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About the Conference

TLM goes global

Transformer Life Management 2017

07. – 08. Nov. 2017

Jasmine Hotel – Bangkok

This year the TLM symposium will take place with a special focus on the question:

How can the safety and operation of the transformers in the network be assured in the face of increasing loading and age?

The TLM 2017 attempts to answer this question. Manufacturers, operators, engineers and scientists will present methods and possibilities for transformer condition assessment and improvement, giving you the information to help develop an efficient maintenance concept.

The different diagnostic methods lead to a holistic condition appraisal, helping to identify age related changes and malfunctions at an early stage. This procedure allows early intervention to implement condition improvements that optimize operational reliability.

The main objective of this event is to find ways for prolonging the residual lifetime of transformers and to reduce unplanned outages.

The symposium and associated technical exhibition is directed at engineers, physicists, chemists, technicians and consultants involved in the manufacturing, design, operation, assessment and maintenance of transformers, as well as universities and research institutes with an interest in the reliable operation of electrical networks.

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Conference Program - Jasmine City Hotel

Tuesday 07.11.2017

11^{00}-13^{00}	Check-in with welcome Snack and Distribution of the Conference Papers	
13^{00}-13^{30}	Chairman - Welcome and Introducing **Prof. Dr.-Ing. Hossein Borsi, University of Hannover**	
13^{30}-14^{00}	Technical and Economic Impacts of Distributed Generationon Distribution Systems **Mr. Nattachote Rugthaicharoencheep Ph.D.**	S1
14^{00}-14^{30}	Asset Management of Transformer fleets - An Overview **Prof.Dr.Ing. Peter Werle, University of Hannover**	S2
14^{30}-15^{00}	IEC 60296 (ed. 4) From a Transformer Oil Manufacturer's Perspective **Nils Herlenius, Ergon**	S3
15^{00}-16^{00}	Coffee Break, Visit the Exhibition	
16^{00}-16^{30}	Mitigating Murphy´s Law While Test **Frederic Dollinger, Haefely Hipotronics**	S4
16^{30}-17^{00}	Properties of Ageing Mineral Insulating Oils in Service **Chian Yaw Toh, Nynas**	S5
17^{00}	Dinner at Jasmine Hotel	

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Conference Program - Jasmine City Hotel

Wednesday 08.11.2017

09^{30}-10^{00}	Chairman - Summarising of First Day **Prof. Dr.-Ing. Peter Werle, University of Hannover**	
10^{00}-10^{30}	Material Testing with VLF on Transformers **Jürgen Jakober, b2 High Voltage**	S6
10^{30}-11^{00}	Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes **Prof. Dr.-Ing. Hossein Borsi, University of Hannover**	S7
11^{00}-11^{30}	Frequency Converter as Power Supply for Transformer Testing **Frederic Dollinger, Haefely Hipotronics**	S8
11^{30}-12^{00}	Real Life Assesment of Natural Ester Filled **Rajaram Shinde, Cargill**	S9
12^{00}-13^{30}	Lunch - Visit the Exhibition	
13^{30}-14^{00}	Stray Gassing of different refinery streams and impact of metal deatctivators **Nils Herlenius, Ergon**	S10
14^{00}-14^{30}	Demystifying transformer Oil Treatment and regeneration **Igor Kudela, Ekofluid**	S11
14^{30}-15^{00}	Detection of winding faults with frequency response analysis (FRA) **Prof. Dr.-Ing. Hossein Borsi, University of Hannover**	S12
15^{00}-16^{00}	Coffee Break - Visit the Exhibition	
16^{00}-16^{30}	Naphthenic Mineral Insulating Oils in a Challenging Market Dynamics **Mr. Sutarmono, Nynas**	S13
16^{30}-17^{00}	Measuring Methods for Solubility of Gases in Insulation Liquids- Summary of the day **Prof. Dr.-Ing. Peter Werle, University of Hannover**	S14

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We aspire to fulfill and to exceed the continuously increasing safety requirements of our costumers in more than 100 countries.

EMB SMART Buchholz relay

Capacitive sensor (NM-series):

- For analogue measuring of gas accumulation
- Reliable & continuous monitoring of Buchholz gases starting already at 50 cm³

Temperature sensor:

- For continuous oil temperature monitoring
- Available separately or combined with humidity sensor

Humidity sensor:

- Constant monitoring of humidity in oil
- For early detection & preventive measuring to extend transformer life time

Buchholz relay 3+3

- Buchholz relay with 6 independent contacts
- 3 contacts for alarm & 3 contacts for disconnection
- Also available with mechanical pre-alarm system

Buchholz gas tester BGT 4.2

- Measuring and analysis of Buchholz gas directly on site
- Detection & analysis of H_2, CO, CO_2, C_2H_2, CH_4+
- Enables to decide about the continuous operation of the transformer
- Easy handling via touch display
- Incl. Buchholz gas sampler BGS

Breathing buffer box G3B

- For significant lifetime extension of open type transformers
- Sustained reduction of oxygen in oil through hermetic sealing
- To slow down the aging process of transformer insulating material

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Kooperationspartner Transformatorgase GATRON

Technical and Economic Impacts of Distributed Generationon Distribution Systems

Nattachote Rugthaicharoencheep, Ph.D.
Associate Professor in Electrical Engineering

Education

- Ph.D.(Electrical Engineering) King Mongkut's University of Technology North Bangkok, THAILAND
- M.Eng.(Electrical Engineering) Thammasat University, THAILAND
- B.Eng.(Electrical Engineering) Rajamangala University of Technology Phra Nakhon, THAILAND
- B.S.Tech.Ed.(Electrical Engineering) Rajamangala Institute of Technology Thewes Campus, THAILAND

Lecture

Bachelor Degree in Electrical Engineering
- 1. Electric Power System Analysis
- 2. Electric Power System Laboratory
- 3. Electric System Design

Master Degree in Electrical Engineering
- 1. Computer Analysis in Power Systems
- 2. Power Quality
- 3. Thesis

Professional Memberships

- Chair of Master degree program in the Electrical Engineering at Rajamangala University of Technology Phra Nakhon
- Committees of National and International Conferences, EECON, EENET and ICPSE 2014
- Keynote speaker of IEEE International Conference Circuit, Power and Computing Technologies, 2014
- Member of the Academic Council of Rajamangala University of Technology Phra Nakhon, 2015

Technical and Economic Impacts of Distributed Generationon Distribution Systems

Technical and Economic impacts of Distributed Generation on Distribution System

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Rajamangala University of Technology Phra Nakhon
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Abstract

Electric demand is substantially increasing as a result of economic and social growths, the construction of a large sized power plant is running into financial and technical difficulties because it is capital intensive and needs considerable amount of time. An ideal alternative on electric distributions to electric users is the installation of a small sized generator or commonly known as distributed generation (DG). DG is a small-scale active generating unit located on or near the site where it is to be used (i.e., in distribution systems). The primary energy resources of DG could be wind, solar, biomass, fuel cells and hydrogen, etc. The introduction of DG units, however, brings a number of technical issues to the system; important among them is the active power loss. It is therefore proposed in this research to investigate the impact of distributed generation on distribution system in the context of planning and operation, illustrated respectively by distributed generation placement and feeder reconfiguration with DG.

The distributed generation placement problem is twofold that need to be simultaneously determined- firstly, location and secondly, number and sizes. In this research, the objective function of the problem is to minimize the system active power loss while retaining the voltage magnitudes of all load points within prescribed allowable limits for different load levels. Mathematical models and a technique based on Tabu search is developed to solve for optimal placement and sizing of DGs. The effectiveness of the developed method is demonstrated by 28-bus Provincial Electricity Authority (PEA) distribution systems. The study results indicate that the method manages to give the optimal placement and sizing of generators that yield the lowest total cost over the planning horizon.

Feeder reconfiguration is accomplished by altering topological structures of the network by changing the statuses of tie and disconnecting switches. To give an appropriate connection for several reasons such as loss reduction, load balancing, and voltage improvement. A methodology based on fuzzy multiobjective and Tabu search is formulated to determine the optimal on/off patterns of tie and sectionalizing switches for feeder reconfiguration with DGs. Three main objectives taken into account in the feeder reconfiguration problem consist of power loss, feeder load balancing, and number of switching operations of the switches. The performance of the developed methodology is demonstrated by a 69-bus radial distribution system. On the basis of the simulation results obtained, the satisfaction level of one objective can be improved at the expense of that of the others. The decision maker can, therefore, flexibly prioritize his or her own objectives by adjusting some of the fuzzy parameters. In addition, in order to increase the advantages of the feeder reconfiguration, the dispatch of the distributed generators is assumed to be implemented, where its dispatch schedule that gives the minimum total cost of generation is solved by an optimal power flow.

Keyword: Distribution Planning and Operation, Distributed Generation, Feeder Reconfiguration, Optimization

Asset Management of Transformer fleets - An Overview

Prof. Dr. Ing. Peter Werle

University of Hannover

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.

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Asset Management of Transformer fleets - An Overview

Asset Management of Transformer Fleets
An Overview

Oleg Kuzmin, ABB Transformer Service, Germany
Peter Werle, Leibniz Universität Hannover, Schering-Institute

Leibniz Universität Hannover IfES TLM ABB

Introduction
Transformer failures can lead to serious damages

- **Condition assessment is highly important**
  - In order to avoid outages
  - In order to spent the maintenance budget for the right transformers

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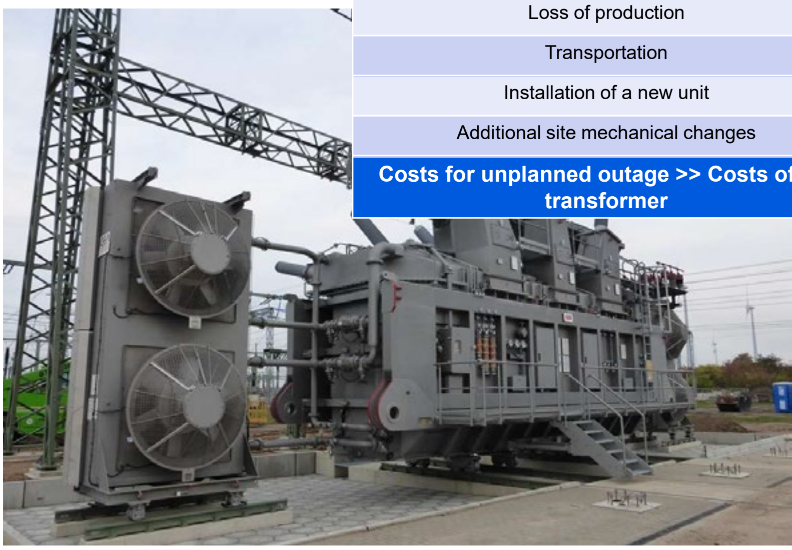
Asset Management of Transformer fleets - An Overview

Transformer Outages
Costs of outages

What are costs of an unplanned outage?
Environmental impact
Loss of production
Transportation
Installation of a new unit
Additional site mechanical changes
Costs for unplanned outage >> Costs of the transformer



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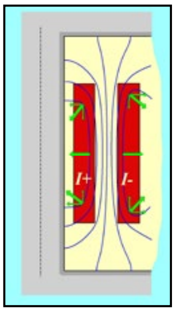
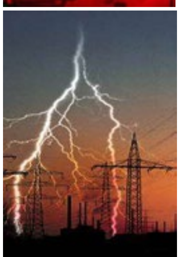
Transformer Fleets
Typical Situation

- Majority of assets are > 30 years old
- Limited maintenance
- Assets have varied loading
  - Changing stresses
  - Mechanical
  - Thermal
  - Dielectric
- Spare reliability not always known
- High reliability must be maintained
- Need to make best use of the capital & resources





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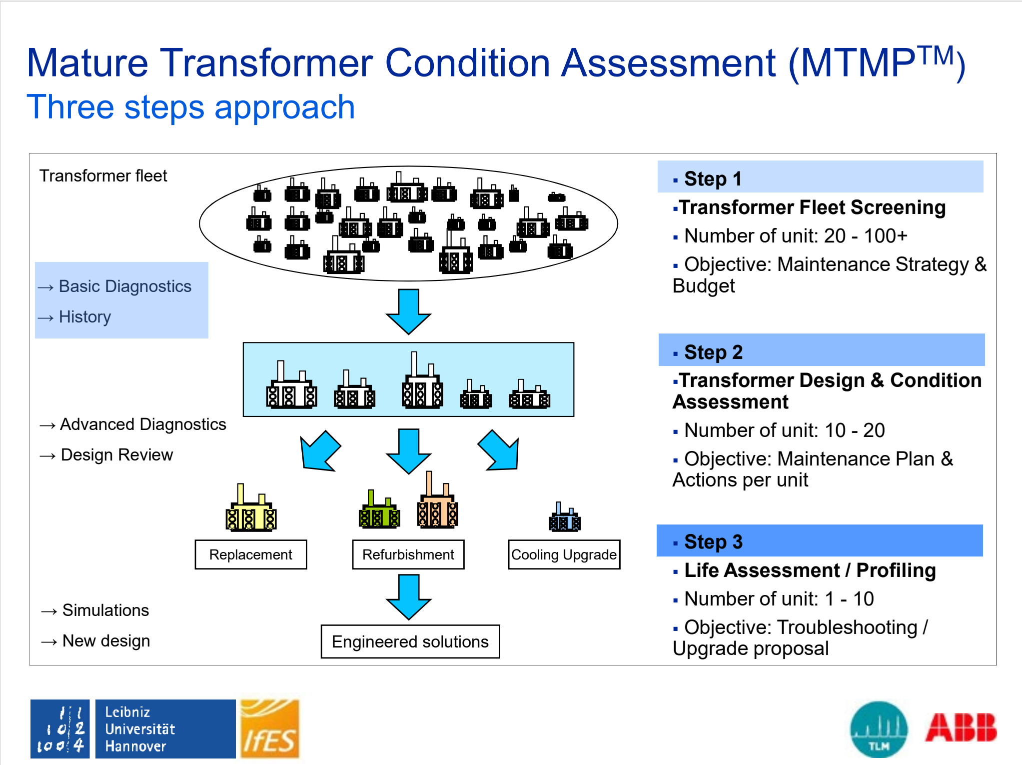
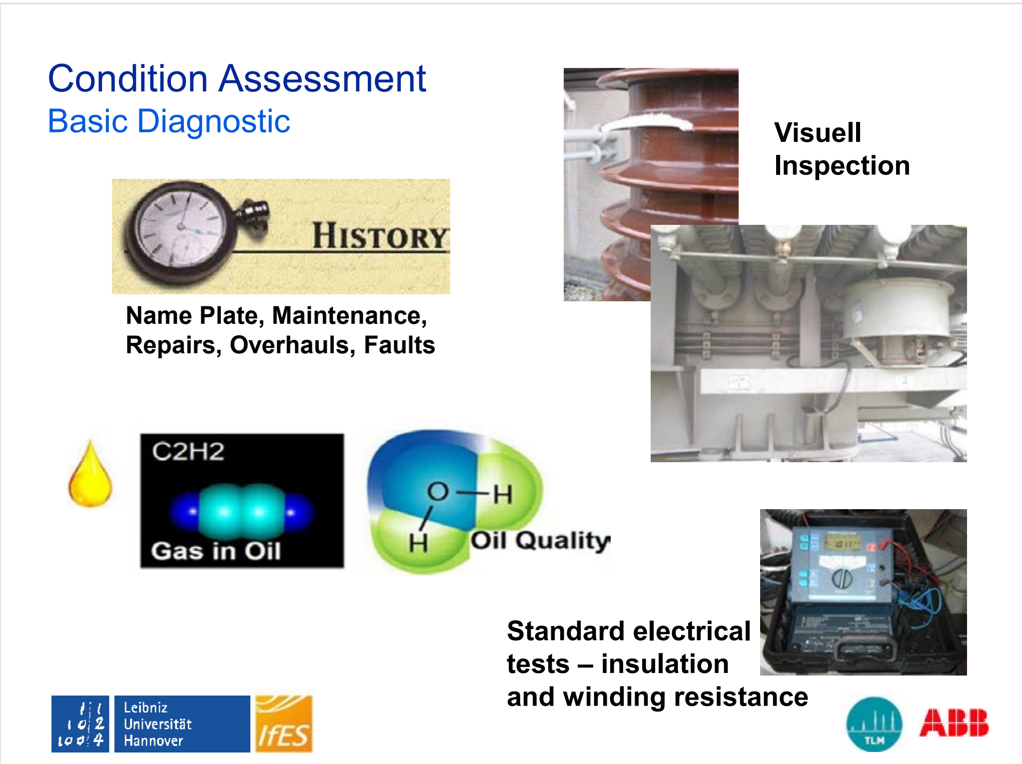
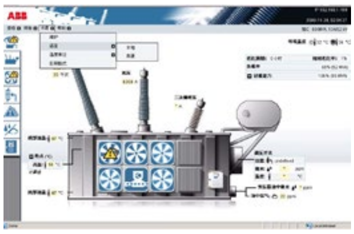
Asset Management of Transformer fleets - An Overview





Asset Management of Transformer fleets - An Overview

Transformer Monitoring
Core-Tec



- ABB expertise to turn data into actionable recommendations to operate, maintain and manage transformer assets
- Modular platform to address low to high end applications
- User friendly web interface – no additional software needed on users computer
- Based on a microprocessor and Modular design, possible to add the sensors that the customer requests with additional hardware
- Very strong mechanical stability and temperature endurance => Long lifespan
- Reliable and proven technology (longest serving unit has >15 years in the field)
- Compact and easy to install
- Support for standard communication protocols, including IEC 61850 (certified by SGCC)
- 1’500 installed Worldwide

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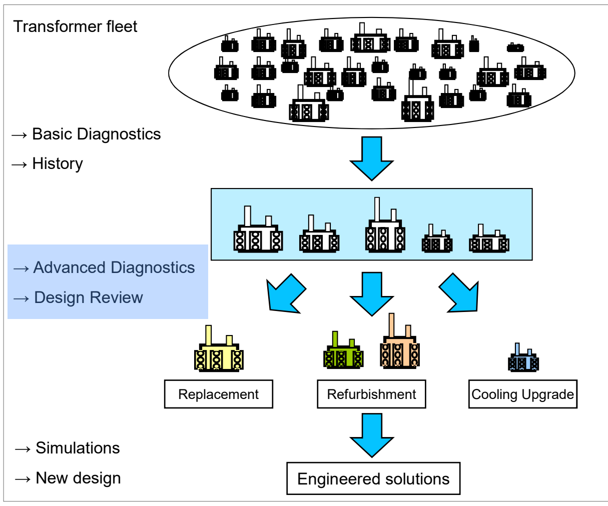
Mature Transformer Condition Assessment (MTMP™)
Three steps approach



- **Step 1**
- **Transformer Fleet Screening**
- Number of unit: 20 - 100+
- Objective: Maintenance Strategy & Budget

- **Step 2**
- **Transformer Design & Condition Assessment**
- Number of unit: 10 - 20
- Objective: Maintenance Plan & Actions per unit

- **Step 3**
- **Life Assessment / Profiling**
- Number of unit: 1 - 10
- Objective: Troubleshooting / Upgrade proposal

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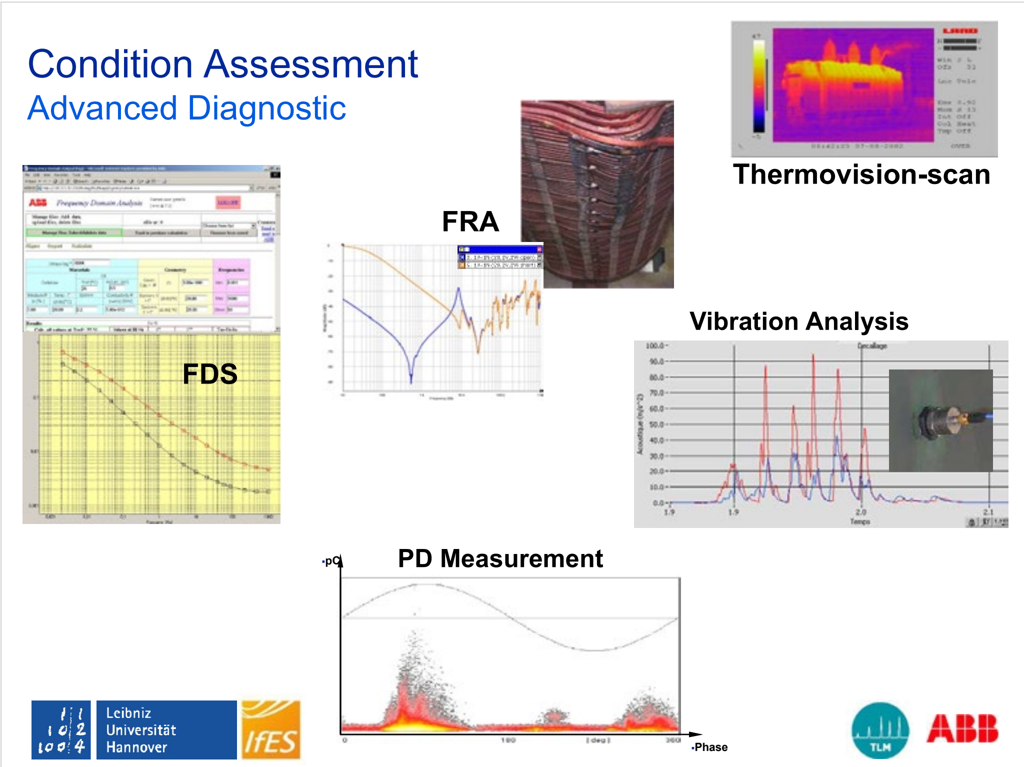
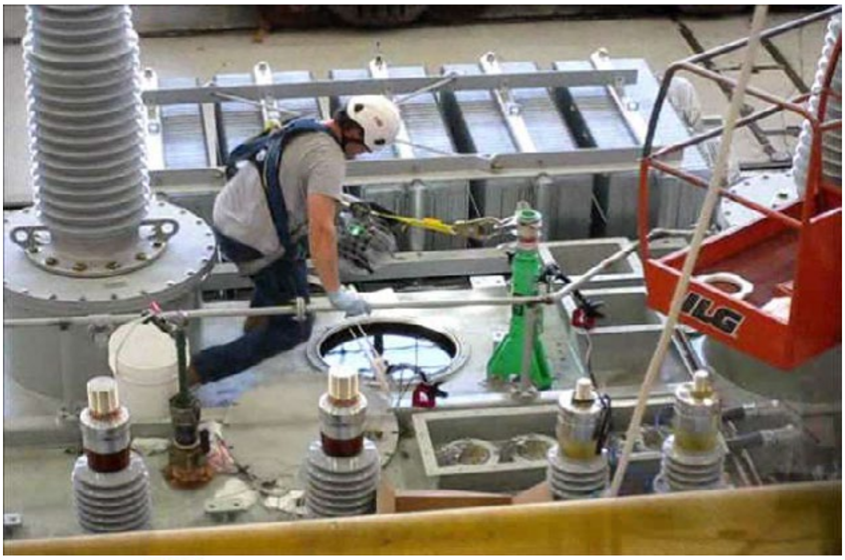
Asset Management of Transformer fleets - An Overview



Active Part Inspection
Patented High Tech



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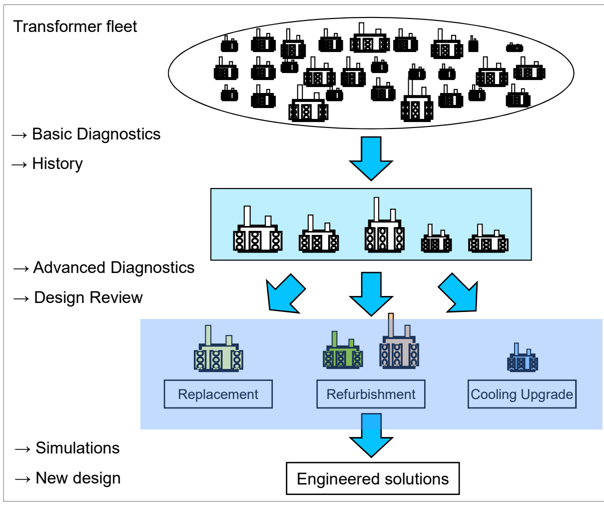
Mature Transformer Condition Assessment (MTMP™)
Three steps approach



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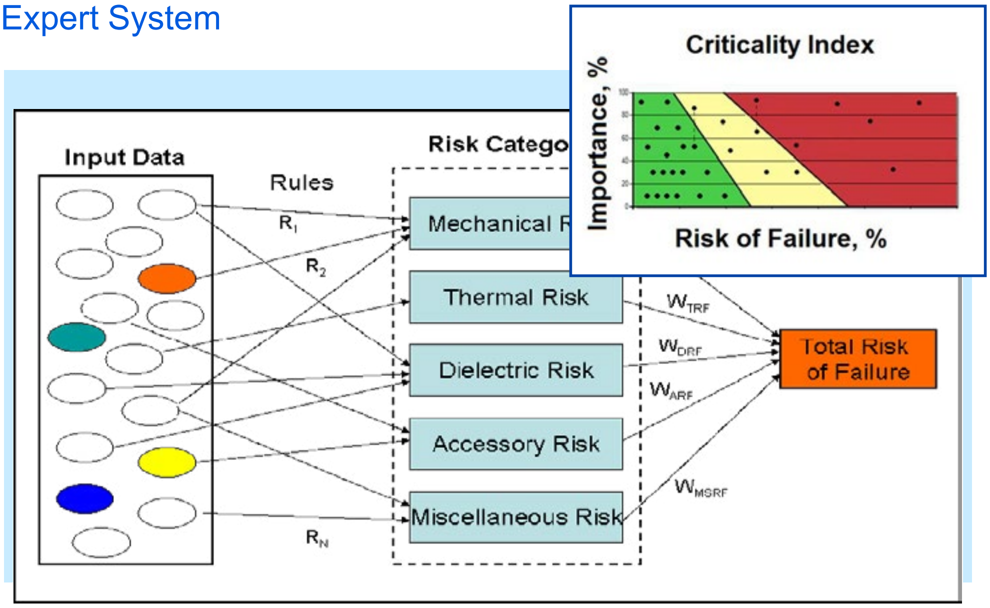
Fleet Screening
Expert System



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Mature Transformer Condition Assessment (MTMP™)
Typical output and recommendations

Plant 1 - Results of condition assessement and action plan

	Mechanical	Electrical	Thermal	Accessories	Overall	Risk Mitigation - Actions
TFO 2	Winding	Arcing	Heating		95	Visual Inspection and repair in factory / rewinding
TFO 5	Tank			OLTC heating	80	Repair on site and OLTC overhaul
TFO 1			Aged oil	Bushing	70	Oil regeneration / filtration and advanced diagnosis / change HV bushing
TFO 6		Arcing		Thermometer	50	Exchange TopOil - thermometer / on line monitoring of DGA
TFO 3				Silicagel	40	Exchange Silicagel
TFO 7					25	Standard maintenance actions and controls
TFO 8					15	Standard maintenance actions and controls / 10 % overload capabilities
TFO 4					10	Standard maintenance actions and controls / 15 % overload capabilities

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Recommendations
Site Actions

- Site internal repairs/upgrades
- Cooling and Control Systems upgrade
- Bushing and OLTC Maintenance or replacement

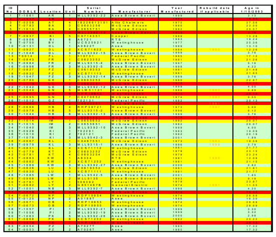
- Oil Reprocessing
- Transformer Active Part Drying
- Biodegradable fluid retro fills

Recommendations
Contingency Planing

What to do in case of a long repair on-site or in the workshop ?

ABB response: World's first hybrid insulated 400kV *mobile transformer*

Mature Transformer Condition Assessment (MTMP^{TM})
Example – US Utility



Customer need:

- Prioritization corrective **actions on a fleet of 128 units**
- Optimize yearly maintenance budget of 1.3 MUSD

ABB response:

- Assessment of the condition and risks of failure with MTMP™
- **Determine the individual risk of failure**
- Proposal for maintenance actions and budget

Customer benefits:

- The maintenance **budget was reduced by 24%** the first year
- The maintenance budget is now spent on the right units, resulting in an increased overall reliability of the fleet at a lower cost:
  - 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%

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Asset Management
Conclusion

- **Asset management strategies need to be based on excellent condition assessment methods**
- **The more precise the condition is known the more efficient actions can be taken**
- **Hightech like robotic applications or on-site testing optimize condition assessment methods and MTMP**
- **ABB offer a variety of technical sophisticated solutions already approved for different fleets**
- **Continuous research and development ensure that condition assessment methods getting better and better leading to optimized asset management strategies**

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Asset Management of Transformer fleets - An Overview

IEC 60296 (ed. 4) From a Transformer Oil Manufacturer's Perspective

Nils Herlenius
ERGON Europe

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.

ERGON
Naphthenic oils. That's our business.

TLM 2017, Transformer Life Management, Bangkok, Thailand

IEC 60296 (ed. 4)

From a Transformer Oil Manufacturer's Perspective

Nils Herlenius
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#29-11, S189767, Singapore
nils@ergon.com

Jimmy Rasco and Edward Casserly
Ergon, Inc.
Jackson, Mississippi 39215-1639, USA

ABSTRACT

This paper highlights some of the major updates in the latest 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 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 corrosive test method IEC 62535 [6], complimenting the already existing corrosive tests DIN 51353 [7] and ASTM 1275B [8].

In 2010 Cigre started the 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)

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

2.1 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 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 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 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 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 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 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 IEC 60296 (ed.4) all additives shall be declared.

An transformer oil that fully complies with the 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 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 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 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

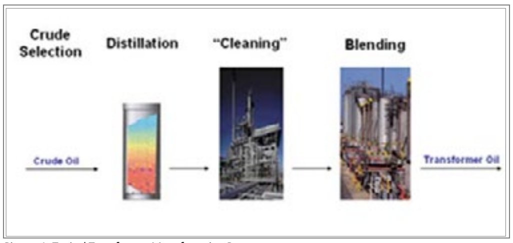
IEC 60296 (ed. 4) From a Transformer Oil Manufacturer's Perspective

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.

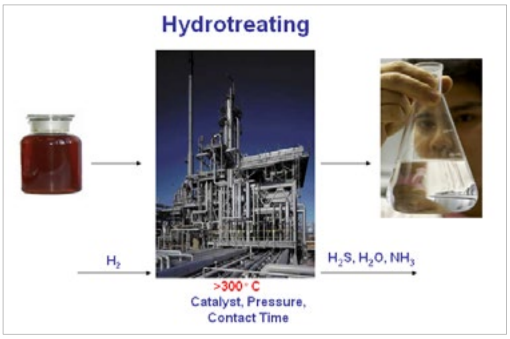
Compound		Boiling Point	Boiling Point
Thiophene		83 °C	183°F
Diethylsulfide	$(C_2H_5)_2S$	92 °C	198°F
Thiophenol		169°C	336°F
Benzothiophene		221°C	430°F
Dibenzyl-disulfide		270°C	518°F
Dibenzothiophene		332°C	630°F

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.



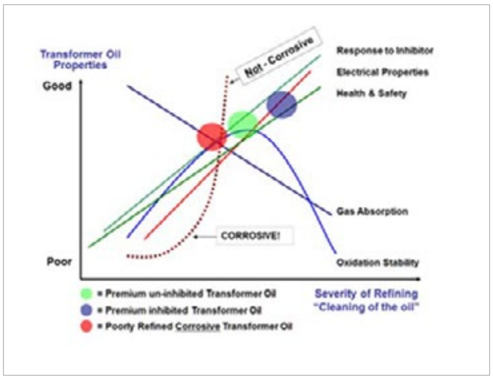
Picture 2: Cleaning the Transformer Oil Distillate by Hydrotreating

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 IEC 60296 (ed.4).

Parameter	Hydrotreating Process	Power Transformer
Pressure	261 KPA	10 - 100 KPA
	1800 PSIG	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 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 IEC 60296 (ed. 4) from 2012 compared to previous IEC 60296 (ed. 3) from 2003. The 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 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 IEC 60296 (ed.4) but it is not a substitute for the IEC 60296 (ed.4). It is therefore highly recommended that the user downloads the latest IEC 60296 from the IEC.

IEC 60296 (ed. 4) From a Transformer Oil Manufacturer's Perspective

TLM 2017, Transformer Life Management, Bangkok, Thailand

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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 more than 20 years in the transformer oil business. 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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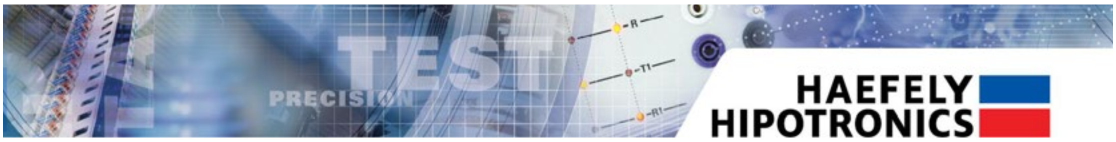
Mitigating Murphy´s Law While Test



ABSTRACT

Mitigating Murphy's Law While Test

Frédéric DOLLINGER, Haefely Hipotronics, Birsstrasse 300, CH-4052 Basel, Switzerland

1. Introduction

As Haefely Hipotronics, we have very large customer database around the world, in the manufacturing, utility, research & development and university sector, which are linked in the transformer, bushing, motor-generator, cable and capacitor industry.
Working close with our customers, we have seen or even sometime have surprisingly discovered situations, which the test was performed in an improper way: typically Murphy's Law. Various causes are involved, such as misinterpretation of standard (IEC/IEEE), or misinterpretation of the instrument settings, or inadequate instrumentation. Those can lead to unconform standard (IEC/IEEE) measurements or wrong measurement results, up to even damage the test object or test system. This presentation is a summary of what have been seen onsite, covering tests like partial discharge measurement, C/tanδ measurement, loss measurement and lightning impulse test.

2. Case Study:

For each group of test, most common case is studied with the mention of the cause of the fault, the fault, the consequence and the solution.

Test	Case Study
1: Partial discharge measurement	-Wrong PD setup connection
	-Wrong PD calibration process
	-Wrong setting of the PD detector
	-Misinterpretation of PD measurement
2: C/tanδ measurement	-Wrong connection setup due to multiple grounding point
	-Wrong UST/GST mode
	-Wrong accuracy class of the instrument compared to application
	-Wrong ambient condition
	-Wrong nominal capacitor
3. Loss measurement	-Wrong PT, CT and wattmeter class
	-Too high voltage THD during the measurement
	-Too high voltage asymmetry during the measurement
	-Slightly too high voltage during the measurement
4. Lightning impulse test	-Wrongly connected voltage divider
	-Wrong grounding setup
	-Too long distance between test object and impulse generator
	-Not updated measuring system
	-Wrong divider ratio

Conclusion:
This case study shares what has been seen and experienced over the last decade onsite, in order to **provide important insight** and to extrapolate key results that help **illuminate previously hidden issues**.

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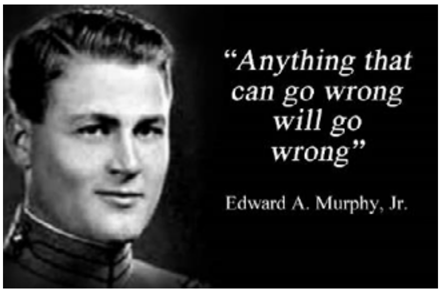

Frédéric Dollinger

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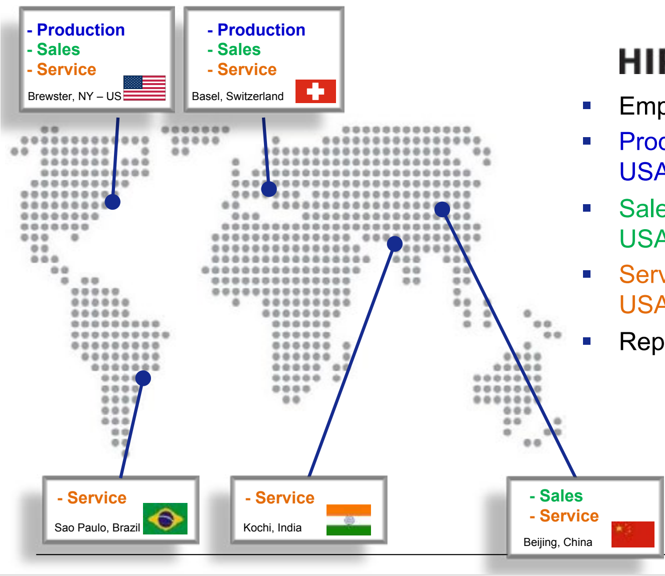

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- Employees: 200+
- Production Areas: USA, Switzerland
- Sales Centers: USA, Switzerland, China
- Service Points: USA, Switzerland, China, India
- Representatives: Worldwide

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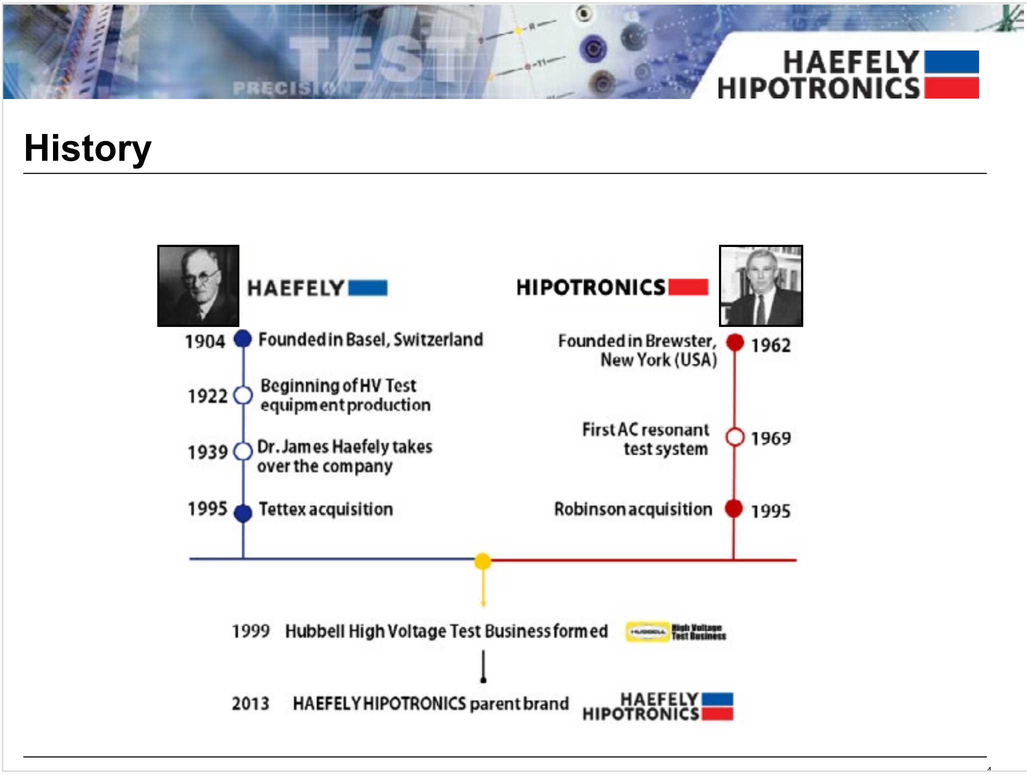

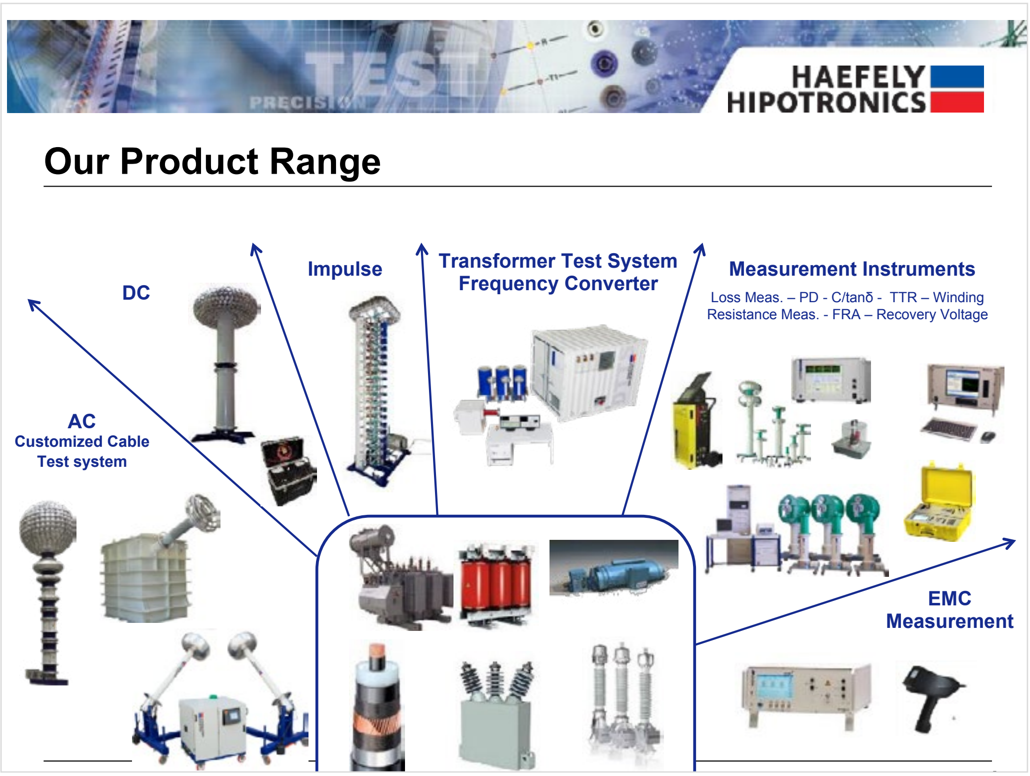

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Agenda

- Introduction to Murphy's Law
- Murphy's Law – Case Study
- Cases Study Analysis

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Introduction to Murphy's Law

7

Mitigating Murphy´s Law While Test

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Anything that can go wrong will go wrong

Synopsis

- The law's author was Edward A. Murphy, Jr., a U.S. Air Force engineer, who, in 1947, was involved in a rocket-led experiment in which all 16 accelerator instruments were installed in the wrong way, resulting in Murphy's observation.

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Case study

- **Origin:** this study shares what has been seen and experienced onsite from us
- **Target:** provide important insight and illuminate previously hidden issues
- **Systematic approach:** each case is studied with the mention of the fault, the cause of the fault, the consequence and the solution.

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Murphy's Law – Case Study

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Case Study: HV 1

Situation

Induced Voltage Test

Problem

C-Bank explosion

Factory on fire

Cause

C-Bank was in the test circuit during the induced voltage test

Consequence

72 kV / 200 Hz applied on a 20 kV 60 Hz C-Bank

Difficulty:
Low

Failure:
System

Can be avoided:
Yes

Dangerous:
Yes

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Mitigating Murphy´s Law While Test

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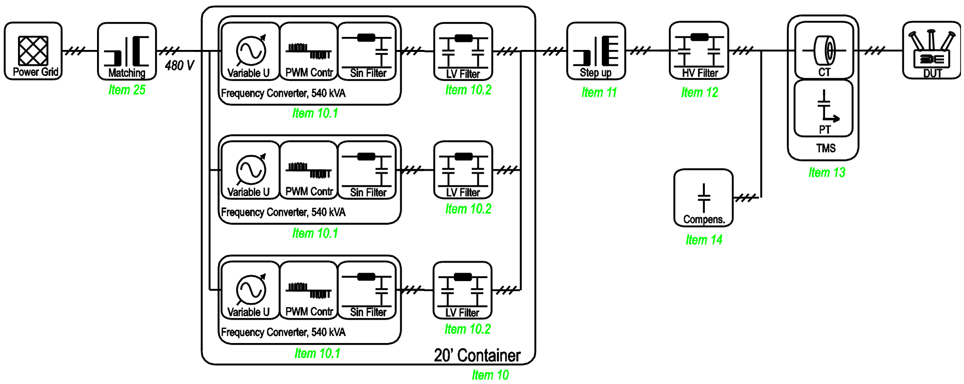
Case Study: HV 1

- Classic test system for induced voltage test, no load and load loss, heat run
- Typical example for heat run: 20 kV / 60 Hz
- Typical example for induced voltage test: 72 kV / 200 Hz



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Case Study: HV 1

- C-Bank fire is most of the time a dramatic situation, as the bank is installed inside the factory!

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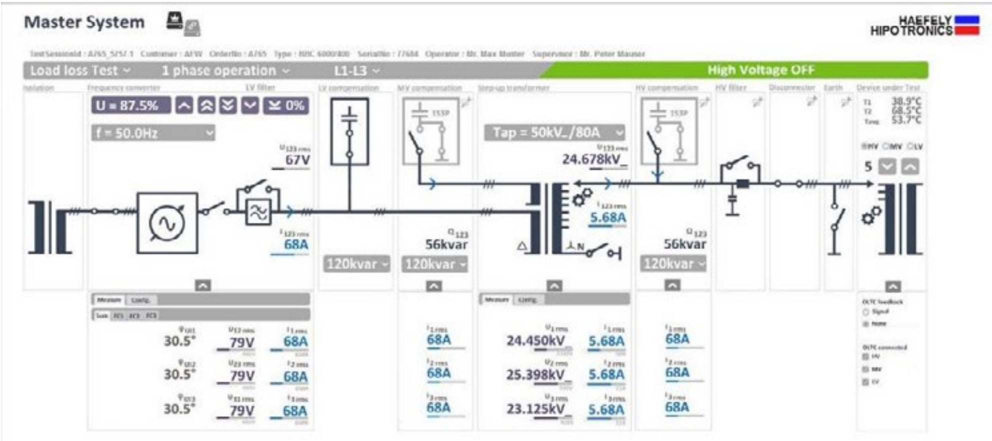
Case Study: HV 1

- Solution: overall test system intelligence should avoid dangerous situation!!



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Case Study: HV 2

Situation

Onsite DC Hipot on submarine cable

Problem

Ultra high voltage DC generator breaks down

Cause

Customer replaced the damping resistance, which was wrongly designed

Consequence

After cable break down, the flash went back to the DC generator, the damping resistance could not stop the high current and the DC generator breaks down

Difficulty:
Low

Failure:
human

Can be avoided:
Yes

Dangerous:
Yes

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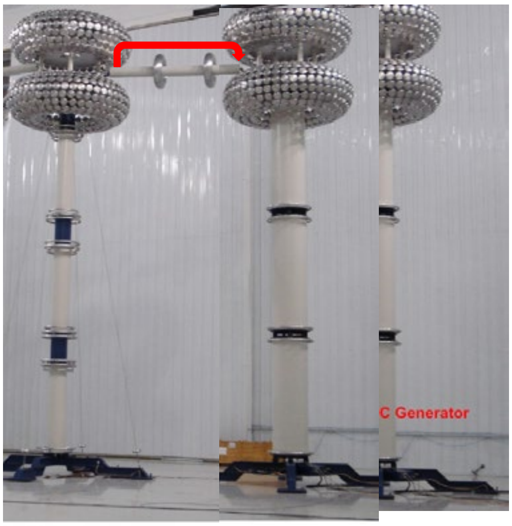
Case Study: HV 2



- Onsite test on a 35 km submarine cable
- The onsite test cabin was too small
- Customer decides the replace the damping resistor with a shorter damping resistor. (same resistance value!)
- DC hipot at 380 kV
- Breakdown of the cable
- Flash back with huge current to the damping resistor, the flash goes over the resistor and destroys the generator

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Case Study: HV 3

Situation	Problem
Applied voltage test	Flash
Cause	**Consequence**
Wrong divider ratio setting	Flash

Difficulty: *Low*

Failure: *Human*

Can be avoided: *Yes*

Dangerous: *Yes*

Mitigating Murphy´s Law While Test

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Case Study: HV 3

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Case Study: Imp 1

Situation

Impulse test on power transformer

Problem

Overlapping oscillation

Cause

Impulse generator too far from test object, no-air cushion to move it closer to the test object

Consequence

High loop inductance L_{loop}

Difficulty: *Low*

Failure: *System*

Can be avoided: *Yes*

Dangerous: *No*

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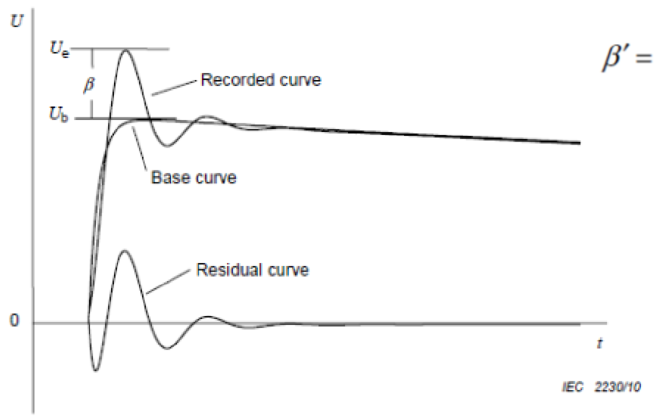
Case Study: Imp 1

- Relative overshoot magnitude **ß' shall not exceed 5%** (IEC 60076-3 ed3.0)



$$\beta' = 100 \cdot \frac{U_e - U_b}{U_e} \quad \%$$

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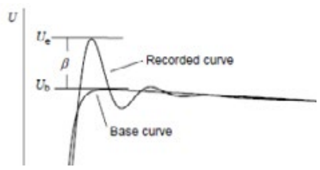
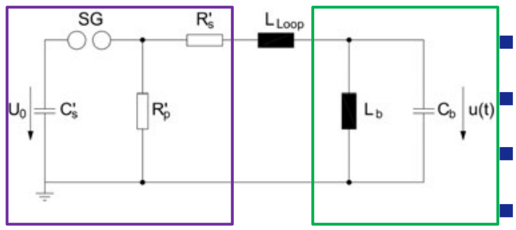
Case Study: Imp 1

- Usual test setup for LI test
- The higher L_{loop}, the higher overlapping oscillation





- C'_s: resulting impulse capacitance
- R'_s: Front (series) resistor
- R'_p: Tail (parallel) resistor
- L_{loop}: inductance of test circuit
- L_b: inductance of transformer
- C_b: capacitance of transformer

Mitigating Murphy´s Law While Test

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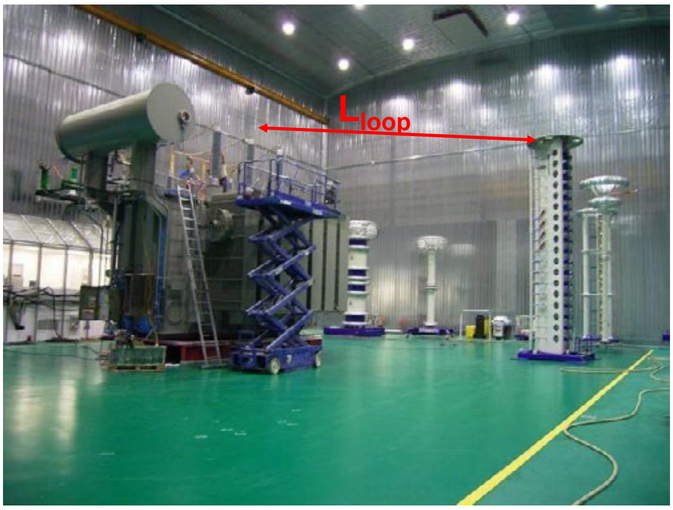
Case Study: Imp 1

- Solution: have an impulse generator with air cushion



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Case Study: Imp 1

- Solution: have an impulse generator with air cushion

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HAEFELY HIPOTRONICS

Case Study: Imp 2

Situation

LI test on power transformer, on the low voltage side

Problem

Tail time t_2 too short, out of the IEC 70076.3 ed 3.0 specification

Cause

Very low transformer winding inductance

Consequence

Short Tail time t_2
Does not fulfill IEC 70076.3 ed 3.0

Difficulty:
Low

Failure:
System

Can be avoided:
Yes

Dangerous:
No

HAEFELY HIPOTRONICS

Case Study: Imp 2

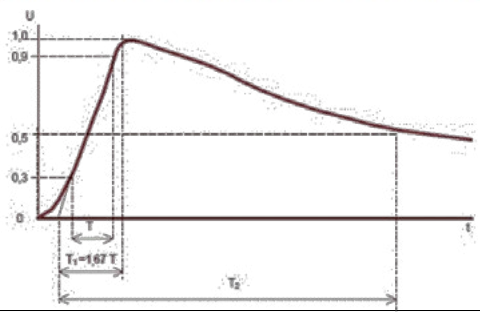
- IEC 60076-3 ed 3.0

13.2 Full wave lightning impulse test (LI)

13.2.1 Wave shape, determination of test voltage value and tolerances

The test impulse shall be a full standard lightning impulse 1,2 ± 30 % / 50 µs ± 20 %..

The test voltage value shall be the test voltage value as defined in IEC 60060-1 (after the test voltage function is applied). If the maximum relative overshoot magnitude is 5 % or less, the test voltage value may be taken as the extreme value as defined in IEC 60060-1.



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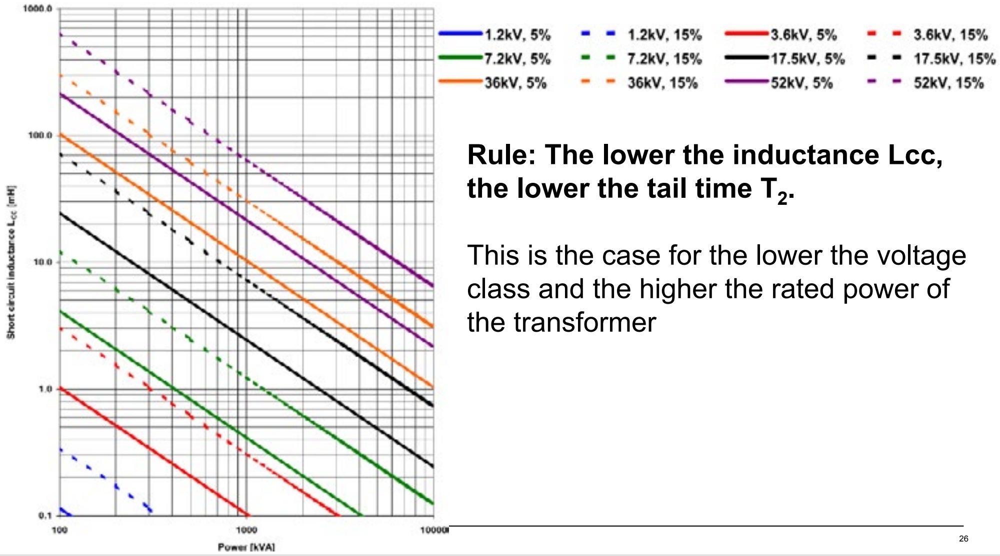
HAEFELY HIPOTRONICS

Case Study: Imp 2



Rule: The lower the inductance Lcc, the lower the tail time T_2.

This is the case for the lower the voltage class and the higher the rated power of the transformer

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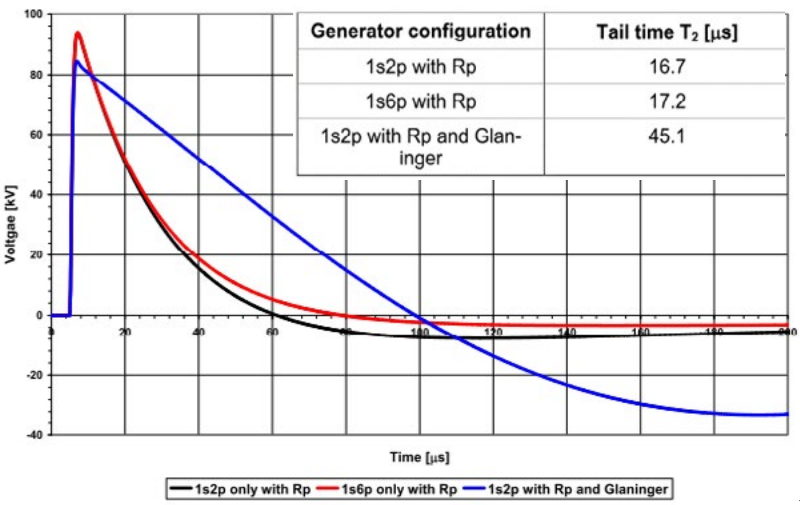
HAEFELY HIPOTRONICS

Case Study: Imp 2



Generator configuration	Tail time T_2 [µs]
1s2p with Rp	16.7
1s6p with Rp	17.2
1s2p with Rp and Glan-inger	45.1

- C_b: 13nF
- L_b: 1.1mH

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Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

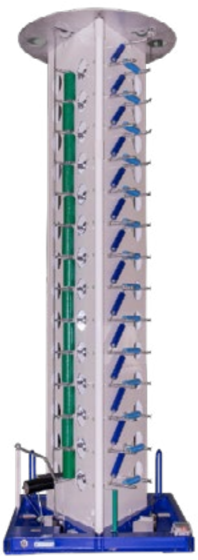
Case Study: Imp 2

Generator configuration	Tail time T_2 [µs]
1s2p with Rp	16.7
1s6p with Rp	17.2
1s2p with Rp and Glan-inger	45.1

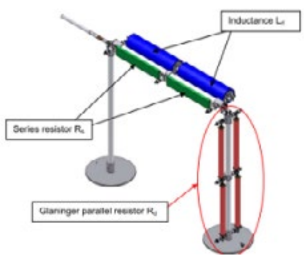
- Even with more capacitance, T_2 would not rise
- Glaninger: T_2 is 270 % higher as with the 1s2p config.
- **Glaninger is the smart solution**

HAEFELY HIPOTRONICS

Case Study: Imp 2



- Solution: Glaninger Circuit



HAEFELY HIPOTRONICS

Case Study: Imp 3

Situation

Impulse voltage test

Problem:

During the impulse generator configuration:
low / medium energy discharge to the operator

Cause

Capacitor was not grounded after use; the capacitor is charging alone back due to internal polarization phenome

Consequence

Risk of low / medium discharge to the operator, risk to fall down from the sky lift

Difficulty:
Low

Failure:
System

Can be avoided:
Yes

Dangerous:
Yes

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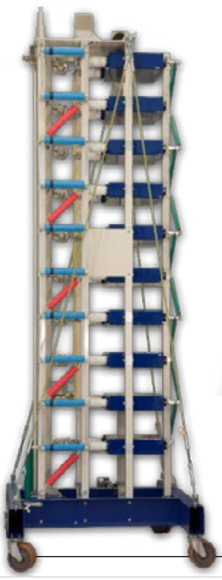
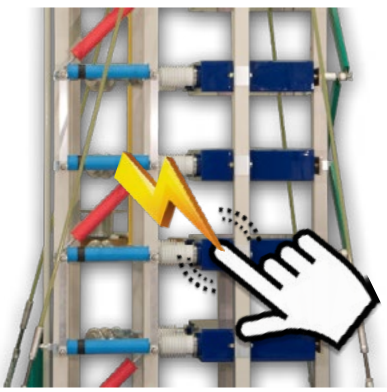
HAEFELY HIPOTRONICS

Case Study: Imp 3





Caution without grounding:
Risk of discharge!

the capacitor is charging alones back due to internal polarization phenome

Cap.: 1-3 uF / 100 KV

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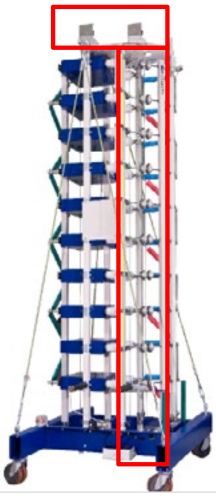
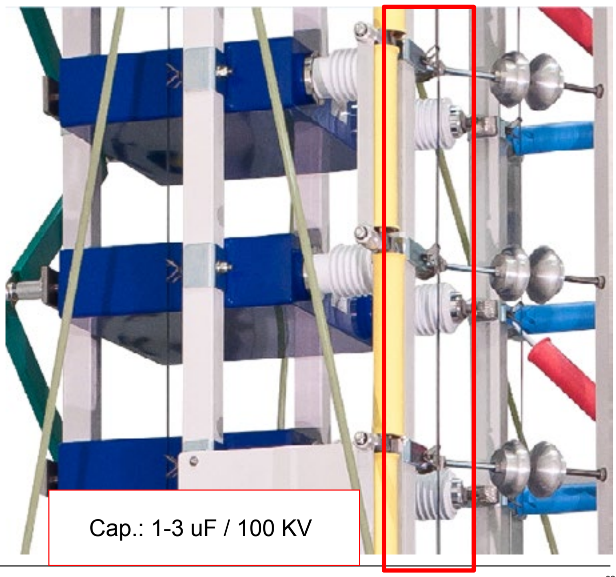
HAEFELY HIPOTRONICS

Case Study: Imp 3

Solution: Auto. grounding





HAEFELY HIPOTRONICS

Case Study: PD 1

Situation

PD measurement

Problem

Flash

Cause

Floating coupling capacitor

Consequence

Flash between divider and ground

Difficulty:
High

Failure:
Human

Can be avoided:
Yes - no

Dangerous:
Yes

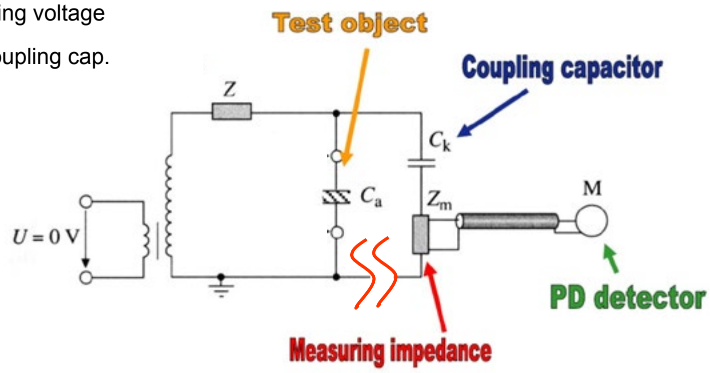
HAEFELY HIPOTRONICS

Case Study: PD 1

HAEFELY HIPOTRONICS

Case Study: PD 1

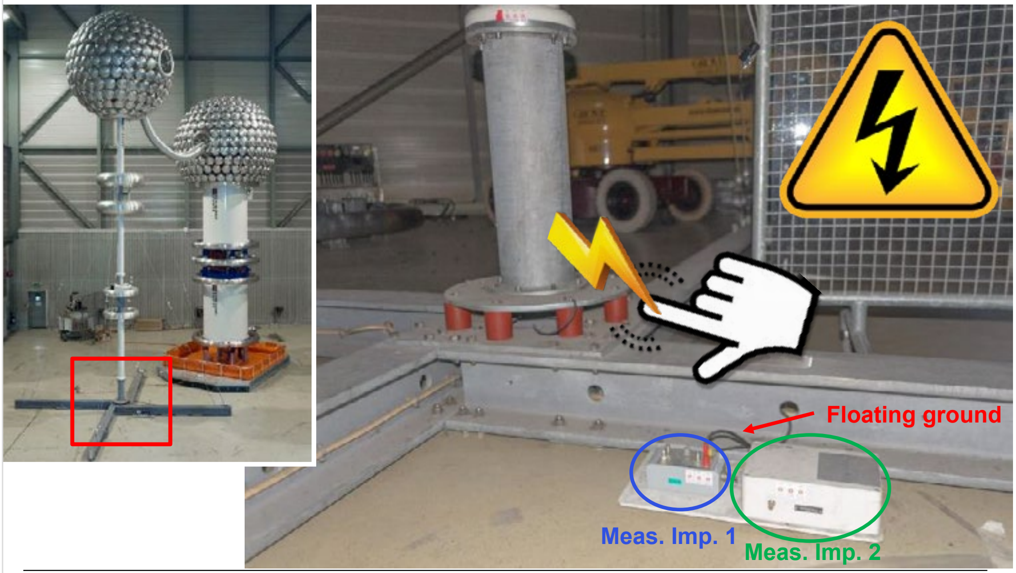
- Usual test setup: AC source + coupling capacitor + meas. Imp. + PD detector
- Test engineer has 2 PD detectors / measuring impedances (end user request)
- He changes the measuring impedance and forgets to ground it
- Coupling capacitor is floating
- Flash occurs while rising voltage
- After power off, the coupling cap. remains charged: dangerous situation



Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

Case Study: PD 1



HAEFELY HIPOTRONICS

Case Study: PD 2

Situation	Problem:
PD Measurement on transformer	Wrong PD values/measurement
Cause	**Consequence**
Operator did not calibrate the measuring circuit for each new test object	Each test object has different capacitance, which makes impossible to know the PD amplitude

Difficulty: *Low*

Failure: *Human*

Can be avoided: *Yes*

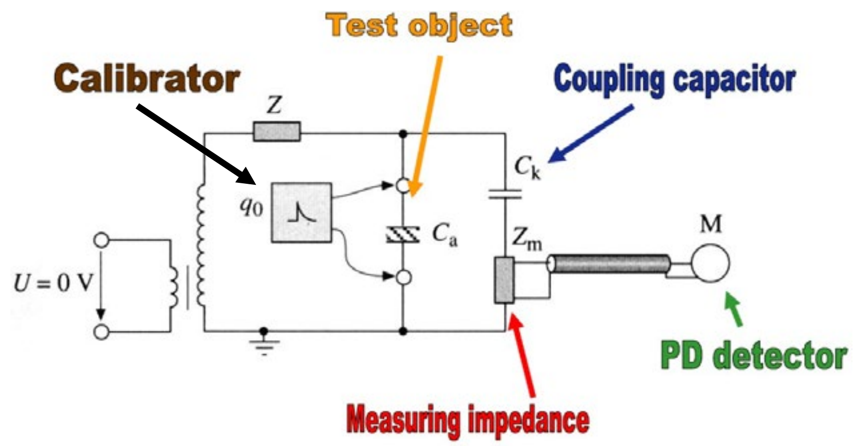
Dangerous: *No*

Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

Case Study: PD 2

- Calibration procedure: inject an know q_0 impulse and adjust the ratio at the detector.



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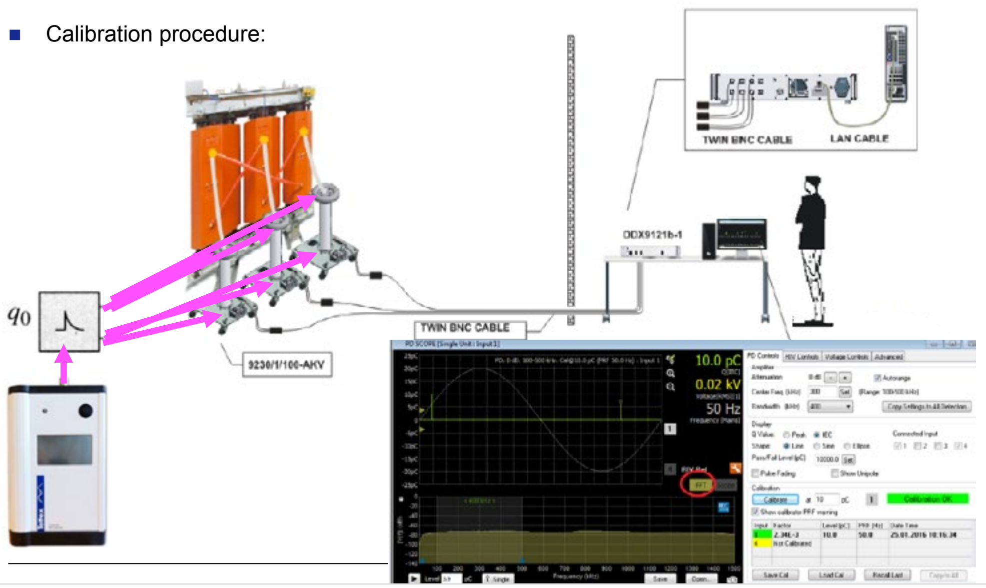
HAEFELY HIPOTRONICS

Case Study: PD 2

- Calibration procedure:



Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

Case Study: PD 3

Situation	Problem:
PD Measurement on transformer	High PD values/measurement
Cause	**Consequence**
Fixed dead time leading to ambiguous recognition of partial discharge pulse	Partial discharge undershoot is interpreted as pulse

Difficulty:
Medium

Failure:
System

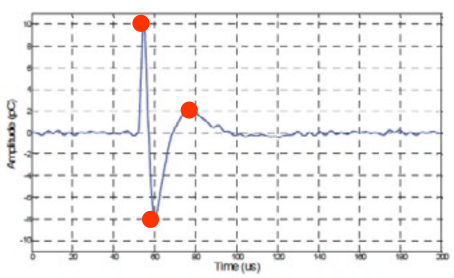
Can be avoided:
Yes

Dangerous:
No

HAEFELY HIPOTRONICS

Case Study: PD 3

- Dynamic dead time VS fixed dead time



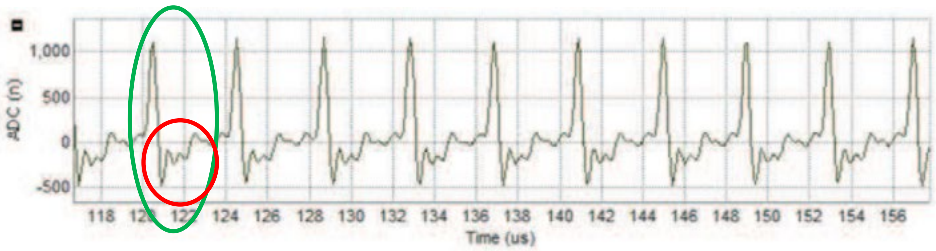
- Dynamic dead time: 1 pulse
- Fixed dead time: up to 3 pulses

Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

Case Study: PD 3

- Typical situation:



- This is one partial discharge pulse
- Dead time: time to blind out the undershoot

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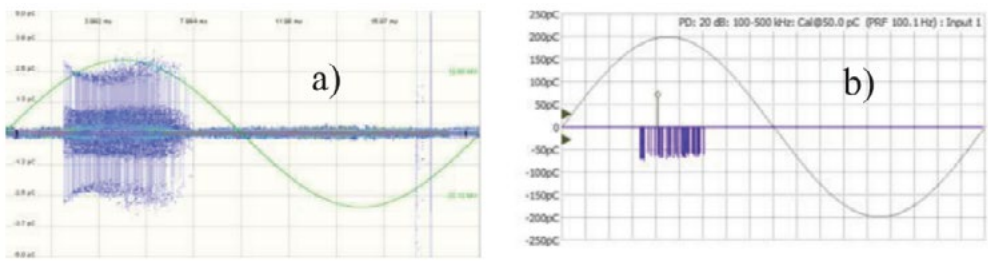
HAEFELY HIPOTRONICS

Case Study: PD 3

- Dynamic dead time VS fixed dead time:



- Pulse polarity:
  - a) ambiguous recognition due to **fixed** dead time, wrongly set
  - b) distinct recognition without ambiguity, thanks to **dynamic** dead time (automatic)

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HAEFELY HIPOTRONICS

Case Study: PD 3

- Dynamic dead time VS fixed dead time:
  - Challenge with fixed dead time settings: each PD source might need another setting!
  - Inner PD source
    - Internal cavity/void in insulating material
    - Air bubbles in oil
    - Non-uniformities in SF6 insulation system
  - Outer PD source:
    - Corona
    - Surface (gliding/creeping discharges)

HAEFELY HIPOTRONICS

Case Study: PD 4

Situation

PD Measurement on transformer

Problem:

Wrong PD measurement

Cause

Measurement out of the IEC standard measurement band (higher frequency range)

Consequence

On the higher frequency range, the PD activity is not visibile anymore

Difficulty:
Low

Failure:
System / human

Can be avoided:
Yes

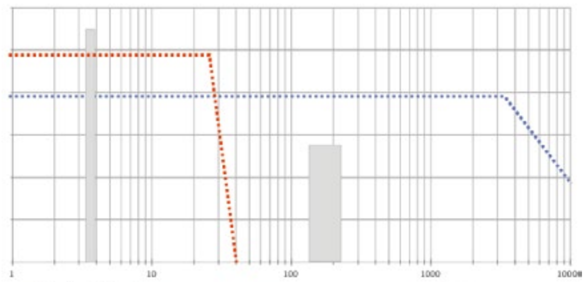
Dangerous:
No

Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

Case Study: PD 4

- Wide-band PD instruments (chapter 4.3.4 in IEC 60270:2015)
  - 30 kHz ≤ f1 ≤ 100 kHz,
  - f2 ≤ 1000 kHz
  - 100 kHz ≤ Δf ≤ 900 kHz
  - PD pulse loses high frequency content while travelling thru transformer



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HAEFELY HIPOTRONICS

Case Study: WR 1

Situation	Problem	Difficulty: Low
Onsite winding resistance measurement on power transformer	At transformer reconnection, the substation switches off	Failure: System
Cause	**Consequence**	Can be avoided: Yes
The winding resistance is a DC measurement. The core remains magnetized after measurement	-Magnetized core -DC offset -Inrush current -Substation switches off	Dangerous: Yes

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Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

Case Study: Loss 1

Situation	Problem
Load Loss measurement on a power transformer	Higher loss readings
Cause	**Consequence**
Wrong accuracy class of the Wattmeter	Small power factor leads to high loss error readings

Difficulty:
Low

Failure:
System

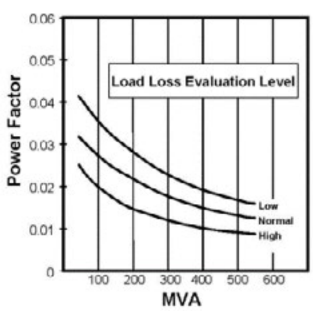
Can be avoided:
Yes

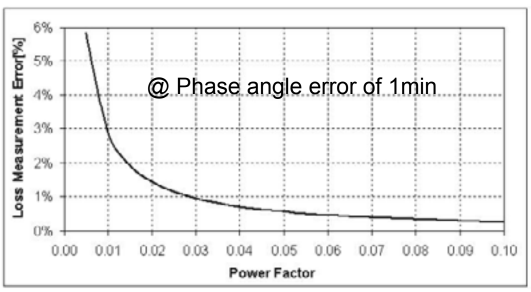
Dangerous:
No

HAEFELY HIPOTRONICS

Case Study: Loss 1

- Phase angle error of 1min in the voltage or current will result in approx. 3 % error in loss meas. for a power factor of 0.01
- **Load loss at low power factor are very sensitive to phase angle errors**





IEEE Std C57.123-2010 [4.3]

Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

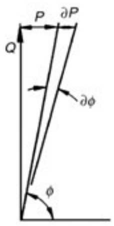
Case Study: Loss 1

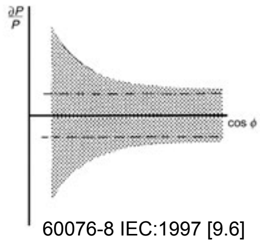
- During meas: the transformer behaves inductive
- Power factor tends to fall with rising values of rated power
  - Typical example:
    - **1'000 kVA** transformer: load loss 1 %, short circuit impedance 6 % of ref. impedance – power factor of the series impedance: **0.167**
    - **100 MVA transformer**: load loss 0.4 %, short circuit impedance 15 % of ref. impedance – power factor of the series impedance: **0.027**

$$P = U \times I \times \cos\phi$$

$$\frac{\partial P}{P} = \frac{\partial U}{U} + \frac{\partial I}{I} - \frac{\sin\phi}{\cos\phi} \times \partial\phi$$

$$-\frac{\sin\phi}{\cos\phi} = -\frac{\left(1-\cos^2\phi\right)^{\frac{1}{2}}}{\cos\phi} \approx -\frac{1}{\cos\phi}$$





60076-8 IEC:1997 [9.6]

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HAEFELY HIPOTRONICS

Case Study: Loss 1

- IEC 60076-8:1997

10.2 *Traceability, quality aspects on measuring technique*

Traceability of measurements means that a chain of calibrations and comparisons have been carried out, through which the validity of the individual measurement can be traced back to national and international standards of units preserved in recognized institutions of metrology. Evidence of such traceability should contain the following items.

a) Certified information about errors (amplitude errors and phase angle errors) of the components of the measuring system (transducers for voltage, current and power, voltage dividers and shunts, indicating or recording instruments, etc.)

This may comprise:

– certificates from the manufacturers of individual components;

– certification from calibrations carried out at independent precision laboratories;

– certificates of calibrations made in the plant by means of precision instrumentation and specialist staff brought there for that purpose;

– direct comparisons of the test room installation with a complete precision measuring system (overall system calibration).

Power Factor	Components Accuracy [1]		Overall System Accuracy [1]		Range
	Standard [2]	Extended [3]	Standard [2]	Extended [3]	
cos φ = 1.0	± 0.15%	± 0.06%	± 0.35%	± 0.3%	105V/√3V .. 4200V/√3V; 0.5A .. 500A
cos φ = 0.5	± 0.5%	± 0.12%	± 0.7%	± 0.3%	105V/√3V .. 4200V/√3V; 0.5A .. 500A
cos φ = 0.3	± 0.79%	± 0.16%	± 1.2%	± 0.4%	105V/√3V .. 4200V/√3V; 0.5A .. 500A
cos φ = 0.1	± 2.14%	± 0.36%	± 3%	± 1.2%	105V/√3V .. 4200V/√3V; 0.5A .. 500A
Voltmeter	Class 0.1				Ratio 3500V/√3 : 100V Range 105V/√3..4200V/√3 (3%..120%)
Currentmeter	Class 0.1				0.5A .. 500A

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HAEFELY HIPOTRONICS

Case Study: Loss 2

Situation	Problem
No Load Loss measurement on a distribution transformer	Higher loss readings
Cause	**Consequence**
Deviation on the excitation voltage	Higher loss readings

Difficulty:
Low

Failure:
System

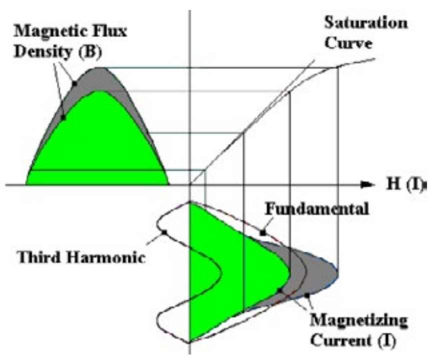
Can be avoided:
Yes

Dangerous:
No

HAEFELY HIPOTRONICS

Case Study: Loss 2

- **1% deviation on the applied voltage would increase 1% to 3 % the losses**
- **Solution: accurate voltage output** (step less adjustment, feedback loop with the measurement)



During no load loss measuring, the transformer is in the saturation working area

Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

Case Study: Loss 3

Situation	Problem
No Load Loss measurement on a distribution transformer	Higher loss readings
Cause	**Consequence**
High THD on the voltage waveshape	Higher loss readings

Difficulty:
Low

Failure:
System

Can be avoided:
Yes

Dangerous:
No

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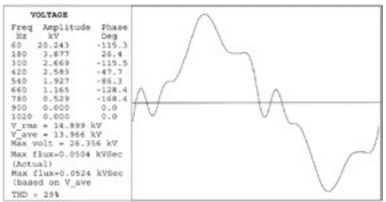
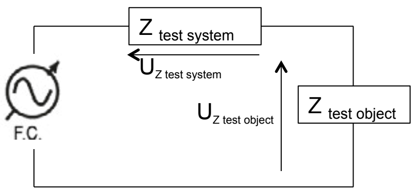
HAEFELY HIPOTRONICS

Case Study: Loss 3

- **T.H.D.:** Total Harmonic Distortion
- IEC 60076-1:2011 [11.1.1]: Voltage: THD < 5%
- **T.H.D. cause:**
  T.H.D. on the voltage waveshape comes mainly from the short circuit impedance of the test system
- **T.H.D. problem**:
  Peaked waves with higher r.m.s. **can lead to higher losses**





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Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

Case Study: Loss 3

Example on a 2'500 kVA, 33 kV / 400 V transformer

- Without THD Control

- With THD Control

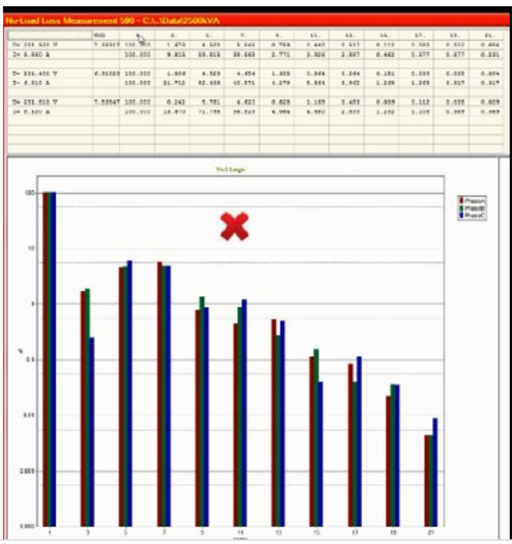
3% Difference

HAEFELY HIPOTRONICS

Case Study: Loss 3

Example on a 2'500 kVA, 33 kV / 400 V transformer

Without THD Control



With THD Control

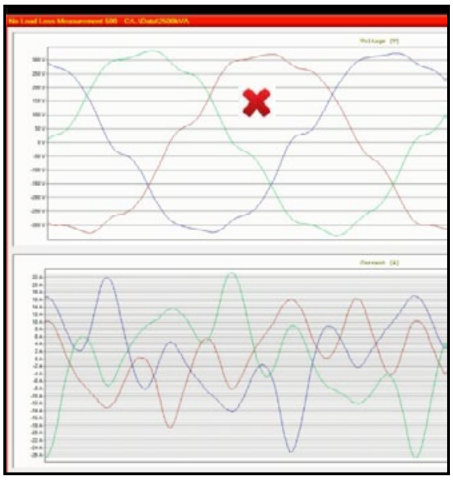
Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

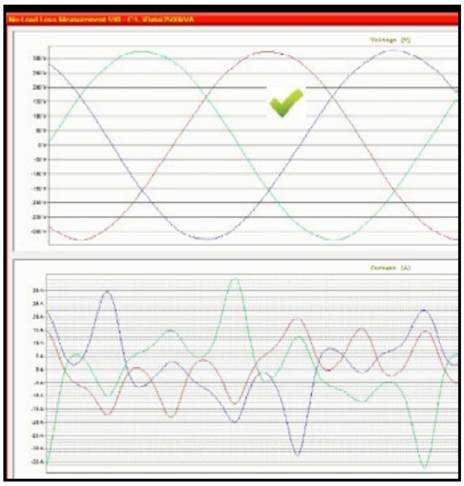
Case Study: Loss 3

Example on a 2’500 kVA, 33 kV / 400 V transformer

Without THD Control



With THD Control



HAEFELY HIPOTRONICS

Case Study: Loss 4

Situation	Problem
No Load Loss measurement on a distribution transformer	Higher loss readings
Cause	**Consequence**
Unsymmetric voltage waveshape	Higher loss readings

Difficulty:
Low

Failure:
System

Can be avoided:
Yes

Dangerous:
No

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HAEFELY HIPOTRONICS

Case Study: Loss 4

Example on a 2'500 kVA, 33 kV / 400 V transformer

- Without Symmetry Control

- With Symmetry Control

3% Difference

HAEFELY HIPOTRONICS

Case Study: Loss 5

Situation	Problem
No Load Loss measurement on a transformer	Higher loss readings
Cause	**Consequence**
Magnetized core	Higher loss readings

Difficulty:
Low

Failure:
Human

Can be avoided:
Yes

Dangerous:
No

Mitigating Murphy´s Law While Test

Case Study: Loss 5

- Prehistory of magnetization
  - Remanence in the core after saturation during winding resistance meas. or by unidirectional long-duration impulses, may leave a trace in the no load loss meas.
  - A systematic demagnetization of the core before no load meas. is recommended to establish representative results

IEEE Std C57.123-2010 [3.2.2]
60076-8 IEC:1997 [9.6]

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Case Study: Loss 5

- ABB Book: ABB_2010_Testing of Power Transformers and Shunt Reactors, Routine Type and Special Tests, page 72 - the No-Load loss:

Before the loss measurements actually take place the transformer to be tested must be excited by 1,1 to 1,15 times rated voltage. The over-excitation reduces the effects of remanence caused by DC current excitation during resistance measurements or from the switching impulse. The correct no-load loss cannot be seen until there have been several cycles of the magnetizing characteristic. During this process the readings of the ammeters and wattmeter decrease. When the measured figures are steady, the actual loss measurements can start.

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Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

Case Study: FRA

Situation

FRA Measurement on power transformer

Problem:

Measurement differs from reference

Cause

Multiple: Oil, magnetization, connection, temperature

Consequence

FRA shows deviation

Difficulty:
Medium - High

Failure:
human

Can be avoided:
Yes

Dangerous:
No

HAEFELY HIPOTRONICS

Case Study: FRA

- Power Transformer filled with different oil onsite as at the factory

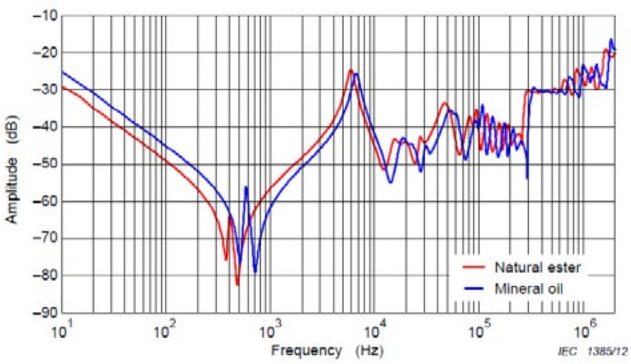

Figure B.12 – Effect of different types of insulating fluid on frequency response

Ref: IEC 60076-18 ed 1.0

Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

Case Study: FRA

- Power transformer measured onsite before filling the oil

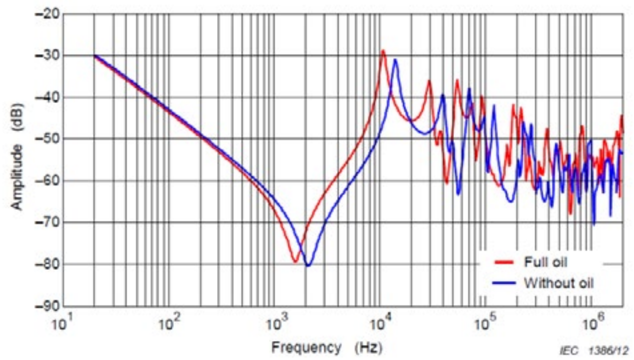

Figure B.13 – Effect of oil filling on frequency response

Ref: IEC 60076-18 ed 1.0

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HAEFELY HIPOTRONICS

Case Study: FRA

- Power transformer measured after winding resistance measurement without demagnetization

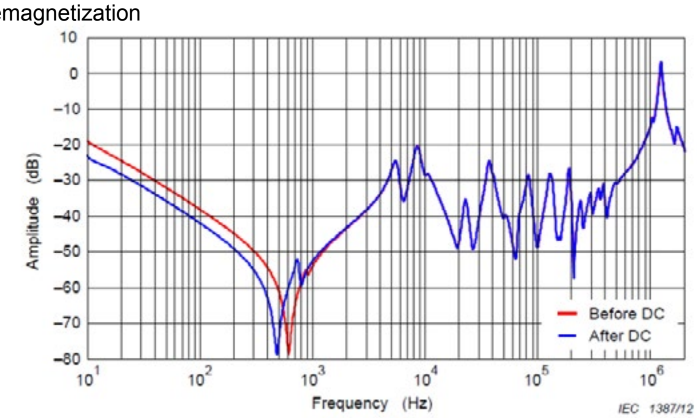

Figure B.14 – Effect of a DC injection test on the frequency response

Ref: IEC 60076-18 ed 1.0

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Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

Case Study: FRA

- Power transformer measured at different temperature

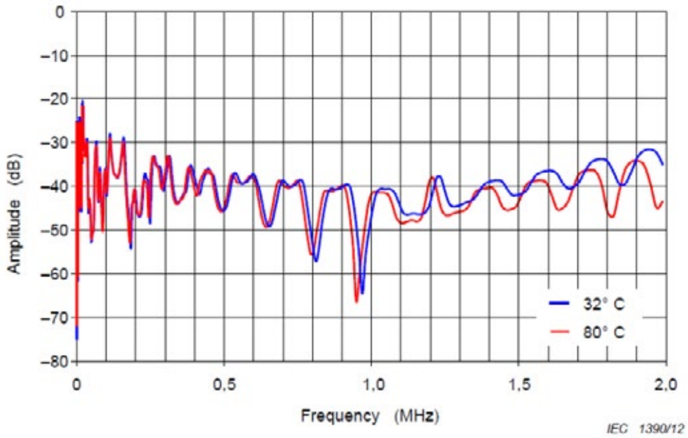


Figure B.16 – Effect of temperature on frequency response

Ref: IEC 60076-18 ed 1.0

HAEFELY HIPOTRONICS

Case Study: FRA

- Power transformer measured with bad connection

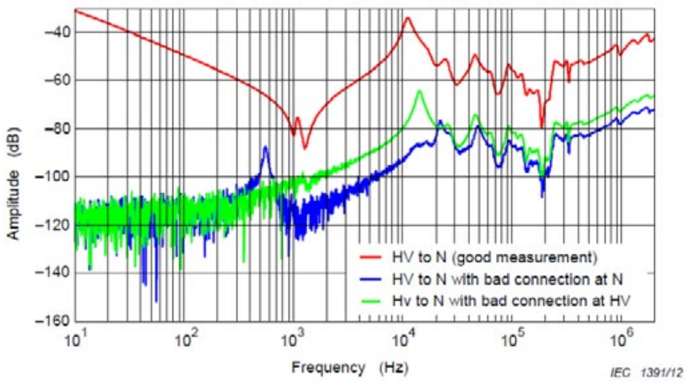


Figure B.17 – Examples of bad measurement practice

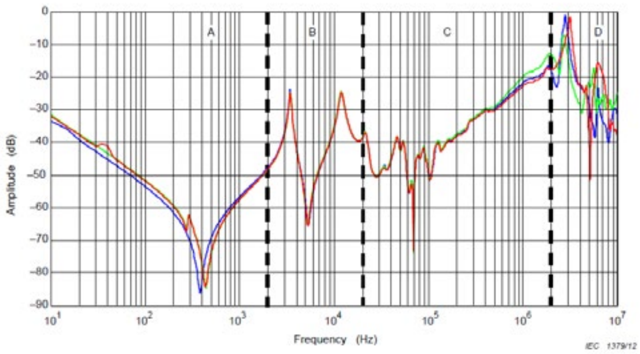
Ref: IEC 60076-18 ed 1.0

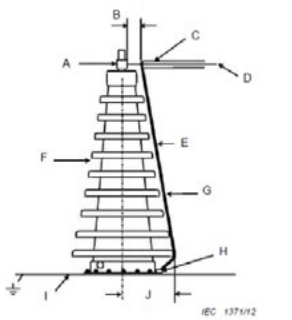
Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

Case Study: FRA

At the highest frequencies of above 1 MHz (> 72,5 kV) or above 2 MHz (≤ 72,5 kV), the response is less repeatable and is influenced by the measurement set-up, especially by the earthing connections, which effectively relies on the length of the bushing.





Influence regions:

- A core
- B interaction between windings
- C winding structure
- D measurement setup and lead (including earthing connection)

- A connection clamp
- B unshielded length to be made as short as possible
- C measurement cable shield
- D central conductor
- E shortest braid
- F bushing
- G earth connection
- H earth clamp
- I tank
- J smallest loop

Ref: IEC 60076-18 ed 1.0

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HAEFELY HIPOTRONICS

Case Study: PF 1

Situation Power factor measurement on transformer	**Problem:** Wrong measurement	*Difficulty:* *Low* *Failure:* *human*
Cause Dirty bushing	**Consequence** Leakage current increases the power factor	*Can be avoided:* *Yes* *Dangerous:* *No*

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Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

Case Study: PF 1

HAEFELY HIPOTRONICS

Case Study: PF 2

Situation Power factor measurement on transformer	**Problem:** Wrong measurement	*Difficulty:* *Low* *Failure:* *human*
Cause High humidity during the measurement (morning, after rain, snow, etc…)	**Consequence** Leakage current increases the power factor	*Can be avoided:* *Yes* *Dangerous:* *No*

Mitigating Murphy´s Law While Test

Case Study: PF 2

- Rules of dump
  - 65 % rel. humidity: 10 x higher leakage current
  - 80 % rel. humidity: 100 x higher leakage current
  - 95% rel. humidity: 1000 x higher leakage current

- Depending on the test object, leakage current can have a large impact. We do not recommend to measure above 65 % - 80 % rel. humidity

HAEFELY HIPOTRONICS

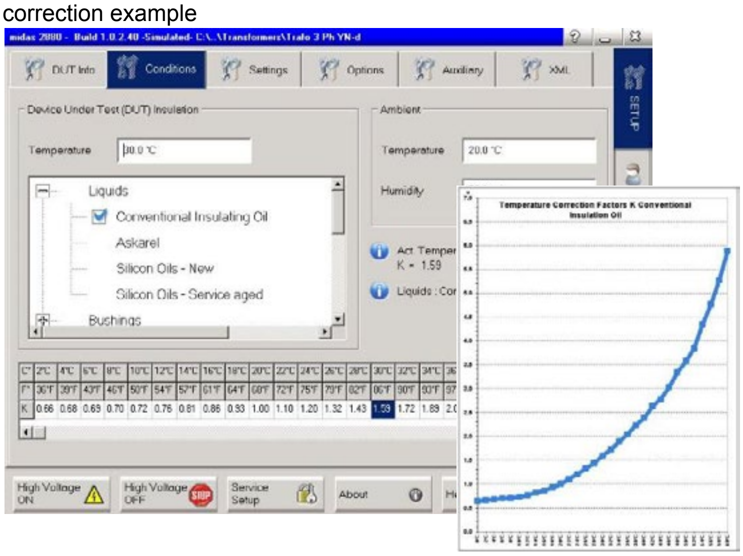
Case Study: PF 3

Situation Power factor measurement on transformer	**Problem:** Wrong measurement	*Difficulty:* *Low* *Failure:* *human*
Cause Wrong temperature correction	**Consequence** Temperature correction depends on the test object. A wrong setup gives high deviation	*Can be avoided:* *Yes* *Dangerous:* *No*

HAEFELY HIPOTRONICS

Case Study: PF 3

- Temperature correction example



HAEFELY HIPOTRONICS

Case Study: PF 4

Situation	Problem:
Power factor measurement on transformer	Impossible to perform correct measurement
Cause	**Consequence**
GST setup is needed, but the power supply is not compatible	If the power supply does not have a separate ground output, is it impossible to perform a GST measurement.

Difficulty:
Low

Failure:
System

Can be avoided:
Yes

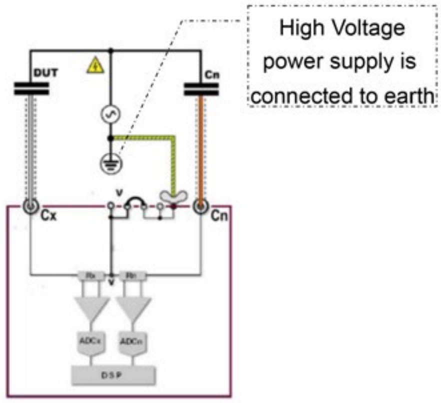
Dangerous:
No

Mitigating Murphy´s Law While Test

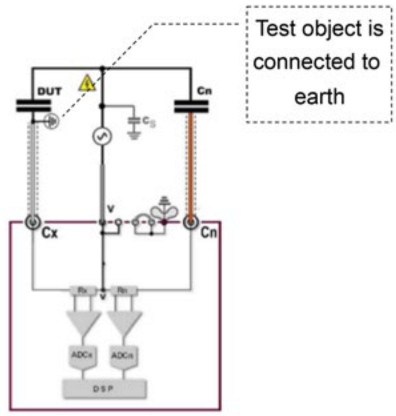
HAEFELY HIPOTRONICS

Case Study: PF 4

- UST and GST test setup:



Ungrounded specimen test **UST**



Grounded specimen test **GST**

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HAEFELY HIPOTRONICS

Cases Study Analysis

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Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

Anything that can go wrong will go wrong,

But all situations could have been avoided!!!!!!!!

HAEFELY HIPOTRONICS

Technology level

- If a system is the cause of a fault, upgrading the system would be the solution

Better technology will avoid system failure!

Mitigating Murphy´s Law While Test

HAEFELY HIPOTRONICS

Safety

- Half of the dangerous situations are caused by the system technology. Upgrading the system would fix the problem.

Think safety first and if requested upgrade the system!

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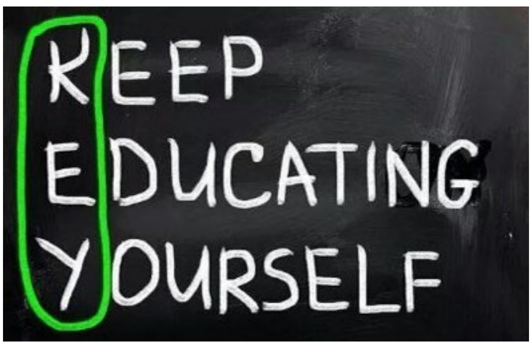
HAEFELY HIPOTRONICS

Knowledge

- Half of the problems are linked to operator knowledge. Read the user manual first and get trained!



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Mitigating Murphy´s Law While Test

Chian Yaw Toh

Nynas Pte Ltd

Chian Yaw started to work for Nynas Pte Ltd (Singapore) in May 2008. During the period of 2008-2014, he worked as Regional Sales Manager for South East Asia and parts of North East Asia, including Taiwan and Japan. Starting January 2015, Chian Yaw embarked on his new role as Head of Technical Development & Market Support for Asia Pacific, and continued to be based in Singapore. This position covers a variety of applications for Nynas specialty mineral oils and particularly that of insulating oils.

Prior to working in Nynas, Chian Yaw has worked in several application developments, technical and commercial roles with Eastman Chemicals, Dow Chemicals, DuPont Dow Elastomers, 3M and ICI Polyurethanes.

Chian Yaw received his Bachelor Degree in Chemical Engineering from the National University of Singapore. He also has a Master Degree in Business Administration from the Royal Melbourne Institute of Technology, Australia.

Properties of aging mineral insulating oils in service

Mr. C.Y. Toh, Nynas Pte Ltd, Singapore
Dr. B. Pahlavanpour, Nynas Naphthenics Ltd, United Kingdom
Mr. J. Nunes, Nynas Ltda, Brazil

Abstract

The electricity grid infrastructure in the hitherto industrialized world was to a large extent built up with a peak in investments around 1960-1980. This means that a flotilla of power transformers is now starting to reach projected lifetime of around 40 years. During the last couple of decades, there has also been an ongoing deregulation and privatization of electricity generation and distribution which has led to higher utilization of existing equipment. The demand for planned asset management, investments and reliability of power delivery, has also increased. To ensure that aging equipment is working satisfactory and will do so for yet some time, there has been a growing interest in aging behaviour of power equipment. Yet, there is little information openly available on how the insulating materials in transformers behave over longer periods of time. Such information is valuable both from the perspective of transformer maintenance/asset management, and as background data to make informed choices on which type of insulating liquid to employ in new equipment.

In this study, there is a total of 144 individual samples from separate transformers (all samples collected around the same time for analysis), of which 113 are inhibited and 31 uninhibited. The inhibited oil samples came from transformers in the Nordic region, whereas the uninhibited samples came mainly from the Middle East. The transformers ages span from only a few years up to 45 years. The samples were analysed for acidity, interfacial tension, dielectric loss (DDF) and peroxide content. The inhibited samples were also analysed for inhibitor content. These parameters except peroxide content are standard measurements, but little information exists on how they relate to each other statistically. The peroxide measurements were performed according to a method Nynas developed and which should tell us more about the oxidation behaviour and the efficiency of oxidation inhibitors. From one point of view, it makes sense to treat all samples together regardless of whether they are of inhibited or uninhibited type (or trace inhibited). After all, both types are mineral oils with some sort of built-in system to fight oxidation. In the case of inhibited oils, it is mainly the added antioxidant (inhibitor) that fulfils this function. In the uninhibited oils, it is natural organic sulphur compounds resulting from a specific refining process and which serves the same function.

From the standards governing the oxidation stability properties of insulating oil (such as IEC 60296 and ASTM D3487), it is easy to measure in the laboratory the increasing oxidation stability performance from uninhibited to trace inhibited to inhibited oils. However, one question this paper is looking at is whether the same observations can be made for oil in service.

Material Testing with VLF on Transformers

Jürgen Jakober
b2 High Voltage

Continuous Condition Monitoring of Insulation Oils in HV Transformers

OilQSens®

TLM Conference
Bangkok Nov. 2017

Mr. Juergen Jakober
b2 electronic GmbH

Content:
Dr.-Ing. Manfred R. Mauntz
Dr. rer. nat. Jörn Peuser
cmc Instruments GmbH

High-Voltage

Jürgen Jakober
b2 electronic GmbH

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

Mr. Jürgen Jakober
Sales Director

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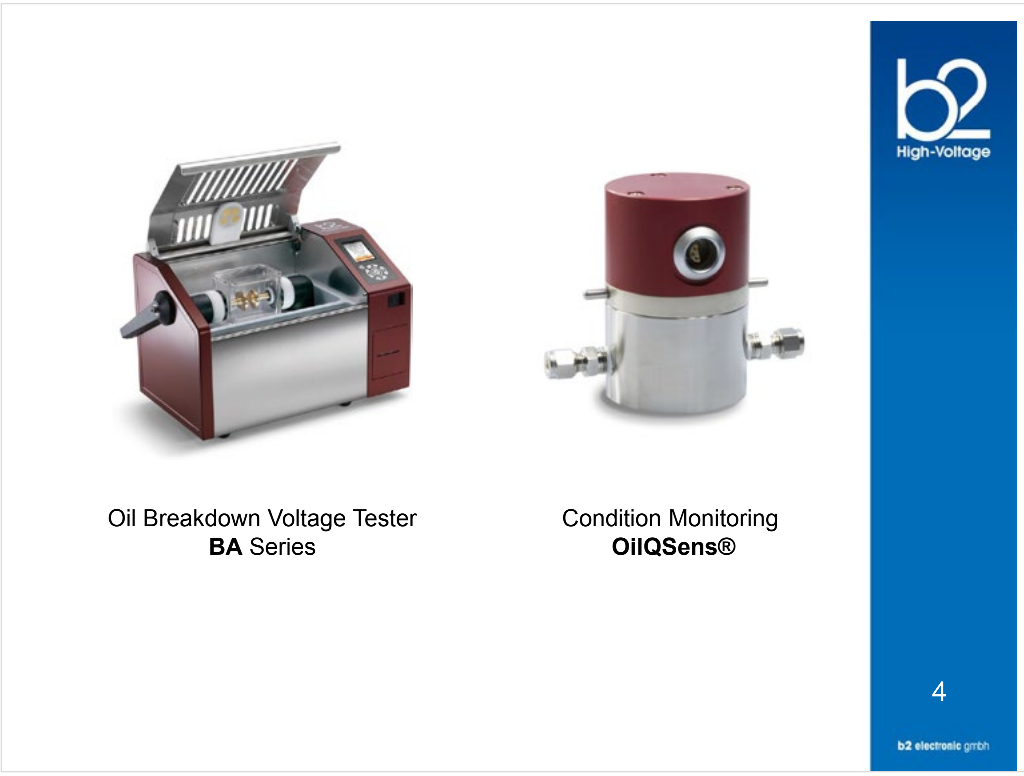

Content

b2 High-Voltage

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

Transformer oils

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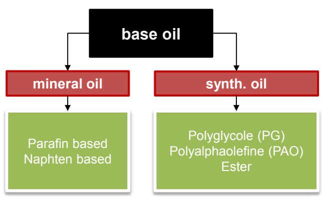
Mineral oil based transformer oils :

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

Synthetic transformer oils :

- Silicon oil
- synthetic ester



Why using synthetic transformer oils (Esters)?

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

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

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Transformer oils

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We need :

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

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Insufficient maintenance

High-Voltage

Disaster waiting to happen!

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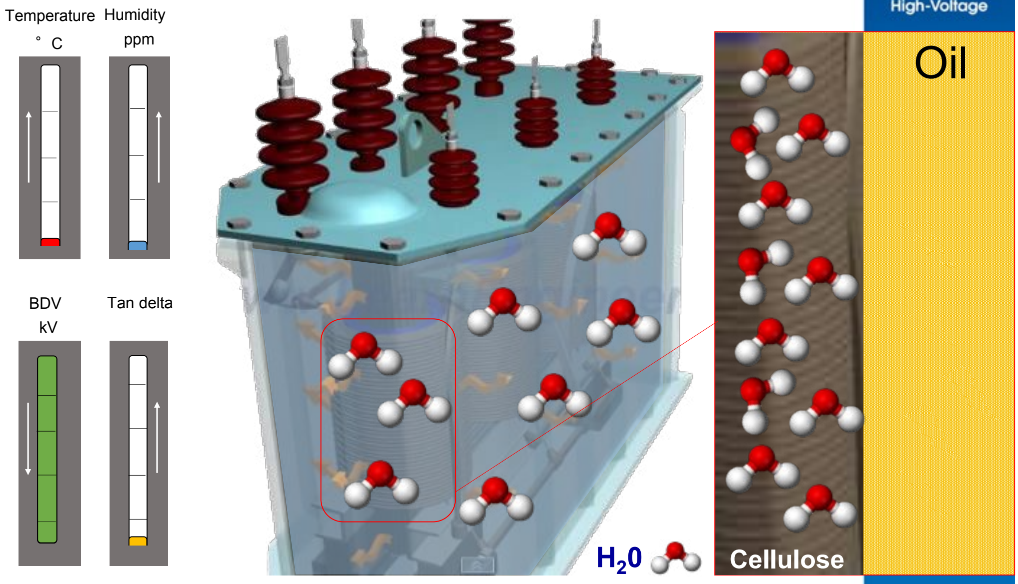
Model humidity in HV transformers



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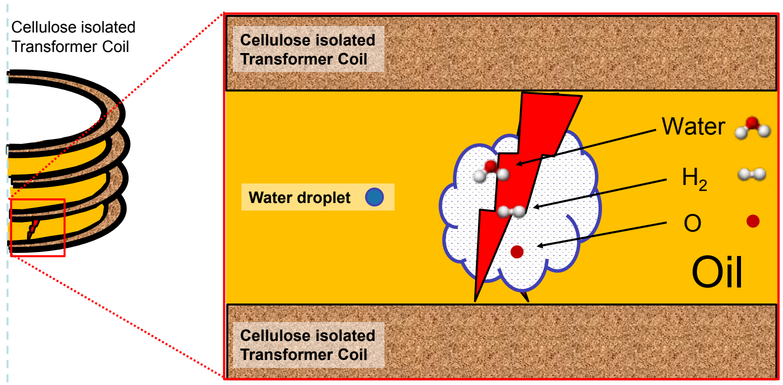
Model humidity in HV transformers



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

- Which can result in a discharge
- rises the temperature locally and evaporates the water
- Due to the gas bubble (containing a mix of H_2O, H_2, O), the dielectrical strength is lowered further.
- H_2 gets solved into the transformer oil.

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The Water Hazard

Where does the water come from?
New transformers:
• Improper or inadequate drying • Improper installation • Inadequate drying of new oil.
In service units:
• Leaks • defective breathers • Maintenance • ageing of insulation

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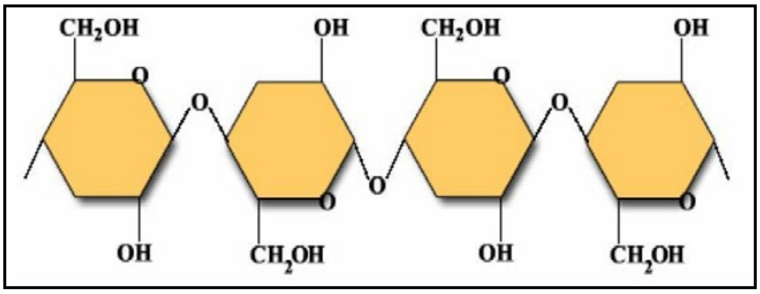
Solid insulation degradation

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



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

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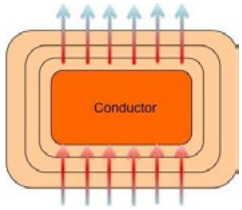
Material Testing with VLF on Transformers

Photo macrograph (250 x) of new Kraft Paper

Fibres clear and undamaged

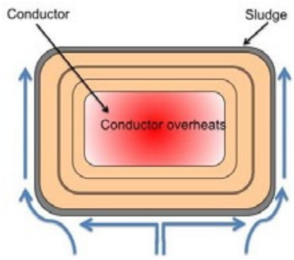
Acidity level of oil 0.03mgKOH/gm



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

From aged transformer. Surface coated.

Acidity level of oil 0.3mgKOH/gm



Oil flow

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

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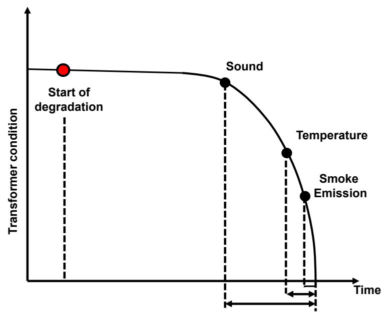
The problem

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



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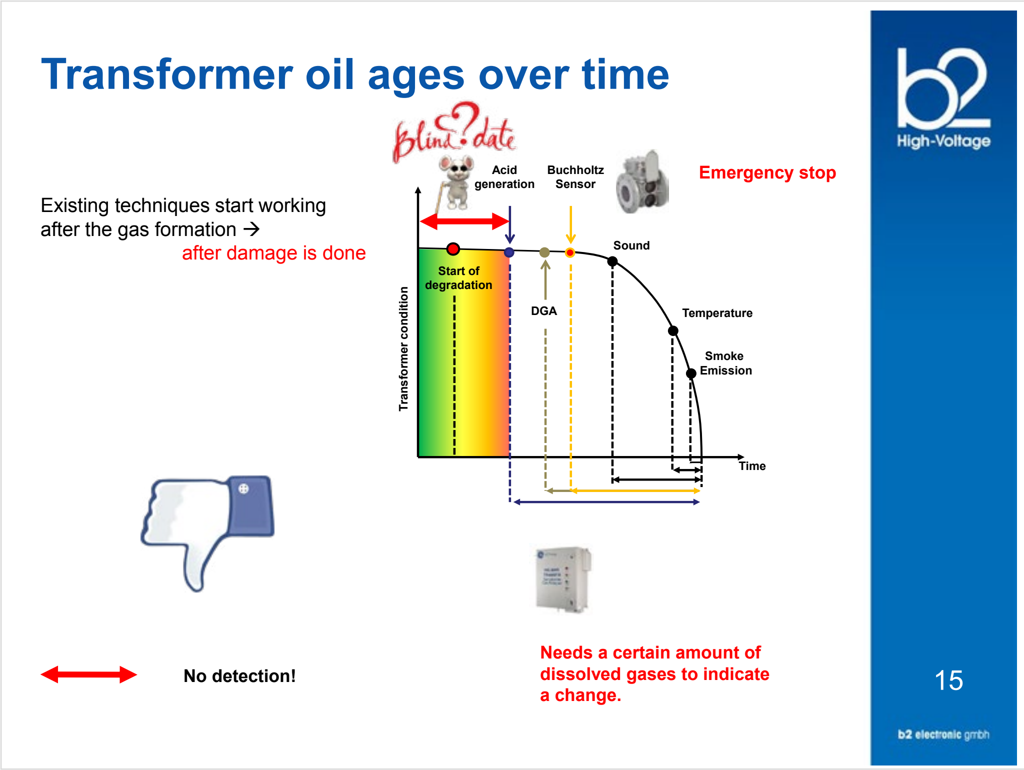
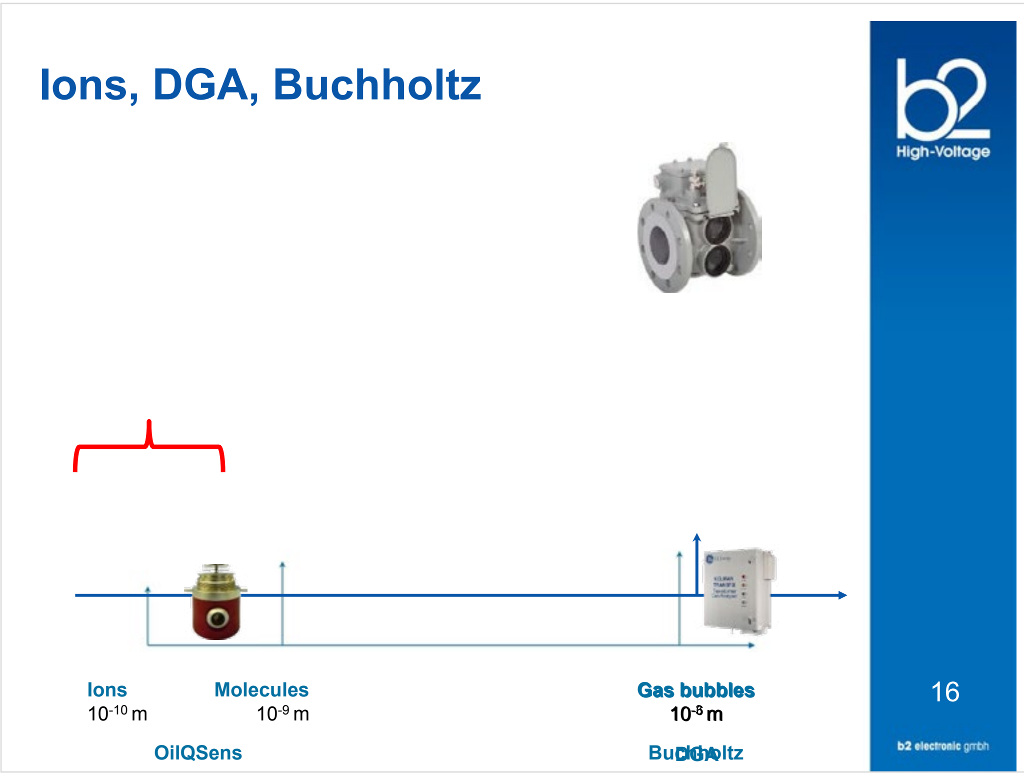
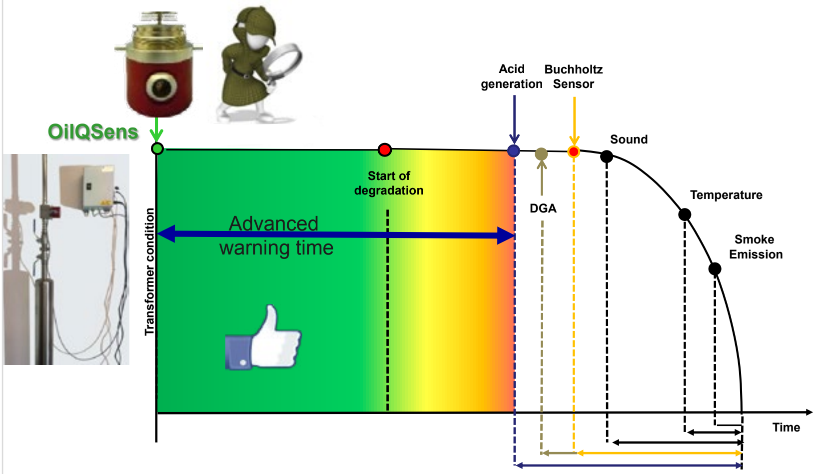




Material Testing with VLF on Transformers

OilQSens® provides an advanced warning time



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

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

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

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Material Testing with VLF on Transformers

Measurements and Calculations

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Values of interest:

- Dissipation factor tan δ *
- Breakthrough voltage estimation and trending
- Humidity estimation and trending

Source values:

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

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

(*) $\tan\delta = \frac{\kappa}{\varepsilon_r \varepsilon_0 \omega}$

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

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Sensitivity: electrical conductivity κ

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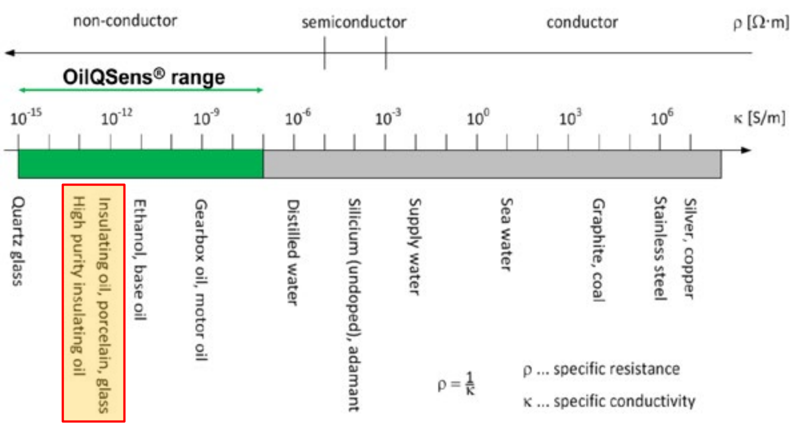
OilQSens® combines an excellent *high sensitivity* with *low noise* and a *broad detection range!*



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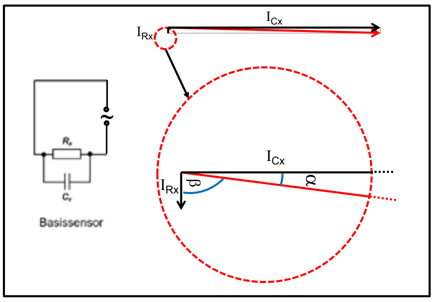
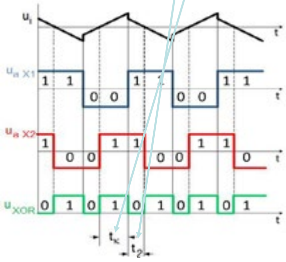
Basic sensor concept



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

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

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



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

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

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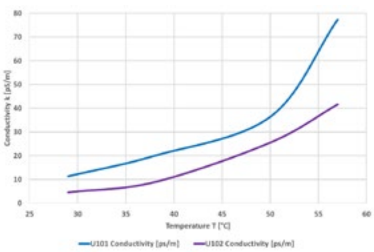
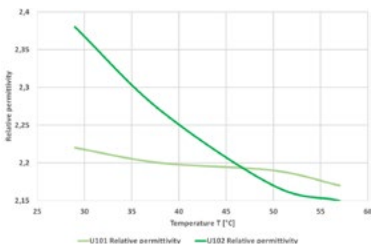
Temperature dependency of κ and ε_r

Increase of temperature results in



increase of the **conductivity κ**

decrease of the **relative permittivity ε_r**



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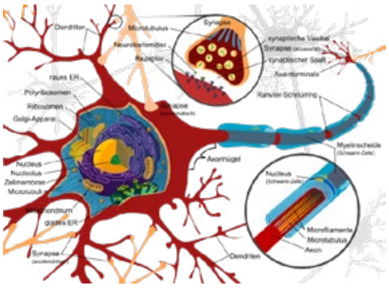
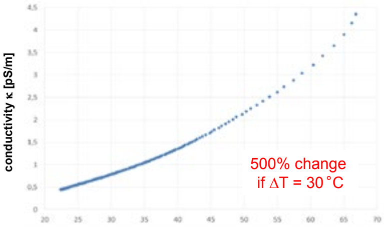
Adaptive temperature compensation of κ and ε_r based on neuronal network



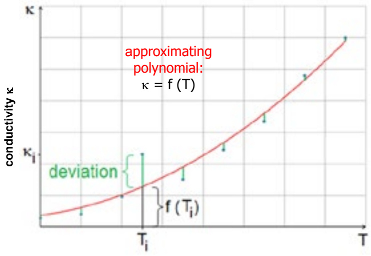


approximating polynomial:

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

$$R = \sum_{i=1}^{N} \left(\left(\kappa_i - \kappa_{T0} - a\Delta T_i - b\Delta T_i^2 - c\Delta T_i^3 \right) \cdot e^{-ti \cdot \ln(2)/th} \right)^2$$

*Gaussian least squares method with risk function



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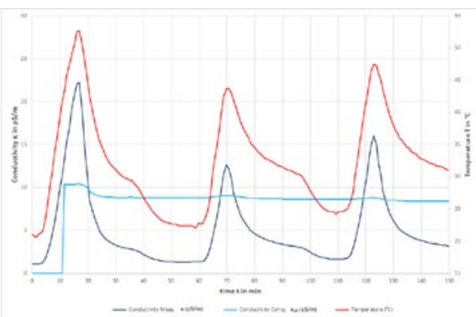
The measured values
– after temperature compensation

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

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



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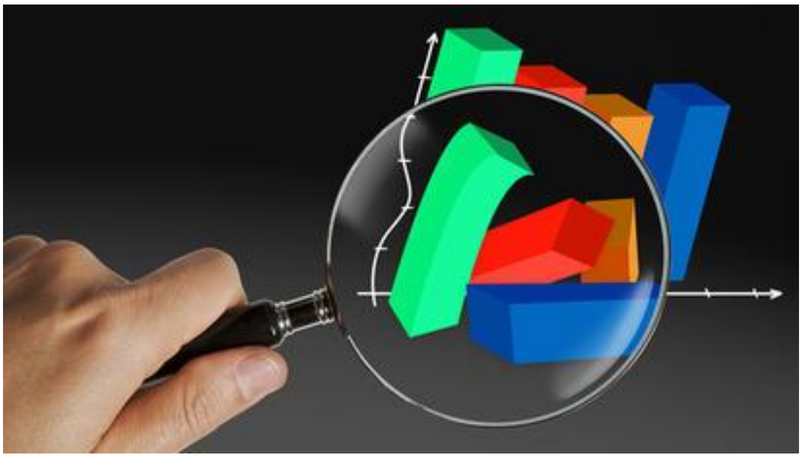
Without adaptive temperature compensation of κ and ε_r …



… no reliable statement is possible!

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Laboratory measurements

Loss factor tan delta

Comparison with 3rd party device

of different transformer oils

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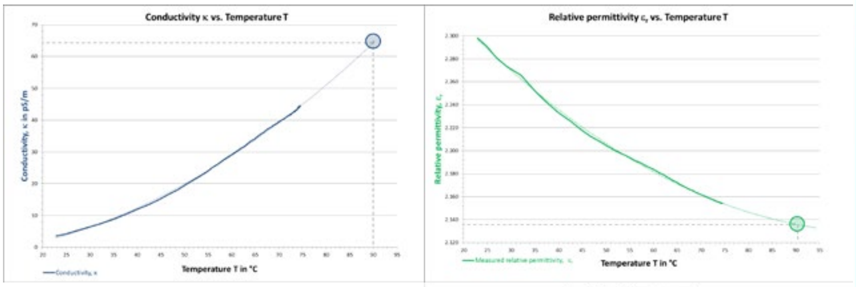
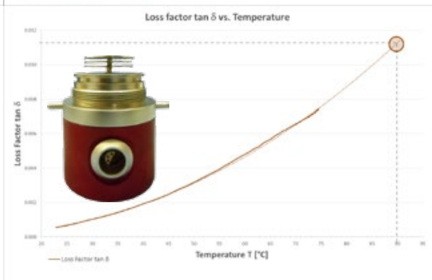
Loss factor tan delta - OilQSens®



Measurement time per Sample
10 min

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



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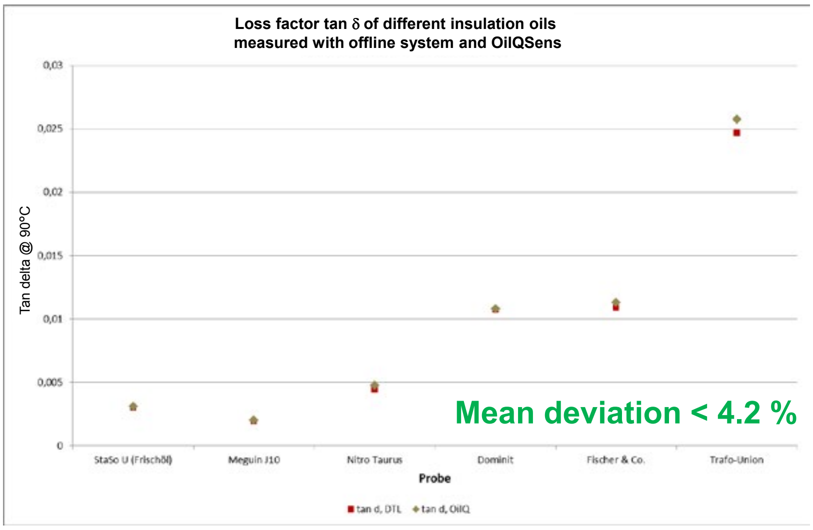
Loss factor tan delta - Comparison



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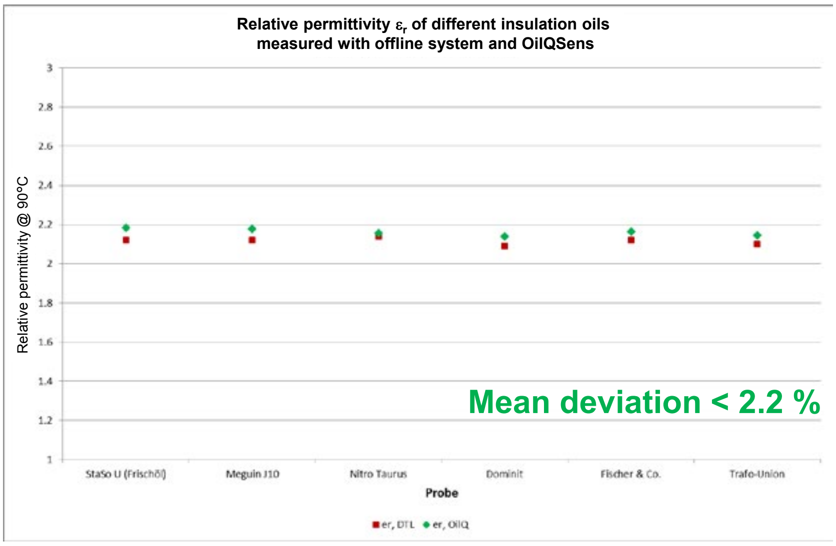
Relative permittivity - Comparison



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Application Examples

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OilQSens® provides online process control in oil regeneration plants

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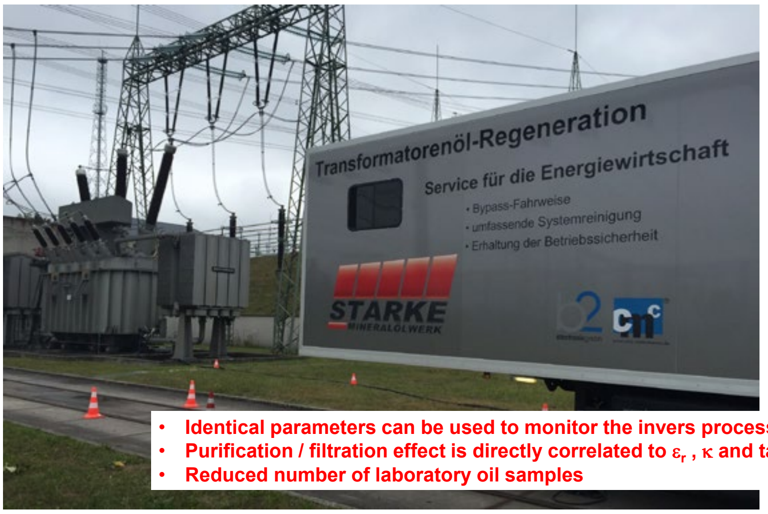

- Identical parameters can be used to monitor the invers process:
- Purification / filtration effect is directly correlated to ε_r , κ and tan δ
- Reduced number of laboratory oil samples

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Application: oil regeneration plant

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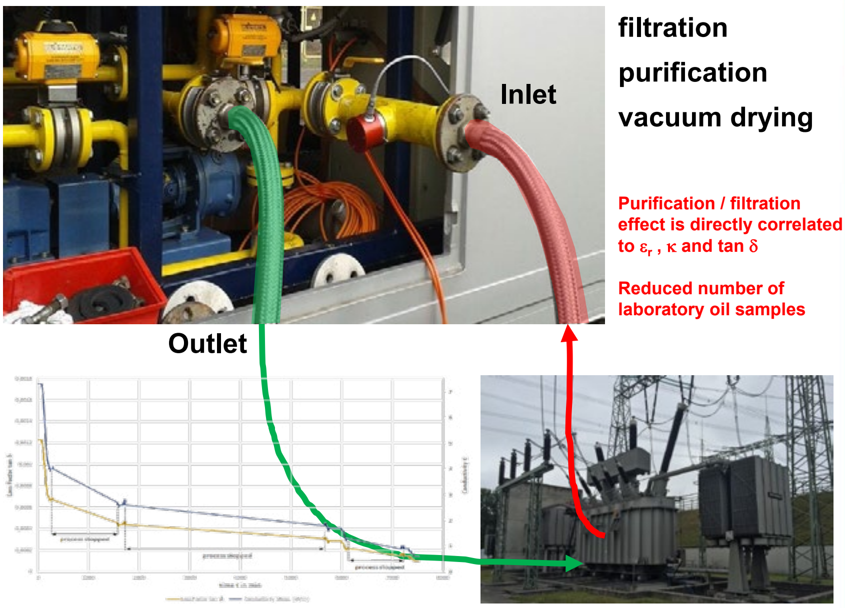

filtration

purification

vacuum drying

Purification / filtration effect is directly correlated to ε_r , κ and tan δ

Reduced number of laboratory oil samples

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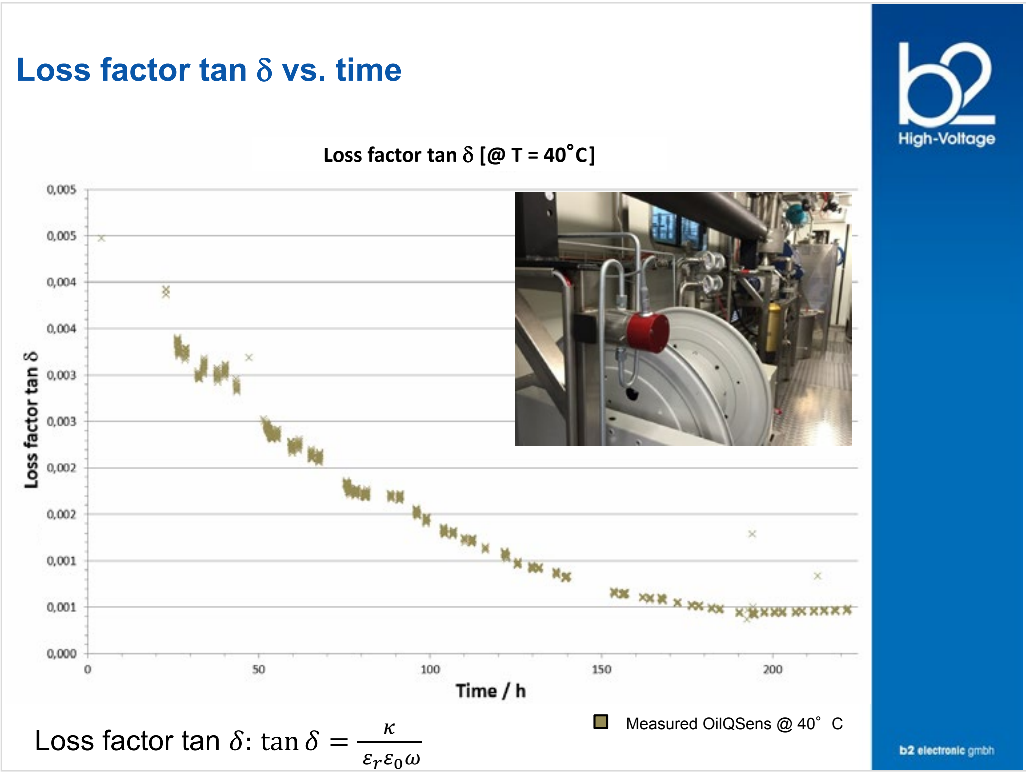
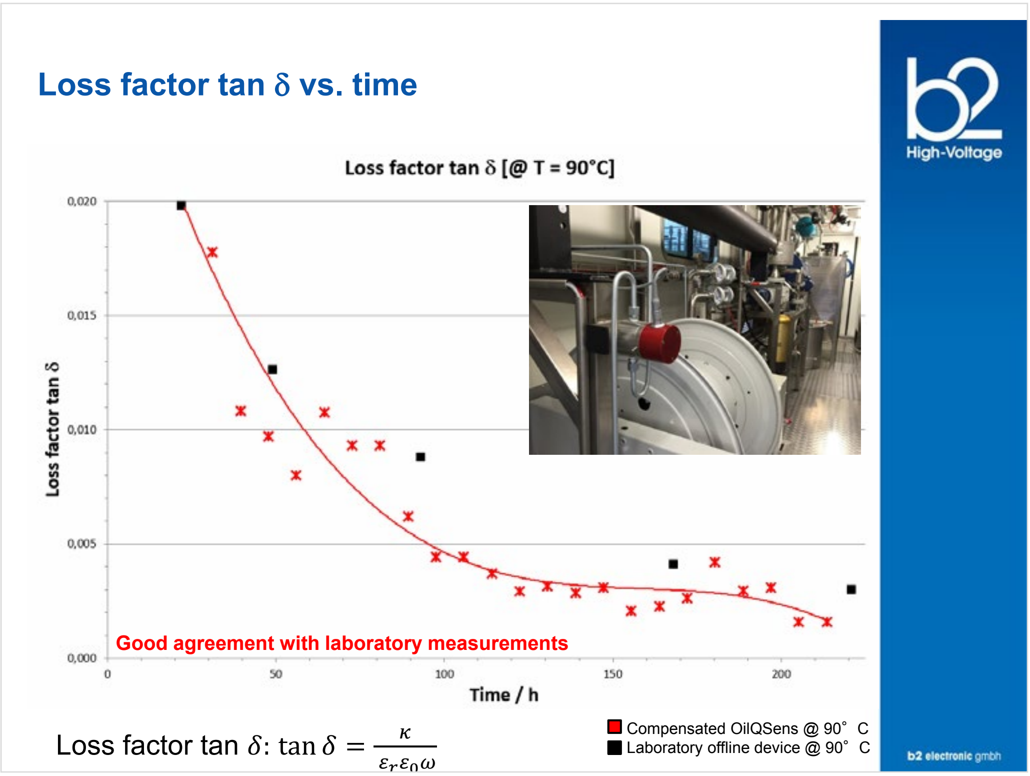
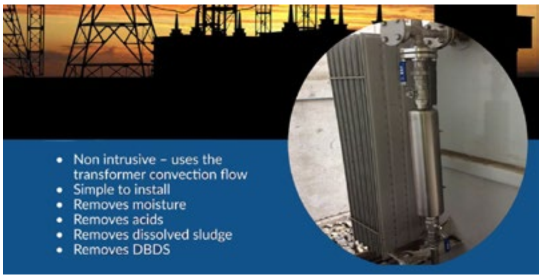
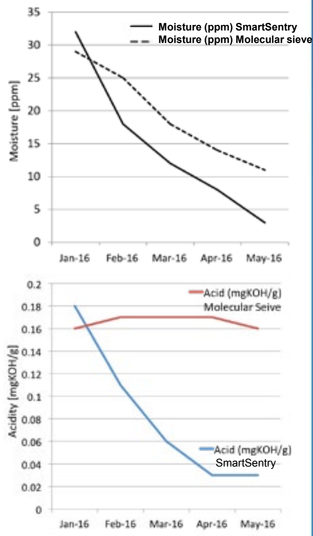




Material Testing with VLF on Transformers

Online Regeneration & Oil Condition Monitoring
High Voltage Transformer Protection





Online oil condition measurement

Permanent purification & dehydreation 24 / 7 / 365

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Key technology – Adsorbents.

Low cost, online, oil conditioning unit.

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

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

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

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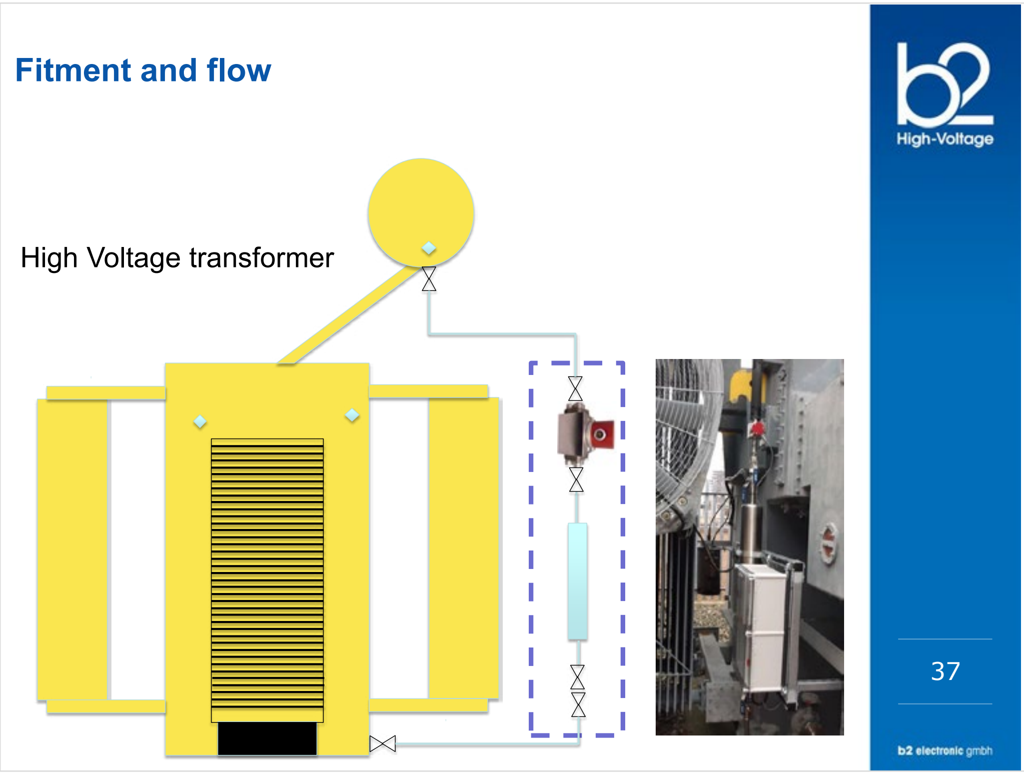

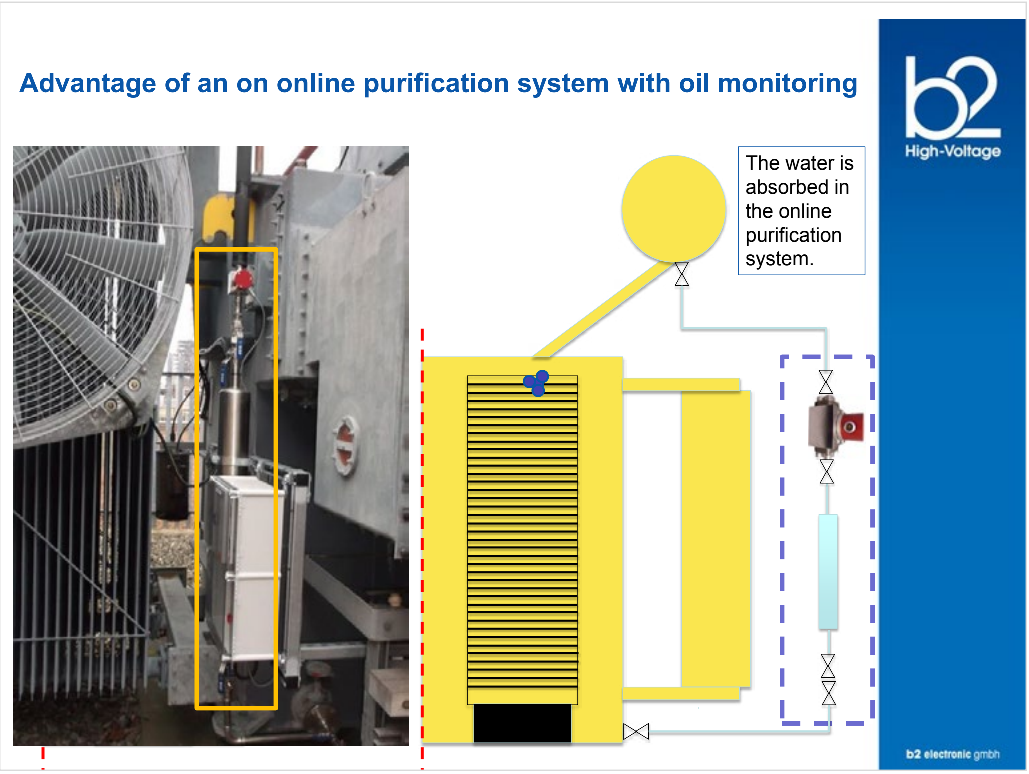

Material Testing with VLF on Transformers

Installations

Fitted to a 30 MVA

Passive, no pump required.

Controls:

- Moisture
- Acids
- Dissolved sludge

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

Economical & long life and can be recycled.

Maintains oil in peak condition

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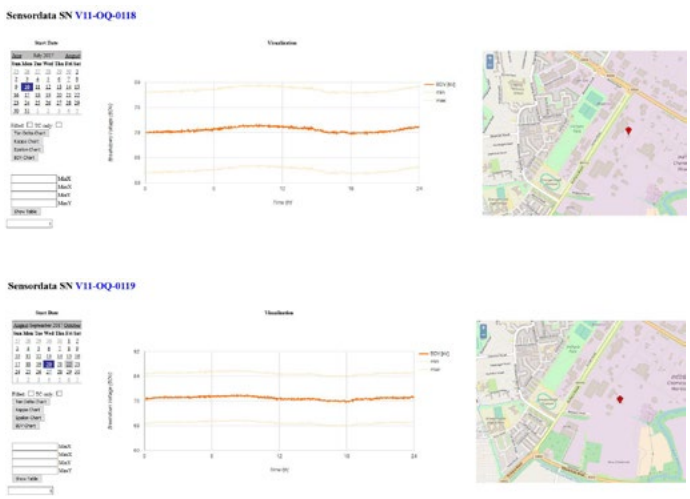
CMS Server-Interface via Internet Browser
REMOTE ACCESS 24 / 7



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Material Testing with VLF on Transformers

TLM

TRANSFORMER-LIFE-MANAGEMENT
CONFERENCE

Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

Prof. Dr.-Ing. Hossein Borsi
University of Hannover

Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

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Mineral based Transformer oil is used for over 100 years in transformers

It fulfills different tasks and properties

TLM- Bangkok

Page 2

Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

Functions of an insulating liquid

Insulation
Impregnation
Heat transfer (cooling)
Fire Extinguishing
Dielectric
Diagnostic

Requirements of insulating oils

1. 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.

2. 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.

Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

Requirements of insulating oils

3. 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.

Requirements of insulating oils

4. To have low viscosity to enable Optimum impregnation of the solid insulation in transformer

5. Measuring different parameters of the oil such as Gas in Oil analysis allows a Diagnostic of the condition of transformer

Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

IfES Different Kinds of insulating liquids

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Mineral oils

Paraffins	(40 % - 60 %)	saturated
Naphtenes	(30 % - 50 %)	Hydrocarbons
Aromates	(5 - 20 %)	unsaturated
Olefines	(bis 1 %)	hydrocarbons

Thermal and electrical aging increases the loss tangent and lowers the breakdown voltage

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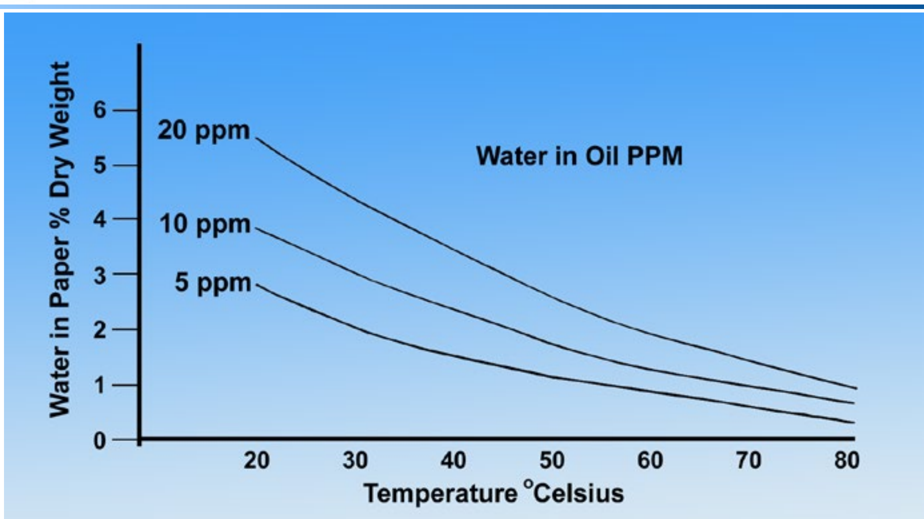
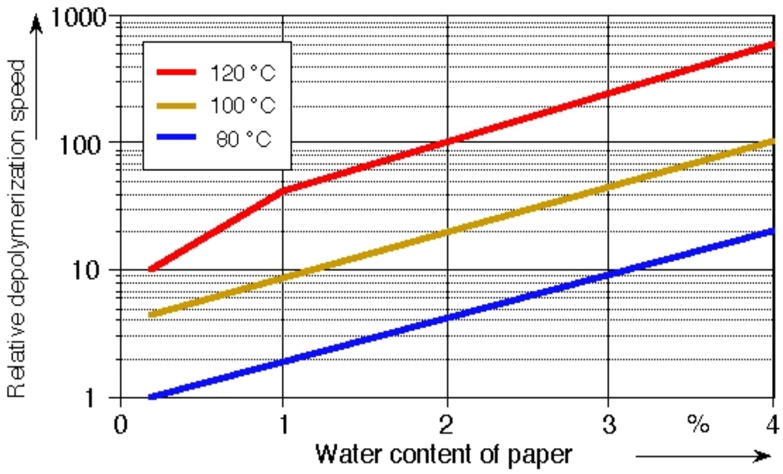


Moisture equilibrium in oil paper system

Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

Relative depolymerisation speed



Bouvier, D(80°C and moisture of cellulose 0,2%) = 1

THE EFFECT OF MOISTURE ON CELLULOSIC INSTULATION	
Transformer $H_2$0 Content By Percent Dry Weight in Cellulose	Aging Rate (Reduction in Tensile Strength)
0.3% 2.0% 4.0%	1.0 6-16x 12-45x
A. Stannett (1965)	

Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

Sludge Formation in Oil

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

Deterioration results from the effects of oxidation.

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.

Sludge Formation in Oil

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.

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

Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

TRANSFORMER OIL CLASSIFICATIONS

Class	NN	IFT	Color no	Color	M.I.N.
1. Good Oils	0.00 - 0.10	30.0 - 45.0		(Pale Yellow)	300 - 1500
2. Proposition A Oils	0.05 - 0.10	27.1 - 29.9	0.5-1.0	(Yellow)	271 - 600
3. Marginal Oils	0.11 - 0.15	24.0 - 27.0	1.0-2.5	(Bright Yellow)	160 - 318
4. Bad Oils	0.16 - 0.40	18.0 - 23.9	2.5-4.0	(Amber)	45 - 159
5. Very Bad Oils	0.41 - 0.65	14.0 - 17.9	4.0-5.5	(Brown)	22 - 44
6. Extremely Bad Oils	0.66 - 1.50	9.0 - 13.9	5.5-7.0	(Dark Brown)	6 - 21
7. Oils in Disastrous Condition	1.51 or more		7.0-8.5	(Black)	

Ref:
Oil condition based on ASTM D 1500 color testing comparisons

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	Symptoms	Diagnosis	Treatment
1.	Breakdown voltage low	Moisture or solids in oil	Oil purification
2.	Oil colour orange/brown	Oil deterioration	Oil regeneration
3.	Visible sludge in oil/transformer	Insulation deterioration	Transformer desludging
4.	Free water in oil or oil cloudy	Insulation Saturated	Transformer dry-out

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Oil Parameters (IEC 60422, VDE 0370-2)

- Colour
- Particle
  - General status
- water content
  - Important parameter
- breakdown voltage
  - Important parameter

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Oil parameters

- Tan-Delta
  - Leads to increased thermal stress
- Interfacial tension
  - Oil aging, degradation products
- Acidity (total acid number)
  - Acid aging products degrade paper insulation
- Inhibitor content
  - Consumption is a measure for aging
- PCB-content
  - Is not more permitted
- Density, flashing point, viscosity

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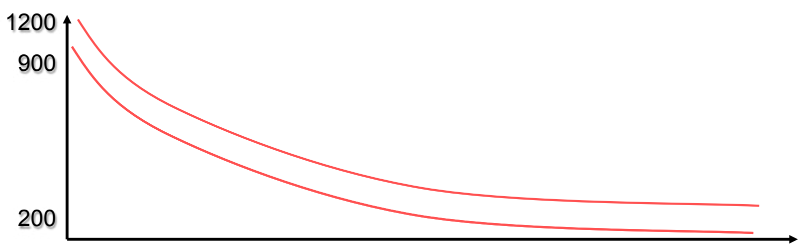
Furan analysis

- 5-Hydroxylmethyl-2-Furfurol (5HMF)
- 2-Furfurylalcohol (2FOL)
- 2-Furfurol (2FAL)
- 2-Acetylfurane (2ACF)
- 5-Methyl-2-Furfurol (5MEF)



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DGA (Dissolved Gas Analysis)

- Nitrogen N2
- Oxygen O2
- hydrogenH2
- carbon monoxide CO
- carbon dioxide CO2
- Methane CH4
- Ethane C2H6
- Etylene C2H4
- Acetylene C2H2

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DGA Diagnostic Tools

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DGA (IEC 60599 VDE 0370-7)

- Electrical fault
  - Partial discharge
  - Low energy discharge
  - High energy discharge
- Thermal Fault
  - Lower than 300°C
  - Between 300 and 700°C
  - Above 700°C

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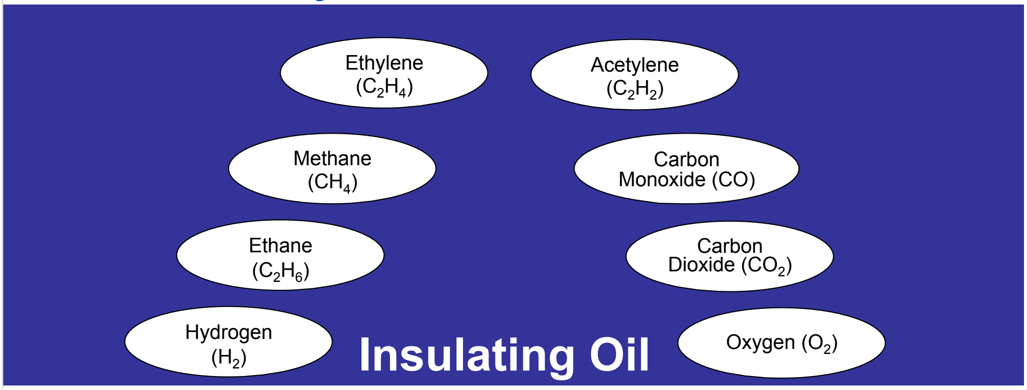
Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

Which Gases are Generated?

Eight key gases in transformer oil are associated with fault conditions.

DGA detects the level of gases indicative of various faults that may lead to transformer failure.



Most severe faults:

- Faults D2 in paper and in oil (high-energy arcing)
- Faults T2-T3 in paper (>300 °C)
- faults D1 in paper (tracking, arcing)
- faults T3 in oil (>700 °C)

Less severe faults:

- Faults PD/ D1 in oil (sparking)
- Faults T1 in paper (<300 °C)
- Faults T2 in oil (<700 °C)
- Are difficult to find by inspection

A fault in paper is generally considered as more serious than a fault in oil because paper is often placed in a HV area (windings, barriers)

Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

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IEEE Std. C57.104 2008 IEEE Guide for the Interpretation of Gases Generated in Oil Immersed Transformers

IEC 60599-1999 Mineral Oil Impregnated Electrical Equipment in Service: Guide to the Interpretation of Dissolved and Free Gas Analysis.

IEC 60599-1999, Amendment 1, 04/2007

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CO_2 vs. CO Ratio

This ratio may be used as an indicator of thermal decomposition of cellulose.

Levels should exceed minimum values for the ratio to be valid

CO $\geq$500 ppm

CO_2 $\geq$5,000 ppm

Best used as a complement to other diagnosis methods for a more accurate assessment

CO_2/CO Ratio	Thermal decomposition state
<3	Excessive
>7	Normal
<10	Normal
>10	Excessive

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Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

The Duval Triangle: (per IEC 60599 Guidelines)

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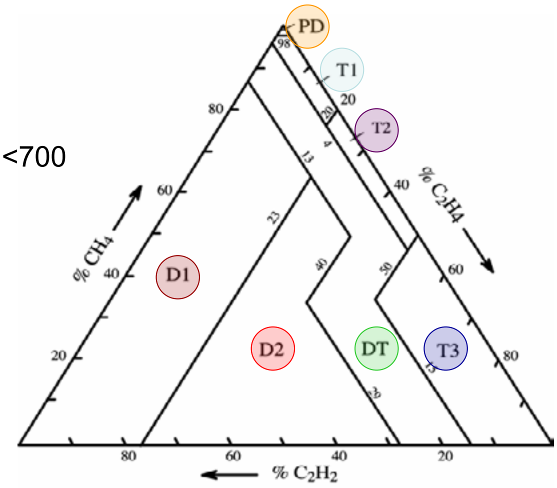
PD = Partial Discharges
D1 = Discharges of low energy
D2 = Discharges of high energy

T1 = Thermal fault, < 300 °C
T2 = Thermal fault, >300 °C and <700 °C
T3 = Thermal fault, >700 °C

DT = Discharge or Thermal indeterminate zone

Gas percentages add to 100%
- 2 gases indicates problem
- 3rd gas confirms



Using the Triangle Method

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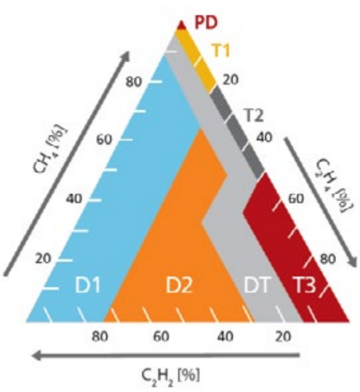
DUVAL TRIANGLE (IEC 60599-2007-05)		
	**ZONE**	**FAULT INDICATION**
	T1	Thermal fault, ≤300 °C
	T2	Thermal fault, >300 °C, ≤700 °C
	T3	Thermal fault, >700 °C
	D1	Discharges of low-energy
	D2	Discharges of high-energy
	DT	Combination of thermal faults and discharges
	PD	Partial discharge

Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

Alternative Liquids

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Gas to Liquid (GTL)

Synthetic Ester
Midel 7131
Beckfluid

Natural Ester

Silicon Fluid Basilone M50

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Gas to liquid (GTL) based inhibited transformer oil

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Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

Inhibited GTL versus conventional inhibited oils oxidative stability

	Limits IEC 60296	IEC 60296 – sect 7.1 Higher oxid stab & low sulphur	Inhibited Shell Diala S3 ZX-I	Inhibited Shell Diala 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**	**<0.01**
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**

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GtL inhibited Oils - Exceptional resistance to degradation

Comparison of different liquids

Characteristics	Ester liquid	Silikon liquid	Mineral oil	PCB
Dielectric dissipation factor 25°C	10	0,9	< 10	30
Permitivity ε 23 °C, 50 Hz	3.3	2.7	2.2	4.4
Breakdown voltage IEC 60156 (kV)	55	50	60	50
Combustion point (°C) (ASTM D 92)	310	>335	150-175	-
Flash point (°C) (ASTM D 92)	257	>300	135-145	200
Combustion heat (kJ/kg 10^3)	36.8	32.2		12.6

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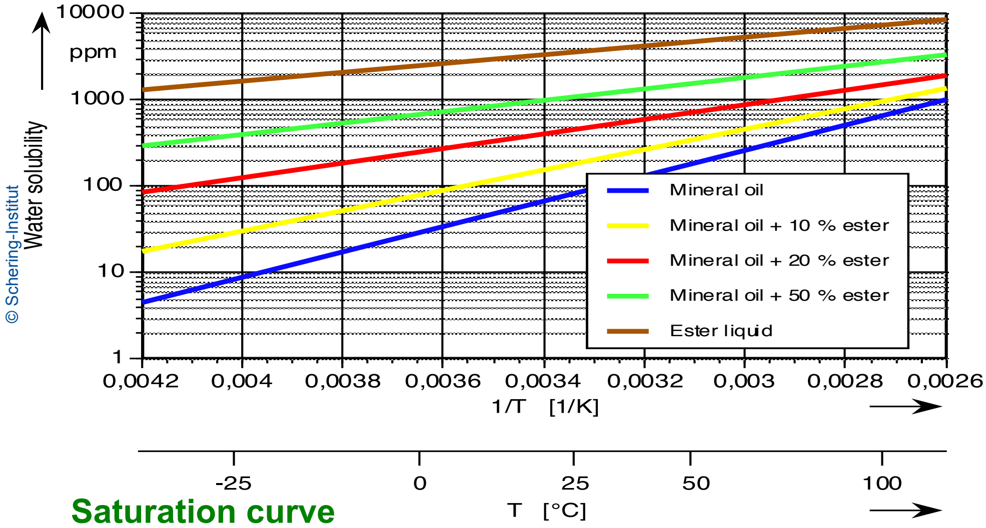
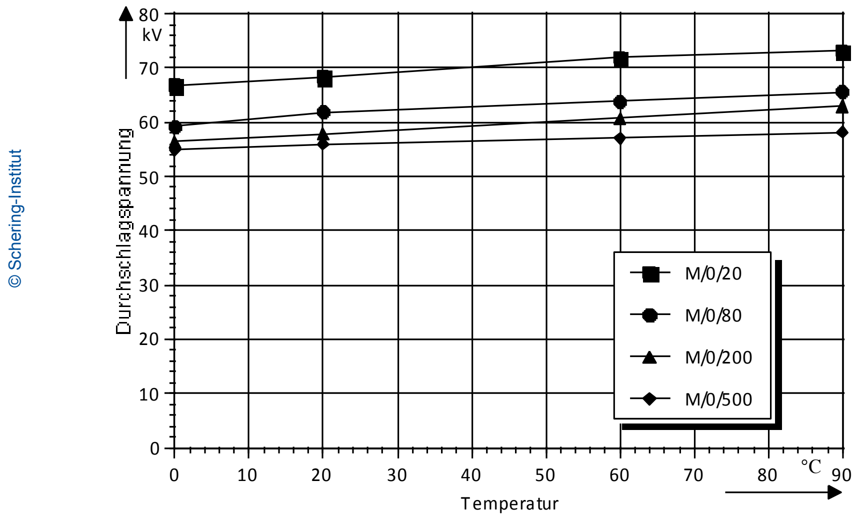
water in Midel 7131, in Mineral oil and mixture Midel/Mineral oil



Saturation curve

Breakdown voltage of new Midel 7131 versus the temperature at different water contents



Prof. Dr.-Ing. Hossein Borsi

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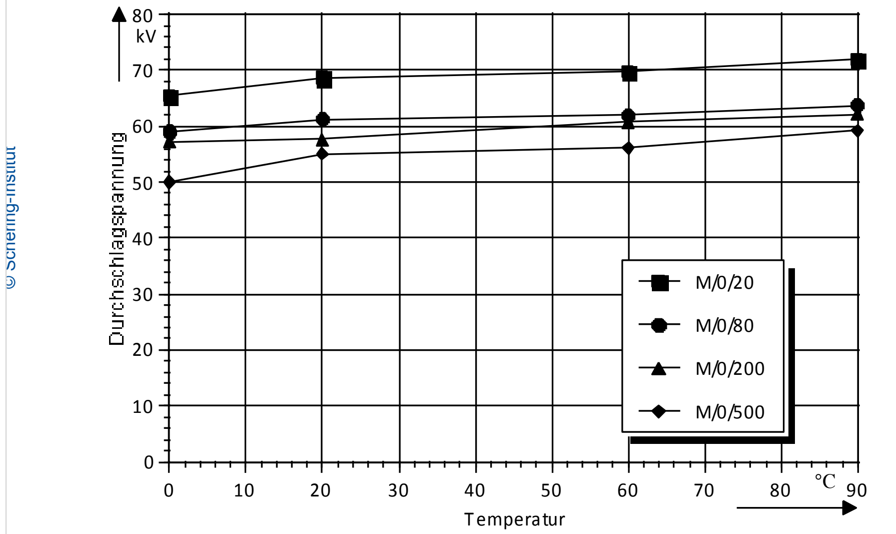
Breakdown voltage of aged Midel 7131 versus the temperature at different water contents



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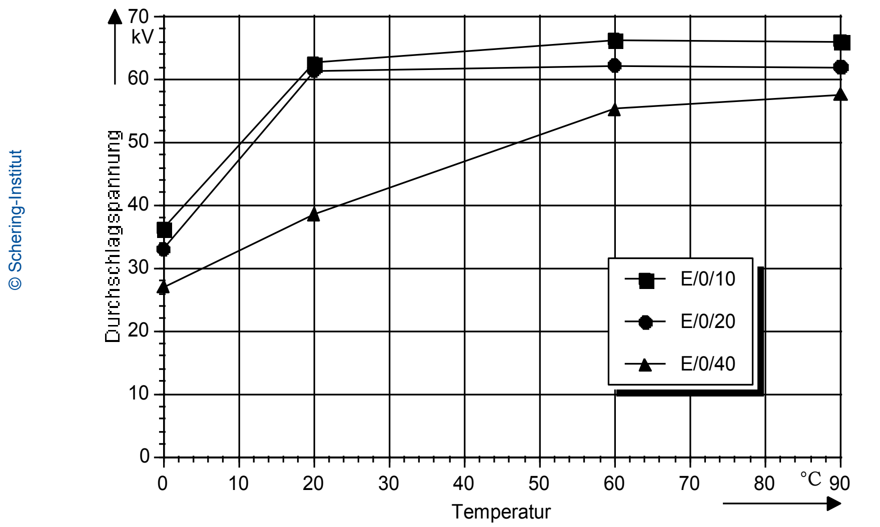
Breakdown voltage of new mineral oil versus the temperature at different water contents



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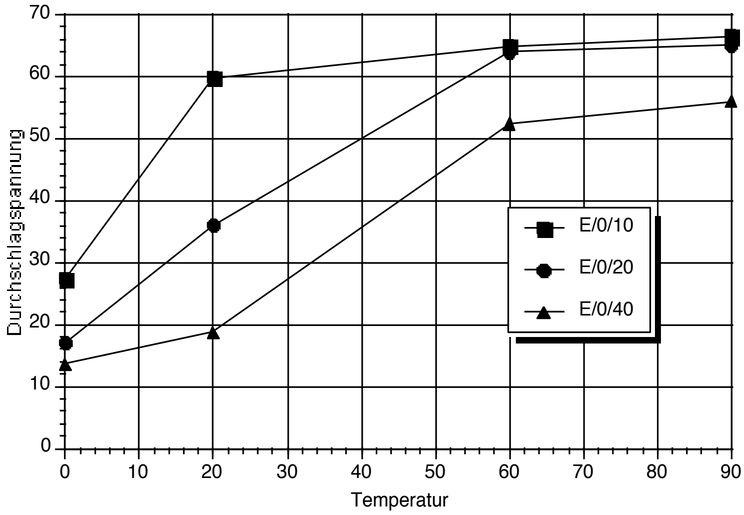
Breakdown voltage of aged mineral oil versus the temperature at different water contents



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Advantages of Esterfluid

takes the heat aging water from the cellulose

keeps the cellulose dry and improves the cold start conditions

is extending the lifetime of the transformer

Fire point *Midel 7131* = 322°C, max. operating temperature 130°C

flash point mineral oil 160°C, max. operating temperature 105°C

Midel 7131 is selfextinguishing Not fire propagating

classified for less flammable liquid insulated transformers

according to NEC 450-23, 1996

less costs for safety equipment, fire walls, etc

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Insulating Liquids for Power Transformers and their use for Condition Assessment Purposes

Frequency Converter as Power Supply for Transformer Testing

Frédéric Dollinger
Haefely Hipotronics

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  factory Basel – Switzerland
- Area Sales & Marketing Manager
- Dipl. –Ing. / M.Sc. Mechatronic
- Language: English, German, French

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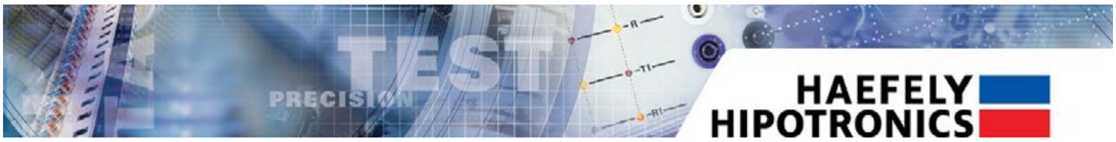
Frequency Converter as Power Supply for Transformer Testing



Frequency converter as power supply for transformer testing

Frédéric DOLLINGER, Haefely Hipotronics, Birsstrasse 300, CH-4052 Basel, Switzerland

1. Introduction

Frequency converter technology is used more and more often in a variety of applications, as the knowledge about it has matured and as new control circuitry has become available. The transformer testing field is very conservative and is now making the move to use this technology for performing routine and type test. Frequency converters make for a compact and clean power supply and competently replace traditionally used voltage regulators and motor generators.

2. The 9 main benefits for using frequency converter as power supply for transformer testing

Main benefit	Features
1: Compact hardware	It has an optimized kW/kg and kW/m3 ratio, it generates no vibration. The containerized solution is a plug and play design, which makes transportation easy and factory relocation.
2: Maintenance free	Frequency converter technology is maintenance free, as there is no moving parts apart from the cooling fan.
3: Ease of service	The frequency converter used for transformer testing is based on commercial standard hardware with customized software. As standard hardware, spare parts are available all around the word. Online monitoring makes service case very efficient.
4: Safety	“Safety integrate”: the converter reacts smart and safe to various situations with voltage and currents trip detection. Short response times provide the highest safety level during unexpected situation.
5: Redundancy	Frequency converters can be used in parallel; in this case double power is available for testing. This feature allows setting a 2 test bays configuration as standalone or parallel, for testing two transformers simultaneously or one twice larger transformer.
6: Decoupled power supply	The DC link provides decoupling from the feeding power mains voltage, frequency, distortion and asymmetry. There is a clear frequency interface separation between the test system and the company workshop.
7: Compatible with partial discharge measurement	Frequency converter associated with various filtering enables partial discharge measurement; with extremely low back ground noise.
8: Variable frequency	Variable frequency from 50 to 200 Hz allows performing the applied voltage test and the loss measurement at 50 Hz and 60 Hz. The induced voltage test can be performed at any frequency, allowing finding the ideal frequency with the lowest current, which will increase the testing capability.
9: Advanced control software	There is a real time feedback loop from the measurement to the frequency converter controller, to adjust the voltage symmetry and reduce the total harmonics distortion.

Haefely Test AG | Birsstrasse 300 | 4052 Basel, Switzerland | +41 61 373 4111 | www.haefely-hipotronics.com | sales@haefely.com

Frequency Converter as Power Supply for Transformer Testing

3. Improved measurements

The IEC 60076-1:2011 specifies for all tests a frequency within 1% of the rated frequency, a voltage total harmonic distortion below 5% and a difference between minimum and maximum phase voltage below 3%.
This specification is a mandatory, but higher performances can be achieved for better readings of the no load loss measurement.
During no load loss, the voltage distortion having peaked waves with higher r.m.s. leads to higher no losses reading. Same behaviour applies in case of voltage asymmetry. Frequency converters with real time feedback loop from the measurement can drop the total harmonics distortion below 1% and the voltage symmetry below 1% and no load loss can be improved from 3%. For example, see Fig. 1.

Fig. 1. (a) THD impact on no load loss on a 2.5 MVA transformer

4. Conclusion

In the overall process, a transformer is only as good as it can be tested and the frequency converter technology opens new possibilities thanks to real time feedback loop.

References

[3] IEC 60076-1:2011 [11.1.1]

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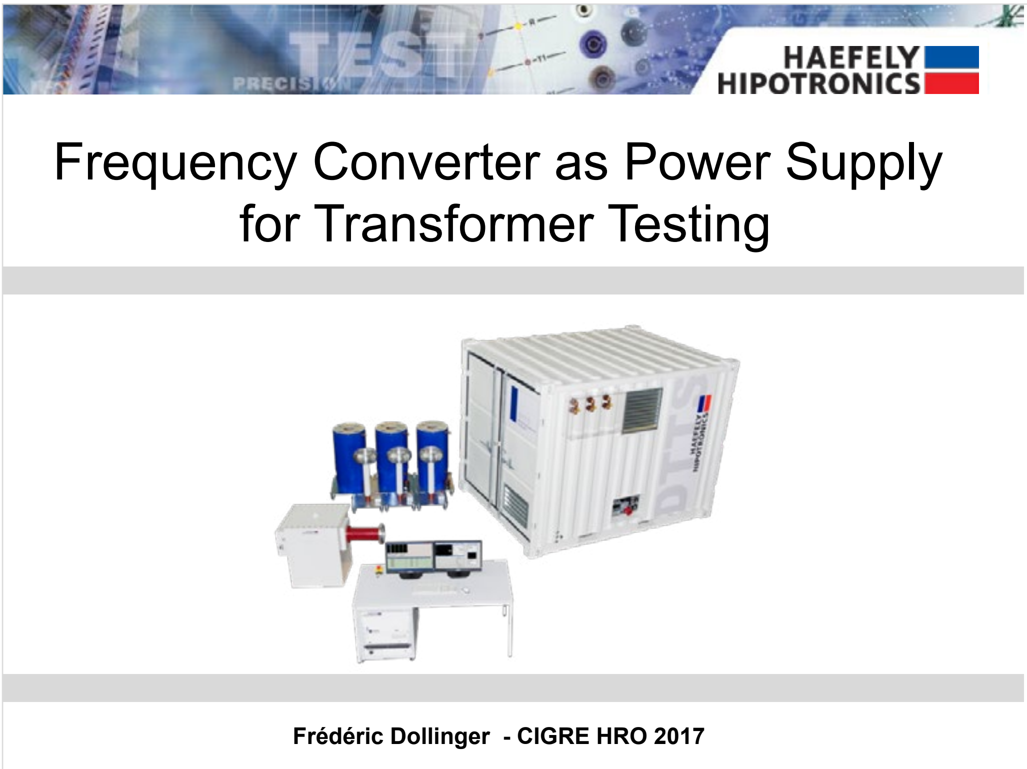

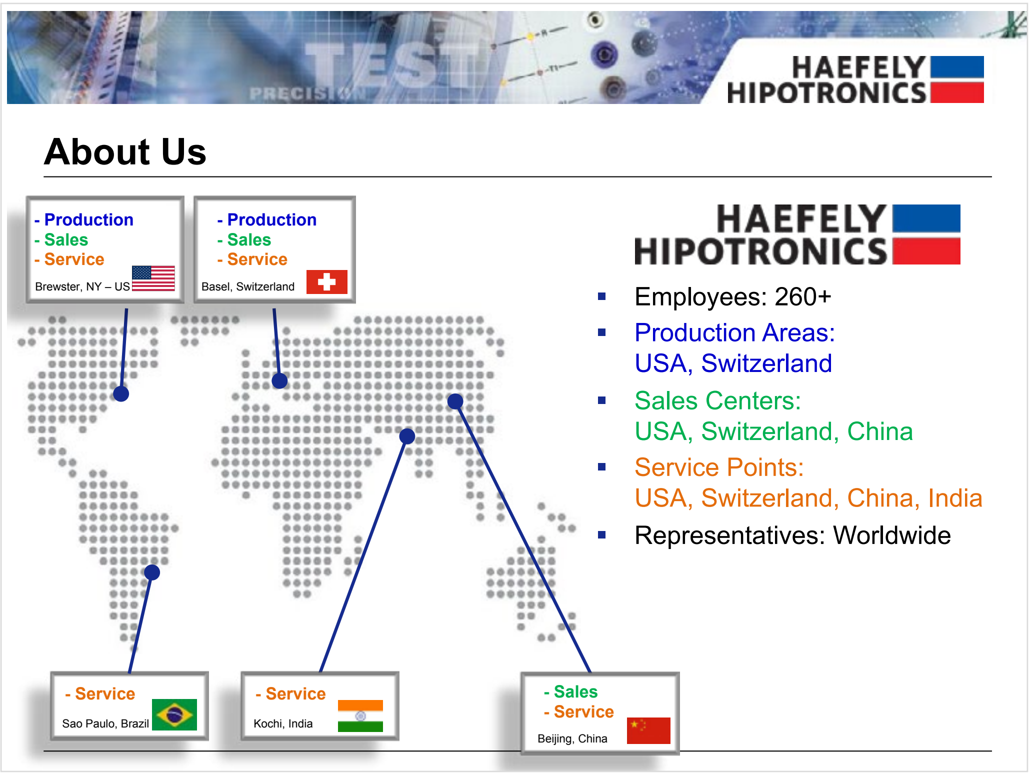

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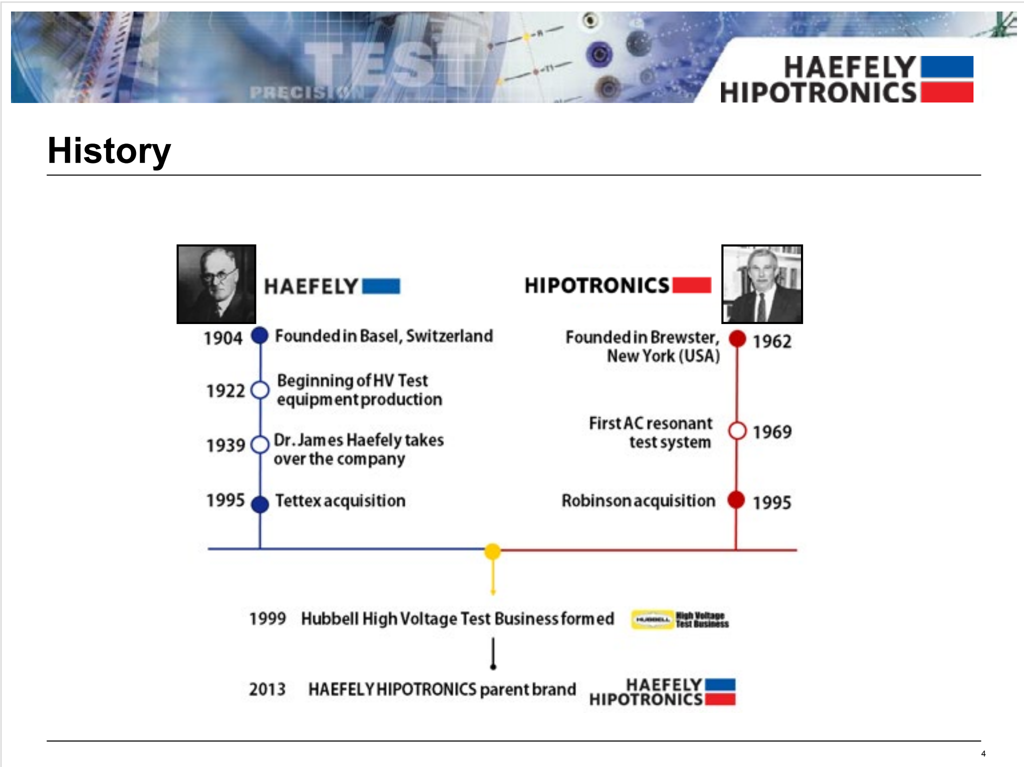
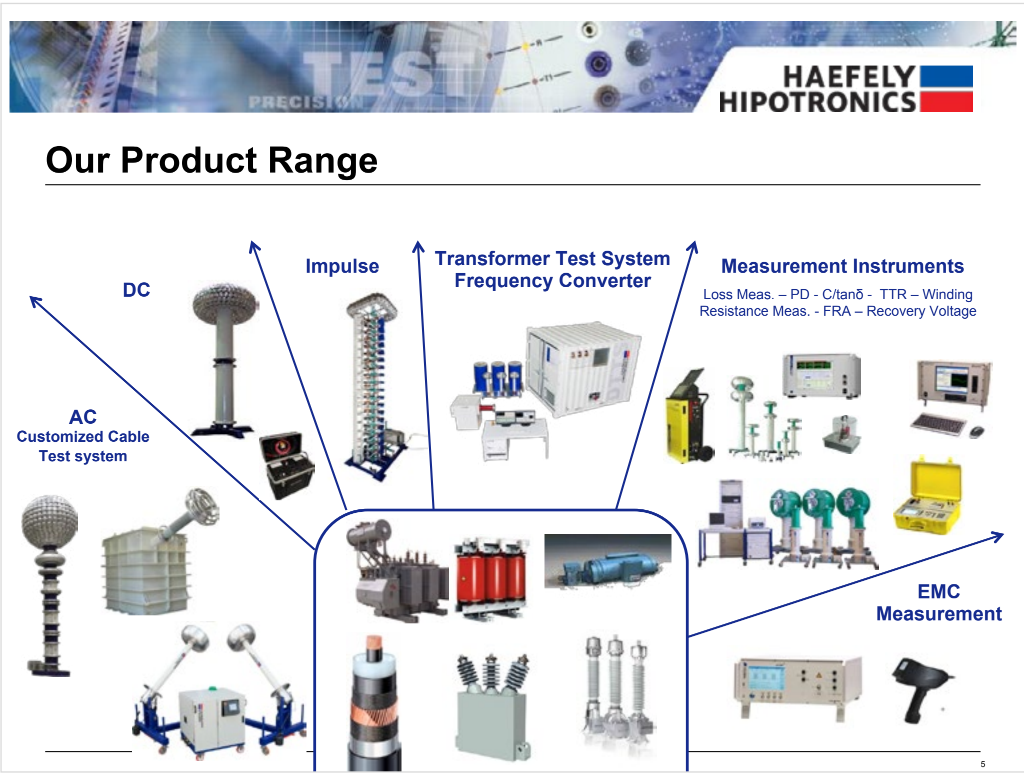




Frequency Converter as Power Supply for Transformer Testing

Agenda

- Introduction to Frequency Converter
- 9 Benefits of Frequency Converter
- Improved Measurements

6

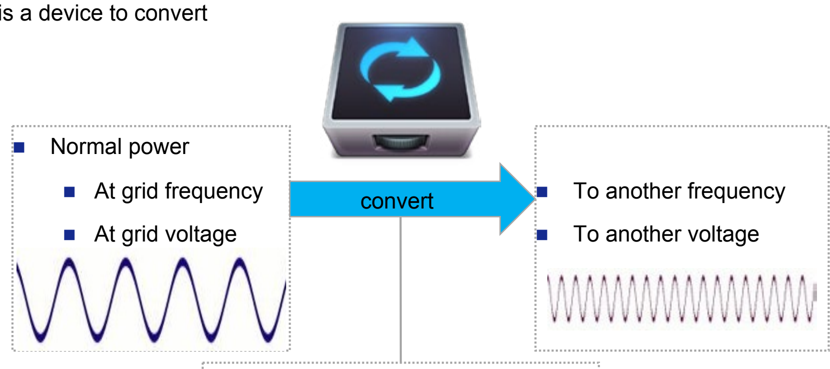
Introduction to Frequency Converter

7

Frequency Converter as Power Supply for Transformer Testing

What is a Frequency Converter?

- **Frequency Converter or F.C.:** electronic power supply or frequency inverter or frequency changer
- It is a device to convert



- Normal power
  - At grid frequency
  - At grid voltage

convert

- To another frequency
- To another voltage

- By using semiconductor switching

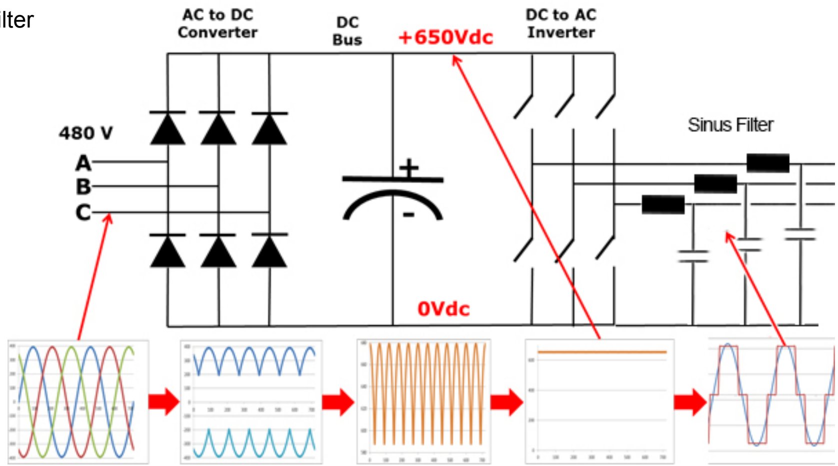
Market

- Global F.C. market: USD 18.85 Billion (2017)
- Comparison: power transformer market: USD 20.7 Billion (2015)
- Main players: (2012)
  - ABB Ltd (Switzerland): 19% market share
  - Siemens Industry Inc. (U.S.): 13.8 % market share
  - Schneider Electric SA (France): 8.5 % market share

Frequency Converter as Power Supply for Transformer Testing

How does electronic power supply work?

- 1: Convert AC to DC
- 2: Inverter DC to AC
- 3: Sinus filter



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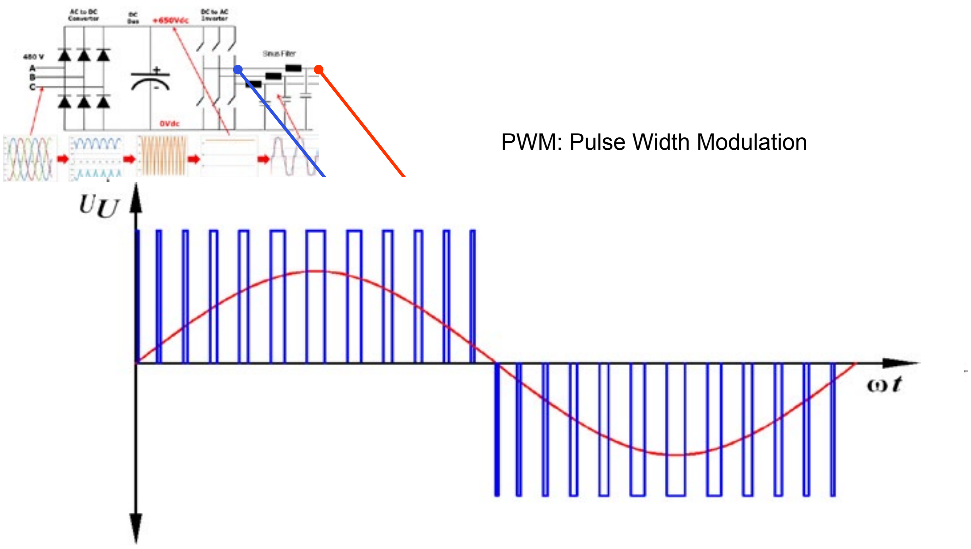
How does F.C. work?



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Frequency Converter as Power Supply for Transformer Testing

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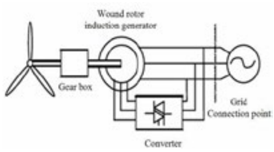
Typical applications

- Motor drive in industrial application: control speed and torque of AC motor (pumps, fans, etc…)

- Airline industries:
  - airplanes use power at 400 Hz, the F.C. will power supply the airplane on the ground
  - On board F.C. as power supply to passengers for laptop or other devices



- Renewable energy system: F.C. is an essential component of doubly fed induction generators (DFIGs)

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9 Benefits of Frequency Converter

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Frequency Converter as Power Supply for Transformer Testing

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1: Compact hardware

Compact hardware

F.C.

- Optimized kW/kg and kW/m³ ratio
- No Vibration

- Ease of integration in existing test lab
  - Plug & play design
- Ease of transportation
  - For delivery
  - In case of factory relocation

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2: Maintenance free

Compact hardware

Maintenance free

F.C.

- Maintenance free
  - No maintenance plan or agenda to follow

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Frequency Converter as Power Supply for Transformer Testing

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3: Ease of service

F.C. → Compact hardware, Maintenance free, Ease of service

- Ease of service
  - Commercial standard hardware
  - Haefely Hipotronics software
  - Strong after sales service available
- Online monitoring and diagnostic

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4: Safety

F.C. → Compact hardware, Maintenance free, Ease of service, Safety

- **“Safety integrated”**
  - PLC for F.C. and safety control
  - Smart and safe reactions to various situations
- **F.C.: high dynamic**
  - Voltage or current trip detection
  - Short response times provide the highest safety level during unexpected situation

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Frequency Converter as Power Supply for Transformer Testing

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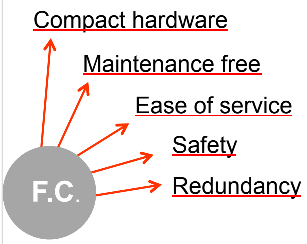
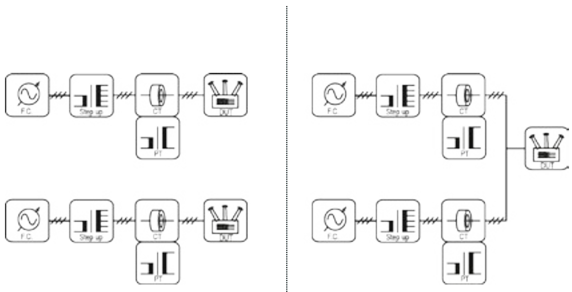
5: Redundancy



- Parallel or standalone use
- Easy to upgrade the power



- Standalone
- Parallel

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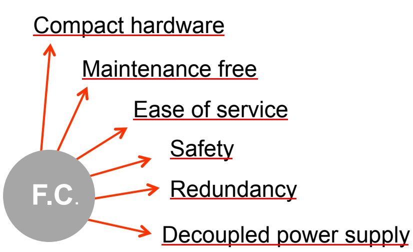
6: Decoupled power supply



- Decoupling from:
  - Feeding power mains voltage
  - Feeding power mains frequency
  - Feeding power mains distortion
  - Feeding power mains asymmetry
- Frequency interface separation:
  - Network frequency interference will be filtered out and not impact the test system
  - Test system frequency interference will not go back to the network

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Frequency Converter as Power Supply for Transformer Testing

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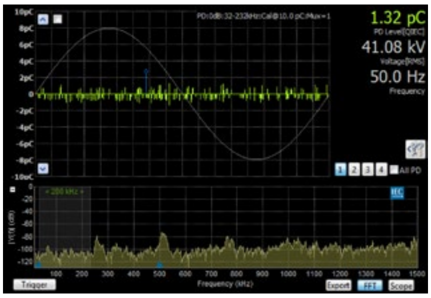
7: Compatible with partial discharge measurement

F.C.
- Compact hardware
- Maintenance free
- Ease of service
- Safety
- Redundancy
- Decoupled power supply
- Compatible with P.D. meas.

- Various filtering stages enables partial discharge measurement according IEC and IEEE



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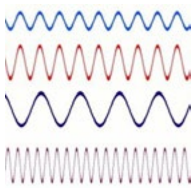
8: Variable frequency

F.C.
- Compact hardware
- Maintenance free
- Ease of service
- Safety
- Redundancy
- Decoupled power supply
- Compatible with P.D. meas.
- Variable frequency

- **Variable frequency**: from 50 Hz to 200 Hz
  - Can perform applied voltage at 50 Hz and 60 Hz
  - Can measure losses at 50 Hz and 60 Hz
  - Can perform induced voltage at any frequency
  - Change the frequency without reconnection



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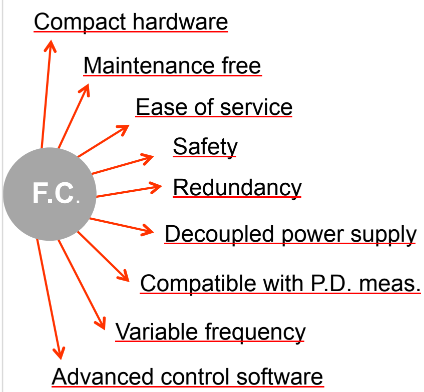
9: Advanced control software



- Voltage Symmetry control
- Voltage THD control

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Improved Measurements

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Frequency Converter as Power Supply for Transformer Testing

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IEC Reminder

- IEC 60076-1:2011 [11.1.1]: For **all** measurement and tests:
    - Frequency: within 1 % of the rated frequency
    - Voltage: THD < 5%
    - Symmetry: Difference between min & max Phase voltage < 3%

- IEC 60076-1:2011 [11.5]: No-Load loss:
    - Relative diff. between mean and r.m.s. voltage < 3%

$$P_o = P_m\,(1 + d)$$

$$d = \frac{U' - U}{U'}$$

U: r.m.s value
U': mean value
P_m: meas. No load loss
P_o: corrected loss
d: correction factor

- Note:
    - Peaked waves with higher r.m.s. lead to higher losses
    - Shallow waves with a smaller r.m.s. value cause lower losses

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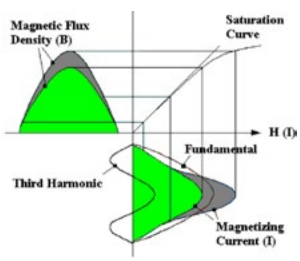
HAEFELY HIPOTRONICS

Influence of asymmetric waveshape

- **Asymmetry cause:**
  Transformer 3 legs geometry

- **Asymmetry problem:**
  Unbalanced 3 phase voltage can lead to core saturation and **it can lead to higher no load losses**



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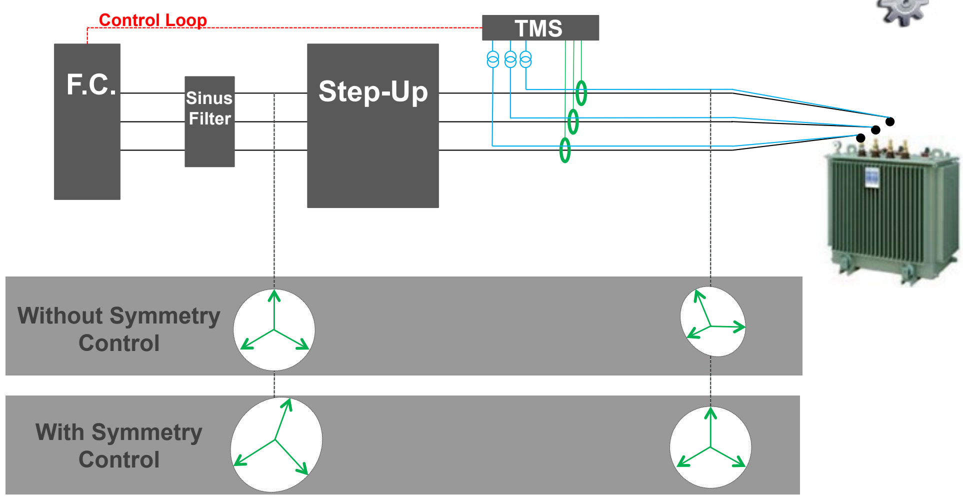
Frequency Converter as Power Supply for Transformer Testing

HAEFELY HIPOTRONICS

Voltage symmetry control

- Real time voltage symmetry control



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HAEFELY HIPOTRONICS

Voltage symmetry control

Example on a 2'500 kVA, 33 kV / 400 V transformer

- Without Symmetry Control

No-Load Loss Measurement 590 - C:\...\Data\2500kVA

	Phase A	Phase B	Phase C	SUM/AVG
Voltage RMS	232.147 V	234.035 V	230.442 V	232.208 V
Loss	1.073 kW	546.000 W	1.290 kW	2.909 kW
cos(Φ)	0.328	0.211	0.482	0.343
Current [%]	33.852 %	26.483 %	27.967 %	29.434 %
U THD	2.450 %	2.170 %	2.760 %	2.460 %
U THD	2.450 %	2.170 %	2.760 %	2.460 %
cos(Φ)	0.328	0.211	0.482	0.343
Idle Power	3.087 kvar	2.530 kvar	2.347 kvar	7.963 kvar
U THD	2.450 %	2.170 %	2.760 %	2.460 %

3%

- With Symmetry Control

No-Load Loss Measurement 590 - C:\...\Data\2500kVA

	Phase A	Phase B	Phase C	SUM/AVG
Voltage RMS	230.501 V	229.952 V	230.344 V	230.266 V
Loss	813.000 W	603.000 W	1.410 kW	2.826 kW
cos(Φ)	0.293	0.307	0.531	0.385
Current [%]	28.852 %	20.431 %	27.560 %	25.614 %
U THD	0.865 %	1.050 %	0.868 %	0.926 %
U THD	0.865 %	1.050 %	0.868 %	0.926 %
cos(Φ)	0.293	0.307	0.531	0.385
Idle Power	2.657 kvar	1.870 kvar	2.248 kvar	6.776 kvar
U THD	0.865 %	1.050 %	0.868 %	0.926 %

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Frequency Converter as Power Supply for Transformer Testing

HAEFELY HIPOTRONICS

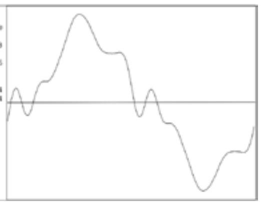
Influence of distorted waveshape

- **T.H.D.:**
  Total Harmonic Distortion

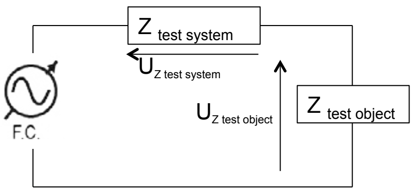
VOLTAGE

Freq Hz	Amplitude kV	Phase Deg
60	20.243	-115.3
180	3.877	26.4
300	2.669	-115.5
420	2.583	-47.7
540	1.927	-86.3
660	1.165	-128.4
780	0.529	-168.4
900	0.000	0.0
1020	0.000	0.0

V_rms = 14.899 kV
V_ave = 13.966 kV
Max volt = 26.356 kV
Max flux=0.0504 kVSec (Actual)
Max flux=0.0524 kVSec (based on V_ave
THD = 29%



- **T.H.D. cause:**
  T.H.D. on the voltage waveshape comes mainly from the short circuit impedance of the test system



- **T.H.D. problem**:
  Peaked waves with higher r.m.s. **can lead to higher losses**

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HAEFELY HIPOTRONICS

Influence of distorted waveshape

- Actual peak voltage: 26.356 kV
- Rated peak voltage: 19.5 kV
- Difference: 35 %

- To high distortion lead to peak voltage which may reach values above dielectric withstand of the insulation:
- Possible damage or failure of the transformer

VOLTAGE

Freq Hz	Amplitude kV	Phase Deg
60	20.243	-115.3
180	3.877	26.4
300	2.669	-115.5
420	2.583	-47.7
540	1.927	-86.3
660	1.165	-128.4
780	0.529	-168.4
900	0.000	0.0
1020	0.000	0.0

V_rms = 14.899 kV
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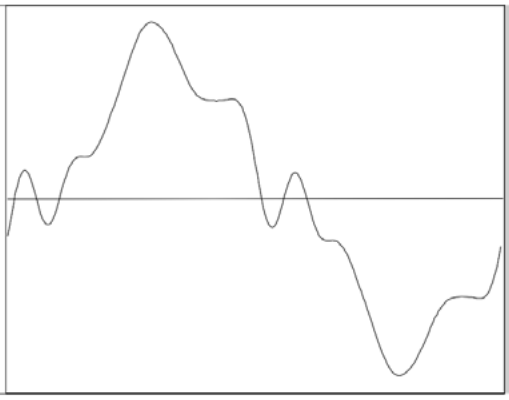

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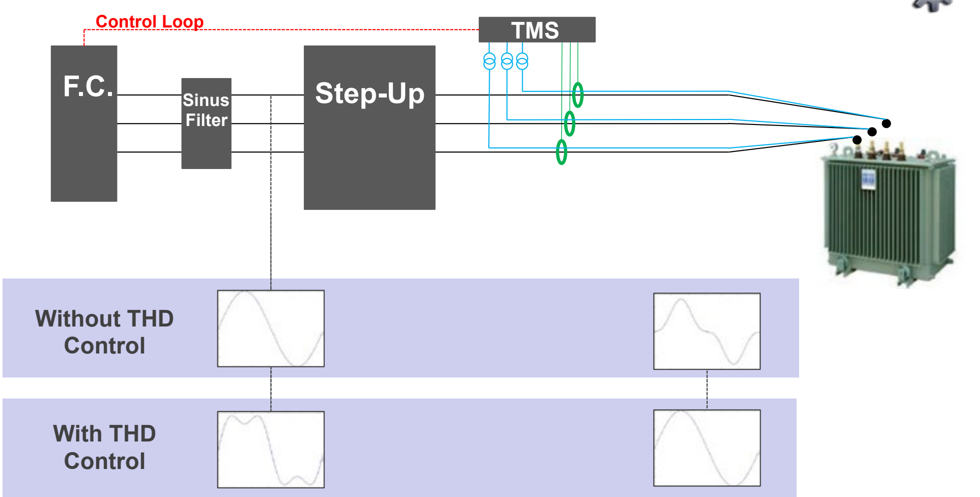
Frequency Converter as Power Supply for Transformer Testing

HAEFELY HIPOTRONICS

T.H.D. Control

- Real time voltage T.H.D. control



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HAEFELY HIPOTRONICS

T.H.D. Control

Example on a 2'500 kVA, 33 kV / 400 V transformer

- Without THD Control

No-Load Loss Measurement 590 - C:\..\Data\2500kVA

	Phase A	Phase B	Phase C	SUM/AVG
Voltage RMC	228.974 V_	232.116 V_	230.091 V_	230.394 V
Loss	928.000 W	684.000 W	1.298 kW	2.910 kW
cos(Φ)	0.352	0.320	0.502	0.397
Current [%]	27.081 %	21.962 %	26.531 %	25.191 %
U THD	7.710 %	7.250 %	7.820 %	7.590 %
U THD	7.710 %	7.250 %	7.820 %	7.590 %
cos(Φ)	0.352	0.320	0.502	0.397
Idle Power	2.472 kvar	2.022 kvar	2.235 kvar	6.729 kvar
U THD	7.710 %	7.250 %	7.820 %	7.590 %

3%

- With THD Control

No-Load Loss Measurement 590 - C:\..\Data\2500kVA

	Phase A	Phase B	Phase C	SUM/AVG
Voltage RMC	230.501 V_	229.952 V_	230.344 V_	230.266 V
Loss	813.000 W	603.000 W	1.410 kW	2.826 kW
cos(Φ)	0.293	0.307	0.531	0.385
Current [%]	28.852 %	20.431 %	27.560 %	25.614 %
U THD	0.865 %	1.050 %	0.868 %	0.926 %
U THD	0.865 %	1.050 %	0.868 %	0.926 %
cos(Φ)	0.293	0.307	0.531	0.385
Idle Power	2.657 kvar	1.870 kvar	2.248 kvar	6.776 kvar
U THD	0.865 %	1.050 %	0.868 %	0.926 %

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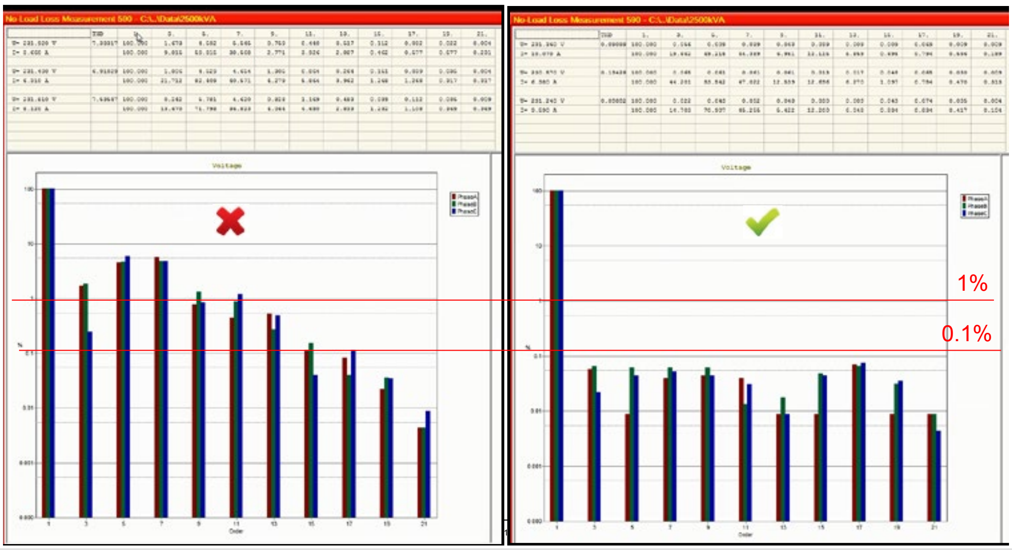
Frequency Converter as Power Supply for Transformer Testing

HAEFELY HIPOTRONICS

T.H.D. Control

Example on a 2'500 kVA, 33 kV / 400 V transformer

Without THD Control | With THD Control

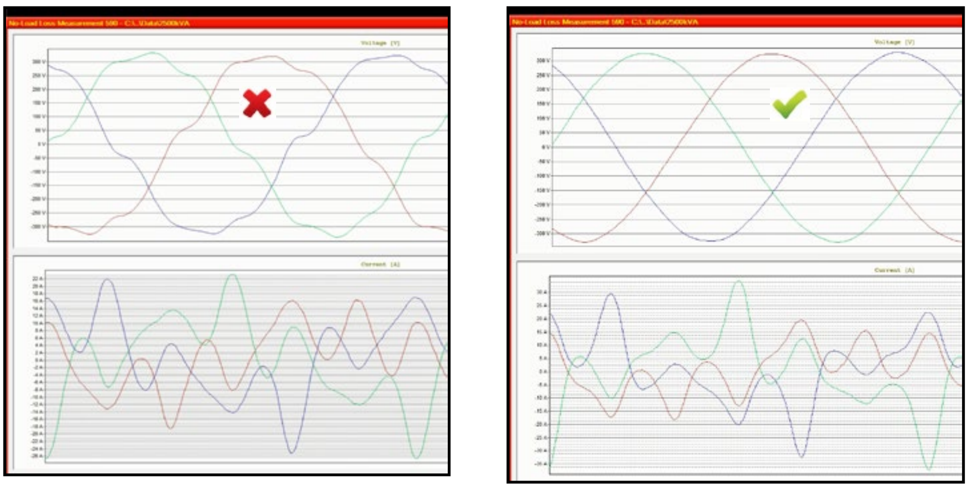


HAEFELY HIPOTRONICS

T.H.D. Control

Example on a 2'500 kVA, 33 kV / 400 V transformer

Without THD Control | With THD Control



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Frequency Converter as Power Supply for Transformer Testing

Wrap Up

- Frequency Converter is a widely used hardware on market
- Hardware with multiple benefits for the transformer test application
- Need customized control for transformer test application
- Symmetry and T.H.D. control:
  - Required to fulfill IEC & IEEE
  - More accurate / better loss reading
  - Especially important for low loss transformer design

KEY ADD ONE

HAEFELY HIPOTRONICS

Our solutions for distribution to power transformer

- Distribution Transformer Test System
  < 5 MVA test object
- Power Transformer Test System
  > 200 MVA test object

- Our references: 38 systems installed all around the world

Frequency Converter as Power Supply for Transformer Testing

HAEFELY HIPOTRONICS

Conclusion / The Vision

- Build a high quality transformer:
  - Good design
  - Good quality of materials
  - Good manufacturing machines
  - Good testing

- "In every chain of reasoning, the evidence of the last conclusion can be no greater than that of the weakest link of the chain, whatever may be the strength of the rest.“
  Thomas Reid's *Essays on the Intellectual Powers of Man*, 1786

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HAEFELY HIPOTRONICS

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Real Life Assesment of Natural Ester Filled

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Real life assessment of Natural Ester Filled (Envirotemp™ FR3™ Dielectric fluid) Transformers.

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Abstract: *Dielectrics fluid and Electrical Insulation paper are dedicated to transformer insulation. The transformer is a very essential apparatus in an electric power system and its reliability is of utmost importance as transformer failure results in a very costly and difficult to predict interruption of energy delivery. Transformer's performance depends heavily on its insulation system; therefore, the insulation is perhaps the most critical transformer part. The prime function transformer oil of transformer has always been to insulate and cool the system. In the present times, its role has been expanded far beyond these two important functions. [1]*

As Per IEC 60076:2013 Part 14, table C.2 Natural ester dielectric fluid is high thermal class insulation, provides fire safety as well as prevent thermal ageing. It helps to improve the load capacity without changing design of transformer. Today the Natural esters are the most accurate diagnostic media amongst available alternate fluids to monitor and assess the overall health of the power transformers IEEE C57.155 (DGA Guide).

safety, firewalls, deluge systems, and fluid containment are some of the fire protection requirements, users should address while installing mineral oil filled transformers. Aging substation infrastructure, environmental protection, and resource sustainability are other growing issues. Ester based alternate fluids are now available in market viz. Natural Esters which take over the limitations of conventional mineral oil in terms of partial biodegradability, low fire point and consequent safety issues with transformer explosions and fires that can cause catastrophic damages.

however, a good number of distribution transformers up to 33 kV have been retro filled with ester liquids. In case of power transformers, GETCO has taken lead and used natural ester liquids in 2 Nos. 66 kV class 15 MVA transformers to have first-hand experience. Also, Siemens 420 KV/ 400KVA transformer. In this paper, we are discussing about the integral role of Natural ester EnvirotempTM FR3TM dielectric fluids in the life management of transformers

Keywords: Transformer, Fire safety, Ester Fluid, Natural Ester, Life assessment.

Real Life Assesment of Natural Ester Filled

INTRODUCTION

Insulation system plays vital role in the transformer. Its primarily function as di-electric insulating and cooling medium in the transformer. The operational stress inside the equipment in service and chemical reaction cause generation of moisture, acids and gases. Excessive presence of the decay products will lead to accelerated deterioration in the dielectric strength of the fluid apart from damaging the insulation paper (Typically in case of mineral oil). This will call for timely detailed analysis of dielectric fluid to determine whether re-conditioning will be sufficient or replacement is the solution for prevention of transformer failure.

1. Effect of Moisture Contamination in the System:

Entry of moisture from atmosphere via breather, structural components inside the transformer one of them is source of moisture. The presence of oxygen coupled with moisture and high temperature will causes serious hazard to the insulation system. Even trace of moisture is harmful to power transformer. As per experts, oxygen levels more than 2,000 ppm in dielectric fluid greatly accelerate insulation paper deterioration. It is recommended that if oxygen reaches 10,000 ppm in the (Dissolved Gas Analysis) DGA, the oil should be de-gassed and new oxygen inhibitor installed in typically mineral oil filled transformers. Unless it will result into major failure in the transformer.

2. Effect of Particulate Contamination in the System:

Presences of Particles in insulating oil in transformers area major concern in the life management of the asset. Particle such as Cellulose fiber, iron, aluminum, copper, zinc and carbon particles are generated at the manufacturing stage and due to operational wear and ageing. Carbon particle contaminate the vital part of the transformer. Which block the flow of Insulation oil or slow down it, which will affect the cooling process in mineral oil filled transformers. Continues monitoring is needed. [2]

3. Ageing Effect of Insulation (Oil and Paper) System:

Ageing of insulation system is an unavoidable phenomenon during the service life of transformer. Ageing of insulation (Oil and Paper) is mainly due to polymerization and oxidation. Temperature, moisture and oxygen are the main agents like cancer of cellulose and oil decomposition. Polymerization leading to continuous decomposition of insulation even at110-120°C temperatures. The ageing process of insulation is initiated by moisture & oxygen in presence of acid catalysts from the oxidized oil. Acids generated in mineral oil are highly corrosive & reactive in nature. Ageing process can be slow down if timely preventive actions are introduced to remove water, oxygen, acids and keeping the system cool in mineral oil filled transformers. The transformer mineral oil insulation also several other abnormalities developing inside transformers in service such as,

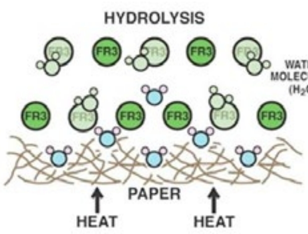
- Conductive particles– reduction in dielectric strength.
- Dissolved water – reduction in dielectric safety.
- Bubble formation – partial discharge-PD, reduction in interfacial tension- IFT
- Sludge formation – increase in viscosity, increase in acidity of the oil

To resolve all the above problems and improve the life of the power transformer natural ester Envirotemp™ FR3™ Dielectric fluid is a proven solution. With its unique electrical properties of high thermal Capability, higher fire point & hydrolysis help to improve the life of insulation paper. FR3 fluid directly enhances the life of insulation system & Transformer.

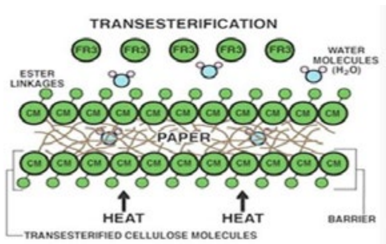
ENVIROTEMP FR3 DIELECTRIC FLUID

1. Slow down Thermal Ageing:

Typically, operating temperatures for power transformers lie between 65°C to 90°C. At these temperatures, the insulation materials undergo slow ageing with concurrent loss in electrical and mechanical properties. The insulation properties can also degrade due to the presence of moisture. Within a transformer when the insulating paper ages, water molecules are released from the insulation which accelerate further degradation of the cellulose due to hydrolysis leads to corrosive reaction in mineral oil. [3] However, with FR3 fluid, a hydrolysis reaction occurs whereby a molecule of water is converted to a non-reactive, long chain, free fatty acid thus absorbing the water molecule into the carbonyl structure of the natural ester. These fatty acids have no negative impact on the performance of the fluid or transformer. Also, they are non-corrosive & non-reactive as compared to acids generated with mineral oil shown in fig. (2)



(Figure 1. a)



(Figure 1.b)

Figure 1: Hydrolysis process with Natural ester FR3 dielectric fluid.

Result with (2.a) Mineral oil (2.b) FR3 dielectric fluid.

Figure 2: comparison of Corrosive effect with mineral oil and Natural Ester FR3 dielectric fluid

In figure (1.a.) Shows that in hydrolysis process Natural ester FR3 dielectric fluid consumes water molecules creates fatty acids. In this way, it will remove dissolved water (Moisture).In figure (1.b.) Shows combination natural ester attached to the weak point of the cellulose. During hydrolysis, fatty acids form attached to cellulose and strengthening the insulation paper.

With a FR3 fluid-filled transformer, the water volume (ppm) allowed before reaching saturation and acid counts will be higher. That's not a bad thing – that's normal for FR3 fluid compared to a mineral oil transformer. By being able to absorb the extra water produced as part of the thermal aging process and having a higher water saturation point, FR3 fluid protects the insulation paper (essentially 'self-drying') thus extending the asset life and helping improve the grid reliability. FR3 fluid can extend the insulation life of new transformers or the residual insulation life in a retro-filled transformer.

2. Impact on transformer life extension

Envirotemp™ FR3™ fluid extends insulation life by a factor of as much as 5-8 times because it has the unique ability to draw out retained moisture and absorb water driven off by aging paper. It also helps prevent paper molecules from severing when exposed to heat. These properties can result in an increase of overloadability and/or longer transformer insulation life, resulting in both lower life cycle cost and delayed asset replacement.

Figure 3: Sealed test on insulation paper with Mineral oil and with FR3 Fluid

In Figure 3. We can find that in seal tube test after 80 years of service life of transformer insulation paper still with working state as compare to mineral oil. Conclude that natural ester Envirotemp FR3 dielectric fluid accelerate the life of asset by improving the life of insulation system.

As per IEC 60076-14 brings the following table 1.3.1 in Annex C.2, It is clearly stated that when paper is impregnated with Natural Esters it will increase of the thermal class of paper

Table 1. Annex - C.2-C amparing of ageing result

	Constant a	Temperature T °C	Thermal index	Thermal class
IEEE mineral oil/thermally upgraded paper	$9,80 \times 10^{-18}$	110,0	110	120
Natural ester liquid/thermally upgraded paper	$7,25 \times 10^{-17}$	130,6	130	140
IEEE mineral oil/kraft paper	$2,00 \times 10^{-18}$	95,1	95	105
Natural ester liquid/kraft paper	$1,06 \times 10^{-17}$	110,8	110	120

Real Life Assesment of Natural Ester Filled

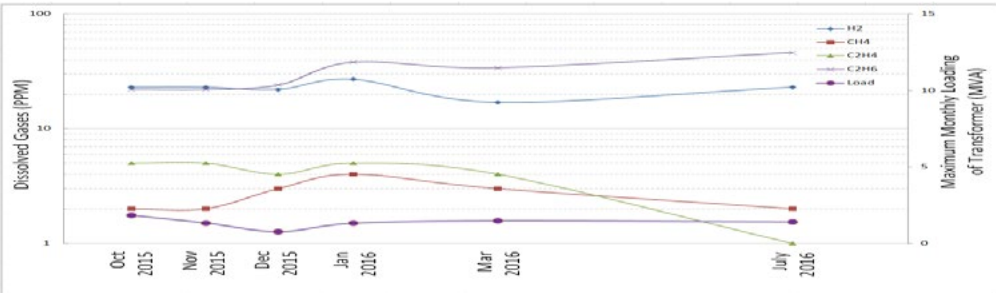
CASE STUDY

A. GETCO Retro-fill: The transformers were manufactured for Gujarat Energy Transmission Corporation Limited (GETCO), the state transmission utility in Gujarat. This is a two-winding transformer containing 7.4 tons of natural ester fluid, which was successfully tested by the company in May 2015 in the presence of customer's representatives. Ester based insulating fluids provide an alternative to mineral oil and are favored for their fire safety, full biodegradability and Life extension.

Figure 4: T&R India Ltd has manufactured two 66 kV, 15 MVA, three phase power transformers filled with Envirotemp FR3 natural ester fluid supplied by Cargill.

Commissioning of both the transformers was done one by one by GETCO under supervision of T&R representative. All the required precautions were taken such that there would not be direct contact of NE with air. The pre-commissioning checks and tests were carried out. The transformer was charged on 09.11.2015. Over nine months in service, both the transformers have undergone periodic dissolved gas monitoring and other natural ester properties.

Dissolved gas analysis was used to study the types of gases produced inside the transformer during its time in operation. Graphical representation of key gases for both transformers with respect to loading conditions during this period is given in figure (5). There was no generation of Acetylene (C_2H_2). As the loading conditions during the period under review were minimal, the maximum oil and winding temperature were of the order of 58 °C.



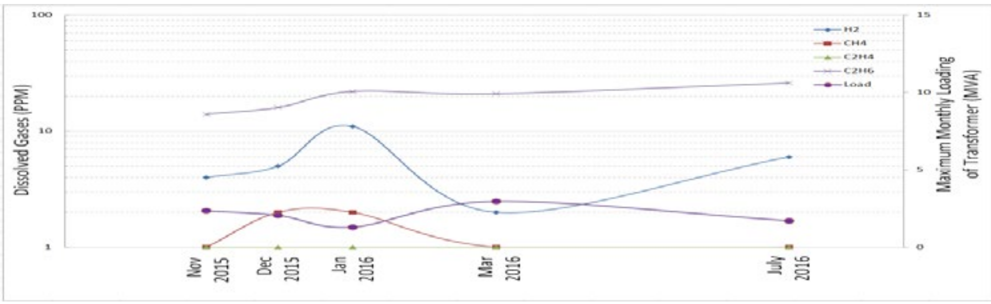


Figure 5. Graphical representations of periodic Oil DGA test results

From figure 5. GETCO found that Non-mineral oils appear to be more stray gassing type than mineral oils. Gassing data from many transformers retro filled with Envirotemp FR3 liquids since 2001 have indicated significant difference with stray gassing in ester liquid as compared to mineral oil. Ethane (C2H6) gas formation can be attributed to the stray gassing of FR3, which is the unexpected gas formation from mineral oils at relatively low temperatures in the 80 to 250°C range2,3. These are not considered a fault or a concern with the transformer and such experiences are presented in various platforms to distinguish this stray gassing from more serious faults in service.

Experience with use of Natural Ester (FR3) in 15 MVA 66 kV class transformers has been satisfactory. At works testing, in dielectric high voltage tests, transformer filled with this liquids with same design as for mineral oil filled type, did not give any problem. However, same temperature rises require about 10% increase in cooling radiators. Up to 66 kV, it is a kind of retro filling experience. Globally, transformers upto 420 kV class have been built using ester liquids. Environmental demands and fire safety need more and more use of such liquids.

B. Transnet BW, Germany: The transmission network of TranetBW, Germany needed innovative technologies for the future of energy. It is particularly important for them that the natural ester fluid filled transformer is not only for technological progress and performance, but also for the protection of human beings and the environment. The new 400kV 300MVA natural ester fluid filled transformer is an essential component in establishing a sustainable network infrastructure that will ensure long-term power supply to the region.

Figure 6. The 300MVA, 420-kV natural ester FR3 filled Power Transformer in the test bay and during delivery.

Experiences from the field:

Over the past four years it is in service, the transformer has undergone many tests and measurements. These included gas analysis, as well as water content, breakdown voltage and tan delta analyses of natural ester samples, and more.

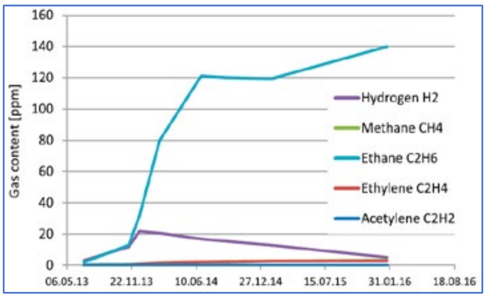


Figure 7. Concentrations of gases dissolved in natural ester

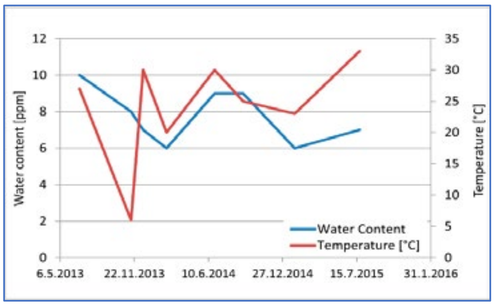


Figure 8. Water content in natural ester samples

Dissolved gas analysis (Figure 7) was used to reveal the types of gas produced inside the transformer during its time in operation. Notably, the presence of ethane increased over the four years in service. In comparison to the transformers using mineral oil, ethane is generated by different natural decomposition processes taking place inside the transformer with an insulation system which is a combination of natural ester and cellulose. These differences between the two insulation systems are based on the chemical structure of the various liquids, and they are explained in detail in the IEEE DGA guide [6]. Another distinction lies in a different solubility of gases in mineral oil and natural esters. Consequently, many, but not all, normally operating transformers filled with FR3 fluid have a higher ethane content than their mineral oil counterparts. Other hydrocarbon gases remained low [7].

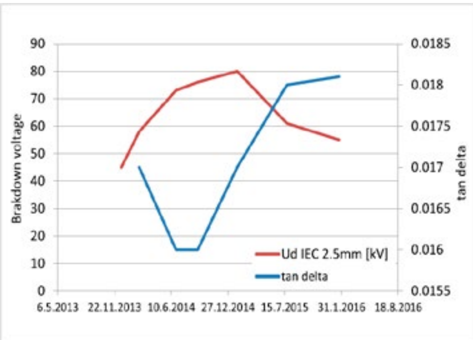


Figure 8. Breakdown voltage and tan delta of FR3 natural ester samples

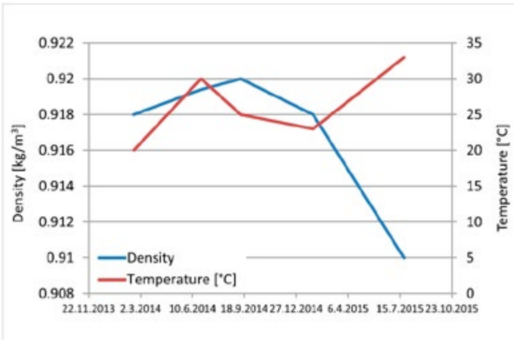


Figure 9. Density of natural ester sample

The analysis of the moisture in the transformer oil (Figure 8) was based on the oil samples which were taken from the transformer at quarterly intervals in order to evaluate the transformer condition. Breakdown voltage and tan delta of natural ester samples were also regularly measured and showed no significant changes with respect to the required values (Figure 8).

Other parameters, such as the density of natural ester sample (Figure 9) and oil viscosity, were also measured to further check the condition of the transformer. While some of these measurements are done on every third sample, all of these parameters help us establish that the transformer is in good condition and that the condition of the natural ester itself has no influence on its performance. The performed measurements and their results show that there have been no abnormalities in the operation of the transformer and that its performance has been perfect and according to all standard expectation.

CONCLUSION

In the early days, there were certain concerns about building a large power transformer with the use of natural ester FR3 fluids. However, all of the findings collected from monitoring data of the world's largest transformer of this type demonstrate that this is a transformer with a perfectly normal behavior, causing absolutely no concern and operating according to all expectations and standards prescribed by the IEEE reference guide. Any differences in the values are acceptable according to the IEEE guide.

The water content, dielectric strength and tan delta results indicate that this is a well prepared and a perfectly normally operating transformer – and the DGA results support this. All these findings suggest that this solution is the future for power transformers, serving not only as an alternative to mineral oil now, but also as its replacement in the future. With this in view, applying these solutions now is becoming increasingly important in order to gain experience with the alternative liquids that seem to be a perfectly suitable replacement for mineral oil.

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Stray Gassing of different refinery streams and impact of metal deatctivators

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ERGON Europe

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.

ERGON
Naphthenic oils. That's our business.

Stray Gassing Of Refinery Streams And Transformer Oil Produced From Them

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Abstract— Refinery processing determines the chemistry of the base oils used in transformer oils. Increasing the severity of the processing leads to a more stable base oil. Performance additives can modify the chemistry of the system and potentially lead to unintended consequences. This study examines how processing differences and additives affect the generation of stray gasses at low temperatures.

Keywords—stray gassing; refinery streams; severe hydroprocessing; passivators

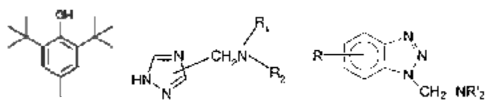
I. Introduction

Since the early 1990's the phenomenon of new transformer oil releasing high concentrations of gases at low temperatures (90°C to 200°C) has been reported [1]. This process of generating gases, primarily hydrogen, at low temperatures was termed "Stray Gassing" by CIGRE. Many of the instances of stray gassing have been noticed during transformer factory acceptance tests before they are ever put into service. After 2000 this phenomenon increased to the point that both Doble [2] and CIGRE started investigations to find the cause. They studied oil types, transformers, building materials and transformer operating conditions.

This project was performed to see if refining processes could be the cause of stray gassing. In some prior presentations and reports it has been suggested that more severe refining technology could be responsible for stray gassing [3-5]. Hopefully, this project will shed more light on this possibility. Refiners have access to streams before and after additives are added or blending performed to make the finished transformer oil. The data should show whether stray gassing is the result of different refining processes used on oils or other actions taken to produce a final product. This project is limited to refining differences and chemical additives. It does not investigate other potential parameters such as oxygen content, water content, paper insulation, metals, varnish/paint, acid generation, variable temperatures, or inhibitor content.

II. Project Basis

Mineral oils used as transformer oils are processed using two basic techniques (1) solvent extraction and (2) severe hydroprocessing which is the predominate process used today. Refinery streams were selected and testing was set up to analyze them neat and after they were blended with other streams or additized with property enhancing substances. Three naphthenic base stocks used to make Ergon's transformer oils and the finished transformer oil products were selected. The naphthenic base stocks were treated to two different levels of saturation. One base stock was treated to high saturation and the second to very high saturation. An Isoparaffin 60 was selected because of the very severe hydro-cracking process used to produce it. The Isoparaffin 60 was obtained from a distributor and it is not known if it was stored under conditions appropriate for transformer oil. Chemical additives, e.g., 2,6-di-tert-butyl-p-cresol (BHT or DBPC), Irgamet® 30, Irgamet® 39, see Fig. 1, and refinery blend components, e.g., Aromatic Naphtha and a Solvent Neutral, were selected.



(a) (b) (c)

Fig. 1. (a) BHT or DBPC; (b) Irgamet 30; and (c) Irgamet 39

Each sample was tested for stray gas generation using the procedure from CIGRE document 296. They were tested first with no heat incubation, degassed under vacuum, saturated with air then heated in a 30 cm^3 syringe for 16 hours at 120°C. Samples were tested for hydrogen, oxygen, nitrogen, carbon monoxide, carbon dioxide, methane, ethane, ethylene, acetylene and total combustible gases (TCG).

Ergon's finished products are formulated to meet ASTM Type II (Hyvolt II), IEC 60296 Standard Grade (Hyvolt I) and IEC 60296 Special Application (Hyvolt III). Hyvolt II and Hyvolt III are made using the straight base stocks from the refinery with only BHT added as an oxidation inhibitor. Hyvolt I is a specialized blend of the refinery base stock and a secondary base stock to supply natural inhibitors for oxidation stability.

Stray Gassing of different refinery streams and impact of metal deatctivators

The Hyvolt I and Hyvolt II base stocks are hydrotreated to the same level and are equivalent in their chemistry. The Hyvolt III base stock is more highly hydrotreated and will have lower aromatics and different chemistry. The Isoparaffin 60 is a hydro-cracked stock and has the highest saturation level of these base stocks. The solvent neutral is an extracted base stock and is used for its specialized chemistry. Aromatic naphtha is another refinery stream added to products to obtain specialized characteristics. The additives BHT, Irgamet 30 and Irgamet 39 are used to enhance oxidation stability or as passivators. BHT is an approved additive by both ASTM and IEC for enhancing oxidation stability. Irgamet 30 and Irgamet 39 have been used to passivate oil for corrosive sulfur but are also thought to enhance oxidation stability. Additives were added to the neat base stocks and finished formulated products to look for differences in stray gas generation.

III. Project

First, the neat refinery base stocks were tested for stray gassing without any additives. Then the individual base stocks were additized with specific additives and retested. BHT was added at 0.27 wt% for ASTM Type II or 0.37 wt% for IEC Special Application grades. The Irgamets were added at 100 mg/kg, the aromatic naphtha at 0.4 wt% and the solvent neutral at 3 wt%.

All samples were tested at zero hours at 20°C. There was no stray gas generated except for two samples that had 2 µL/L of methane.

A. *Neat Base Stocks*

Table I, Section 1 shows the data for the four neat base stocks. The base stocks differed by the type of processing (severe hydroprocessing, hydro-cracking, solvent extraction) and the severity of the processing. The solvent neutral had the highest amount of gassing, 99 µL/L of hydrogen, 178 µL/L of CO, 247 µL/L of CO_2, 2 µL/L of methane and 2 µL/L ethylene. The oxygen level was severely reduced indicating the onset of oxidation. The two severely hydrotreated naphthenic base stocks had no detectable amounts of gassing. The oxygen levels were maintained indicating no oxidation. The two base stocks differed only by the severity of the hydroprocessing. The Isoparaffin 60 showed gassing and oxidation, however, it was concluded that contamination could be the issue.

B. *Formulated Commercial Samples*

The second samples testing involved the formulated transformer oils made from the base stocks. Samples were taken from actual customer shipments. Data from this testing are shown in Table I, Section 2.

Hyvolt I and Hyvolt II are produced from the same base stock. Hyvolt I is enhanced with a secondary base stock while Hyvolt II is additized with 0.27 wt% BHT. Hyvolt III is produced from a more severely processed base stock and it is additized with 0.37 wt% BHT.

Hyvolt I, uninhibited, generated a level of gassing with a significant reduction in the oxygen level. The inhibited oils, Hyvolt II and III, showed no gassing and no reduction in the oxygen level. This suggests that the secondary, non-severely hydrotreated base stock in Hyvolt I, which provides natural inhibitors, generates the stray gassing. Natural inhibitors and other reactive molecules remaining in the secondary base stock can participate in the free radical process that generates the stray gassing. These types of reactive molecules are not seen in the severely hydrotreated base stocks.

C. *Additized Samples*

The Ergon commercial samples and the Isoparaffin 60 were tested with the various additives. The data are given in Table I, Sections 3 - 6. Fig. 2 shows the effect of passivators on the formulated transformer oils.

The uninhibited Hyvolt I was additized with BHT, Irgamet 30, Irgamet 39 and Aromatic Naphtha. The results are given in Table I, Section 3. The addition of BHT altered the mix of gases generated but the total amount was about the same. The addition of the Aromatic Naphtha did not significantly affect the gassing, the results were very similar to the Hyvolt I. The addition of either Irgamet 30 or 39 greatly increased the gas generation. The hydrogen content increased from 214 µL/L for the Hyvolt I to 2249 µL/L with the addition of Irgamet 30 and to 1079 µL/L with the addition of Irgamet 39. There were also increases in CO, CO_2, methane, ethane and ethylene.

The inhibited Hyvolt II and III differ by the severity of the processing and the amount of BHT. The Hyvolt III base stock was processed at a higher severity leading to a base stock with a higher degree of saturation. The Hyvolt III also contains slightly more BHT, 0.37 wt% versus 0.27 wt%. The response to the additives was nearly identical. The data are given in Table I, Sections 4 and 5. The Irgamets led to an increase in hydrogen to 350 – 555 µL/L. The CO increased to about 50 µL/L and CO_2 increased to about 100 – 400 µL/L. The Aromatic Naphtha led to a slight increase of hydrogen, about 10 µL/L and slight increases in CO and CO_2, 56 – 84 µL/L. There was only a slight reduction in oxygen levels. The BHT inhibitor reduced the degree of oxidation which reduced the gas generation due to the additives.

The Isoparaffin 60 was tested with 0.37 wt% BHT, 100 mg/kg Irgamet 39 and 3 wt% solvent neutral. The data are given in Table I, Section 6. The Isoparaffin 60 with the BHT was comparable to the Hyvolt III containing the same amount of BHT. Hydrogen was below the detection limit and there was slightly more CO and CO_2. The addition of Irgamet 39 gave results very similar to the Hyvolt III with Irgamet 39.

IV. Conclusions

Several variables were investigated to determine the effects on the generation of stray gassing. Severe hydroprocessing did not have a negative impact on stray gassing. Different levels of hydroprocessing produced base stocks without any

Stray Gassing of different refinery streams and impact of metal deatctivators

stray gassing. The hydrocracked Isoparaffin 60 showed low levels of gassing, but since the oil may not have been maintained at transformer oil quality, those low levels may be an artifact. When the additized Isoparaffin 60 samples were compared to the other oils, the responses were similar which would indicate that the stability was similar. It is believed that some slight contamination led to the oxidation and subsequent gassing. Solvent extraction produced a base stock with some stray gassing.

Severe hydroprocessing, including hydrocracking, produces oxidatively stable base stocks. Unstable and reactive molecules are effectively converted or removed during severe hydroprocessing. This is evidenced by the lack of stray gassing, including CO_2, and the maintaining of the oxygen levels for the neat base stocks. Oils produced under different process conditions, such as the solvent neutral, are less stable and consume oxygen. The Aromatic Naphtha which is used for negative gassing tendency does not significantly impact stray gassing. There is a slight increase in oxidation and gas generation. The addition of solvent neutrals, which are less oxidatively stable than severely hydrotreated oils, increases the oxidation and stray gassing.

Passivators such as Irgamet 30 or 39 are designed to be reactive and are known to chemically bond to metal surfaces. Irgamet 30 and 39 are thought to chemically degrade either due to free radicals such as peroxides [6] or during binding to the copper surface [7]. The chemistry of the passivators is independent of the oxidation of the mineral oil since the highly refined oils exhibited no oxidation and no gas formation in the absence of passivators but exhibited oxidation and gas formation in the presence of passivators.

Oxidation is a complex free radical process. Once the process starts, other reactive components such as the Irgamet additives can participate in the reactions and produce by-products. These by-products can be hydrogen and the lower hydrocarbons.

Since Hyvolt I is an uninhibited oil, it is the most prone to oxidation. When reactive additives are present, they can participate in the free radical reactions. Since there is more oxidation occurring, there are more free radicals generated, and hence more stray gassing. Hyvolt II, Hyvolt III and the Isoparaffin 60 are more oxidatively stable and stray gassing does not occur. When the additives are present, some stray gassing is generated but to a lesser extent since there is less oxidation occurring, less free radicals being generated.

Scatiggio, et al. described "classical stray gassing" as hydrogen and hydrocarbon gasses formation and "passivator induced stray gassing" as entirely due to H_2, CO, and CO_2, without the formation of hydrocarbon gasses [8]. Our observations are in agreement. The severely hydroprocessed base stocks and formulated oils without passivators did not generate gasses. When passivators were added to these oils, only H_2, CO, and CO_2 were observed, leading to "passivator induced stray gassing". The other, less severely processed solvent neutral oil without passivators exhibited "classical stray gassing" and generated H_2, CO, and CO_2 as well as hydrocarbons.

Stray gassing, the low temperature generation of gasses, is a consequence of free radical reactions occurring during the oxidation of the transformer fluid. Severe hydroprocessing produces stable base stocks that resist oxidation and limits the amount of stray gassing. The presence of reactive additives enhances the generation of stray gassing.

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Table I. Stray Gassing Results (120°C after 16 hours, µL/L)

Section 1. Neat Refinery Base Stocks without Additives									
	H_2	O_2	CO	CO_2	CH_4	C_2H_2	C_2H_4	C_2H_6	TCG
Hyvolt I & II base stock	<5	31171	<25	<25	<1	<1	<1	<1	0
Hyvolt III base stock	<5	30908	<25	<25	<1	<1	<1	<1	0
Isoparaffin 60	34	138	101	154	29	<1	5	53	222
Solvent Neutral	99	9282	178	247	2	<1	2	<1	281
Section 2. Formulated Commercial Products									
Hyvolt I	188	1667	157	428	54	<1	65	65	529
Hyvolt II	<5	28200	<25	<25	<1	<1	<1	<1	0
Hyvolt III	<5	30334	<25	<25	<1	<1	<1	<1	0
Section 3. Hyvolt I with Additives									
Neat Hyvolt I	214	234	136	201	68	<1	41	82	541
0.27 wt% BHT	213	7801	296	475	8	<1	55	<1	572
100 mg/kg Irgamet 30	2249	203	161	433	132	<1	30	134	2706
100 mg/kg Irgamet 39	1079	314	200	277	190	<1	32	190	1691
0.4 wt% Aromatic Naphtha	222	177	168	252	82	<1	54	96	622
Section 4. Hyvolt II with Additives									
Neat Hyvolt II	<5	28200	<25	<25	<1	<1	<1	<1	0
100 mg/kg Irgamet 30	545	21403	47	101	<1	<1	<1	<1	592
100 mg/kg Irgamet 39	420	23812	56	415	<1	<1	<1	<1	476
0.4 wt% Aromatic Naphtha	10	21722	60	84	<1	<1	<1	<1	70
Section 5. Hyvolt III with Additives									
Neat Hyvolt III	<5	30334	<25	<25	<1	<1	<1	<1	0
100 mg/kg Irgamet 30	555	22664	58	113	<1	<1	<1	<1	613
100 mg/kg Irgamet 39	350	22433	49	107	<1	<1	<1	<1	399
0.4 wt% Aromatic Naphtha	9	22218	56	63	<1	<1	<1	<1	65
Section 6. Isoparaffin 60 with Additives									
Neat Isoparaffin 60	34	138	101	154	29	<1	5	53	222
0.37 wt% BHT	<5	29256	54	83	2	<1	<1	<1	56
100 mg/kg Irgamet 39	236	28486	35	109	2	<1	<1	<1	273
3 wt% Solvent Neutral	150	28685	<25	148	2	<1	<1	<1	152

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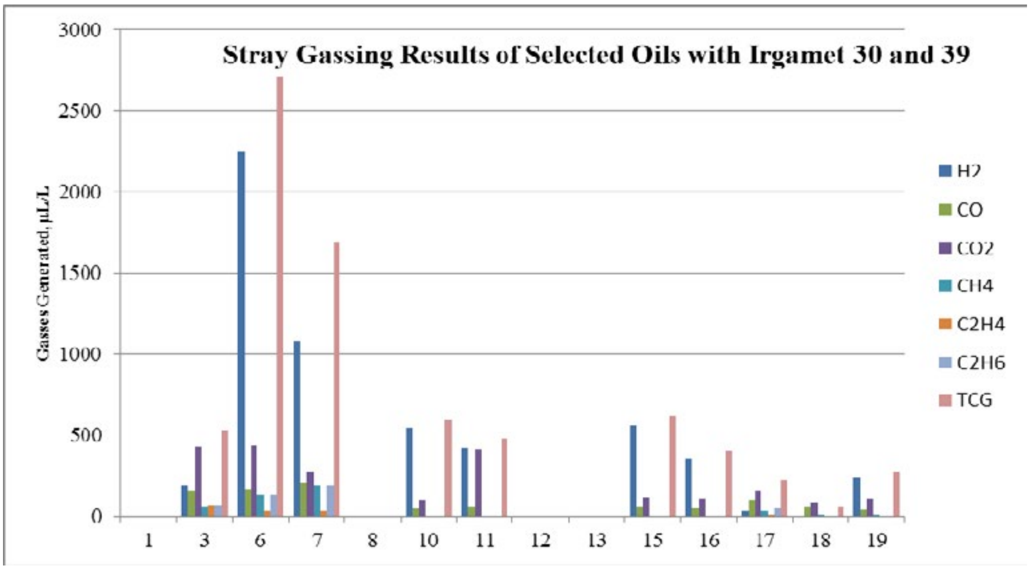

Fig. 2. Stray gassing results for selected neat base stocks, formulated transfomer oils, and samples with Irgamet 30 or Irgamet 39. (1) HyVolt I and II base stock, (3) HyVolt I, (6) HyVolt I with Irgamet 30, (7) HyVolt I with Irgamet 39, (8) HyVolt II, (10) HyVolt II with Irgamet 30, (11) HyVolt II with Irgamet 39, (12) HyVolt III base stock, (13) HyVolt III, (15) HyVolt III with Irgamet 30, (16) HyVolt III with Irgamet 39, (17) Isoparaffin 60 base stock, (18) Isoparaffin 60 with BHT, (19) Isoparaffin with Irgamet 39.

Demystifying transformer Oil Treatment and regeneration

Igor Kudela
Ekofluid

Demystifying transformer Oil Treatment and regeneration

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Demystifying transformer Oil treatment and regeneration

Igor Kudela , Ekofluid GmbH

Ekofluid

Not your average presentation

- No technical speak
- KISS principal
- Establish a common base
- Destroy the false truth
- No graphs , numbers or tables

Demystifying transformer Oil Treatment and regeneration

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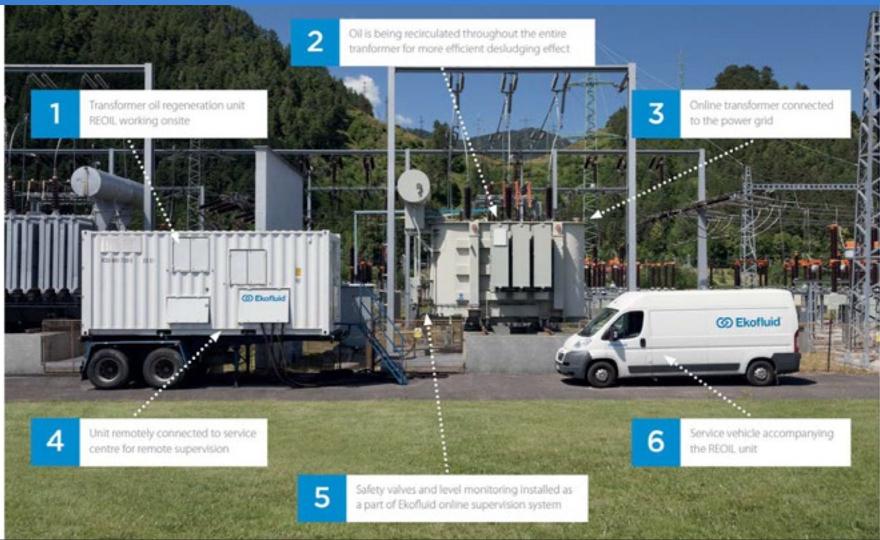
Generic onsite setup



Ekofluid

OIL what ??

- Oil degassing
- Oil filtration
- Oil de humidifying
- Oil treatment
- Oil regeneration
- Oil reclamation
- Oil purification
- Oil drying
- Oil processing

Demystifying transformer Oil Treatment and regeneration

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Which is it ?

Your oil is either wet (full of water) or full of gas
OR
Your oil is old (and can also be wet and full of gas)

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Remove water and gas

- Oil degassing
- Oil filtration
- Oil de humidifying
- Oil treatment
- ~~Oil regeneration~~
- ~~Oil reclamation~~
- Oil purification
- Oil drying
- Oil processing

Ekofluid

What removes the water and gas

- Vacuum inside the vacuum chamber
- Temperature of the oil
- Separation elements (inside the vacuum chamber)

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How do you know when to start

There are 2 factors that can influence your decision

- Time
- Oil test results

Demystifying transformer Oil Treatment and regeneration

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How do you now when to end

- Ask the simple question , is the water and gas gone
- Gone means below the requirements of the standards
- And always confirm with measuring instruments or even better with the accredited laboratory

Ekofluid

Do I have good equipment

Forget about
- Leakage rate
- Absolut vacuum
- Vacuum tight

Concentrate on
- What is inside the vacuum chamber
- Oil flow
- Heating capacity
- Size
- Performance of the plant

Demystifying transformer Oil Treatment and regeneration

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What to look for

- Good vacuum pumps
- Reliable foam sensor
- Inlet and outlet pump
- Good enough heating
- Reliable control system with enough protections
- Safety features

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Oil ……….. Plant

Demystifying transformer Oil Treatment and regeneration

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Common misconceptions

- Offline treatment is different to online treatment
- Vacuum tight
- The bigger the better
- As long as there is a vacuum chamber all is good

Ekofluid

Renews old oil

- ~~Oil degassing~~
- ~~Oil filtration~~
- ~~Oil de humidifying~~
- ~~Oil treatment~~
- Oil regeneration
- Oil reclamation
- ~~Oil purification~~
- ~~Oil drying~~
- ~~Oil processing~~

Demystifying transformer Oil Treatment and regeneration

Ekofluid

What renews the oil ?

Special filters inside the equipment but more importantly what is inside them.

- Fuller earth
- Activated bauxite
- Sorbent

It is a very advanced filter made by nature which attracts everything that is old in the oil and keeps it.

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The big question is:

What happens after these filters are full
They stop to work and you need to renew them

Demystifying transformer Oil Treatment and regeneration

Ekofluid

How do you renew filters

By vacuum and heat

- Its like burning a cigarette only 12 hours long and under vacuum
- The filters are restored to their initial capacity
- This can be done many (up to 300) times
- Than you need to replace them

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Time factor

Renewing of oil takes time
Renewing of filters (material inside them) takes also time
Very different to gas and water removal

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How do you know when to start

There are 3 factors that can influence your decision

- Time
- Oil results
- Life extension

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How do you know when to end

- Ask the simple question , is the oil new again ?
- New means does it meet the required standards ?
- You can do it visually but always ask the local laboratory to confirm.

Ekofluid

Do I have good equipment

Forget about
- Oil flow
- Vacuum capacity

Concentrate on
- Amount of filter media in the filters
- Effectiveness of filter media in the filters (usually defined by the amount of oil in kg before the renew cycle needs to be started)
- Size

Ekofluid

What to look for

- Good vacuum pumps
- Well known PLC and SACADA system
- Good enough heating
- Reliable control system with enough protections
- Safety features

Demystifying transformer Oil Treatment and regeneration

Ekofluid

Oil ……….. Plant

Ekofluid

Common misconceptions

- Offline treatment is different to online treatment
- Capacity of the plant is defined by oil flow
- You can only improve to the initial state of the oil not better

Demystifying transformer Oil Treatment and regeneration

Detection of winding faults with frequency response analysis (FRA)

Prof. Dr.-Ing. Hossein Borsi
University of Hannover

Detection of winding faults with frequency response analysis (FRA)

IfES

Leibniz Universität Hannover

DETECTION OF WINDING FAULTS WITH FREQUENCY RESPONSE ANALYSIS (FRA)

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Seite 1

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FRA – What is it?

- Reliable and sensitive Method to evaluate the mechanical and electrical integrity of transformers active part
- Measurement of the transfer function for every winding over a wide frequency range
- Comparison of current test results with reference data (historical fingerprints, sister units, phase to phase)

Seite 2

Detection of winding faults with frequency response analysis (FRA)

What defects can be detected by FRA?

- Winding deformation axial & radial (buckling, tilting…)
- Axial displacement between HV- and LV windings
- Shorted or open turns
- Faulty grounding of core or screens
- Core movement or shorted laminations
- Problematic internal connections

When we use FRA?

- **Prove the transformer after short circuit testing**
- **Check the integrity of transformers after transportation**
- **Routine testing**
- **Condition assessment after the occurrence of high fault currents**
- **Diagnosis after transformer alarm or protection tripping**

Detection of winding faults with frequency response analysis (FRA)

When we use SFRA?

- Testing after significant changes of monitored values (e.g. combustible gases….)
- Further investigation after the observation of unusual routine test results
- Scientific investigations

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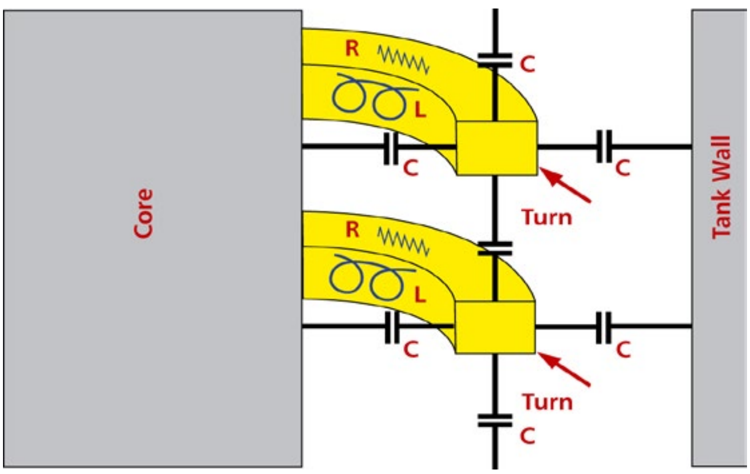
Seite 5

Model of transformer winding

The transformer as a network



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Seite 6

Detection of winding faults with frequency response analysis (FRA)

What about the forces?

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$$F \sim I^2$$

Force direction

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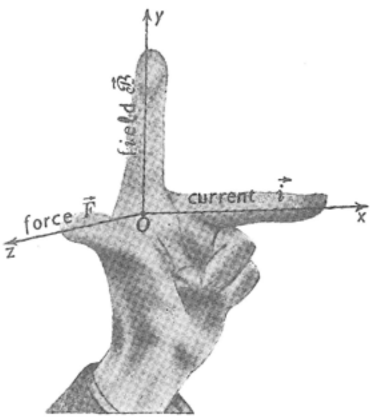
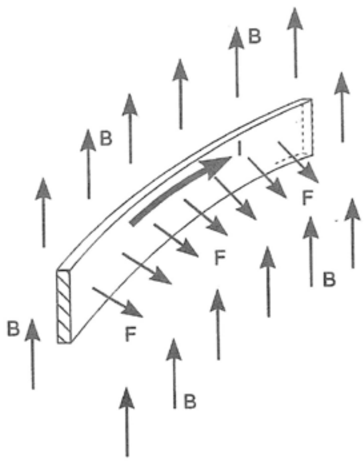
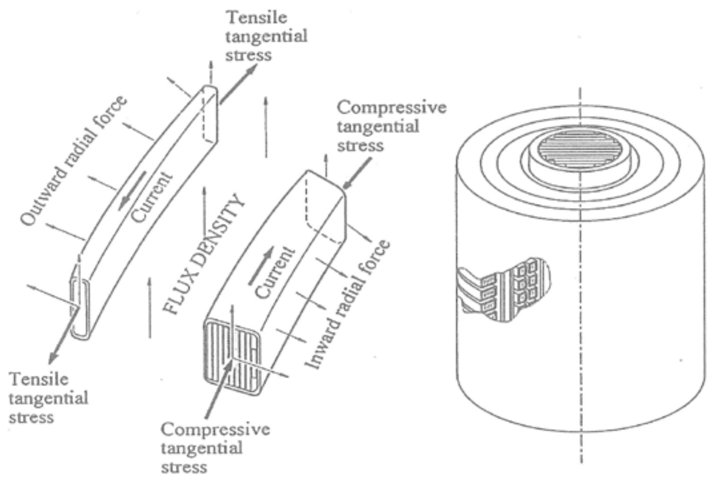




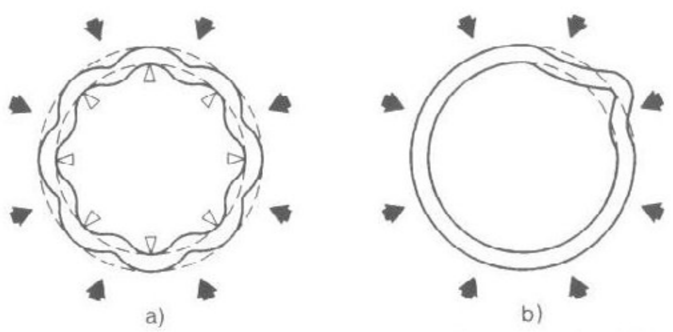
Prof. Dr.-Ing. Hossein Borsi

Detection of winding faults with frequency response analysis (FRA)

Radial forces



Effects of radial forces – buckling



forced buckling   free buckling

Detection of winding faults with frequency response analysis (FRA)

Free and forced buckling

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Source: G. Bertagnolli, Short Circuit Duty of Power Transformers, ABB Trasformatori, Legnano

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Forces due to axial displaced windings

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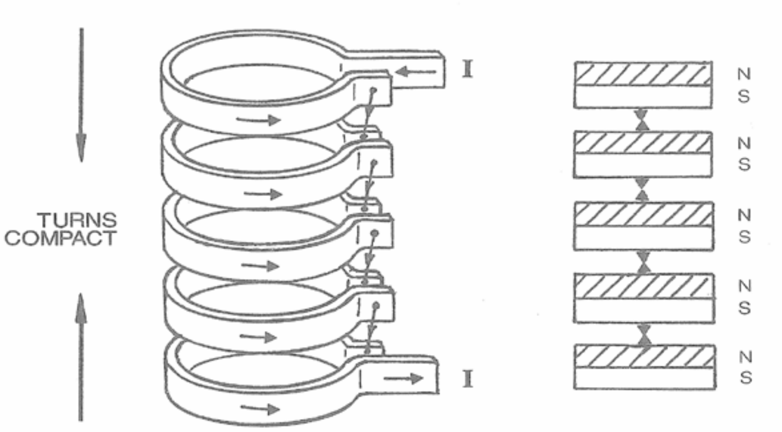

Source: G. Bertagnolli, Short Circuit Duty of Power Transformers, ABB Trasformatori, Legnano

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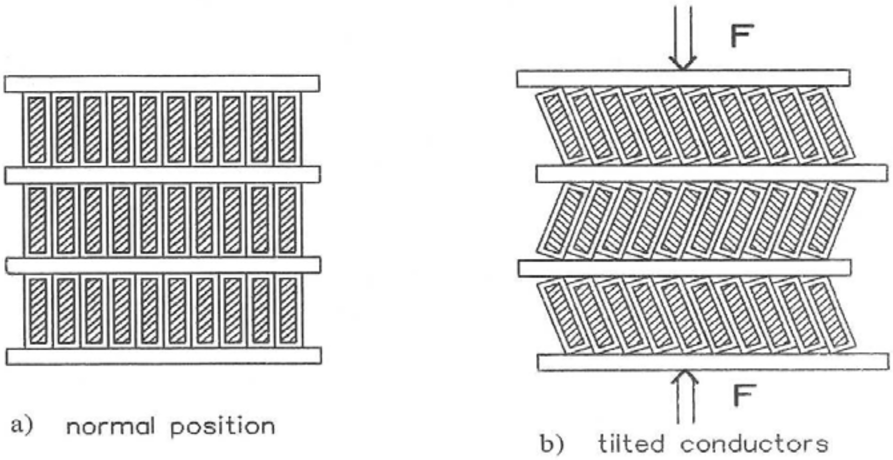
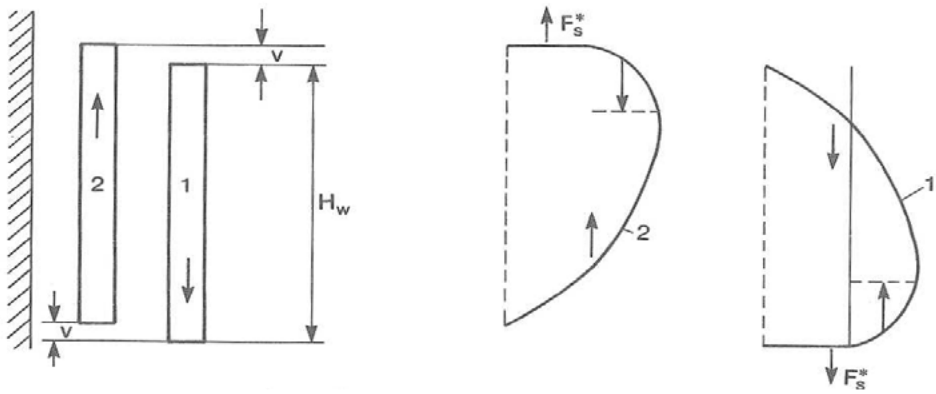
Detection of winding faults with frequency response analysis (FRA)

Tilting due to axial compressive forces



Source: G. Bertagnolli, Short Circuit Duty of Power Transformers, ABB Trasformatori, Legnano

Forces due to axial displaced windings



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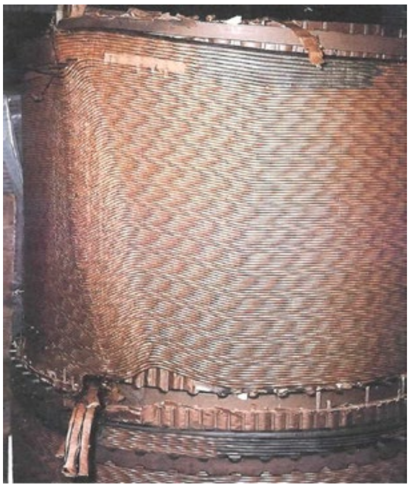
Detection of winding faults with frequency response analysis (FRA)

Axial Collapse



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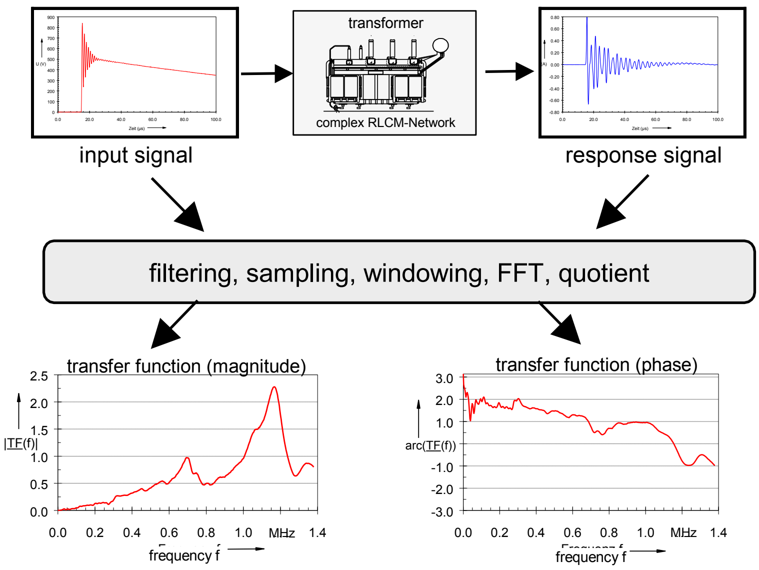
FRA with impulses (IFRA)



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Detection of winding faults with frequency response analysis (FRA)

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Swept Frequency Response Analysis (SFRA)

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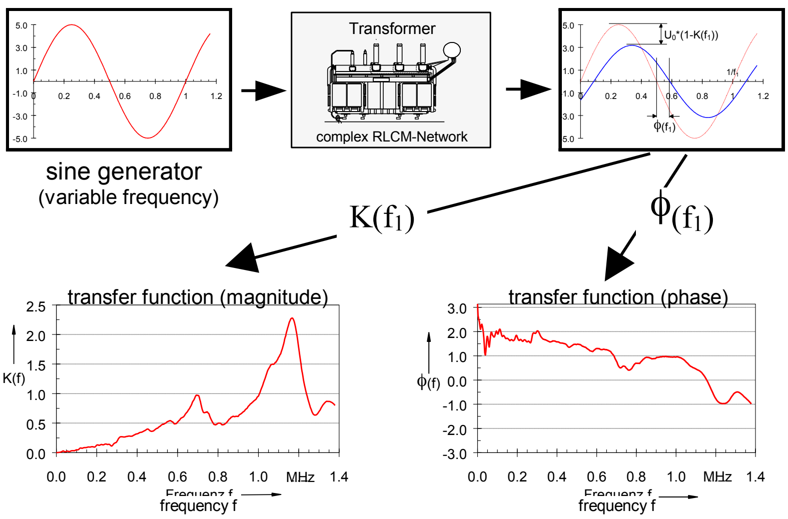

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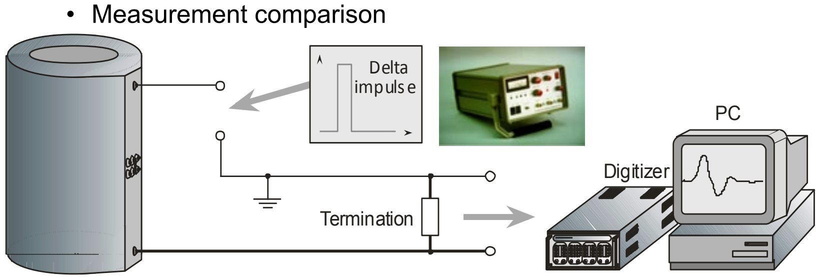
- FRA (Frequency Response Analysis)
  - IRA (Impulse Response Analysis)
  - SRA (Step Response Analysis)
  - FRA (Frequency Response Analysis)
  - System Response Measurement
    - Determination of short circuit in winding as well as winding deformation
    - Measurement comparison



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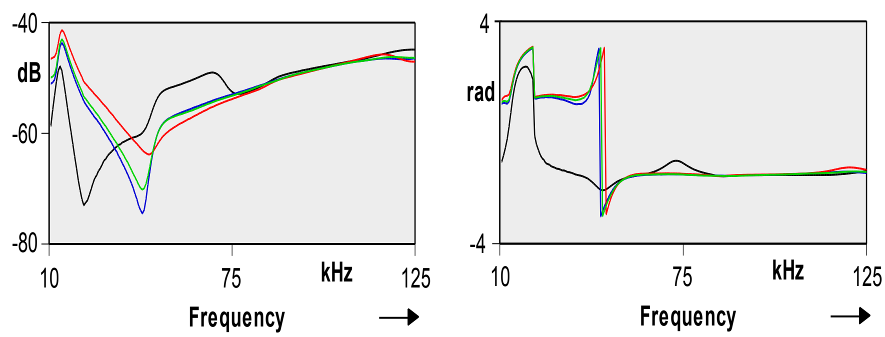
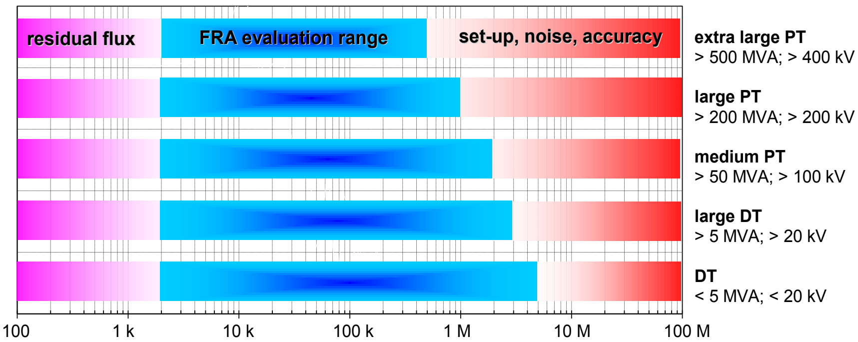
Detection of winding faults with frequency response analysis (FRA)



FRA: frequency ranges

- Rules for a transformer specific frequency range for extra large, large and medium sized power



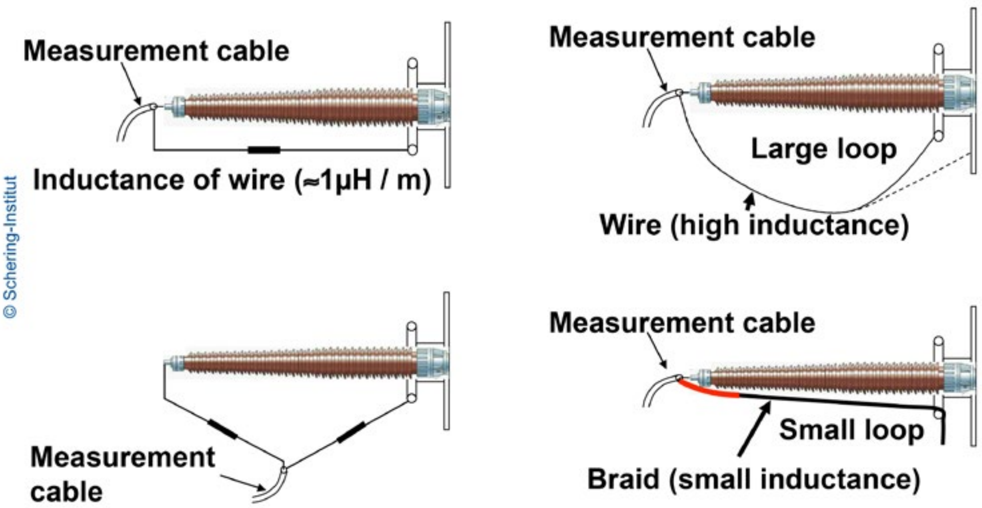
Large PT ⇒ large dimensions for the measuring circuit ⇒ low f_{min} for interference
⇒ low resonance frequencies of windings
low f_{max}(FRA)

Small DT ⇒ small dimensions for the measuring circuit ⇒ high f_{min} for interference
⇒ high resonance frequencies of windings
high f_{max}(FRA)

Prof. Dr.-Ing. Hossein Borsi

Detection of winding faults with frequency response analysis (FRA)

Grounding concept of measurement cables

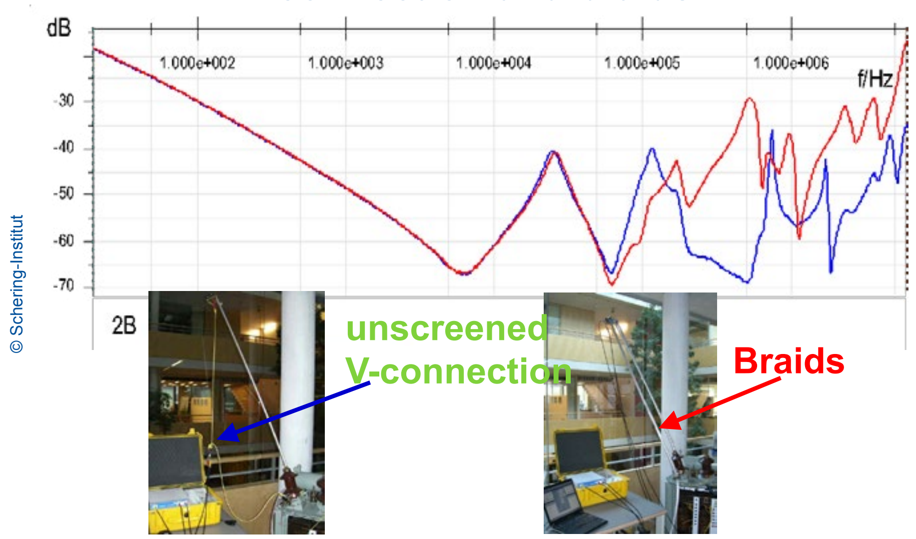


Three case studies

1. Comparison between wire, V-connection and braids
2. Comparison of the reproducibility
3. Measurement on a single phase 333MVA transformer in a substation

Detection of winding faults with frequency response analysis (FRA)

Laboratory measurements
Comparison between unscreened V-connection and braids



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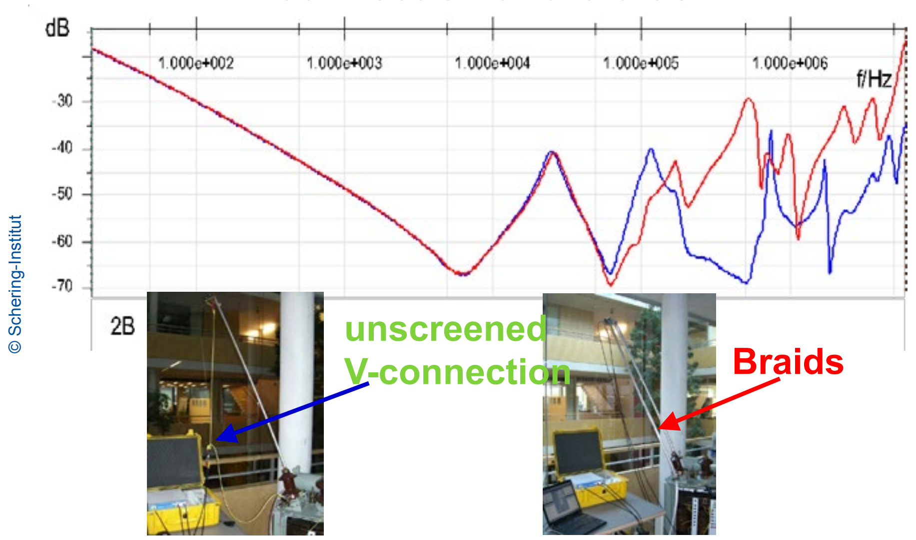
Laboratory measurements
Comparison between unscreened V-connection and braids



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Detection of winding faults with frequency response analysis (FRA)

Reproducibility with wires

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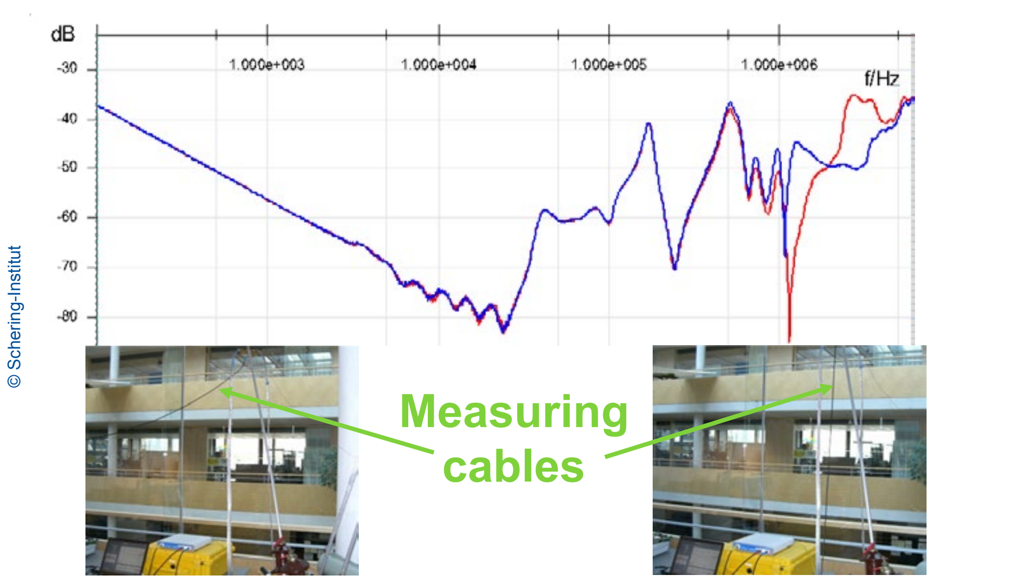

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Reproducibility with braids

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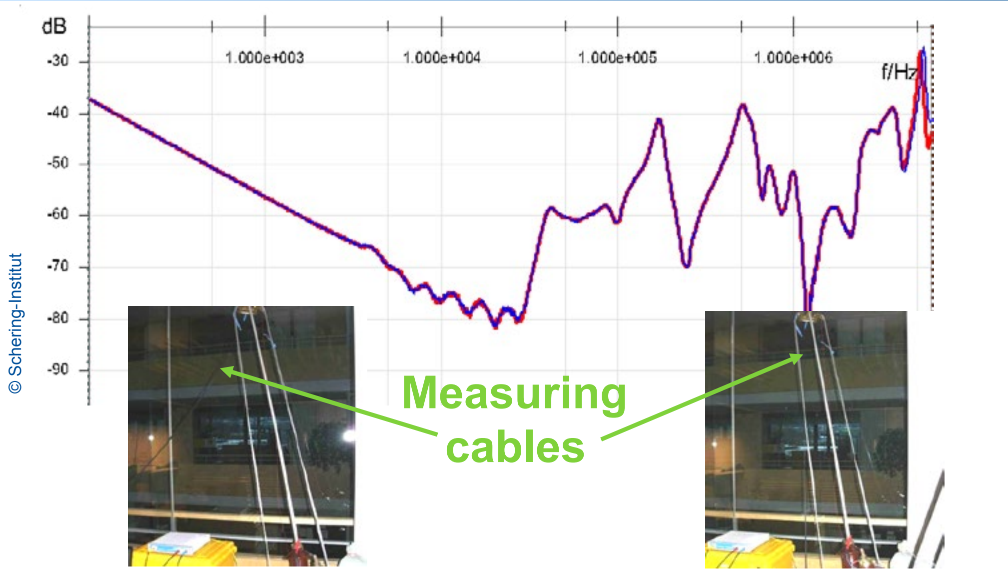

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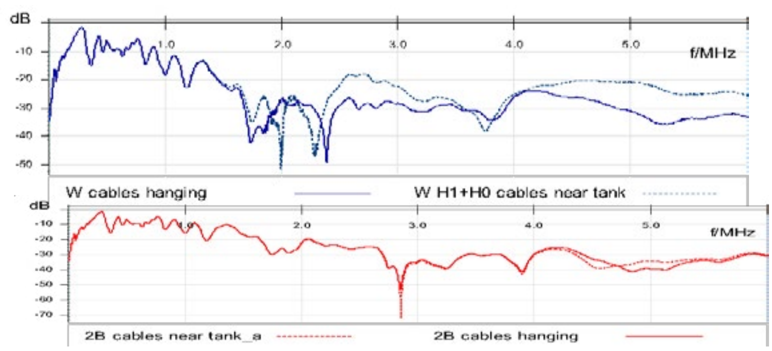
Detection of winding faults with frequency response analysis (FRA)

333MVA transformer
Reproducibility with wires and braids
Measurement cables close to bushing / tank and free hanging



Wires

Braids

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Connection HV side

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Detection of winding faults with frequency response analysis (FRA)

Connection N terminal

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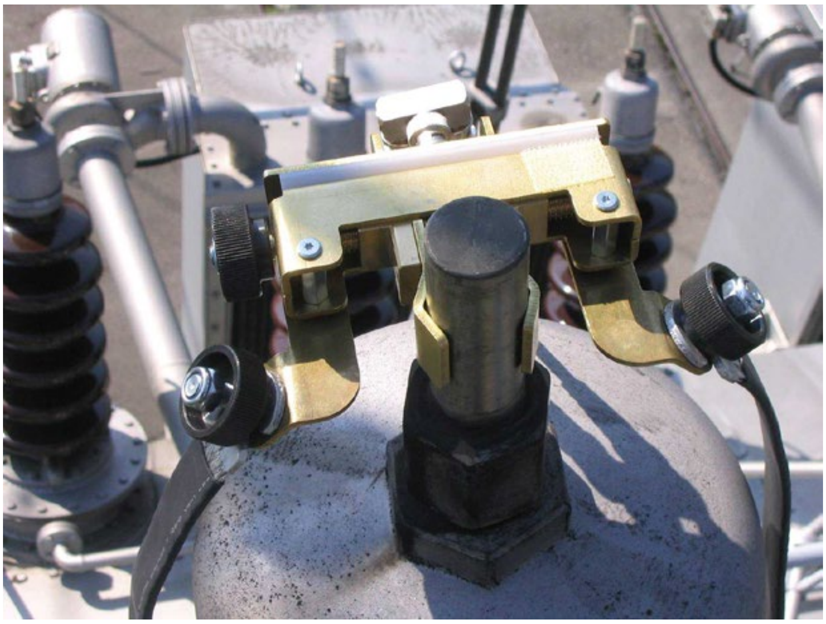
Connection clamp



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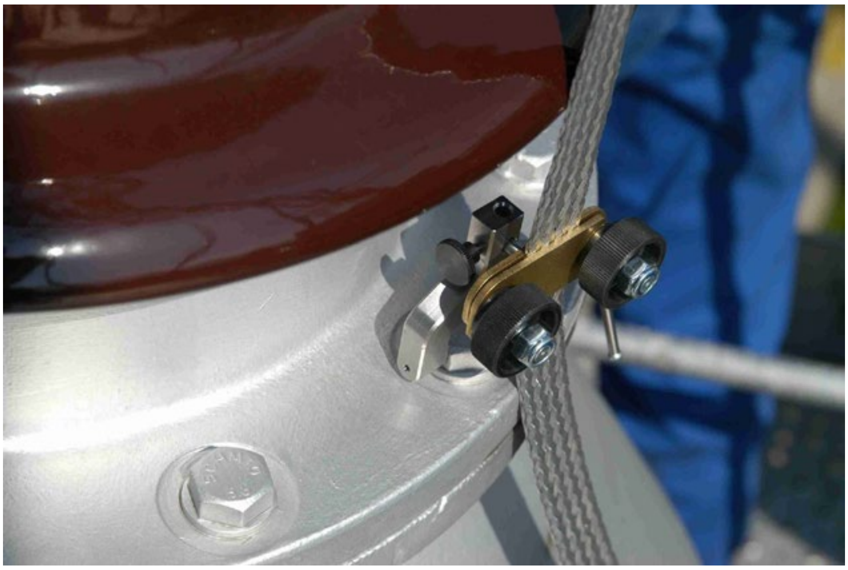
Detection of winding faults with frequency response analysis (FRA)

Connection flange



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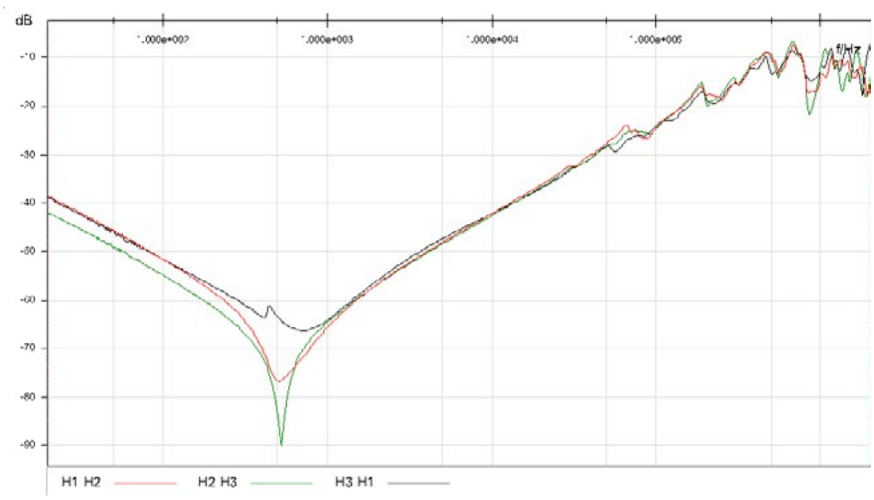
Practical Case: Open delta winding after short circuit testing



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Detection of winding faults with frequency response analysis (FRA)

Practical case: shorted turns

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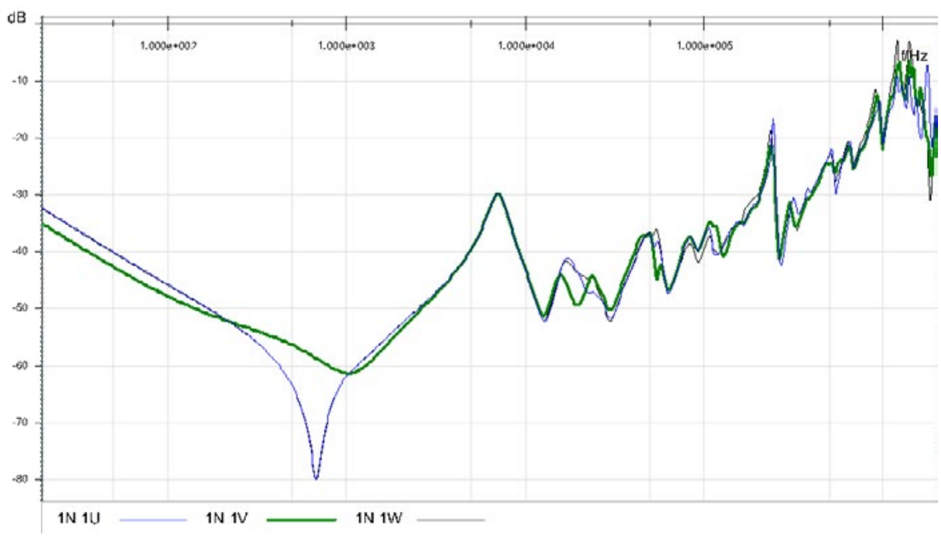

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Practical case: Core damage during transportation

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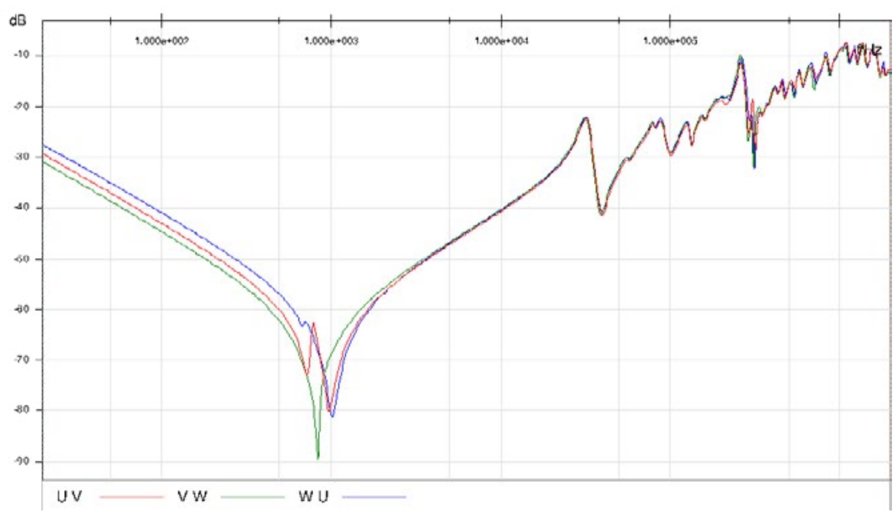

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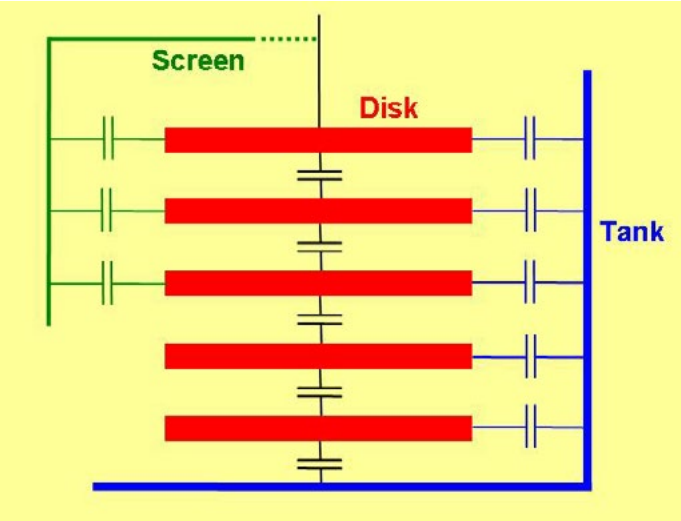
Detection of winding faults with frequency response analysis (FRA)

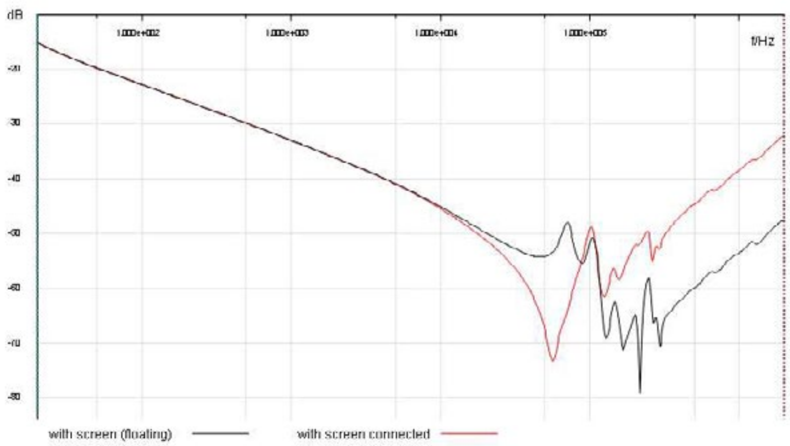
Interrupted screen connection



HV Screen

Detection of winding faults with frequency response analysis (FRA)

Interrupted screen connection



Requirements regarding the connection technique

- Reliable electrical contact to the bushing terminal and the reference potential (usually the tank)
- Ground extension of the coaxial leads of low inductance (broad braids with large surface, made of a large number of small wires to reduce the skin effect at higher frequencies)
- Ground extension to the base of the bushing as short as possible
- Smallest achievable loop of the earth connections to avoid noise interference

Detection of winding faults with frequency response analysis (FRA)

Conclusion

- FRA-devices need a sufficient dynamic range (at least down to -90 dB).

- Impuls measurements are not able to "see" the lower frequency range, which is expressive for several types of failure.

- The connection technique is of outstanding importance for true valuable test results!

Conclusion

- **The SFRA is a powerfull method to evaluate the mechanical and electrical integrity of transformers active part**
- **The reproducibility, absolutely necessary for a comparative method, is certainly achievable with modern test equipment**
- **Highest accurateness is essential when establishing the connections**
- **FRA-Fingerprints are an usefull and valuable investment which can get with small effort**

Detection of winding faults with frequency response analysis (FRA)

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Motivation

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Don 't let something like this happen to YOUR transformers!

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Good transport by ship

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Detection of winding faults with frequency response analysis (FRA)

Good transport by aircraft

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Not so good transport

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Naphthenic Mineral Insulating Oils in a Challenging Market Dynamics

Mr. Sutarmono
Nynas Pte Ltd

Sutarmono started to work with Nynas in October 2009 as the General Manager of PT Nynas Indonesia to take care the activity of Nynas in Indonesia. In his role, he manages the team to cover the different applications and segments where Nynas specialty oils are used in the industry. This includes the four segments in Tyre Industry, Chemical Indutrry, Lube Industry and last but not least the Electrical Industry where Nynas Transformer oil is being used.

On top of his role , Sutarmono also responsible as Area Manager of Transformer Oil for the ASEAN countries.

Prior working with Nynas , back in 1990 Sutarmono started his career in one of the Belgian Transformer manufacturer - Pauwels Trafo , which was taken over by Crompton Greaves in 2005. During his career in Pauwels / CG Power System, he has been working in various functions, in the Design , Materials and Planning, Project and Sales, Procurement and also in Supply Chain.

Sutarmono has a Mechanical Engineering Background from Politeknik Mekanik Swiss – ITB, and completing CBM programme at Prasetya Mulya Business School – Jakarta.

Naphthenic Mineral Insulating Oils in a Challenging Market Dynamics

Naphthenic Mineral Insulating Oils in Challenging Market Dynamics

Mr. Sutarmono, PT Nynas, Indonesia
Mr. Johan Grovik, Nynas AB, Sweden
Mr Chian Yaw Toh, Nynas Pte LTD

Abstract

As a country develops, urbanizes and industrializes, the quest and need for efficient power/electrical generation and effective supply to populated areas become priority. Frequent down time in electrical supplies quickly translates into opportunities losses and adversely affects the social and economic aspects of the country.

Insulating oil, also frequently or more commonly known as transformer oil is one of the essential components in the build-up of transformers. Two important requirements of insulating oil are to provide essential insulation and efficient cooling to the power, transmission and distribution equipment.

The life of the transformer is equated to the life of the paper.
High quality insulating oil which meets in-service demands of the transformer and in combination with the appropriate and correct monitoring/maintenance practices and techniques, protects the paper and in return contributes to the longevity of the transformer.

Selecting the right type and high-quality insulating oil for service is also important. Understanding the requirements and specifications of insulating oil helps and ensures an overall reliable system and the life time of the transformer.

Measuring Methods for Solubility of Gases in Insulation Liquids

Prof. Dr. Ing. Peter Werle
University of Hannover

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.

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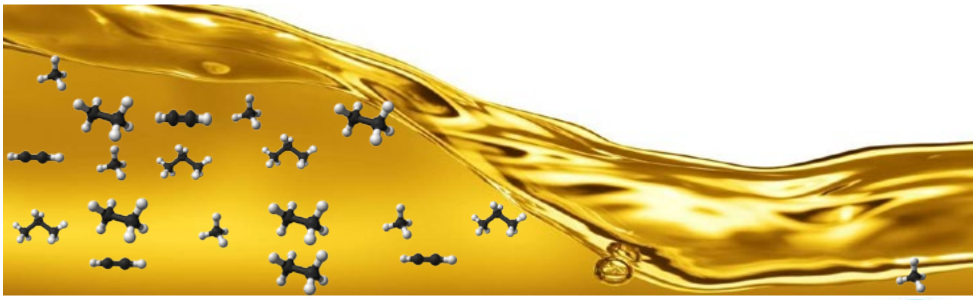
Measuring Methods for Solubility of Gases in Insulation Liquids

Measuring Methods for Solubility of Gases in Insulation Liquids

Prof. Dr.-Ing. Peter Werle
Leibniz Universität Hannover
Institute of Electric Power Systems
Division of High Voltage Engineering and Asset Management, Schering-Institute



International Transformer Life Management Conference
TLM 2017, 7. – 8.11.2017 Bangkok, Thailand

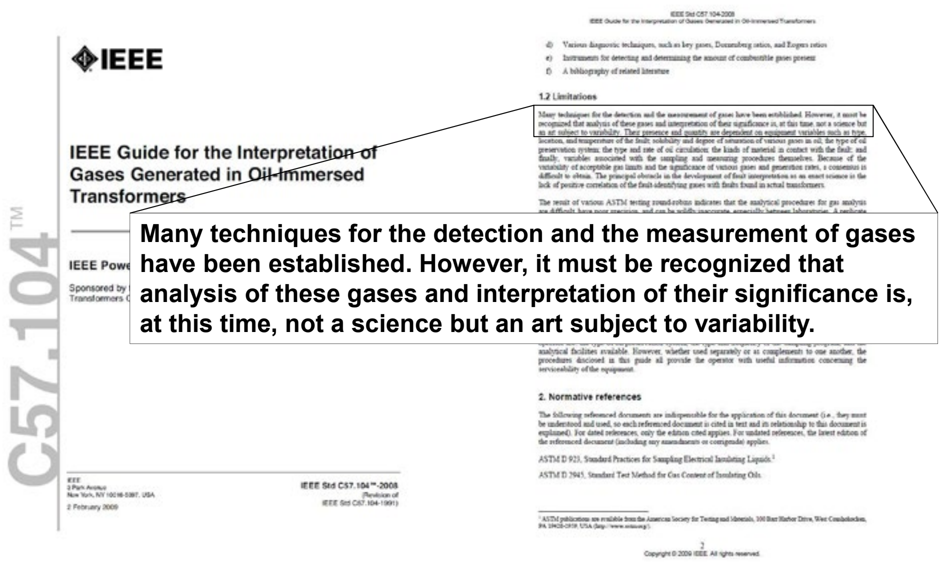
Motivation

- **Knowing the gas solubility in insulating fluids is needed, because**
  - **it is applied for DGA Headspace method**
  - **it governs the gas diffusion into the liquid phase or vice versa in hermitic sealed transformers**
  - **enables a comparison of the undissolved trapped gases in the transformer Buchholz relay and those dissolved in oil, which could deliver information about transformer health condition**
- **No standardized method to quantitatively determine the gas solubility in liquid insulations**

ASTM D2780-92 being already withdrawn!

Measuring Methods for Solubility of Gases in Insulation Liquids

Motivation


IEEE

IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers

C57.104™

1.2 Limitations

Many techniques for the detection and the measurement of gases have been established. However, it must be recognized that analysis of these gases and interpretation of their significance is, at this time, not a science but an art subject to variability.

2. Normative references

Motivation

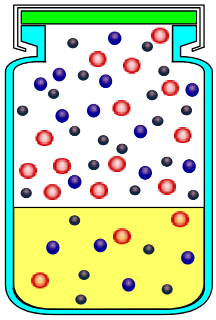
- Gas solubility coefficients provided by IEEE C57.104 and IEC 60599 are inconsistent resulting in misleading DGA interpretations

Gas	k (IEC 60599)	k (IEEE C57.104)	Difference in %
N_2	0.091	0.0745	22.1
H_2	0.056	0.0429	30.5
O_2	0.172	0.138	24.6
CO	0.132	0.102	29.4
CO_2	1.09	0.9	21.1
CH_4	0.429	0.337	27.3
C_2H_6	2.82	1.99	41.7
C_2H_4	1.84	1.35	36.3
C_2H_2	1.24	0.938	32.2

Measuring Methods for Solubility of Gases in Insulation Liquids

Ostwald Coefficient

- **Henry's law:**
  - The ratio of partial pressure to mole fraction of gas in solution is a constant
- **Ostwald coefficient**
  - The solubility of a gas is the volume of gas dissolved per volume of liquid when the gas and liquid are in equilibrium at the specified partial pressure of gas and at the specified temperature



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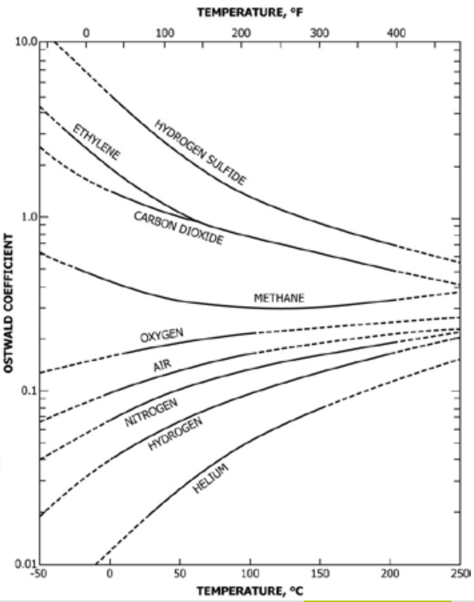
Ostwald Coefficient

- **Ostwald Coefficient dependencies**
  - Pressure
  - Temperature
  - Moisture
  - Solvent and solute compositions
  - …?

$$k = \frac{\text{concentration of gas in liquid phase}}{\text{concentration of gas in gas phase}}$$



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Measuring Methods for Solubility of Gases in Insulation Liquids

Glass Syringe Method

- Measurement procedure
  - A 50ml glass syringe filled with 30ml insulation liquid
  - Residual gas volume decreased to less than 0.3%
  - 20ml pure key gas was injected
  - The syringe kept in a heating chamber at 25°C for 72h
  - And subjected to the periodical shaking

No reliable and reproducible results possible

- Dilemma
  - Gas leakage at elevated temperature (75°C)

Measuring of Dissolved Gases

- Full-Vacuum degassing using TOGA GC
  - Establishment of vacuum ranging from 2 to 200mbar for app. 2min
  - Complying with the standard IEC 60567
  - Detection of extracted gases through Thermal Conductivity Detector (TCD) and a Flame Ionization Detector (FID)

Measuring Methods for Solubility of Gases in Insulation Liquids

New Method

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- Test set-up for gas saturation in liquid
  - The vessel was filled with 150ml of mineral insulating fluid
  - Liquid was treated at room temperature again at a vacuum level of 0.05mbar for 180min to ensure the removal of gas traces dissolved in the investigated oil
  - The pressure of the key gas was regulated at 1020mbar at the temperature of 25°C for 72h
  - Measuring the dissolved gases using a full vacuum degassing unit connected to the GC

New Method

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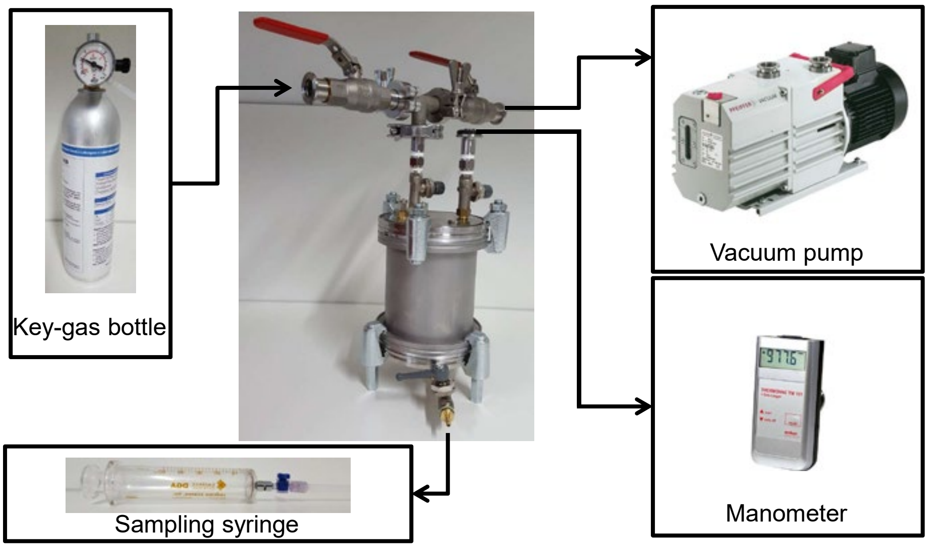
- Test set-up for gas saturation in liquid



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Measuring Methods for Solubility of Gases in Insulation Liquids

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New Method

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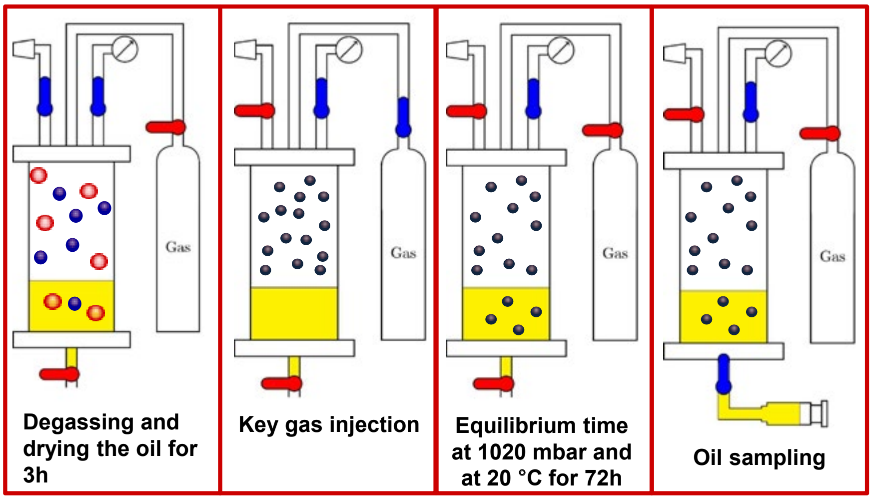
- Gas saturation process



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Results

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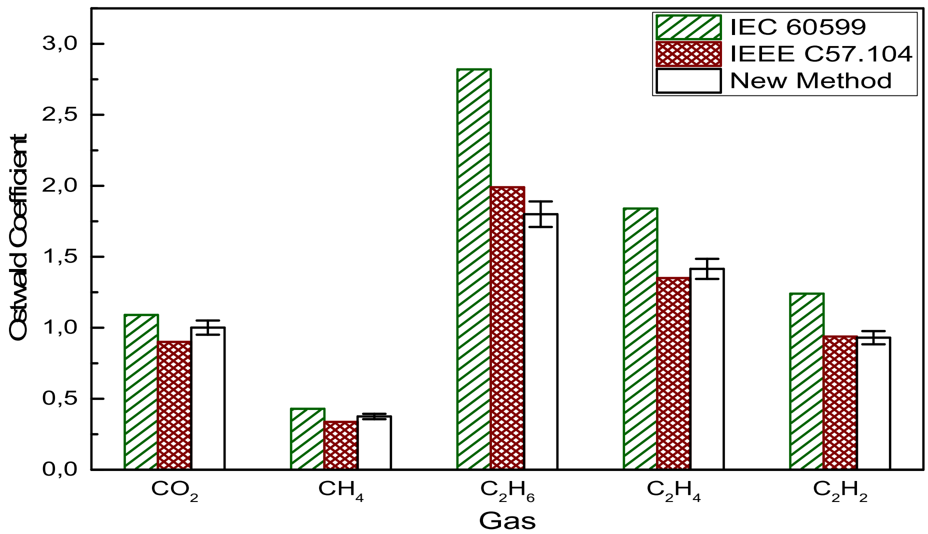
- The measured results are in between IEC and IEEE standard, but more close to IEEE



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Measuring Methods for Solubility of Gases in Insulation Liquids

Results

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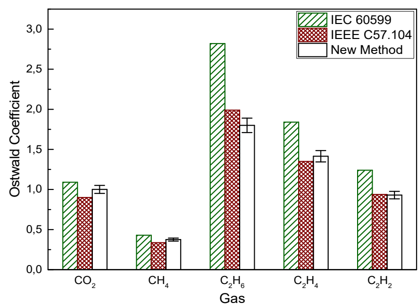
- Ostwald coefficient values by IEEE C57.104 and IEC 60599 are inconsistent
- Measured Ostwald coefficients of key gases in mineral oil is comparable with those provided by IEEE C57.104
- Good reproducibility

Gas	IEC 60599	IEEE C57.104	New Method
N_2	0,091	0,075	
H_2	0,056	0,043	
O_2	0,172	0,138	
CO	0,132	0,102	
CO_2	1,090	0,900	1,001
CH_4	0,429	0,337	0,375
C_2H_6	2,820	1,990	1,800
C_2H_4	1,840	1,350	1,415
C_2H_2	1,240	0,938	0,930



Ostwald coefficient of key gases in mineral oil S2 ZU-I at room temperature and at the pressure of 1020 mbar in comparison to IEC 60599 and IEEE C57.104

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Conclusion

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- Gas solubility coefficients provided by IEEE C57.104 and IEC 60599 are inconsistent resulting in misleading DGA interpretations
- No standardized method to quantitatively determine this dynamic property of the binary gas-liquid system
- Gas solubility measurement on oil S2 ZU-I has verified the applicability of the new proposed method
- Establishment of a new standard method for determination of Ostwald coefficient to substitute ASTM D2780-92 being already withdrawn

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Measuring Methods for Solubility of Gases in Insulation Liquids

Outlook

- Verification of this approach should be subjected to a round robin test
- Influence of the following parameters should be investigated
  - Water content
  - Aging status of the oil (more importantly dispersed cellulose fibers)
  - Cross-influence of gases
- Ostwald coefficients for all important insulation liquids to be determined
  - Synthetic and natural esters
  - Silicone liquid
  - Etc.…

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