011, together with his family. As General Manager of Nynas Dubai, a further growth of the 15 countries under his responsibility has been achieved. Transformer oils remain the main focus of the Naphthenic oils that are being produced by Nynas, next to process-oils, oil for lubes & greases and tyre-oils.

Setting up good cooperation and local partnerships, lobbying for quality prescriptions and passing the knowledge via conferences and seminars, whilst travelling actively to meet the customers, contractors and utilities are the main activities, next to ensuring that the Dubai office keeps delivering its excellent performance in order handling and customer satisfaction.

NYNAS

Properties behind effective Transformer Oil Cooling



NYNAS

Cooling properties of insulating liquid

Properties behind effective Transformer Oil Cooling

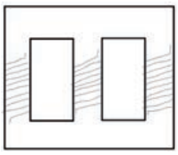
NYNAS

Cooling

- Heat generation in transformers
- Viscosity
- Heat transfer coefficient

NYNAS

Heat generation in transformers



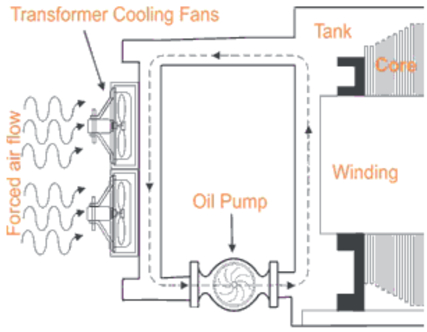
There are two main types of losses of power in transformers: ”No load” losses and Load losses

- **“No load” losses**: Independent of load of transformer
  - Comes from magnetic losses and hysteresis in the iron core
- **Load losses** = Copper electrical resistance loss + Stray losses
  - Copper electrical resistance loss: $Q_R \approx I*R^2$ =
    =Electric Current * Resistance^2
  - Stray losses: Leakage of electric flux and eddy losses to tank and other metal parts
  - Copper electrical resistance loss: $R(T)=R_0 + \alpha*\mathbf{T}$
    - (Where T= Temperature, with constants R_0 and α)

Properties behind effective Transformer Oil Cooling

Example of heat generation in a transformer

- TRAFO: 630 kVA (15kV/0.42 kV), with 3 MT of TRO
- Losses (Q) in TRAFO
  - Q_{Core}= 600 W and Q_{Load}= 4600 W
    - Reference: EFACEC 2012
- To keep temperature steady in the transformer the cooler needs to remove 5200 W from the oil!
- If no cooler is installed, the oil temperature will rise 3°C in 1 hour!
- Cellulose degrades faster at higher temperature!



Oil Forced Air Forced or OFAF Cooling of Transformer

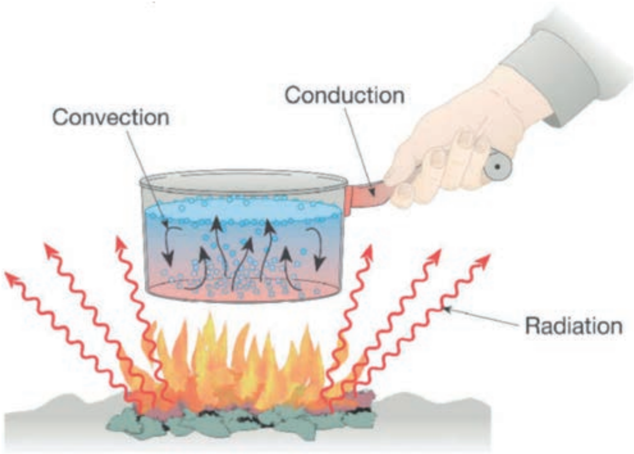
Convective and conductive heat transfer

Convective heat transfer is the cooling from the cold wind (flowing air), and is the chilling effect on your bare skin and through your clothes.

Conductive heat transfer is the cooling through the clothes (in stagnant air) and no wind all.

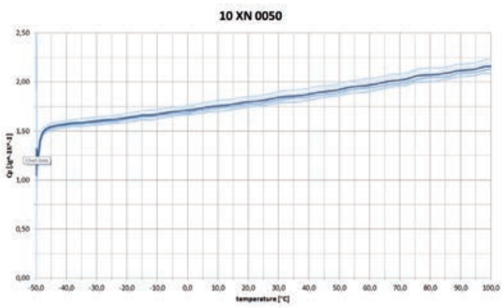
Properties behind effective Transformer Oil Cooling

Heat transfer – overview



Specific heat capacity, c_p

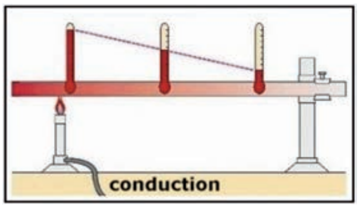
- Specifies the amount of heat required to change the temperature of an object or solid/liquid/gas by a given amount.
  - Example: In order to increase the temperature 1 K of 1 kg naphthenic transformer oil at 40°C : 1875 J/(kg*K). This means that 1875 J is needed to be transfered to 1 kg of oil to increase the temperature to 41°C.
  - The specific heat capacity is changing over increasing temperatures as shown below



Properties behind effective Transformer Oil Cooling

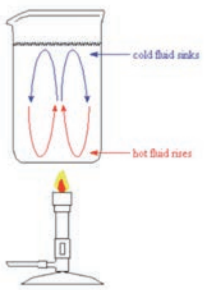
Thermal conductivity

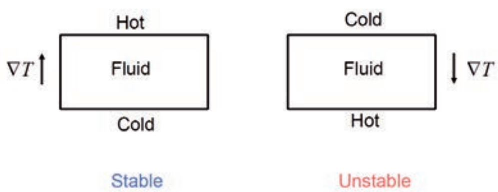
- **Thermal conductivity, k**
  - Specifies how a material conduct heat flux from a point to another. The heat conductivity is measured in stagnant fluid at a certain temperature.
    - In order to transport heat flux through a layer of naphthenic transformer oil at 40°C; k=0,310 W/(m*K)
    - Thermal conductivity is important part of total heat transfer in the boundary layer at laminar flow (high viscosity and/or low flow velocity)



Density and its´role in heat transfer

- Density ρ ; Describes how many kilograms 1 m^3 of fluid weight at a certain temperature.
  - Density is changing over temperature due to volume expansion at higher temperature
  - Natural convection is heat transfer where the density gradient drives the circulation: warm fluid rises (stable) and cold fluid sinks (unstable)

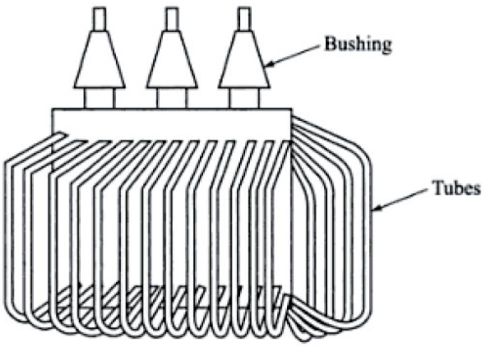


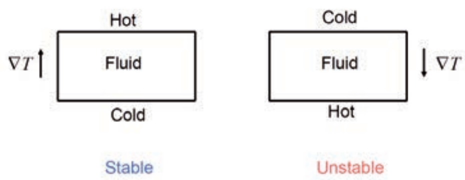


Properties behind effective Transformer Oil Cooling

ONAN cooling of transformer

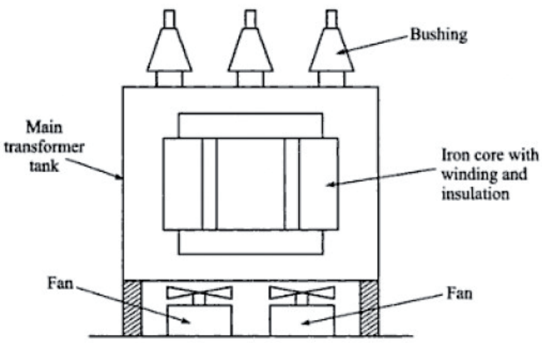
- The warmer oil rises to the top and cools down and flows to the bottom in the tubes mounted in the mantle. For transformers below 25kVA is ONAN common.





ONAF cooling of transformer

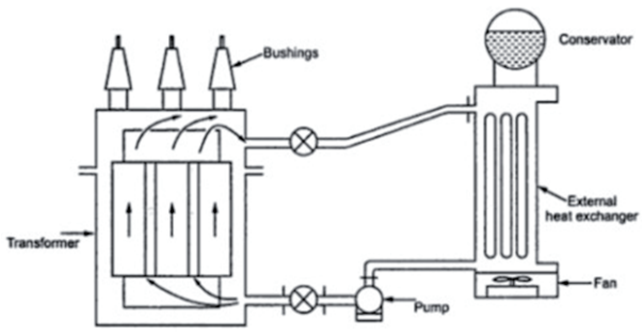
- The oil is cooled by a fan (forced air flow) in the heat transfer zone



Properties behind effective Transformer Oil Cooling

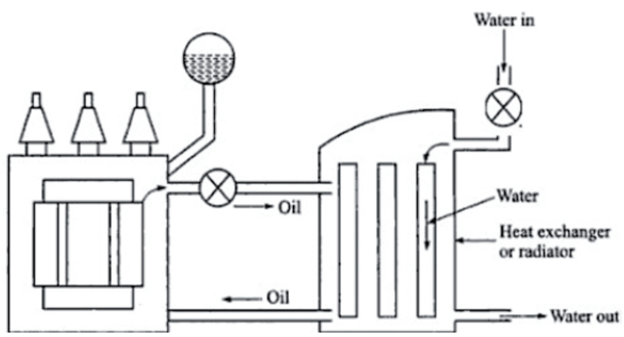
OFAF cooling of transformer

- The oil is (forced or) pumped to the heat transfer zone where the air is forced by a fan. OF cooling is the common choice for transformer above 60MVA.
- OEMs recommends a maximum flow velocity of 1 m/s for the insulation oil .
  - In practice the velocity is around 0.5 m/s and up to 1 m/s.
  - Above 1 m/s there is risk for static electricity charges build up, or ECT



OFWF

- Water cooling is more effiecient than air cooling. Corrosion and leakage might be an issue when used in transformers. Cp and k is much higher for water than for air.



Properties behind effective Transformer Oil Cooling

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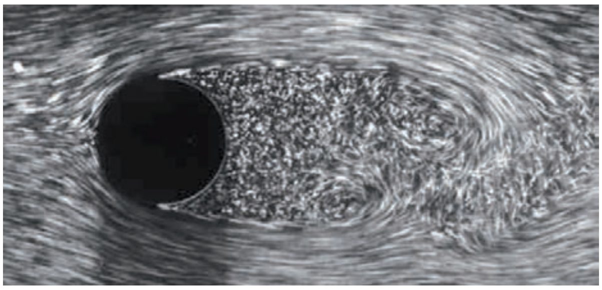
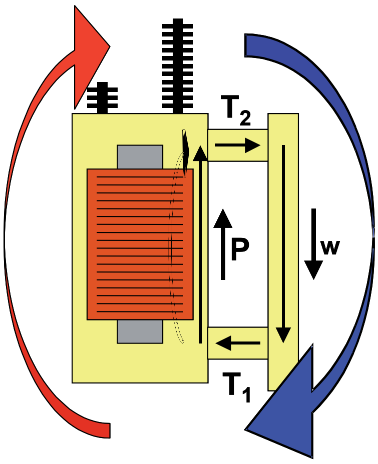
Viscosity

- Lowest possible viscosity is the best way to obtain rapid and efficient cooling in a transformer



Heat transfer in transformers

Virtual Oil Wheel



Calculation of the natural oil circulation speed on basis of the Laws of Bernoulli, Newton, Reynolds and Prandtl.

$$w = f \cdot \frac{\Delta p}{\nu}$$

w = Oil flow speed
f = Calculation factor
n = Kin. viscosity at operation temperature
p = force from buoyancy

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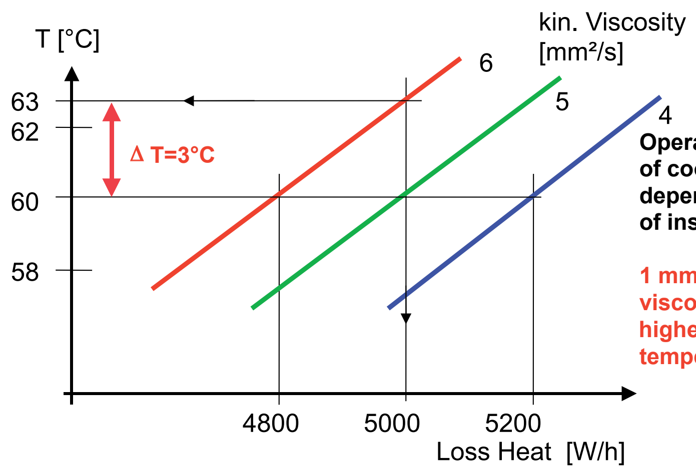
Properties behind effective Transformer Oil Cooling

Influence of Viscosity to Heat Dissipation



Operation temperature of cooling system depends on viscosity of insulating oil

1 mm²/s higher working-viscosity leads to 3°C higher operation-temperature

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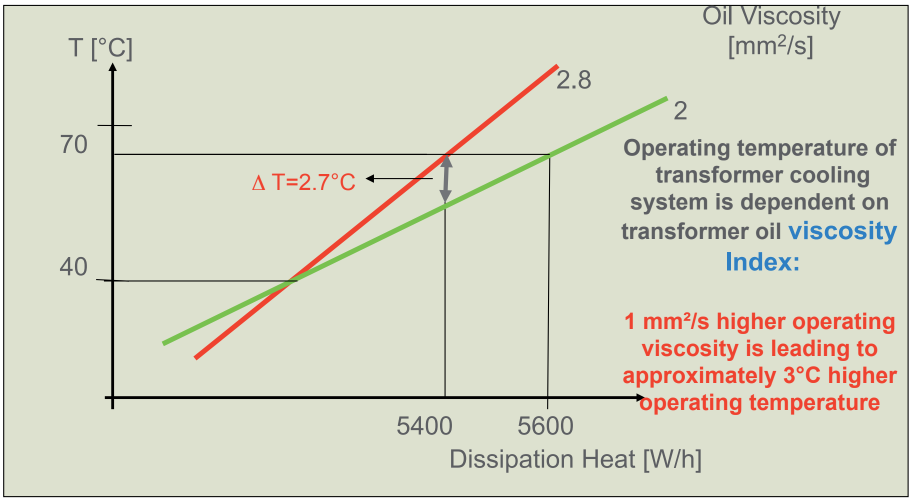
Viscosity index

- Oil with lower viscosity index have better cooling properties
  - Naphthenic oil have lower viscosity index

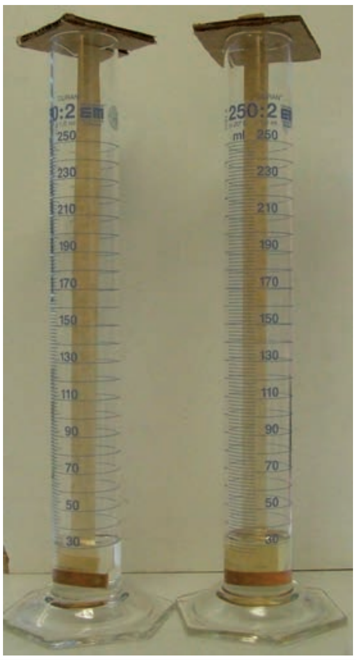
Properties behind effective Transformer Oil Cooling

Transformer Operating Temperature for two oils with the same viscosity at 40 C



Hanging Paper Wetting

- Level of oil wetting checked over 72 h
- Two oils compared
  - Paraffinic
    Visc. 40 ˚C 10.6 cSt
    Visc. 20 ˚C 22.5 cSt
  - Naphthenic
    Visc. 40 ˚C 9.1
    Visc. 20 ˚C 19.5



Properties behind effective Transformer Oil Cooling

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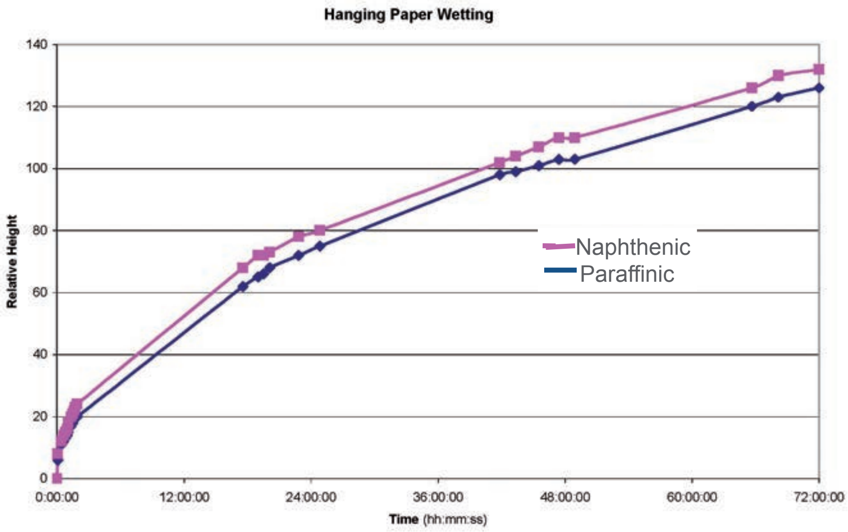
Results over time



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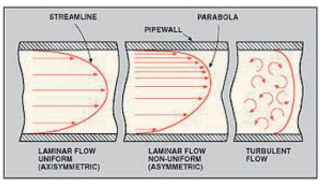
Reynolds number



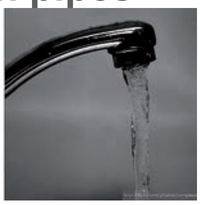
- Reynolds number: Re= $u*D/\nu$
  - u = Flow velocity of the oil in $[m/s]$
  - D= Characteristic lenght, which is for a pipe the diameter in [m]
  - ν = Kinematic viscosity in $[m2/s]$
- In pipes: At Re 2300 the flow will change from laminar to turbulent and over 5000 fully turbulent is developed
- $Inertial\ forces/Viscous\ forces$
  - When the inertial forces dominates over the viscous forces, small turbulent eddys increases mixing between warmer oil and cooler oil during the flow and enhances heat and mass transfer

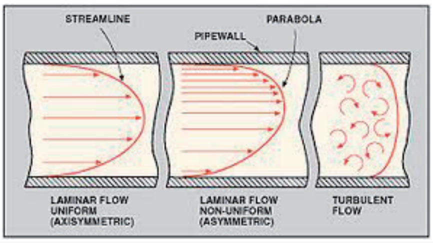
Properties behind effective Transformer Oil Cooling

Flowing fluid and heat transfer in pipes

- At higher flow velocity the fluid will develop turbulence and this will be beneficial for the heat transfer.
- A lower viscosity increases heat transfer and turbulence

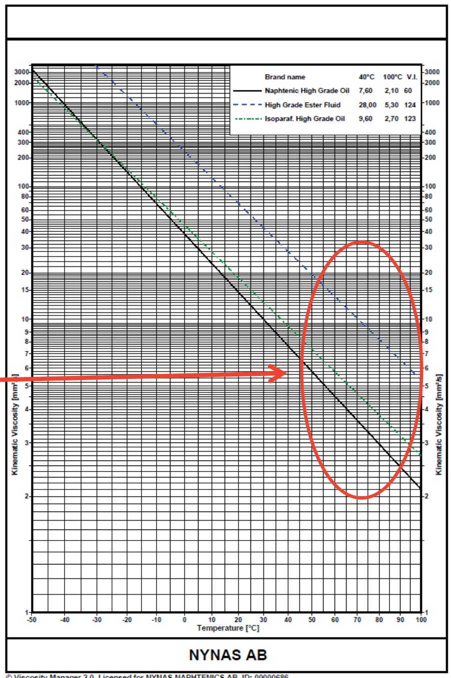

Turbulent flow


Laminar flow



Viscosity and VI

This temperature zone is interesting for investigating cooling properties of oils



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Properties behind effective Transformer Oil Cooling

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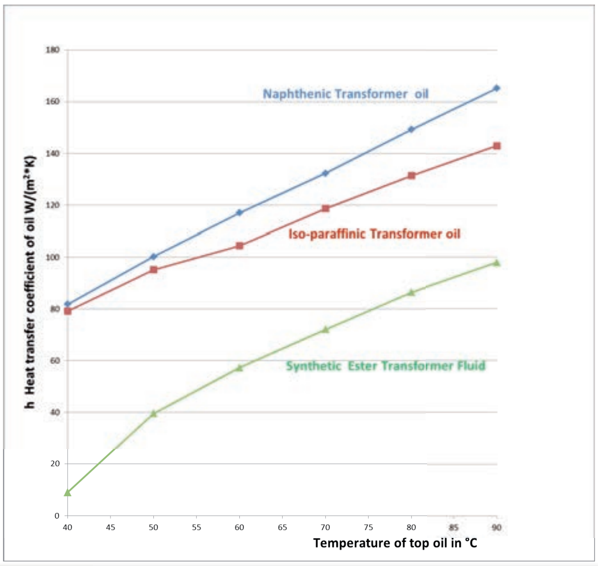
Heat transfer coefficient of three different types of transformer fluids



Cooler data:
Pipe Ø: 10 cm
Velocity: 0.5 m/s

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Conclusions

- The viscosity is the dominant physical property for the heat transfer coefficient
  - A lower viscosity increases heat transfer
  - Oil with lower viscosity have much better cooling properties
  - Oil with lower viscoisty can impregnate insulating paper much faster
- Forced convection is the best way to increase cooling rate on a surface
- A better cooling capacity in a transformer fluid lowers the overall temperatures in the unit and potentially extends cellose life time

Properties behind effective Transformer Oil Cooling

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Thank you! Any questions?

TLM

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Acoustic and electrical methods combined for localizing partial discharge in power transformer

Stefan M. Hoek, Omicron Austria

Stefan Hoek is Product Manager for partial discharge measurement system and joined OMICRON, Austria in 2008. He studied electrical engineering at the University Stuttgart (Germany) and worked there as research assistant with focus on partial discharge detection and localization in GIS with help of measurements in the UHF range. Stefan Hoek is member of VDE ETG and CIGRE working group B3.24 and published several papers.

OMICRON

Acoustic and electrical methods combined for localizing partial discharge in power transformer

ACOUSTIC AND ELECTRICAL METHODS COMBINED FOR LOCALIZING PARTIAL DISCHARGE IN POWER TRANSFORMER

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Abstract: The reliability of electrical systems depends on the quality and availability of the power apparatus. Power transformers are important nodes in the electrical power grid. Common reasons for breakdown are problems in the insulation system. Detecting partial discharges in the insulation system of a power transformer at an early stage reduces the risk of total breakdown. One method to detect partial discharges is acoustic measurement. With this technique detection and localization of partial discharge is possible by placing acoustic sensors on the surface of the transformer tank. The low level of electrical interferences from outside the measurement setup constitutes one of the strengths of this method. A further advantage is the ability to identify the position of the partial discharge source, which is needed to estimate the risk and to enable a fast and effective repair.

1 INTRODUCTION

Partial discharge (PD) measurements on transformers are an accepted tool of quality control in factory and on site. Different PD measurement techniques are using a variety of different physical characteristics of the PD phenomenon, e.g. electric discharge currents (acc. to IEC 60270 [1]), gas formation (DGA - dissolved gas analysis), electromagnetic (UHF Measurement) or acoustic radiation. The main benefits of an acoustic PD measurement are the possibility to detect PD without a shut-down of the transformer, and the ability of localizing a PD source with an accuracy of a few centimeters to a few decimeters. In case of expected PD, an acoustic PD measurement can help to verify it, while the location is important information for further risk assessment and repair planning.

2 THE PROPAGATION BEHAVIOR OF ACOUSTIC PD SIGNALS IN TRANSFORMERS

The acoustic effect of PD inside a transformer is typically measured by piezo-electrical sensors in the frequency range of tens of kHz up to hundreds of kHz [2]. Using the different arrival times of the acoustic PD signal at multiple sensors, algorithms can compute the location of the PD source.
The complex physical processes involved in sound propagation and the large structural variety of different transformer may present a challenge during the measurement. The following parameters have to be considered:

- The PD source position and the inner structure of the transformer mainly influence the propagation path of the acoustical waves.
- More than one propagation path from the PD source to a sensor is possible (direct oil, reflection, steel path).
- The speed of sound depends on the propagation path (crossed medium), frequency and temperature.
- Depending on the location of the source and the inner structure of the transformer, a proper measurement of the direct oil path signal may be impossible due to high signal attenuation.
- Taking into account the individual measurement setup and the inner structure of the device under test (DUT), a cautious interpretation of the measurement results by an experienced person is essential.

Speed and damping of the acoustic waves are dependent on the transfer medium, frequency range and temperature [3], [4]. For example, the propagation speed decreases during the heat-up period of an transformer by approximately 15%, from about 1400 m/s at 20 °C to 1200 m/s at 80 °C. This has to be considered to avoid miss-localizations since the signal speed directly influences the calculated results.

The propagation path is often complex. Multiple propagation paths of the emitted sound wave are possible, as shown in Figure 1. Depending on sensor and PD location, multiple acoustic wave components of the same PD event are potentially detected by one sensor and overlay the direct oil signal as illustrated in Figure 2. The acoustic wave can be reflected by the tank wall, core, winding, flux shields and other components.

Acoustic and electrical methods combined for localizing partial discharge in power transformer

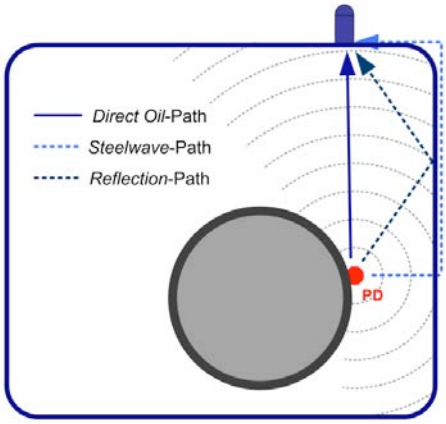

Figure 1: Possible propagation paths in the test object [5]

Components of the reflected wave will arrive at the sensor position later than the signal travelling a direct path. Furthermore, the acoustic wave can couple into the transformer wall and propagate through the steel of the tank. Due to the higher propagation speed in steel of about 3.000 - 5.000 m/s [2], the so-called steel wave signal can reach the sensor earlier than the waves following the direct oil path. This effect complicates the automated determination of the starting point of the direct oil signal.

The measurable direct oil signal at the sensor position depends on the intensity of the causative PD event [6] and on the damping on the propagation path. Therefore, the attenuation by core, winding, transformer board, flux shielding etc. should be as low as possible. For that reason, the search for sensor positions that ensure good signal quality is essential during measurement procedure. The knowledge about the inner structure of the transformer is helpful for a good positioning and repositioning of the sensors.

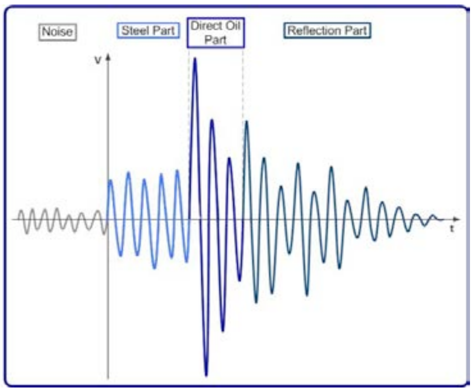

Figure 2: Acoustic PD signal components reflecting the propagation paths

3 LOCALIZATION OF PD

Different algorithms can be used to perform a time-based localization of PD. The input information used by the algorithms is the time of arrival of the signals propagating on direct oil paths to multiple sensors. The exact time of arrival has to be determined by evaluating the measured signal. A criterion for the starting point can be found e.g. by investigation of energy steps [7] or by threshold criteria [8].

The relative arrival times at different sensor positions lead to time differences ($\Delta t_{1,2}$). These time lags are the only available data in all-acoustic measurements, when the data acquisition is triggered by the acoustic signal at one of the sensors. If the time delay between occurrence of a PD and the arrival of the associated acoustic wave is available, the absolute propagation times (t_1, t_2) from source to sensor can be used for localization. Both principles are shown in Figure 3.

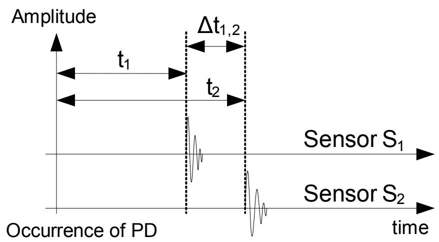

Figure 3: Absolute and relative times in a two-sensor-setup

The exact timing of the emission of the PD signal can be estimated e.g. by an electrical PD measurement according IEC 60270 or a measurement in the ultra-high frequency (UHF) range. In the latter case, sensors within the transformer walls can be used to receive the high frequency electromagnetic wave that is emitted during PD [9]. A measurement setup is shown in Figure 4 [10].

Figure 4: Installed UHF probe

Acoustic and electrical methods combined for localizing partial discharge in power transformer

The distance between sensor and source is calculated using the available absolute or relative propagation times and an estimated average propagation speed. With the determined distances and the sensor positions a geometrical localization of the PD source can be performed in several steps (Figure 5)

The arrival time (t_1) at a single sensor in relation to the PD occurrence leads to a surface in the shape of a sphere around the sensor position on which the PD source is supposedly located. The radius r depends on the absolute propagation time (t_1) and the propagation speed (Figure 6 left)

In all-acoustic measurements the data of a single sensor (without a relation to another sensor signal) does not contain information leading to a triangulation. In this case the data of two acoustical sensors - the relative time $\Delta t_{1,2}$ – deliver a distance difference ($\Delta d_{1,2}$) and therefore a hyperbolic sphere (Figure 6 right).

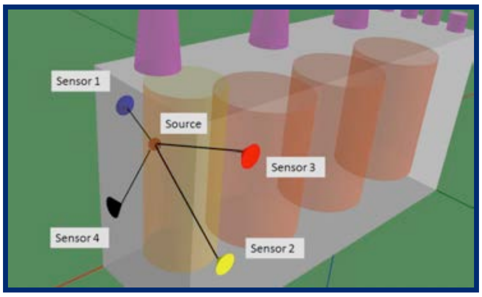

Figure 5: Principle of acoustic localization [5]

The position of the source can be specified with the information from a higher number of sensors. For this purpose several of the described geometrical shapes are intersected. The absolute propagation time of the signal at a second sensor leads to a second sphere, the resulting intersection shape is circular. In a further step the absolute coordinates of the source can be estimated by intersecting the circulars of three sensors.

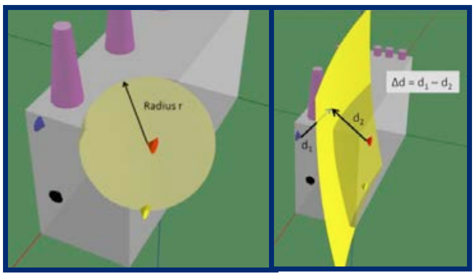

Figure 6: Spatial information from one absolute time (t_1) and from one relative time ($\Delta t_{1,2}$)

This procedure is shown in Figure 7. The figure shows the spheres around three acoustic sensors (black, yellow and blue). The resulting intersection circulars of the spheres are shown as blue rings. The estimated point of the acoustic source is displayed for three or more acoustic sensors like in Figure 15.

In an all-acoustic measurement environment the approach is in principle identical. In this case a fourth sensor delivers the necessary information to estimate a point representing the origin of the PD signals.

The depicted method is based on a direct propagation path for the acoustic wave from source to sensor. As described above, the transformer cannot be considered as an empty box and the propagation speed is highly dependent on the signals travel path. For that reason, the model is always a simplification of the real setup inside the tank. Thus, also an inaccurate localization of the source position is possible.

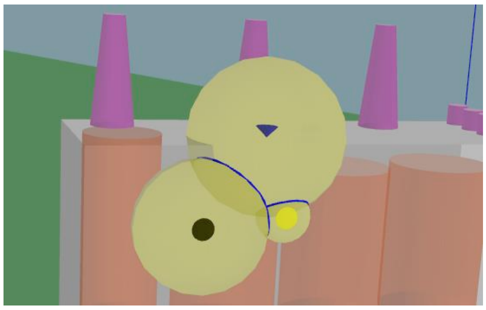

Figure 7: Source localization with three sensors using absolute times

To ensure reliable measurement results, a workflow is proposed that is based on an iterative relocation of the sensors with the intention to find positions with a minimal and undisturbed path between sensor and source.

4 CASE STUDIES OF SUCCESSFUL ACOUSTIC PD FAULT LOCALIZATIONS ON TRANSFORMERS

4.1 PD localization on a 16 MVA transformer using electrical PD signals as trigger source

The described investigation has been performed on a 150 kV/20 kV three-phase power transformer (Yyn0) with a nominal rating of 16 MVA. Figure 8 shows the electrically measured PD pattern of phases V and W indicating a PD problem nearby phase W. Consequently the acoustical sensors were placed on the tank walls close around the suspicious winding. After analyzing the first results, the sensor positions have been optimized. Two sensors had to be placed on top of the transformer housing because of limited accessibility due to the assembled coolers. Figure 10 shows the tested transformer, modeled in the software of the location system and the finally used sensor positions.

Acoustic and electrical methods combined for localizing partial discharge in power transformer

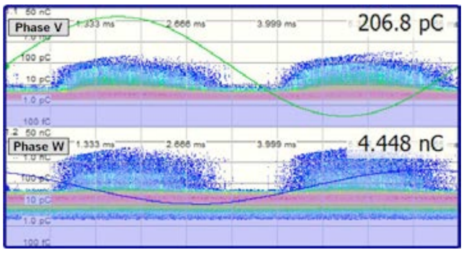

Figure 8: Electrical PD pattern recorded at the bushing taps of phases V and W

An example of the acoustically detected PD signals is shown in Figure 9. The signal shape on all sensors indicated propagation paths with just minor attenuation. The yellow sensor detects the signal first, shows no indication of an acoustical steel path and the highest signal amplitude. These facts indicate this sensor as being the one closest to the PD defect. The black sensor seems to have a short steel path while the sensors blue and red show an increasing signal shape which usually can be considered as an indication for signal damping due to crossed solid insulation. This overall behavior has been found as being reproducible and so a localization could be carried out. The signal speed used for the calculations was set to 1400 m/s and the start points of the signals were determined using the energy criterion and adjustment by hand in some cases. The resulting circles indicating the position of the PD source are automatically given by the location system PDL 650 and are to be seen in Figure 10. A brown dot marks the PD source at the intersection of the circles.

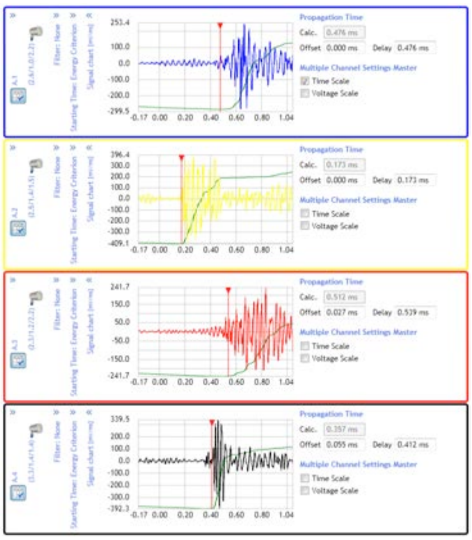

Figure 9: Acoustical PD signals detected during the location procedure

The subsequent inspection of the transformer verified a close match of the defect (Figure 11) and the estimated PD source.

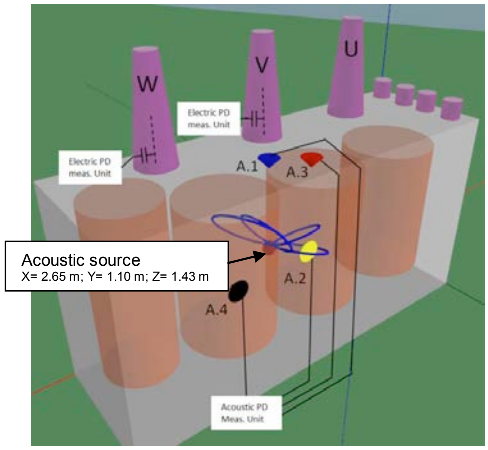

Figure 10: Computer model of the tested transformer, sensor positions and located PD source

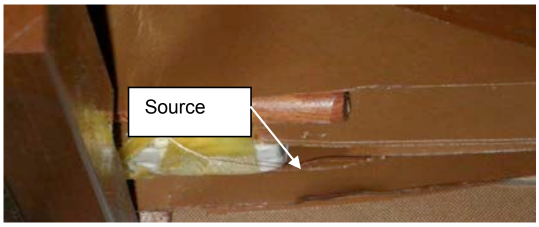

Figure 11: Finding: Bare Wire close to the main insulation found as root cause of PD activity

4.2 PD location on a 100 MVA transformer by using UHF signals as trigger source

The following investigation was performed on a 230 kV/20 kV three-phase power transformer (100 MVA) in a manufacturers test field. The UHF and conventional electrical PD measurement according IEC 60270 [1] revealed the quite comparable PD patterns shown in Figure 12. Both signals were potentially qualified for triggering the acoustical measurement system.

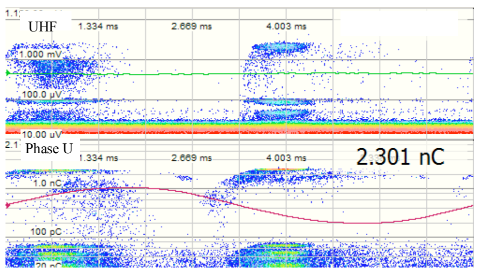

Figure 12: Simultaneously measured PD pattern of the UHF system (top) and conventional PD detector at the bushing tap

Acoustic and electrical methods combined for localizing partial discharge in power transformer

The UHF measurement was performed by using the narrowband acquisition method with a bandwidth of 1.5 MHz. The center frequency of 159.5 MHz was chosen based on the evaluation of the frequency sweep shown in Figure 13. The highest signal energy of the UHF spectrum is shown as the upper line representing the pulses - including the PD - while the sinusoidal or continuous wave (CW) disturbances are shown in the lower curve. The measurement frequency can now be tuned into an area showing a large distance between both lines. This method turned out as being very effective to optimize the signal-to-noise ratio during a UHF PD measurement.

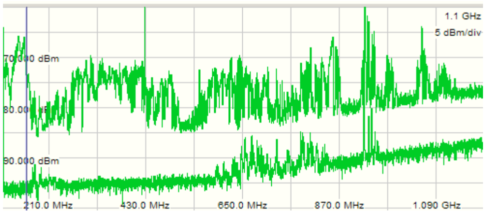

Figure 13: UHF Frequency sweep of the spectrum inside of the transformer and the measurement filter used shown as grey bar at 159.5 MHz

Figure 14 shows the 3D computer model of the transformer with the final sensor positions and the electric-acoustic test setup.

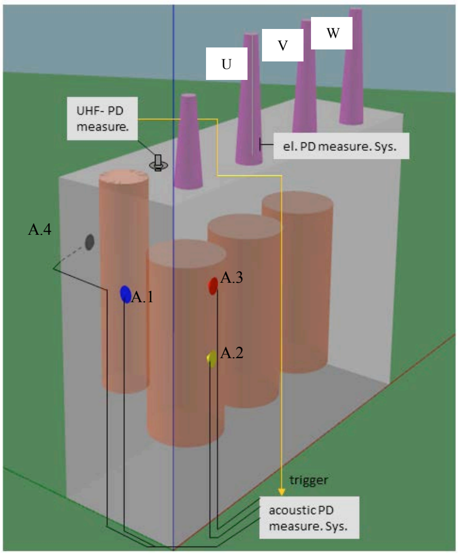

Figure 14: Test setup (UHF, el. and acoustic PD)

After optimizing the UHF signal quality the pulses detected by the UHF 620 system were used to trigger the acoustic PD localization. The evaluated time delay led to PD source positions on the outer surface of the tab winding between winding and tap changer as shown in Figure 15.

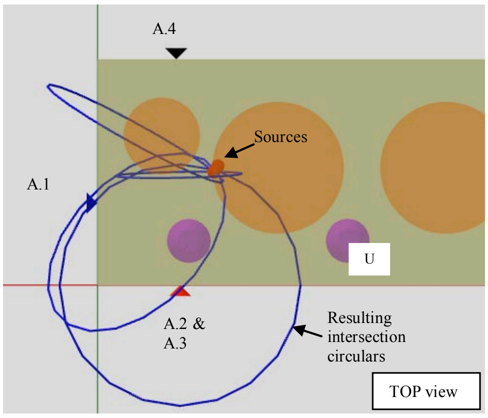

Figure 15: Estimated PD source location and some intersection circulars

The subsequent inspection of the transformer verified a close match of the defect and the estimated PD source.

4.3 PD location on a 500 MVA transformer in the field (all acoustic)

A 500 MVA unit showed significant increase of hydrogen and methane a few months after installation. Figure 16 shows the transformer and its modelling in the localization software.

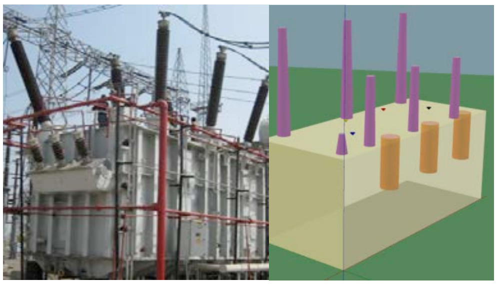

Figure 16: The unit under test and its representation in the localization software. Sensors are visible on the top.

In this case the internal structures shown are the tap changer compartments. During the initial PD location electrical triggering could not be utilized. Furthermore a detection of acoustic signals on the tank walls was not possible, presumably due to the magnetic shunts which are known to have a significant sound damping characteristic. Thus, the acoustic sensors had to be attached on top of the transformer. The results measured with the first sensor arrangement indicated a PD location at the middle phase, near the tap changer or the 220 kV bushing (see Figure 17, left). Therefore the

Acoustic and electrical methods combined for localizing partial discharge in power transformer

sensors were re-positioned closer to the expected PD spot, what led to improved signal quality and higher sound levels. The resulting surfaces representing the mathematical solutions of the localizing equations can be seen on the right-hand side of Figure 17 and confirm the initial expectation about the PD location. The internal inspection of the tab changer connection via a man-hole discovered defects of different insulation elements which have been replaced. The transformer has been put back into service again and is in operation now without any indication of remaining PD problems.

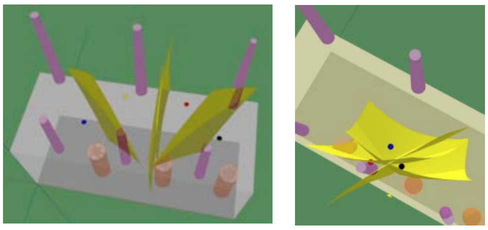

Figure 17: Results with initial sensor placement (left) and after sensor-repositioning (right). PD source indicated to be close to the tap changer or MV bushing of the middle phase.

5 CONCLUSIONS

This paper describes the basic idea of time based acoustical localization of PD faults in power transformers and similar equipment. The PD signals are captured using three or more piezoelectric acoustic sensors, magnetically mounted on the tank at different locations. For localizing the source, the time delays between the recorded acoustic signals or between an electrical signal and the acoustic signals are used to get information about the propagation of the acoustic signal inside the transformer tank and the distances between signal source and sensors. The received sensor signals are processed to obtain the difference between the signal arrival times at each sensor.

In addition to the acoustical measurement, a parallel electrical PD measurement can be used to obtain a trigger signal. This can be essential for the success of the localization. Alternative to the electrical measurement through the bushing taps or with external coupling capacitors, unconventional measurement techniques, e.g. in the UHF range, can be used to gain a trigger source for an acoustic measurement. Case studies of successful PD localization of a significant PD source have been shown. The procedure and successes of an acoustical measurement with electrical triggering has been shown. The results are analyzed and visualized by using a 3D model.

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Oilregeneration, positive Solutions

Milan Rybensky, Filtervac

Milan Rybensky the President of Filtervac International Inc. and Enviro International, an active member of the Ontario Professional Engineers Canada, founded Filtervac International Inc. in 1993 after a long career with a well known US based company called Keene-Bowser Corporation. Milan held positions as the Chief Engineer of Keene-Bowser Corp. at both the Canadian and United States Divisions and during this period, where he gained valuable experience, Keene-Bowser was known as the world leader in oil dehydration equipment used for insulating oil applications in the electrical and power industry.

Milan Rybensky graduated from the University of Brno in Czech Republic with a bachelor degree in Mechanical Engineering and shortly after that immigrated to Canada. Throughout his career he worked in various senior engineering roles dealing with Filtration/Separation, Mixers and Pressure Vessels, Oil Treatment and Water Treatment in several countries and his carrier culminated in 1993 when he started Filtervac International in Waterloo, Ontario. With over 50 years of engineering experience Milan Rybensky is considered one of the pioneering engineers in the Transformer Oil Regeneration process and at present Filtervac International Inc is the major leader in design and manufacturing of Transformer Oil Regeneration Plants with over 40 systems operating around the world.

FILTERVAC

Oilregeneration, positive Solutions

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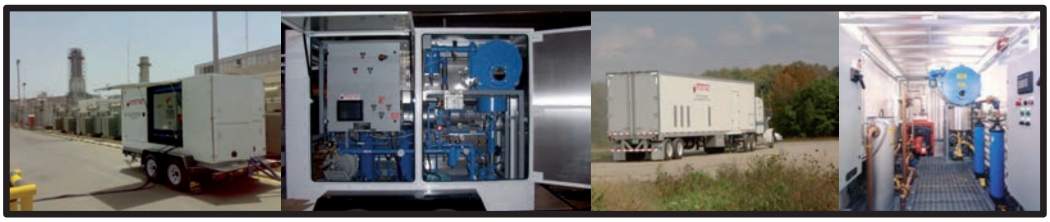

Oil Re-Generation, Positive Solutions

1

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OIL RE-GENERATION

2

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FILTERVAC INTERNATIONAL INC.

PRESENTATION OVERVIEW

- Transformer Main Components
- Oil & Paper Solid Insulation
- Regeneration of Insulating Oils
- Moisture in the Oil
- Sludge Formation in Oil
- Effects of Oil Regeneration and Oil Changing
- Oil Changing
- Oil Regeneration Advantages
- The Advantages of Oil Regeneration Over Oil Changing
- When Should Regeneration Takes Place?
  - Oil Colour
  - Oil Regeneration and Sludge
  - Corrosive Sulphur
  - Oil Passivation
- Filtervac ECoil Oil Regeneration System
- Typical Oil Regeneration Results
- Conclusion

3

FILTERVAC INTERNATIONAL INC.

TRANSFORMER MAIN COMPONENTS

Solid Insulation

- Life of transformer is highly effected by the life of insulation
- Insulation represents the weakest point in the transformer
- It is critical to maintain the insulation system in any transformer
- Damage to insulating paper is irreversible

4

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OIL & PAPER INSULATION DEGRADATION FACTORS

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- **Heat: Chemical reaction proceed faster at higher temperatures**
  Each 8 ˚C rise above design will cut the life of the paper in half
- **Oxygen: The more oxygen, the faster the reaction of oil**
  10 times the life at same temperature if oxygen is < 300 ppm
- **Water: Doubling moisture content will cut transformer life by half**
  Moisture content in insulation paper is hundreds of times that of the oil
- **Oil oxidation by-products: Acids, Alcohols, Aldehydes, Epoxides, Kentones, Peroxides and Soaps**
  Insulation paper has an affinity for acids, peroxides and other oxidation products

5

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REQUIREMENTS OF INSULATING OILS

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The three main functional requirements of Insulating oils are:

- To meet the **Insulation function,** the oil must have high dielectric strength and low dielectric dissipation factor to withstand the electric stresses imposed in service.
- To meet the **Heat transfer and Cooling functions,** the oil must have viscosity and pour point that are sufficiently low to ensure that oil circulation is not impaired at the most extreme low temperature conditions for the equipment.
- To meet the **Arc quenching function,** the oil requires a combination of high dielectric strength, low viscosity and high flash point to provide sufficient insulation and cooling to ensure the arching is extinguished.

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MOISTURE IN THE OIL

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- Water is frequently found at the bottom of transformer tanks but is relatively harmless at this point. Water is found in suspension in the oil (emulsified) but is usually only a problem when polar contaminants are dissolved in the oil that the water can cling to.
- Water is also found dissolved in the oil and this water will migrate into the cellulose depending on the temperature (and temperature depends on load). Migration of water between the oil and the cellulosic paper will eventually reach equilibrium.
- At equilibrium the moisture concentration in the paper will be hundreds of times greater than in the oil. Moisture content in the oil can be measured by laboratory test but does not by itself establish insulation dryness. However, 50 parts per million (ppm) of water from a top oil

Moisture in the Oil
Sample is critical as it indicates the paper insulation is wet.

7

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SLUDGE FORMATION IN OIL

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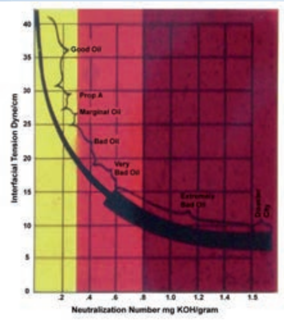
Oxidation begins as soon as the oil is placed in the transformer.

- **Deterioration: results from the effects of oxidation.**
- **Contamination results from moisture or other foreign substances and starts after the transformer is energized.**

Unstable hydrocarbons plus oxygen, moisture, heat, vibration, and electrical stresses result finally in the terminal stage of oil degradation as an insulating medium, that is the formation of sludge. Sludge precipitates out of the oil where it attacks solid insulation and can reduce effective cooling. The sludge builds up in layers whose hardness depends on how the unit has been operated and how long maintenance has been ignored.

Sludge formation depends on the presence of oxygen in an energized transformer. This oxygen may come from outside air, but also comes from the breakdown of the Kraft paper insulation.



A precise classification of transformer insulation oils involves the unique relationship between interfacial tension (IFT) and neutralization number (NN). Several 1940 studies show that an increase in NN should normally be followed by a typical drop in IFT.

If the values of IFT versus NN for a given oil sample do not fall within a reasonable range on either side of the median line, further investigation is in order.

The probability of sludge accumulation increases if the oil shows an increase in neutralization (acid) number, a drop in interfacial tension, and a deepening of oil colour

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EFFECTS OF OIL RE-GENERATION AND OIL CHANGING

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Both oil change and Re-generation has been performed on two identical transformer.

- **Oil change:-** The acidity increases rapidly after oil change. As early as few months the acidity level could reach nearly same as before the oil change. This increase is caused by contamination from the residual oil/sludge left in the tank, core and in the winding insulation, which contaminates the new oil faster.

- **Oil Re-generation:-** Considering the transformer from which the oil was re-generated, six years later the acidity level is approximately at the same low level. According to our world wide experience the acidity and other aging parameters, have acceptable values many years after oil re-generation process.

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OIL CHANGING

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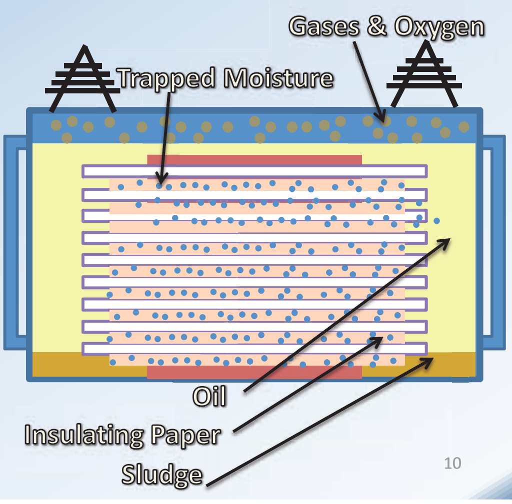
- **Transformer insulation paper has high content of moisture and other contaminates that will not be removed by changing oil**
- **Sludge and contaminates are still available in the transformer**
- **Oxygen and gases trapped in transformer will not be removed by changing the oil**
- **Sludge/Colour are the first visible sign that oil needs to be regenerated.**



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CHANGING THE TRANSFORMER OIL WILL NOT SOLVE THE PROBLEM

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Regeneration of transformer oil is energy efficient, environmentally friendly and less expensive than refilling an older transformer with new oil. Further, it must be appreciated that simply replacing poor quality oil with new or reclaimed oil is not the answer, as the oil will in turn, rapidly deteriorate due to re-contamination by internal components of the transformer.

Oil Sludge will form at the lower section of the electrical transformer leading to frailer

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THE SOLUTION

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Oil Regeneration

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OIL REGENERATION

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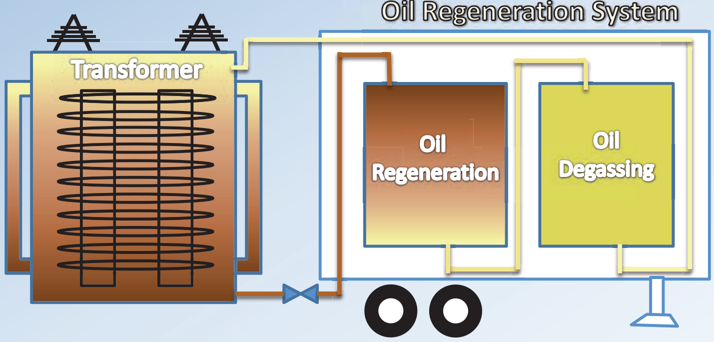
Regeneration of Oil is a process which eliminates, by chemical and adsorbent means, the acidic and colloidal contaminants and products of oil deterioration from the oil, to obtain an oil with many characteristics similar to those of a new product

Mobile Onsite Transformer Oil Regeneration System



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OIL REGENERATION ADVANTAGES

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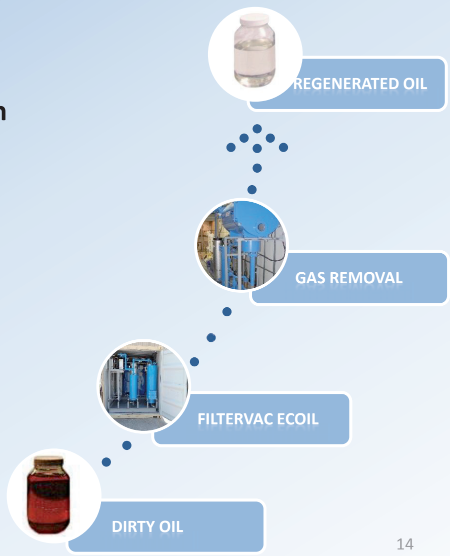
- Interfacial Tension Improvement by Removing Oxidation Products
- Colour Improvement and Restoration
- Acid Removal and Improve Neutralization Number
- Sludge Removal
- Depolarization by Removing Corrosive Sulfur and DBDS Products
- Dehydration by Water Removal Through High Vacuum Process to improve Dielectric Breakdown Voltage
- Gas Removal
- Filtration by Particulate Matter Removal
- Oil Passivation to Prevent Copper Sulfide Formation in Transformer Winding



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THE ADVANTAGES OF REGENERATION OVER AN OIL CHANGE

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- No transformer service interruptions
- Saves resources
- Additional removal of moisture
- Great and stable long-term cleaning effect
- Optional desludging possible

Regeneration process provides a clear improvement in ageing stability when compared to oil changing option. During oil change, up to 15% of the old oil and almost all embedded and deposited ageing residue products remain in the transformer and cause the rapid onset of ageing of the new oil filling; meanwhile oil regeneration process will treat the electrical transformer and oil at the same time. Oil regeneration is recommended for high-aged transformers that must continue to operate. The condition of the solid insulation is preserved in this way, counteracting progressive ageing.

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WHEN SHOULD REGENERATION TAKE PLACE?

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When the oil shows unacceptable results for neutralization number, interfacial tension and dissipation factor then the regeneration should be considered.

Since the aging of insulation is an irreversible process, it is important to reclaim at the right time before the degradation has gone too far

Limits for oil to be Re-generated	
For Group I Oil	Maximum **0.1** mg KOH/g Oil
For Group II Oil	Maximum **0.2** mg KOH/g Oil
For Group III Oil	Maximum **0.5** mg KOH/g Oil

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OIL COLOUR

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GOOD	PROP A	MARGINAL	BAD	VERY BAD	EXTREMELY BAD	CLASS 7 OILS
Effect on transformer						
Providing these functions 1.Efficient Cooling 2.Preserving insulation.	Polar compounds (sludges) in solution (products of oil oxidation) causes the drop in IFT.	Fatty Acids coat the windings. Sludges in solution ready for initial fall-out. Sludges in insulation voids highly probable.	In almost 100% of the transformers in this range sludges are deposited on core and coils. **Sludges are first deposited in fin areas.**	Deposited sludges continue to oxidize and harden. **Insulation shrinkage is taking place.** Premature failure a good possibility.	Sludges insulate cooling fins, block vents causing higher operating temperatures.	
Acid (Neut) No.mg KOH/g						
0.03 to 0.10	0.05 to 0.10	0.11 to 0.15	0.16 to 0.40	0.41 to 0.65	0.66 to 1.50	1.50 and higher
Interfacial Tension Dynes/CM						
30-45	27-29	24-27	18-24	14-18	19-14	6-9

Transformer oil colour and classification chart

- New Oil is Visually Clear in colour
- Cloudiness, turbidity, visible sludge, carbon and free water could have effect on oil colour
- Acceptable oil will be clear and bright, free from and visible contamination

TRANSFORMER OIL CLASSIFICATIONS

1. Good Oils
NN 0.00 - 0.10
IFT 30.0 - 45.0
(Pale Yellow)
M.I.N. 300 - 1500

2. Proposition A Oils
NN 0.05 - 0.10
IFT 27.1 - 29.9
(Yellow)
M.I.N. 271 - 600

3. Marginal Oils
NN 0.11 - 0.15
IFT 24.0 - 27.0
(Bright Yellow)
M.I.N. 160 - 318

4. Bad Oils
NN 0.16 - 0.40
IFT 18.0 - 23.9
(Amber)
M.I.N. 45 - 159

5. Very Bad Oils
NN 0.41 - 0.65
IFT 14.0 - 17.9
(Brown)
M.I.N. 22 - 44

6. Extremely Bad Oils
NN 0.66 - 1.50
IFT 9.0 - 13.9
(Dark Brown)
M.I.N. 6 - 21

7. Oils in Disastrous Condition
NN 1.51 or more
(Black)

Ref: Oil condition based on ASTM D 1500 colour testing

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OIL COLOUR RESTORATION

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End of Oil Regeneration Process

Start of Oil Regeneration Process

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OIL REGENERATION AND SLUDGE

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- Recommended when there is a lack in preventive transformer maintenance.
- It avoids formation of oil sludge in the transformer.
- The regenerated insulating oil possesses excellent sludge-dissolving properties at sufficiently high temperature process of transformer oil aniline point. This avoids rapid failure of the transformer insulating system and improves cooling effect in the oil during high load condition. Sludged oil has poor cooling effect.
- In the course of an optional de sludging mode within the oil regeneration process, oil sludge that has already been deposited in the transformer core & winding can be dissolved and removed by Regeneration process.

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CORROSIVE SULPHUR

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- "Elemental sulphur and thermally unstable sulphur compounds in electrical insulating oil that can cause corrosion of certain transformer metals such as copper and silver" ASTM D2864
- Not formed in transformer's normal operational conditions
  - Known sources of contamination: poorly refined crude oil, addition of chemical compounds
  - Other Suspected sources: gaskets, water-based glues, copper and Kraft paper

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SULPHUR COMPOUNDS

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- Multiple Sources = Multiple Compounds
- Thiophens, Disulphides, Thio-ethers, Mercaptans, Sulphur

Increasing order of corrosion →

- Dibenzyl-disulphide (DBDS) was identified experimentally to be primary compound in corrosive sulphur related faults

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MITIGATING TECHNIQUES

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- Oil Replacement
  - 5-15% of contaminated oil remains after retro filling
  - Quantity of oil absorption materials, shape of the transformer tank, the location of the drainage valve
- Oil Depolarisation/Regeneration
  - Combination of solid reagents, chemicals & sorbents to reduce sulphur in oil
  - Reduces DBDS content to 10 mg/kg (10 ppm)
  - Transformer can be processed on or off-load
  - Also removes Acidity, sludge, additives, metal passivator and water content
- Oil Passivation
  - Metal passivators bind to copper surfaces and create an impermeable boundary between the bulk of the metal and the surrounding insulating cellulose and oil.
  - Metal passivators can only prevent corrosion on copper, but not recover corroded copper, nor recover paper contaminated with copper sulphide
  - Metal Passivator is likely to be consumed with time, therefore monitoring should be applied every 6 months.

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OIL PASSIVATION

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- Passivation is a technical term used to define the formation of non-permeable surface layers on metal
- Triazole-based passivators
  - 1,2,3-benzotriazole (BTA)
  - Irgamet 39™ (CIBA Speciality, Basel, Switzerland)
- Previous use of passivators:
  - Japan for reducing streaming charging tendency, Australia for improved oxidation inhibition

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EFFECTS OF PASSIVATION

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- Short-term
  - Suppress Copper Sulphide
  - The increase of H_2, CO and CO_2 concentration is occurs in the first seven days after passivating the insulation oil.
- Long-term
  - Long term effects are unknown , the passivation is depleted and oil returns to its corrosive level
  - Because of the amount of hydrogen that is produced possible misinterpretation of the results can occur (partial discharge, electrolysis, effects of passivator, core lamination heating, etc.)
  - The production of gasses from the passivator suggest that there is some degradation of the passivator that is occurring Metal passivators

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FILTERVAC ECOIL OIL REGENERATION SYSTEM

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FILTERVAC ECOIL OIL REGENERATION SYSTEM FEATUERS

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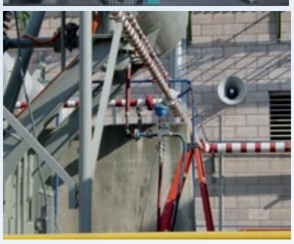
- Online transformer oil regeneration
- Fully automated operation with remote accessibility
- Can be provided for stationary or mobile applications
- Over 40 systems in operation world wide
- Proven technology through long track record
- Fuller earth can be reactivated up to 300 times
- Short reactivation time (10 to 12 hours)

LM Option Operation on Live Transformer



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TYPICAL FILTERVAC ECOIL OIL REGENERATION RESULTS

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No	T8est Parameter	ASTM Test	Unit	Before Regeneration (Dirty Oil)	After Regeneration (Cleaned Oil)	IEEE limits
1	Colour	D-1500	L	8.5	0.5	Max. 2.0
2	Corrosive Sulphur	ASTM 1275B	1a-3b	Corrosive	Non-Corrosive	
3	Breakdown Voltage (2mm Gap)	ASTM D 1816	KV	15	40 -60	Min. 30
4	Gas content	D-3612	%	15	0.1	
5	Interfacial Tension	D-971	Dynes/cm	10	40 -50	Min. 30
6	Neutralization Number	D-974e	mg KOH/g	0.8	0.01	Max. 0.05
7	Water Content	D-1533	ppm	100	> 10	Max. 20

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SAMPLE OF FILTERVAC ECOIL SYSTEM CUSTOMERS

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- SAUDI ELECTRIC CORPORATION (over 15 systems)
- ABB (3 systems)
- ALBA (ALUMINIUM BAHRAIN)
- JST TRANFORMATEURS S.A. (LYON, FRANCE)
- BC HYDRO (BC, CANADA)
- ITOIL - BRAZIL
- LAWRENCE LIVERMORE TESTING (UNIVERSITY OF CALIFORNIA) USA
- LINEMANS TESTING LABAROTARY (TORONTO, CANADA)
- ALTALINK (CALGARY, ALBERTA, CANADA)
- ADMINISTRACION NACIONAL DE USINAS Y (URAGUAY)
- GLOBAL TESTING (AUSTRALIA)
- CHRIS-EJIK GROUP, (NIGERIA)
- ORIENT OIL (PAKISTAN)
- ROUCH POWER LIMITED (PAKISTAN)
- MODEL (COLUMBIA)

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SERVICES OFFERED BY FILTERVAC/ENVIRO

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New power transformers services

- Vacuum oil filling of transformers at the time of installation
- Continuous moisture content analysis (PPM)

Maintenance of transformer including

- Oil degasification, dehydration / de-sludge (Online and Offline)
- Oil regeneration (Online and Offline)
- Oil depolarization services (physical process to reduce oil corrosive and DBDS level in electrical transformers)
- Oil passivation services (for transformers containing corrosive oil by adding Irgamet 39 or Nypass 0.10% to prevent further formation of copper sulfide in the transformer winding)
- Gasket leaks
- Tap changer inspection services
- Oil sampling
- Troubleshooting and problem analysis

Transformer Oil Services
Enviro International

ENVIRO FLEET

www.filtervac.com

ECOIL TRANSFORMER OIL REGENERATION PLANTS

NO	Model Number	System Description Combined Oil Regeneration with Vacuum Degasification System and Additive Injection System
1	RS-M-5000-14-383-LM-EC-CR1-T-W1-AI	Mobile (Semi Trailer) System- 14 Fuller's Earth Columns, **System Capacity:** 1,200 USGPH (5,000 LPH) **Year Built:** 2003
2	RS-S-6000/3000-6-383-LM-EC-CR1-20-W1-AI-DGA	Stationary 20ft Containerized System - 6 Fuller's Earth Columns **System Capacity:** 6,000LPH **Year Built:** 2005
3	RS-M-5000-14-383-LM-EC-CR1-T-W1-AI	Mobile (Semi Trailer) System – 14 Fuller's Earth Columns, **System Capacity:** 5,000 LPH **Year Built:** 2006
4	RS-M-383-5000-16/2-EH-LM-CR1-T-W1-AI	Mobile (Semi Trailer) System 16 Column Regeneration System (8 columns x 2) **System Capacity:** 5,000 LPH **Year Built:** 2012

Oilregeneration, positive Solutions

Transformer Oil Services

Enviro International

ENVIRO FLEET

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HIGH VACUUM TRANSFORMER OIL PURIFICATION/DRY OUT SYSTEMS

NO	Model Number	System Description
1	VPH-MCT/2-383-2400-PF-B-RPVP-MMI/1-V2-H2-FM-LM-XCR1-XV	Mobile (Semi Trailer) System for oil purification transformer evacuation **System Capacity:** 2400 GPH **Year Built:** 2012
2	VPH-MCT/2-383-2400-PF-B-RPVP-XDVP/B-MMI/1-V2-H2-FM-LM-AI-XCR1-X1/ME	Mobile (Semi Trailer) System for oil purification transformer evacuation with double vacuum packages for large transformer evacuation **System Capacity:** 2400 GPH **Year Built:** 2013

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CONCLUSION

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Oil Regeneration

1. Improves the quality of insulating oil close to new oil quality
2. Improves the oil dehydration over new oils
3. Cost efficient and cheaper than changing with new oil
4. Prolongs the lifetime and increased reliability of old transformers
5. Preventive action against the progressive insulation ageing process
6. Sustainable improvement in the condition of the paper insulation
7. Suitable for all Power & Distribution Transformers
8. Economically independent of the current price of new oil
9. No service interruptions
10. Great and long-lasting cleaning effect

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Oilregeneration, positive Solutions

TLM

TRANSFORMER-LIFE-MANAGEMENT
CONFERENCE

On –site Power Transformer demagnetization

Girish Narayana
Haefely, Switzerland

TLM

TRANSFORMER-LIFE-MANAGEMENT
CONFERENCE

On –site Power Transformer demagnetization

Technique for on-site demagnetization of power transformers using a portable device, basics and validation by frequency response analysis

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Abstract:. After a power or distribution transformer is disconnected from the power grid or when a DC current is applied to it, for example during a routine winding resistance measurement, the transformer core is likely to have some remnant magnetism. This remnant magnetism will generate high over currents when the transformer is reconnected to the grid, and this is commonly known as transformer Inrush Current. This Inrush current, which runs for a few cycles, reaches a maximum when the polarity of the half cycle is the same as the polarity of the remnant magnetism, and could damage the transformer itself, or other components connected to it. To avoid this undesirable effect the transformer should be demagnetized before being reconnected to the grid by applying an AC voltage and reducing it slowly. The dimensions and price of the necessary high voltage three phases AC power supply to do so make this task on site almost impossible. The method presented in this paper shows the possibility of demagnetizing a transformer using a special iterative method and a small power supply.

Frequency response of a transformer will show a discernible displacement of the first minimum if the transformer is still magnetized. So frequency response can be considered a very sensitive and reliable method of validating proper demagnetization. Frequency response measurements using a three phase power supply and the new technique for demagnetizing a transformer are analysed to validate the new technique.

1 INTRODUCTION

An ideal transformer is based on two principles; a variable electric current produces a variable magnetic field; and this variable magnetic field produces a voltage across the ends of the coil. For better coupling of the two effects a ferromagnetic material is used for transferring the magnetic flux from one to the other (fig 1)

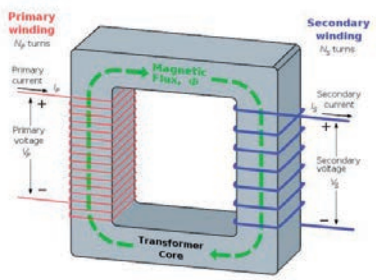


Fig 1. Transformer function sketch

Figure 2 shows this relation for a normal grain oriented magnetic steel used for the manufacturing of power transformers, it can be noticed that the flux density increases in proportion to the field strength until it reaches a certain value where it cannot be increased any more (saturation status).

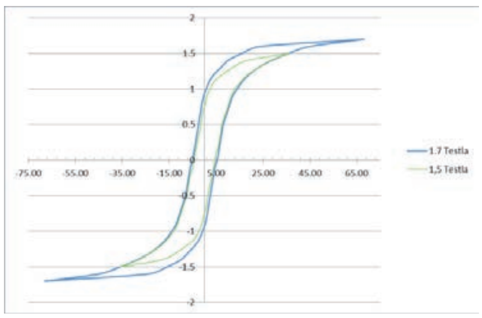


Figure 2: Hysteresis loop of grain oriented magnetic steel

The effect of magnetic hysteresis shows that the magnetisation process of a ferromagnetic core and therefore the flux density depends on which part of the curve the ferromagnetic core is magnetised in, as this depends upon the circuit's past history giving the core a form of "memory". However, soft ferromagnetic materials such as iron or silicon steel have very narrow magnetic hysteresis loops resulting in very small amounts of residual magnetism.

The hysteresis loop affects in two main ways; When the transformer is in service, it generates losses(That's why the area inside the hysteresis loop should be kept as small as possible). when transformer is disconnected from the grid, the real

On –site Power Transformer demagnetization

status of the magnetic core is unknown due to the remnant magnetism.

If a DC current is applied to the transformer, while measuring winding resistance for example or for any other reason, the transformer will be magnetized and therefore when the DC power supply is disconnected, the transformer will stay in an unknown state defined by the remnant magnetism of the transformer.

This unknown state can generate different problems, some of them are well known.

1. Inrush current while reconnecting the transformer
2. Wrong ratio measurement results
3. Wrong FRA (frequency response analysis) measurement results

Demagnetizing the transformer, (removing any remnant magnetism), thus would avoid the above undesirable effects.

The known technique to demagnetize the transformer is to apply an AC voltage to the LV or Tertiary winding of enough amplitude (110% of nominal) to saturate the transformer and then reducing the voltage slowly. This procedure is cumbersome and not feasible on-site because of size and weight considerations of the necessary 3 Phase power supply.

2 INRUSH CURRENTS

2.1 On a demagnetized transformer

The inrush current is described as the overcurrent that appears at the transformer input when the transformer is connected to the grid from steady state conditions. It can be easily described based on the basic transformer equations. For a sinusoidal voltage it would be.

$$e = E\sin\varpi t = \frac{d\Phi}{dt}$$

$$\Phi = \int edt = E\int \sin\varpi tdt$$

$$\varphi' = (Vm/\varpi)\int_0^{\Pi} \varpi\sin\varpi tdt$$

$$\varphi' = \varphi_m\int_0^{\Pi} \varpi\sin\varpi tdt = 2\varphi_m$$

φ_m = *Maximum flux in normal operation*

From above equations, it can be deduced that the maximum flux after half a cycle when starting from steady state condition is 2 times the flux in normal operation.

As we already noticed, the flux density increases in proportion to the field strength in a non linear manner, reaching a maximum (saturation status) and becoming an almost horizontal line. Figure 3 shows the relation between voltages and currents in permanent cycle and during the transformer's first connection. The non-linear behaviour of the magnetization curve introduces an overcurrent while switching whose maximum will be defined by the slope of the magnetization curve.

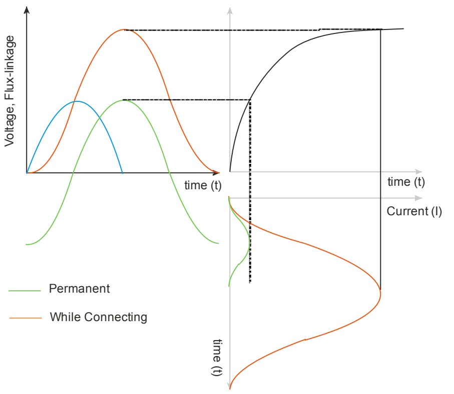


Figure 3: Voltage-currents while connecting and in permanent cycle

2.2 On a magnetized transformer

The magnetic material used for manufacturing the transformer's cores include this "memory" effect, which also influences the inrush current, increasing it drastically when remnant magnetism is opposite to the supposed value in normal operation. Fig 4 shows the particular condition.

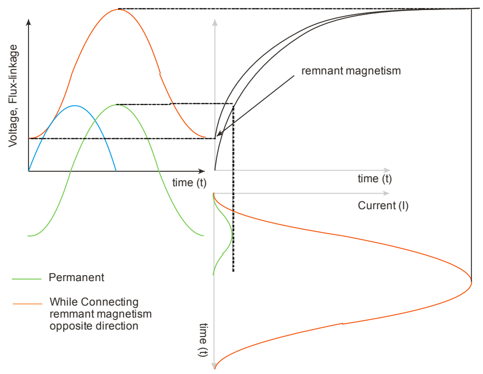


Figure 4: Voltage-currents while connecting and in permanent cycle, remnant magnetism opposite direction

On –site Power Transformer demagnetization

2.3 Starting complete transient

The inrush current transient occurring at the energization is damped as the transformer shifts to continuous operation phase.

Bertagnolli and Spetch developed mathematical formulae to calculate the envelope of this damped effect, while Holcomb proposed an improved analytical equation. These equations are commonly used by transformer manufacturers who normally adjust some experimental parameters, based on their experience, to calculate the inrush currents during connection.

Figure 5: Inrush current transient behaviour

3 EFFECTS ON OTHER PARAMETERS

3.1 Turns ratio

Turns ratio of power transformers is normally measured by applying some voltage to one or more phases, and measuring the voltage at the other winding. Voltages used for this measurement are normally in some tens of volts, and although it is an AC voltage, it is not enough to remove the remnant magnetism.

This remnant magnetism will affect the ratio measured as it moves the core to a less linear part of the magnetizing curve.

3.2 Frequency response analysis

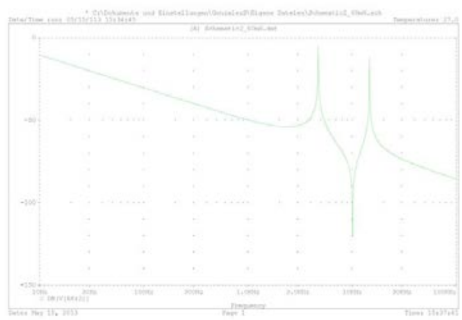
Frequency response is the quantitative measure of the output spectrum of a system or device in response to a stimulus. It is a measure of magnitude and phase of the output as a function of frequency, in comparison to the input.

The normal implementation of this test is based on impressing a variable frequency sinusoidal signal and measuring the magnitude and phase at the other side of the element measured.

A transformer can be considered as a complex network of inductances and capacitances, and this network depends mostly on mechanical/electrical parameters, the frequency response of a particular transformer acts as a fingerprint of this transformer and should remain the same during its life.

The interpretation of FRA results is based on the comparison of the fingerprint over time and therefore any parameter that could have an influence on the curve has to be avoided as this could inadvertently be understood as a transformer problem.

Remnant magnetism in the transformer core decreases its inductance values. The change is normally reflected in the position of the first minimum in the FRA results. Using PSPICE with a transformer equivalent circuit, 2%, 5% 10% and 20% inductance changes have been applied to the circuit, Figure 6 shows the results of these simulations.



Inductance variation	f (min)
L	10'209 Hz
L (+ 2%)	10'116 Hz
L (+5%)	10'000 Hz
L (+10%)	9'770 Hz
L(+20%)	9'550 Hz

Figure 6: Variation on FRA first minimum by inductance changes

From the results of the above simulations, it is clear that FRA test is very sensitive to remnant magnetism.

It is also important to state that remnant magnetism will move the FRA first minimum to the right side (higher frequencies) as lower inductances are involved.

4 DEMAGNETIZATION

4.1 Background

As described before, demagnetizing a transformer is of major interest as it avoids several negative effects (some of them described above). Due to the power supply needed to perform the demagnetization by using the traditional method (applying an AC voltage and reducing the same slowly) the necessity of a portable device to allow the demagnetization on site increases. Several approaches were then taken into consideration to develop this function.

The method consists of two sub procedures, analysing the transformer by applying some power and an iterative reduction of the remaining magnetization by using a computerized algorithm. Since it is an iterative process multiple cycles are necessary.

5 METHOD VALIDATION USING FRA TEST

5.1 Demagnetization validation procedure description

A Three phase YYn 12,5MVA power transformer was used for the validation of the new demagnetization procedure. The FRA measurement has been selected as validation test because of its high sensitivity to remnant magnetism.

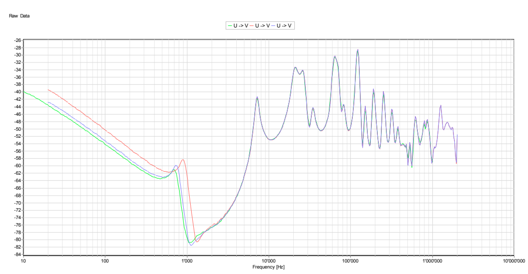
Procedure for the validation is described below.

1. No load losses test; applying voltage on the LV side, and slowly reducing to remove any remnant magnetism.
2. FRA test on the HV side of the transformer between Phase A and B.
3. High DC current applied to magnetize the core.
4. Repetition of the FRA test on same phase.
5. Demagnetization algorithms used on the transformer
6. Repetition of the FRA test on same phases.

5.2 Demagnetization algorithms validation

Figure 7 shows the results of the demagnetization algorithms.

	Demagne-tized	After resistance test	After demagnetiza-tion
U - V	Green trace	Red trace	Blue trace



As expected FRA trace moves left, back to the original status after application of the demagnetization algorithm.

6 CONCLUSIONS

This paper shows the importance of a proper demagnetization of a power transformer before connecting to the power grid (due to inrush currents), and before conventional maintenance tests are done (especially frequency response analysis and turns ratio), as unreliable measurements could be collected as a result of remnant magnetism.

The FRA test has been described as the most sensitive test to detect this unwanted effect and it has been used to validate the new procedure.

From the results of the validation, it can be concluded that the new procedure, implemented in a small portable device (18 kg), allows a reliable demagnetization of the transformer.

7 REFERENCES

1. Power Transformer Modelling for Inrush Current Calculation, Nicola Chiesa, Norwegian University of Science and Technology
2. High Frequency Modelling of Power Transformers, Stresses and Diagnostics, Eilert Bjerkan, Faculty of Information Technology Trondheim.
3. Transformer magnetizing inrush current, T.R. Specht, 1951.
4. Voltage Sag effect on Three Phase Five Leg Transformers, M.R. Dolatian and A. Jalilian. International Journal of Electrical and Electronics Engineering 1:2 2007
5. Service Hand book for transformers, ABB.

Trends and Opportunities of Transformer Monitoring

TAYYAR EGELI, WEIDMANN ELECTRICAL TECHNOLOGY AG

Career Summary

2010 –	WEIDMANN Electrical Technology AG, Switzerland
2013 -	General Manager, Weidmann Factory in Turkey
2010 -	Sales & Marketing Director, End-User Products & Services, EMEA
2009 – 2010	Enpay A.S., Kocaeli, Turkey

Sales & Marketing Director

2006 – 2009	Nexans Turkey A.S., Istanbul, Turkey
2008 – 2009	Business Unit Manager
2006 – 2008	Commercial Director
1994 – 2006	Areva T&D, Gebze, Turkey (Formerly known as ALSTOM T&D)
2002 – 2006	Sales & Marketing Manager
2000 – 2002	Special Projects Manager
1998 – 2000	Export Sales Manager
1994 – 1998	Export Sales Engineer
1990 – 1993	TÜBİTAK, Ankara, Turkey
	Project Engineer

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Trends and Opportunities of Transformer Monitoring

TRANSFORMER LIFE MANAGEMENT 2013

OPPORTUNITIES AND TRENDS OF TRANSFORMER MONITORING

TAYYAR EGELI

Dubai, 22-23rd October

WEIDMANN

WEIDMANN ELECTRICAL TECHNOLOGY AG
A Member of the WICOR Group

Trends and Opportunities of Transformer Monitoring

WEIDMANN

AGENDA

1. **Introduction – Why to monitor?**
2. Monitoring types
3. Monitoring from an insulation manufacturer's perspective.. What really to monitor?
4. Sensors, Models and New Products
5. Summary

WEIDMANN

WHY MONITOR TRANSFORMERS ?

LIFE CYCLE AND CONDITION MONITORING

Critical equipment

High reliability of power supply

Overloading of transformers

Extend the maintenance interval

Avoid Power black-out

Reduced insurance cost

TLM

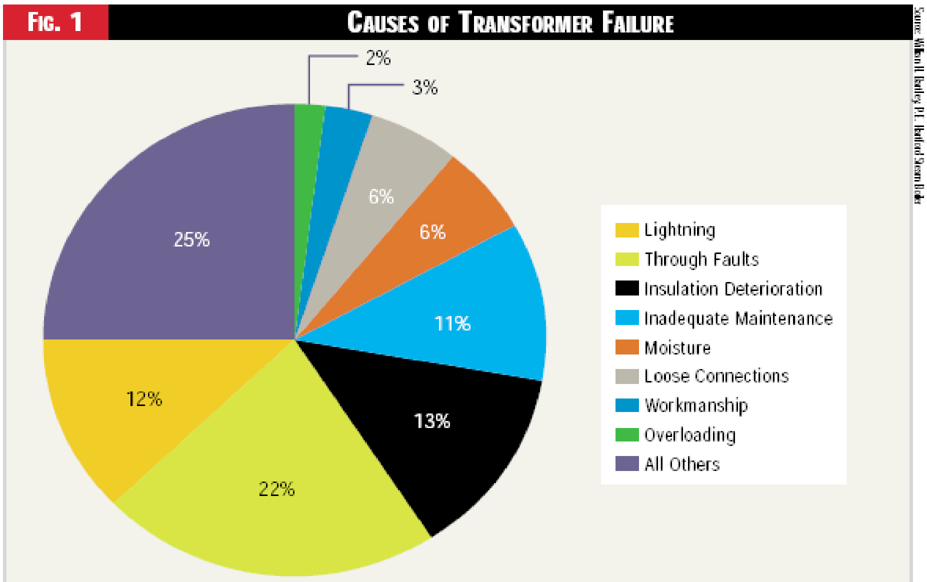
TRANSFORMER-LIFE-MANAGEMENT
CONFERENCE

Trends and Opportunities of Transformer Monitoring

WEIDMANN

WHAT SHOULD WE BE MONITORING ?

Developing Monitors Aimed at Specific Failure Modes



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WHEN THE LIGHTS GO OUT IN THE CITY !

TRANSFORMER-LIFE-MANAGEMENT CONFERENCE

Trends and Opportunities of Transformer Monitoring

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HIGH-ENERGY SHORT CIRCUIT EVENTS

How can we mitigate this risk?

WEIDMANN INTRODUCTION

MONITORING AND GOALS – DEFINITION AND GOALS

Monitoring is the continual supervision of important parameters determining function and product lifetime, independent of their protective devices

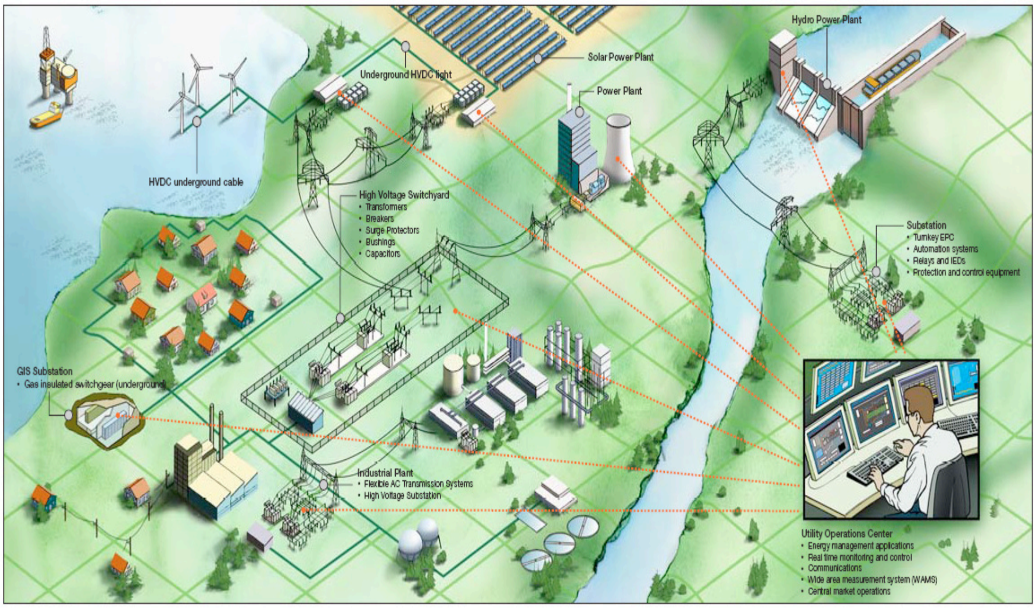
Goals:
- The insurance of operational efficiency
- Life Management (recording of operational parameters)
- Optimal utilization of operating resources
- Condition monitoring
  - As a prerequisite for a cost-effective, condition based maintenance
  - Early fault detection – to increase the service reliability
- Support for fault identification
- Operational optimization

Indication of source: DVG Recommendation of the interconnected companies for monitoring systems for large transformers (German version 1998) - Quelle: DVG Empfehlung der Verbundunternehmen für Monitoringsysteme an Grosstransformatoren (1998)

Trends and Opportunities of Transformer Monitoring

WEIDMANN INTRODUCTION

MONITORING ALL TRANSFORMERS ON THE SYSTEM



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Trends and Opportunities of Transformer Monitoring

WEIDMANN TYPES

MONITORING TYPES

INTELLIGENT MONITORS

Function:
- Monitoring of particular parameters or parameter groups: e.g. temperatures, gases, moisture
- Status indication
- Limited modeling (e.g. aging)
- Control of auxiliary equipment (e.g. coolers)

Development trends:
- Increased replacement of electromechanical monitoring systems
- Connection via WLAN

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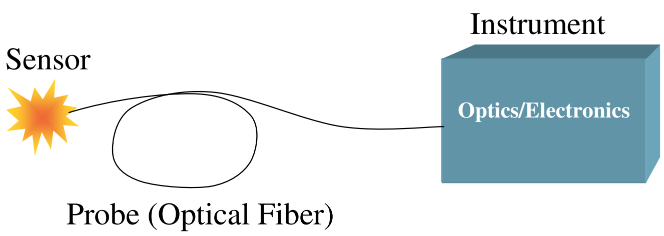
Measuring the temperature using Fiber Optic



•Electronics control a LED source that is pulsed into the optical fiber

•The light from LED excites the sensor at the end of the optical cable

•The sensor emits a decaying light that is returned to an optical separator and the electronics determine the decay time in micro seconds where the decay time is directly related to the sensor temperature.

•Same technology in all packages for over 25 years

•Never requires calibration components designed to match transformer life.

Trends and Opportunities of Transformer Monitoring

WEIDMANN TYPES

DIRECT MEASURING OIL AND WINDING TEMPERATURES

• Faulty installations of fiber optic probes results in frequent breakage and loss of use.

•Improper installation of the fiber-optic probes in the transformer windings can result in inaccurate data or can potentially increase localized stresses in the insulation system.

•Fiber optic probes must be installed in correct location in each winding, and must be installed without disturbing the electrical fields that can result in stress concentration.

•Proper installation must avoid any discontinuity, incompatible materials such as some adhesives, and preclude voids that can reduce the integrity of the overall system.

•Smart Spacers provide the manufacturer and end user with the confidence to install fiber optic probes in the windings that will not compromise the integrity of the insulation system o transformer reliability in the long term.

Pre-assembled SmartSpacer™ T with fiber optic cable and vacuum tight optic connector

WEIDMANN TYPES

MONITORING TYPES

DECENTRALIZED MONITORING

Function:

- Monitoring of a considerable number of parameters on site for individual transformers or groups
- Status indication, condition assessment
- Modeling and forecasting
- SCADA connection

Development trends:

- Are increasingly replaced by central monitoring
- Connection via WLAN

Example: FARADAY® TMCS
Indication of source: GE

Trends and Opportunities of Transformer Monitoring

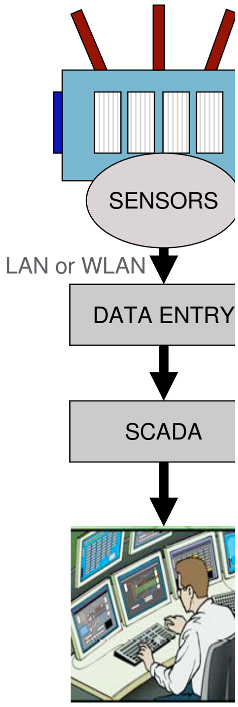
WEIDMANN TYPES

MONITORING TYPES

CENTRAL MONITORING

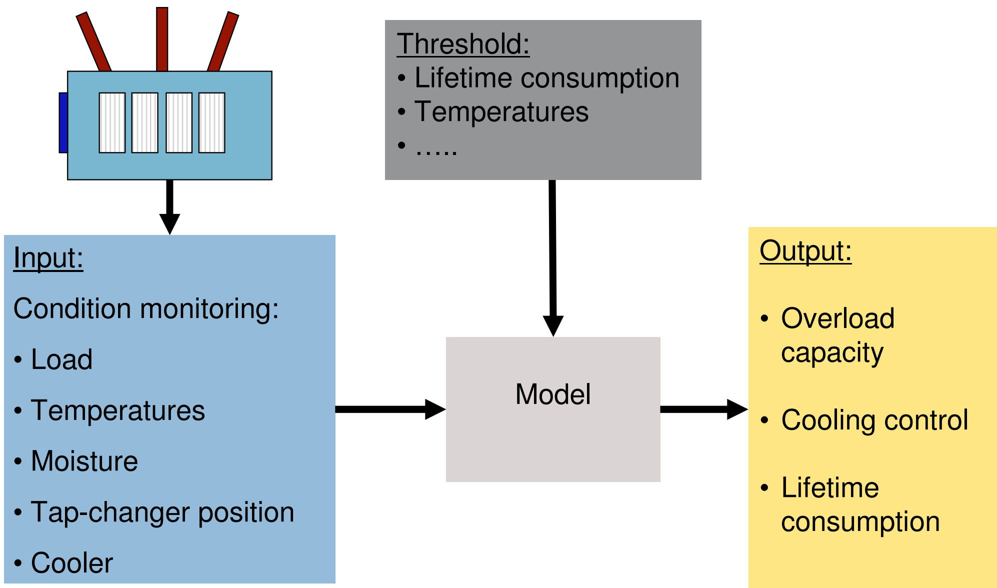
Function:
- Monitoring of a considerable number of parameters
- Only sensors, signal processing and network connection on site
- Status indication, condition assessment, modeling and forecasting managed centrally in control center or service company

Development trends:
- Increasing dissemination, as manufacturers integrate it into the transformers
- The particular sensors are connected to the local service center via WLAN



WEIDMANN MODELS

MONITORING FOR AN EFFICIENT OPERATION MANAGEMENT



Trends and Opportunities of Transformer Monitoring

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TRANSFORMER MONITORING - ESSENTIAL KNOW-HOW

➢Monitoring Transformers on the Smart Grid

➢Monitoring a transformer is directly related to determining the vital signs and condition state of it's insulation system

➢In order to understand the proper diagnostics to perform and interpret the tests or understand monitoring outputs requires a fundamental understanding of the liquid and solid insulation material is essential.

Trends and Opportunities of Transformer Monitoring

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DEFINITION OF TRANSFORMER LIFE

IEEE C57.91-1995 “Guide for Loading Mineral-Oil-Immersed Transformers”

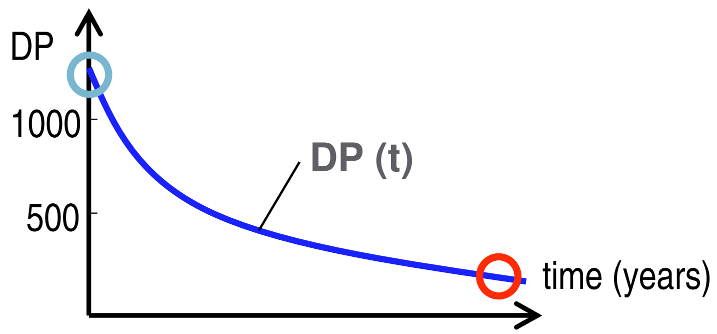
Definitions:

3.5 transformer insulation life: For a given temperature of the transformer insulation, the total time between the initial state for which the insulation is considered new and the final state for which dielectric stress, short circuit stress, or mechanical movement, which could occur in normal service, and would cause an electrical failure.

WEIDMANN

Determination of the aging status by measuring the DP (Degree of Polymerization) of cellulose samples

- In operation, the cellulose degrades continuously with time
- This degradation alters (shortens) the cellulose molecules
- The DP is a good measure of the aging status, because it is proportional to the average length of the cellulose molecules
- The DP of new Kraft pressboard and -paper is about 1200, that of complete aged (end of life) about 200.

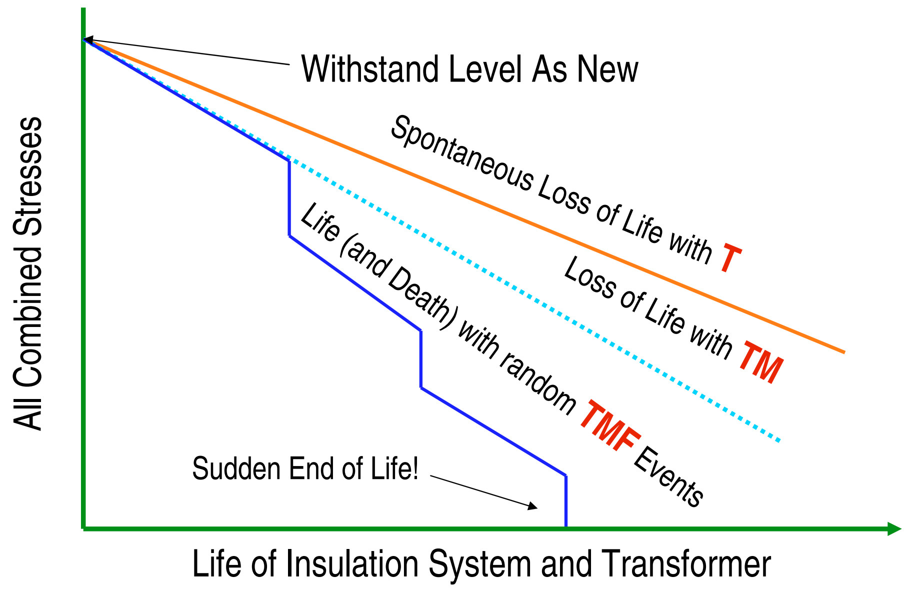


Trends and Opportunities of Transformer Monitoring

WEIDMANN MONITORING

TEMPERATURE – MOISTURE – FORCE

THE TMF Transformer "KILLERS"



WEIDMANN MONITORING

WHICH PARAMETERS SHOULD BE MONITORED ?

FROM AN INSULATION MANUFACTURER'S PERSPECTIVE

temperature | water

↓

Cellulose destruction

↓

Reduction of:
- Clamping force → Loosening of the winding:
  - → Vibration
  - → Destruction in case of short-circuit
- Mechanical strength of the winding insulation
  - → Destruction in case of short-circuit
- Electrical strength (water retention)
  - → Destruction due to partial discharge
  - → Destruction due to overvoltage

TMF = Temperature, Moisture, Force & Gases → TMFG

Trends and Opportunities of Transformer Monitoring

WEIDMANN

SENSORS

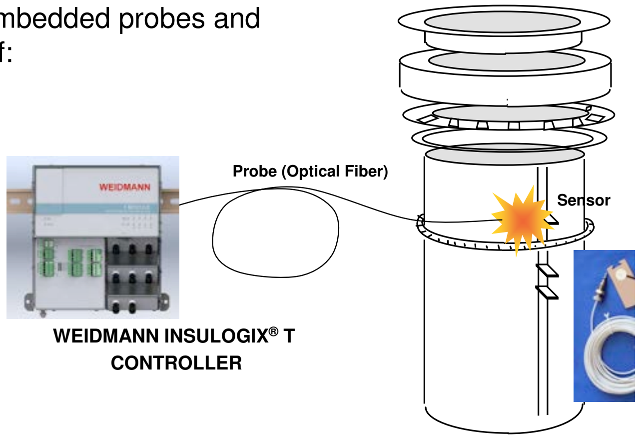
SMART INSULATIONTM SYSTEMS FOR "MONITORING-READY TRANSFORMERS"

Components integrated with embedded probes and sensors for direct monitoring of:

- Winding (hotspot) temperatures
- Direct moisture in paper
- Clamping force

and monitoring devices for:

- Hydrogen in headspace
- Oil dielectric strength
- Partial discharge & arcing
- Dissolved gas in oil
- Bushing current & capacitance



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Hydrogen detectors as an optimum and cost effective solution..

WHY HYDROGEN?

Hydrocarbon (mineral base) oils are used as insulating fluids in electrical equipment because of their high dielectric strength and chemical stability.

Under normal operating conditions very little decomposition of the oil occurs. However, when a fault occurs, the oil insulation will undergo chemical degradation. The fault induced breakdown products are low molecular weight gaseous compounds that are soluble in the oil.

Qualitative analysis of the gases present in the oil allows identification of fault processes such as Partial Discharge, Sparking, Overheating and Arcing.

Hydrogen is the key element for warning signs. The InsuLogix® H Hydrogen Detector can protect your transformer by warning you of these faults.

Pyrolysis (overheating)
•Hydrogen,
•Methane,
•Ethane

Partial discharge
•Hydrogen

Arcing
•Hydrogen,
•Acetylene,
•Methane,
•Ethane,
•Ethylene

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WEIDMANN INTRODUCTION

TRANSFORMER MONITORING – STANDARDS AND GUIDELINES

- CIGRE brochure 343: Recommendation for condition monitoring and condition assessment facilities for transformers
- CIGRE brochure 298: Guide on transformer life time data management
- CIGRE brochure 227: Guide for life management techniques for power transformers
- CIGRE brochure 393: Thermal performance of Transformers
  - Aging, moisture, positioning of FO temperature sensors
- IEC 60076-2: Temperature-rise for liquid-immersed transformers
  - Annex E: Recommendation for the number and positioning of the FO temperature sensors for the hot-spot measurement
- IEC 60076-7: Loading Guide for Oil immersed power transformers
  - Limit temperatures, transient calculations
- IEC 60076-14: Fluid-immersed power transformers with high-temperature insulation: Limit temperatures

Trends and Opportunities of Transformer Monitoring

WEIDMANN INTRODUCTION

CONDITION MONITORING AND EARLY FAULT DETECTION

SENSOR SELECTION RELATED TO FAILURE MODES

Sensor	Ambient temperature	Oil temperatures	Winding temperatures	On-load tap-changer temperatures	Operation currents	Current consumption fans and pumps	Oil levels	Gas pressure	Oil pessure	Pressure sensor	Humidity sensor	Capacity measurement	Loss factor measurement	Gas sensor(s)	electr. a./o. acoust. PD-detection	Vibration sensor
TYPE OF PROBLEM																
Core overheating														x		
Overheating of the winding	x	x	x		x											
Contact heating					x									x		
Partial unloading														x	x	
Oil leakages							x		x							
Coolers/fans/pumps	x	x	x		x	x										
Decreasing winding compression										x						x
Performance monitoring								x		x			x	x		
Water in oil											x				x	
Water in insulation								x			x				x	

WEIDMANN SENSORS

PARAMETERS AND SENSORS FOR OPERATIONAL MONITORING

Parameter	Sensor
Voltage	Bushing tap measurement adaptor (e.g. from University Karlsruhe, Germany)
Currents	Current transformer
Oil temperatures	Boiler/cooler: PT100 Winding: Fiber optics, FOT, GaAs
Winding temperatures	Fiber optics, FOT, GaAs
Relative moisture in oil	Capacitive Sensors e.g. MMT338, Vaisala
Relative moisture in the insulation	Calculation currently via relative oil moisture. Moisture sensor: Under development
Oil and air flows	Calorimetric sensors
On-Load-Tap-Changer (position, temperatures, condition)	Position indication (BCD, resistance matrix), PT100, monitoring system (TAPGARD®)
Gases (H_2, multigas)	Insulogix® H (WEIDMANN), Hydran (GE), GasGuard8 (Siemens)

Trends and Opportunities of Transformer Monitoring

WEIDMANN MODELS

WEIDMANN AS A KEY PLAYER FOR TRANSFORMER MONITORING

• WEIDMANN is the world leader for transformer insulation with worldwide manufacturing plants..

• WEIDMANN is a trend setter for Diagnostics.. Fifteen strategically located Diagnostic Service Centers staffed with qualified chemists who are specialized in diagnostic testing of electrical equipment with the most modern techniques and equipment.. More than 35 years experience with Dissolved Gas Analysis for the detection of incipient failures.

• WEIDMANN is an engineering consultancy company for end-users not only for transformers but also whole power system and network.

• WEIDMANN as an ideal partner for Transformer Monitoring Devices and Systems as expert for Transformer Insulation, Transformer Diagnostics and Transformer Engineering..

WEIDMANN MAKING YOUR TRANSFORMERS BETTER

WEIDMANN'S DEVELOPMENTS IN MONITORING

IS WEIDMANN A „MONITORING COMPANY" ?

- 80ies: Development of first „smart spacer" for fibre optics based T measurement for Luxtron
- 90ies: Development of a moisture sensor (Larson Davies)
- 90ies: Contacts with Micromonitors: (products could not be delivered)
- 2000: Acquisition of ACTI, an American chain of diagnostic labs
- 2006: Acquisition of MIT patent for a dielectric monitor
- 2009: First sales of H sensor (measurement in nitrogen blanket)
- 2011: Agreement with H2Scan, investment in lab/test equipment, specialized resources, R&D projects etc.
- 2013: Granted US Patent for "CLAMPING FORCE SENSOR ASSEMBLY FOR MONITORING TRANSFORMER DEGRADATION"

Trends and Opportunities of Transformer Monitoring

WEIDMANN MODELS

TRANSFORMER SIMULATION TEST FACILITY

- WEIDMANN has designed and built a transformer simulation test facility to, among other things, better understand **TMF** effects on transformer operation and life
- The facility is unique in the industry and capable of simulating the operational variables within a typical power transformer found on electrical grids around the world.
- Key operating parameters such as oil temperature, oil flow, migration of moisture in oil and moisture in insulation materials, onset of bubble formation, axial clamping force, along with winding temperatures and gradient can be closely measured and controlled.

WEIDMANN MAKING YOUR TRANSFORMERS BETTER

TESTING LABORATORY

TESTING LAB IN ST. JOHNSBURY

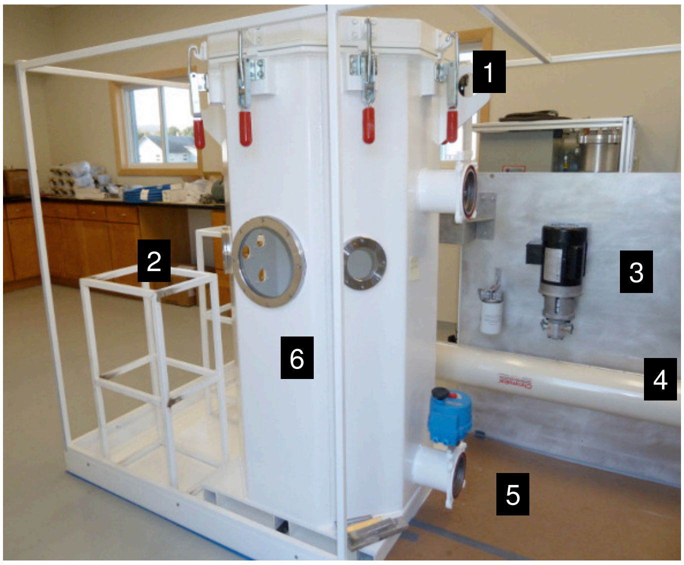
- New test laboratory in St. Johnsbury, USA
- Specialized facility to validate sensors, insulation components, monitoring devices as well as diagnostic software.
- Allows for simulation of dynamic operating conditions within a power transformer

Trends and Opportunities of Transformer Monitoring

WEIDMANN

MODELS

TRANSFORMER SIMULATION TANK IN WDS R&D LAB



1. Transformer simulation tank with removable cover, surrounded by safety frame
2. Frames for mounting torroids for power system
3. Oil circulation pump
4. Oil Heater
5. Connections and valves for mounting radiator
6. Windows and lighting ports to facilitate bubble formation detection

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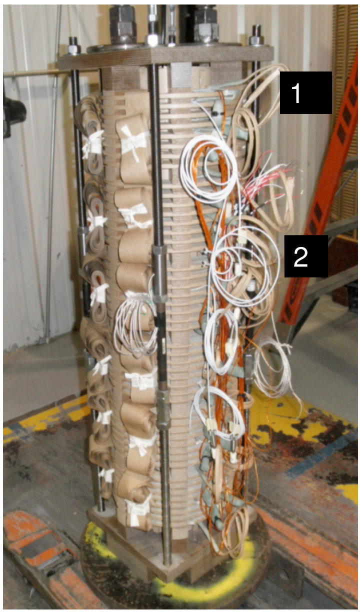
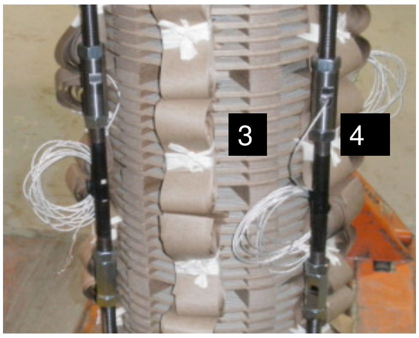
Transformer Simulation Winding and Clamping Assembly





1. Conductor leads for power to each of six sections

2. Fiber Optic and Thermo couples for temp control of each section and overall gradient

3. Insulation coupons in three quadrants and each section for moisture migration testing. Windings by Southwest Electric, OK.

4. Strain gauge (4) for each tie rods for T and M clamp force (F) testing

Trends and Opportunities of Transformer Monitoring

WEIDMANN MAKING YOUR TRANSFORMERS BETTER

MONITOR PORTFOLIO / InsuLogix® - FAMILY

H

✓

H&M

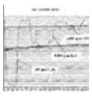
Beta/✓

B

✓

D

Beta

A

R&D

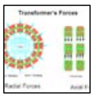
Sensors in oil / main tank and in tap-changer and bushings

T

(✓)

M

R&D

F

R&D

?

Sensors in Solid insulation (Smart Insulation)

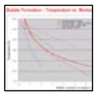
Monitors & Software to optimize transformer operation

eName-plate®

Beta

Smartbox (T)

Beta

Smartbox (T&M&?)

R&D

?

WEIDMANN MAKING YOUR TRANSFORMERS BETTER

HYDROGEN MONITOR - InsuLogix® H

- Sensor allows for H_2 detection directly in transformer oil
- High interest from customers globally
- Units installed across North America, Mexico, Europe and Asia
- Utilities are changing specifications from more costly technologies to InsuLogix® H

Trends and Opportunities of Transformer Monitoring

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SENSORS

SINGLE-GAS (H_2) MONITOR

WEIDMANN INSULOGIX® H – H_2 MONITOR WITH PALLADIUM-DETECTOR

WEIDMANN Insulogix® H - H_2 Monitor

1. Effective range 25ppm-5’000ppm
2. H_2 concentration in oil
3. Test interval: 15 min
4. Internal memory for 1 year
5. (with 15 min test intervals)
6. Outputs:
   - 2 configurable relays
   - 2 x 4..20mA
   - RS485
   - MODBUS protocol, DNP3

- Palladium sensor direct in oil (i.e. no membrane, or filter)

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Installation

INSTALLATION PHOTOS

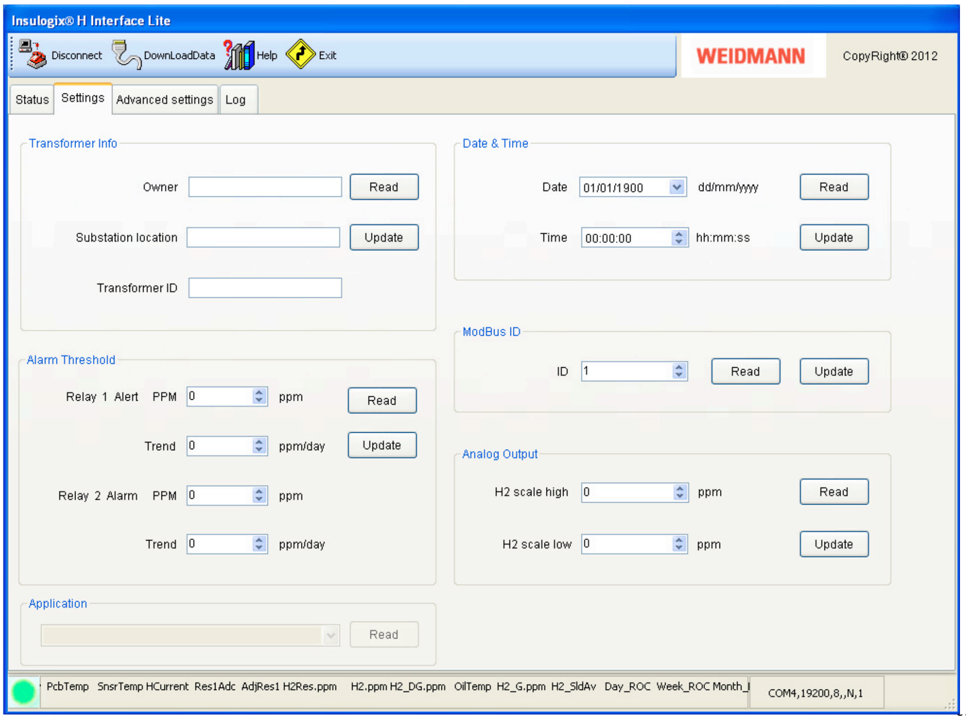
Trends and Opportunities of Transformer Monitoring

WEIDMANN Insulogix H

InsuLogix® H Specifications

Measurement Range (H_2)	25 – 5,000 ppm
Accuracy (H_2)	20% of reading or 25 ppm, whichever is greater
Repeatability (H_2)	10% of reading or 15 ppm, whichever is greater
Response Time (H_2)	< 60 minutes (50% of step change)
Operating Temperature (Ambient)	-40°C +55°C
Storage Temperature	-40°C +85°C
Oil Temperature Range	-40°C + 105°C
Data Storage (Flash Memory)	1 year at one hour testing intervals
Cross-sensitivity to Other Gases (CO_2, C_2H_2, C_2H_4, CO, etc.)	< 2%
Relays	Three relays: two user configurable; one for self test relays are isolated: 3A, 240V contacts; individual NO & NC with one common
Analog Output	1 x 4-20 mA
Serial Output and Protocol	RS232, RS485, MODBUS, DNP3
Expected life	> 10 years
Installation	Compression fitting, on an existing valve, 3/4" or larger
Weight, Dimensions	1.3 kg (2.8 lbs), l 15.88 cm x w 11.75 cm x h 7.94 cm (l 6.25" x w 4.625" x h 3.125")
Power	24V DC nominal (15 to 28V DC) – 30W Max or VAC PSU (110VAC-240VAC)
Warranty	Two years
Standards	EMI/EMC: IEEE STD C37.90.1, EN 55022/FCC PART 15 & EN 55024/EN 610004; IEC 60068-2-6; IP67 (IEC 60529), NEMA 6, CE Mark (IEC 61000)

WEIDMANN Insulogix H - User Interface



TLM

TRANSFORMER-LIFE-MANAGEMENT
CONFERENCE

Trends and Opportunities of Transformer Monitoring

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InsuLogix® H advantages and key points

•Sensor on a micro chip – Palladium-Nickel alloy

•Ruggedized sensor and proven technology for H2 measurement - Thousands of sensors are installed in petrochemical applications, in high pressure and highly corrosive gas streams

•Capable of measuring the H2 in both oil and gas phases of power transformer and other oil filled equipment

•Installation under 45 minutes

•No consumables, no sensor degradation, no moving parts

•Small package, the lowest price in the industry makes it affordable down to network transformers, other distribution transformers, special transformers and LTCs

•4-20mA output, alarm relays (absolute and trend levels), serial communication, system watchdog, MODBUS over RS485, data recording

•Compliant to standards for operation in substation environment, CE marking

•Water submersible

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MAKING YOUR TRANSFORMERS BETTER

HYDROGEN & MOISTURE-IN-OIL MONITOR - InsuLogix® HM

- Sensor allows for simultaneous H_2 and moisture detection directly in transformer oil
- Moisture sensor: Vaisala; separate from H_2 sensor
- First units are being installed in North America and China
- Utilities are changing specifications from more costly (maintenance intensive) technologies to InsuLogix® HM

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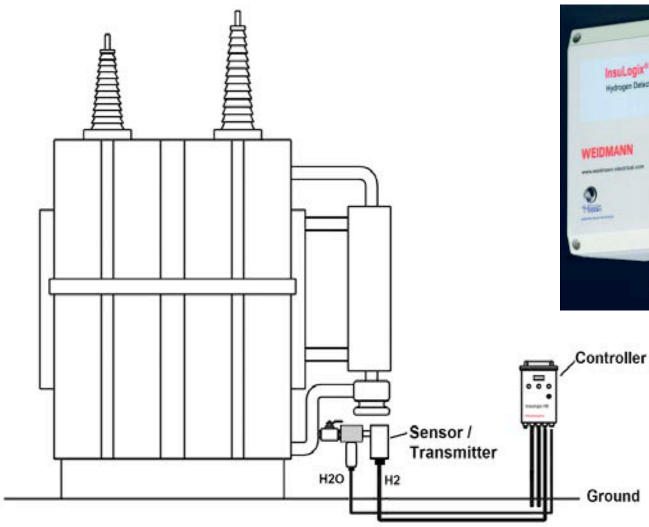
Trends and Opportunities of Transformer Monitoring

WEIDMANN MAKING YOUR TRANSFORMERS BETTER

HYDROGEN & MOISTURE-IN-OIL MONITOR - InsuLogix® HM



WEIDMANN MAKING YOUR TRANSFORMERS BETTER

BUSHING MONITOR - InsuLogix® B

MARKET INTRODUCTION STARTED

- Sensor measuring the condition of the bushing's insulation using power factor / tan δ
- Monitor provides early warnings of a bushing problem using algorithms that simulate Schering Bridge technique
- High interest from customers globally
- First units installed

Trends and Opportunities of Transformer Monitoring

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InsuLogix® B

COMMUNICATION OPTIONS INCLUDE:

- pc Anywhere™
- Windows RDP
- RJ45 Ethernet Interface
- Serial Interface (ASCII)
- LCD Touch Panel Display
- Hardwired or Wireless
- IEC 61850
- DNP3

The InsuLogix® B system can interface to signals from other InsuLogix® line WEIDMANN monitors, and 3rd party devices and IEDs such as: temperature sensors, DGA, or any 0-10 Vdc, 10 V peak, 4-20 mA, or 0-1 mA signal.

BENEFITS

- Condition Based Maintenance
- Reduced Risk of Catastrophic Failure
- Scalable Smart Grid Solution
- Safety for Personnel & Assets
- Integration possible with other monitors from WEIDMANN InsuLogix® line
- Access to WEIDMANN experts for bushing engineering evaluations

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MAKING YOUR TRANSFORMERS BETTER

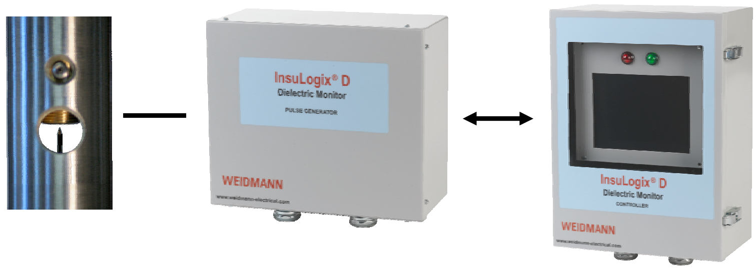
DIELECTRIC MONITOR - InsuLogix® D

- Sensor for direct measurement of dielectric strength of insulating fluids
- Identifies problems in contacting equipment and provides real-time information during oil processing
- InsuLogix® D measures the time-to-breakdown of oil by applying low energy high voltage DC pulses, providing a Normal, Caution or Warning diagnostic.
- Non-destructive test, as compared to existing destructive method.

Trends and Opportunities of Transformer Monitoring

WEIDMANN
Insulogix ® D

INSULOGIX D =



1. Probe/electrode Immerged in oil

2. Pulse Generator Mounted at proximity of probe

3. Controller

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ACETHYLENE MONITOR - InsuLogix® A

RESEARCH PHASE NEARLY COMPLETE

- Sensor principle based on NDIR (non-dispersive infrared sensor) technology
- Target: low cost unit (annunciator)
- Later to be combined with H_2 sensor to form a dual gas monitor

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Trends and Opportunities of Transformer Monitoring

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TEMPERATURE MONITOR - InsuLogix® T

WELL ESTABLISHED IN MARKET

- Temperature sensor fully integrated in the solid insulation – Smart Spacer ®
- Installed fiber optic probes in windings without compromising the integrity of the insulation system or long term transformer reliability.
- Hundreds of certified spacers sold over the past years

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MOISTURE MONITOR - InsuLogix® M

DEVELOPMENT NEARLY COMPLETE

- Measures moisture directly in solid insulation (paper) rather than in oil, using fibre optics based detection technology
- Insulation components integrated with embedded sensors
- Near real time actionable information for decisions related to dynamic loading and insulation loss of life

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Trends and Opportunities of Transformer Monitoring

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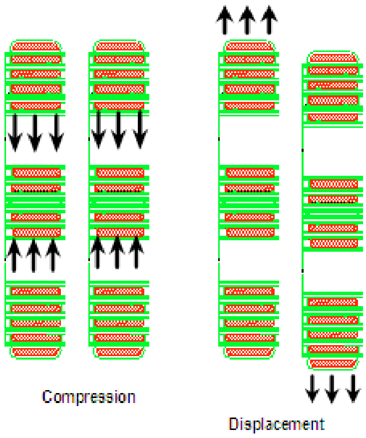
FORCE MONITOR - InsuLogix® F

DEVELOPMENT ONGOING



Axial Forces

- Directly measures transformer clamping force in the insulation / winding clamping structure using fiber optics based technology
- Insulation components integrated with embedded Force sensors
- Actionable information for decisions related to operation risk, condition based maintenance, loss of life, risk of surviving next short circuit event

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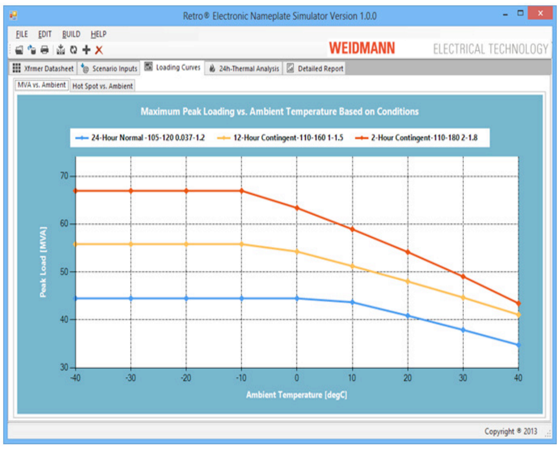
eNameplate® - STAND ALONE SOFTWARE PACKAGE

DEVELOPMENT COMPLETE



- **eNameplate®** = "Electronic Nameplate" allows the user to rewrite a transformer's static nameplate based on its own operating conditions - such as defined in the loading case (Worst Case Ambient, Max LoL, Max Hot Spot, Max Top Oil, Max. Load...etc)
- Simulates Dynamic Loading by using factory final test results.
- **Free trial available, please register now**

Trends and Opportunities of Transformer Monitoring

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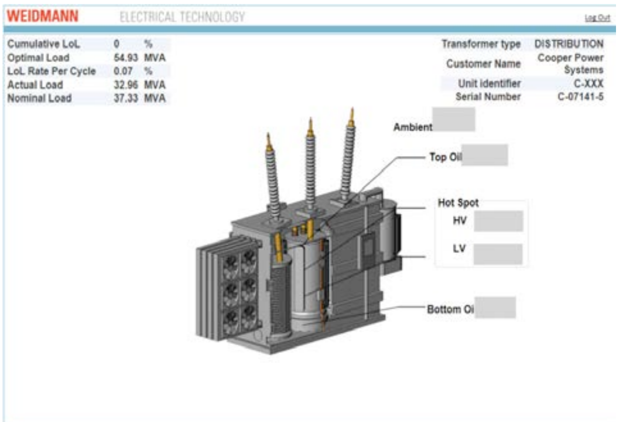
InsuLogix® SMARTBOX „T“
DEVELOPMENT NEARLY COMPLETE



- Dynamic loading monitor using inputs from (fibre optic based) hot-spot temperature sensors
- Calculation of load margins for normal and emergency modes
- Calculation of (cumulative) loss of life in function of actual operating parameter -> tachograph („Fahrtenschreiber“)
- Requires less sensors inputs than conventional dynamic loading algorithms to result in cost effective solution

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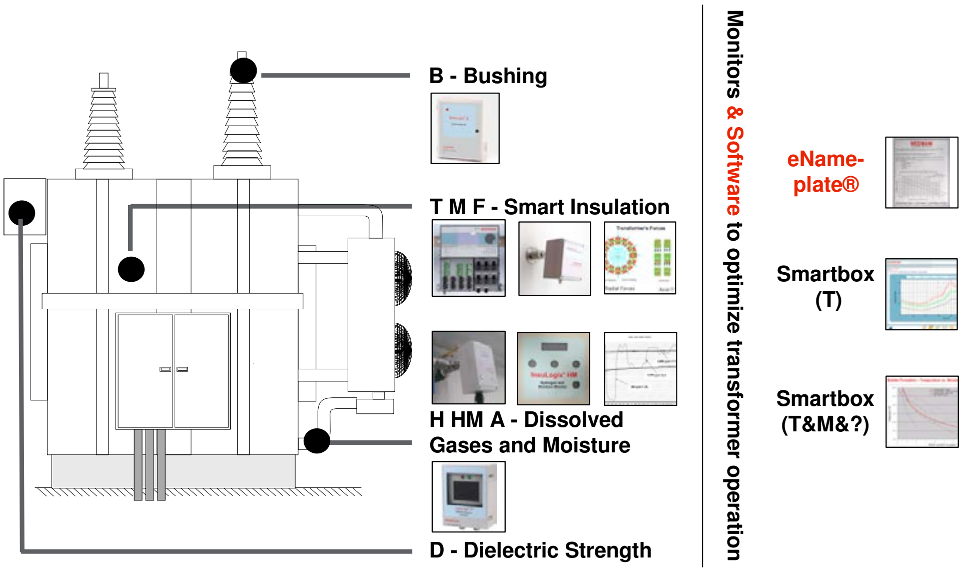
MONITOR PORTFOLIO / InsuLogix® - FAMILY
FOR OPTIMUM PERFORMANCE MONITORING (OPM)



Trends and Opportunities of Transformer Monitoring

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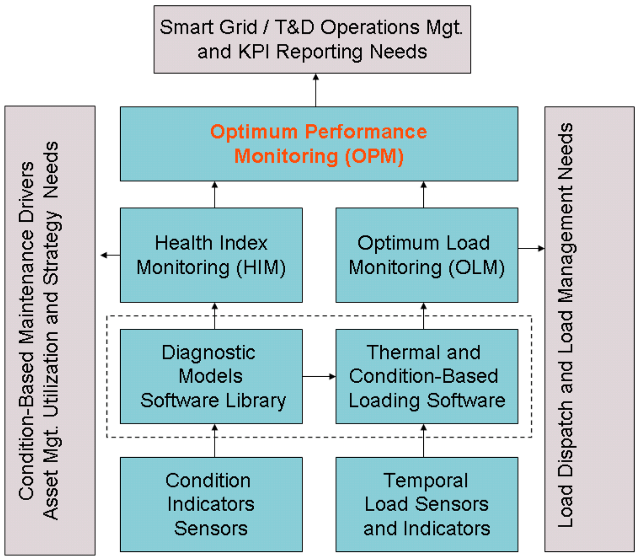
YES ! WEIDMANN IS ALSO A MONITORING COMPANY !

MEETING OUR T&D CUSTOMER NEEDS WITH OPM



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AGENDA

1. Introduction – Why to monitor?
2. Monitoring types
3. Monitoring from an insulation manufacturer‘s perspective.. What really to monitor?
4. Sensors, Models and New Products
5. **Summary**

Trends and Opportunities of Transformer Monitoring

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Monitoring Products:

Support Critical Decision Making

1. Measurements to manage maintenance （condition-based monitoring)

Insulogix® H/HM, Insulogix® D

1. Measurements to manage operations (operation-based monitoring)
2. Measurements to manage end-of-life
3. Insulogix® T/M/F—smart insulation/dynamic loading

Actionable Information not data..

WEIDMANN MODELS

TRANSFORMER MONITORING - ESSENTIAL KNOW-HOW

- Much of the monitoring and diagnostics performed on power transformers is an attempt to determine the health of the insulation system.
- In order to understand the proper diagnostics to perform and interpret the tests or understand monitoring outputs a fundamental understanding of the liquid and solid insulation material is essential.

Trends and Opportunities of Transformer Monitoring

WEIDMANN SUMMARY

SUMMARY

- The use of transformer monitoring systems will increase.

  Drivers mainly are :

  - „Smart Grid"
  - Age of the transformers
  - Decreasing prices for sensors and components
  - Growing use of centralized systems, i.e. only sensors are mounted at the transformers and data preparation, data processing is handled centrally.
- Small, intelligent monitors for the supervision of a limited number of parameters will continue to be used. Increased use of WLAN connection.
- Continued new development and enhancements of sensors
- Integration of the sensors by suppliers →SmartInsulation™
- More complex models and evaluation processes → „Predictive Monitoring"

WEIDMANN SUMMARY

SUMMARY cont.

- Coping with old equipment, such as depending on a vulnerable transformer fleet - much of which is now close to the end of its life – makes it increasingly difficult to meet regulator and customer expectations.
- Greater understanding about such elements as **TMF** - the impact they have on the transformer fleet - and seeking increased accuracy about all information needed to maintain the health and life of each transformer has never been more important than it is today.

Trends and Opportunities of Transformer Monitoring

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THANK YOU!