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**Transformer Diagnose on practical Samples**

**Peter Werle**  
**ABB Transformer Service**



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

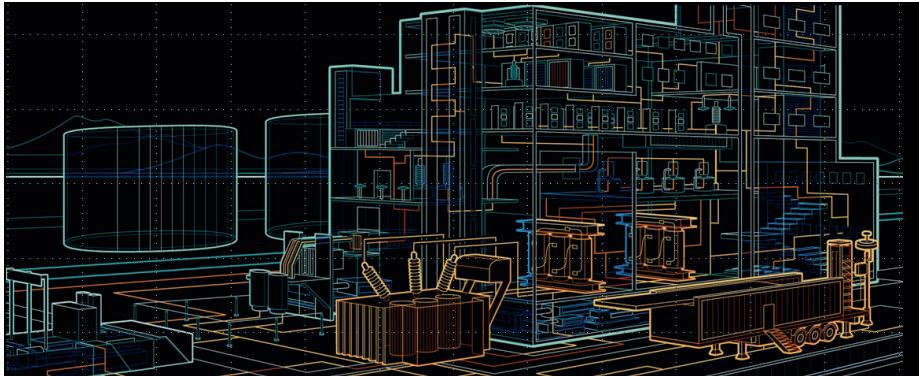
Since 2003 he is with ABB AG, Transformer Service in Halle, Germany, where he has hold different national and international positions. Since 2010 he is the general manager of the Transformer Service Workshop in Halle with more than 200 employees. He is member of VDE, IEEE, DKE K 182 insulation liquids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





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## Transformer Diagnose on practical Samples



Janusz Szczechowski, Dr. Peter Werle, ABB AG, Transformer Service Center Halle, Germany

### Transformer Life Management 2014 Transformer Diagnosis on Practical Examples

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### Introduction Condition Assessment – WHY ?



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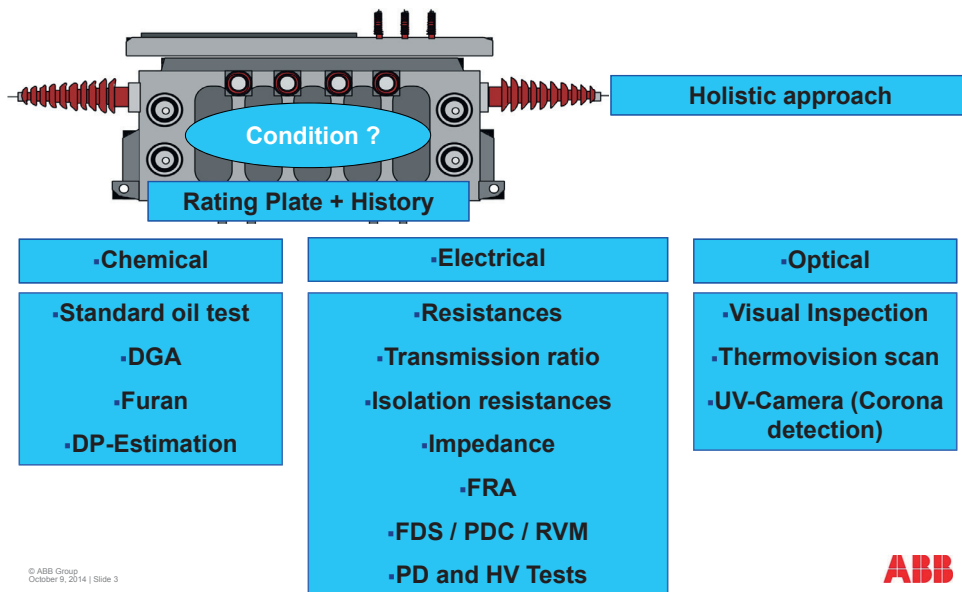
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## Transformer Diagnose on practical Samples

### Condition Assessment Overview of Methods



### Oil Analysis SOT Standard Oil Test

Refraction Index  
Cleanness  
Particles  
Colour  
Breakdown Voltage  
Dielectric Dissipation Factor  
Acidity  
Moisture Content  
Interfacial Tension  
Inhibitor Content



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Transformer Diagnose on practical Samples

Oil Analysis  
Furan Analysis

- 5-Hydroxymethyl-2-Furfurol (5HMF)
- 2-Furfuryl alcohol (2FOL)
- 2-Furfural (2FAL)
- 2-Acetyl furane (2ACF)
- 5-Methyl-2-Furfurol (5MEF)

- Correlation to DP
  - Number of cellulose units (chain length)
  - New kraft paper: ca. 1000-1200
  - Degradation: <200

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Oil Analysis  
DGA Dissolved Gas Analysis

- Nitrogen N<sub>2</sub>
- Oxygen O<sub>2</sub>
- Hydrogen H<sub>2</sub>
- Carbon Monoxyd CO
- Carbon Dioxyd CO<sub>2</sub>
- Methane CH<sub>4</sub>
- Ethane C<sub>2</sub>H<sub>6</sub>
- Ethylene C<sub>2</sub>H<sub>4</sub>
- Acetylene C<sub>2</sub>H<sub>2</sub>
- Propane C<sub>3</sub>H<sub>8</sub>
- Propene C<sub>3</sub>H<sub>6</sub>



Komponente		Ergebnis in mg/l	Messwert (ppm)	Referenz (ppm)	Beurteilung
5-Hydroxymethyl-2-Furfural (5HMF)	0.12	-	-	-	-
2-Furfuryl alcohol (2FOL)	< 0.05	-	-	-	-
2-Furfural (2FAL)	15.52	5	-	210 %	-
2-Acetyl furane (2ACF)	0.11	-	-	-	-
5-Methyl-2-Furfurol (5MEF)	0.80	-	-	-	-
Gesamtgehalt	16.55	5	-	327 %	-

**Prüfergebnisse**

Typ: KDMA 900V20, Problemmenge: 1250 ml  
 Hersteller: Siemens, Probeart: Abstromprobe  
 Leitung: 1.6 MVA, Entnahmest: 23.11.2009  
 Übersetzung: 20 / 0.3 kV, Eingangs im Labor: 26.11.2009  
 Isolierflüssigkeit: - , Prüfung: 07.12.2009  
 Füllstand: - , Anlass: -  
 Ölmenge: 900 kg

**Bewertung:** Basierend auf den vorliegenden Messergebnissen weist die Analyse der Furanfraktionen auf einen höheren DP-Wert des Papiers im Bereich von 100 bis, wobei dieser an Brennstoff beengteren Stellen auch wesentlich niedriger sein kann.

**Empfehlung:** Aufgrund der stark gestiegenen Feststoffkonzentration sollte eine Entschneidung in Erwägung gezogen werden.

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Oil Analysis  
DGA Dissolved Gas Analysis

Nitrogen N<sub>2</sub>  
Oxygen O<sub>2</sub>  
Hydrogen H<sub>2</sub>  
Carbon Monoxyd CO  
Carbon Dioxyd CO<sub>2</sub>  
Methane CH<sub>4</sub>  
Ethane C<sub>2</sub>H<sub>6</sub>  
Ethylene C<sub>2</sub>H<sub>4</sub>  
Acetylene C<sub>2</sub>H<sub>2</sub>  
Propane C<sub>3</sub>H<sub>8</sub>  
Propene C<sub>3</sub>H<sub>6</sub>



MSS  
Rogers  
Duval  
Own  
VDE 0370-7 or  
IEC 60599

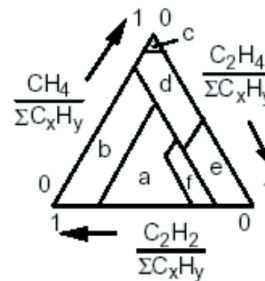
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Oil Analysis  
DGA Dissolved Gas Analysis



MSS  
Rogers  
Duval  
Own  
VDE 0370-7 or  
IEC 60599



**FAULTS**

Electrical (PD, Discharges with low or high energy)  
Thermal (Temperatures < 300°C, < 700°C or > 700°C)

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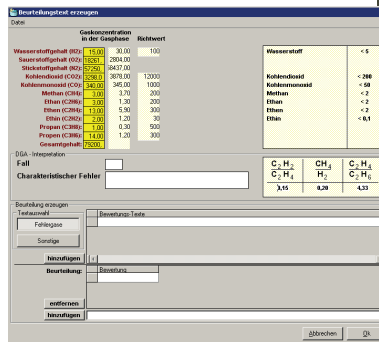
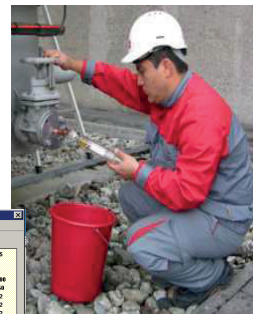


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**Transformer Diagnose on practical Samples**

**Oil Analysis  
Know-How**

- For all oil analyses it is very important
  - To take samples correctly
    - Described in the standards
  - To have experience for the evaluation of the oil parameters
    - ABB has additional rules and large database



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**Oil Analysis  
Evaluation**

- It is important to take all information into consideration !

Test	Result
H <sub>2</sub> [ppm]	3
O <sub>2</sub> [ppm]	28354
N <sub>2</sub> [ppm]	64150
CO <sub>2</sub> [ppm]	453
CO [ppm]	44
CH <sub>4</sub> [ppm]	2
C <sub>2</sub> H <sub>6</sub> [ppm]	1
C <sub>2</sub> H <sub>4</sub> [ppm]	1
C <sub>2</sub> H <sub>2</sub> [ppm]	0
C <sub>3</sub> H <sub>8</sub> [ppm]	2

Is this  
Transformer OK ?

**Transformer is not OK – it has a broken Membrane in the conservator !**

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## Transformer Diagnose on practical Samples

### Example 1 Network Connection Transformer

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### Example 1 Description and Background

- Technical data of the transformer:

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

- Network connecting transformer in Germany
- History:
  - Maintenance actions have been performed regularly

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Transformer Diagnose on practical Samples

Example 1  
Results of the SOT (12/2012)

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

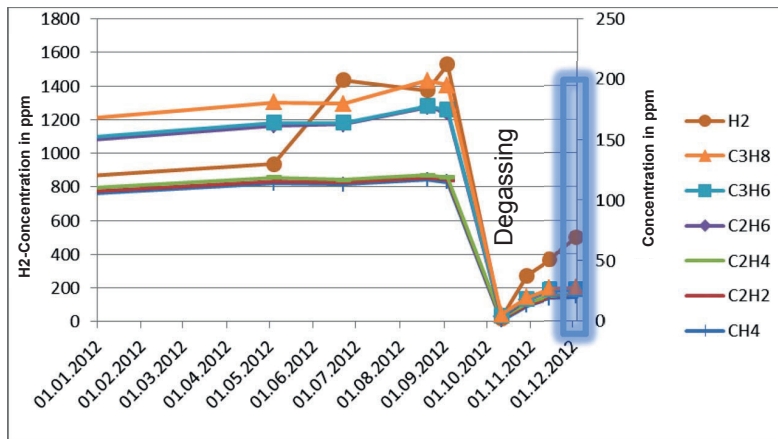
- No abnormalities

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Example 1  
DGA Trend

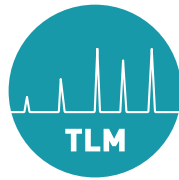
- Time frame 01/2012 – 12/2012



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## Transformer Diagnose on practical Samples

### Example 1 Results of the DGA (12/2012)

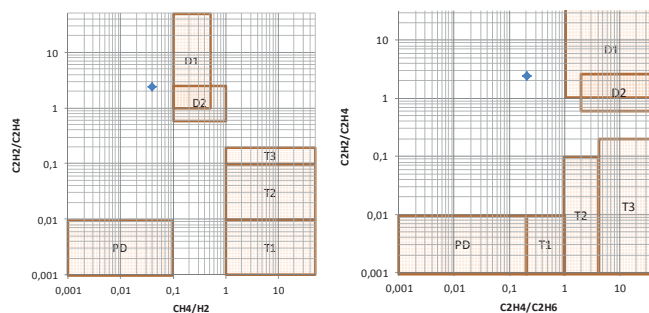
DGA	Gas concentration [ppm]	
H <sub>2</sub> [ppm]	501	
O <sub>2</sub> [ppm]	17556	
N <sub>2</sub> [ppm]	40018	In general (60599)
CO <sub>2</sub> [ppm]	243	H <sub>2</sub> >CH <sub>4</sub> -> Discharge
CO [ppm]	17	
CH <sub>4</sub> [ppm]	20	H <sub>2</sub> <CH <sub>4</sub> -> Thermal Problem
C <sub>2</sub> H <sub>6</sub> [ppm]	3	
C <sub>2</sub> H <sub>4</sub> [ppm]	1	
C <sub>2</sub> H <sub>2</sub> [ppm]	2	
C <sub>3</sub> H <sub>8</sub> [ppm]	1	
C <sub>3</sub> H <sub>6</sub> [ppm]	1	
Total Gas Content [%]	5,8	

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### Example 1 Evaluation of the DGA

- Value H<sub>2</sub> of above the limit
- IEC 60599 Quotients:
  - C<sub>2</sub>H<sub>2</sub>/C<sub>2</sub>H<sub>4</sub>: 2,4; CH<sub>4</sub>/H<sub>2</sub>: 0,04; C<sub>2</sub>H<sub>4</sub>/C<sub>2</sub>H<sub>6</sub>: 0,21
  - Quotients close to PD (see table 2, IEC 60599)
- Graphical evaluation acc. to Dörnenburg



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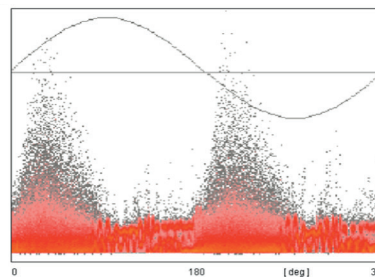
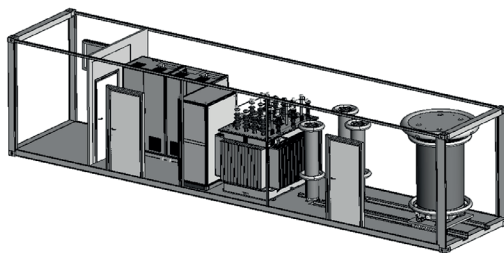




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### Transformer Diagnose on practical Samples

#### Example 1 Further measurements (PD)



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#### Example 1 What was the problem?

- Finally Customer informed ABB that last action was the exchange of the main valve at the bottom of the transformer
- Transformer Tank is not vacuum tight !
- Transformer was sent to ABB's transformer service center
- A vacuum was applied to the transformer in a vacuum chamber
- Oil was filled under vacuum
- HV test in test field, no PD were measured anymore

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## Transformer Diagnose on practical Samples

### Example 2 Industrial Transformer

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### Example 2 Description and Background

- Technical data of the transformer:

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

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

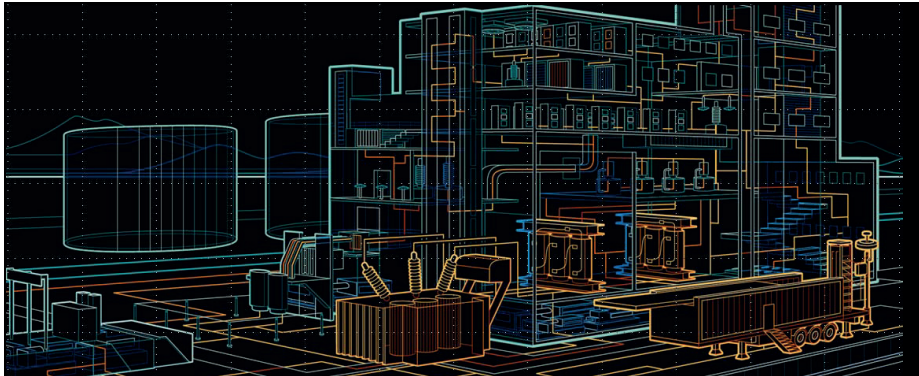
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### Introduction Condition Assessment – WHY ?



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Example 2  
Results of the SOT(07/2013)

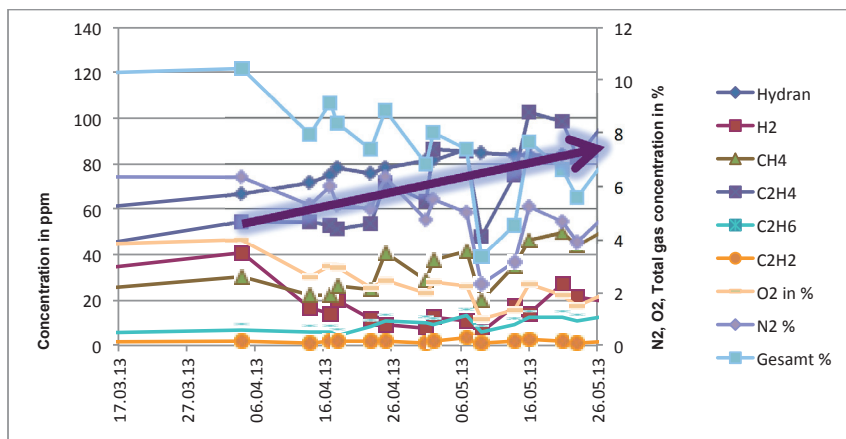
Test	Result
Breakdown Voltage	74 kV
Dielectric dissip. factor	0,9 ‰
Acidity	<0,03 mg <sub>KOH</sub> /g <sub>Öl</sub>
Moisture content	3,8 mg/kg
Interfacial Tension	39,8 mN/m

- No abnormalities

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Example 2  
Trend of the DGA



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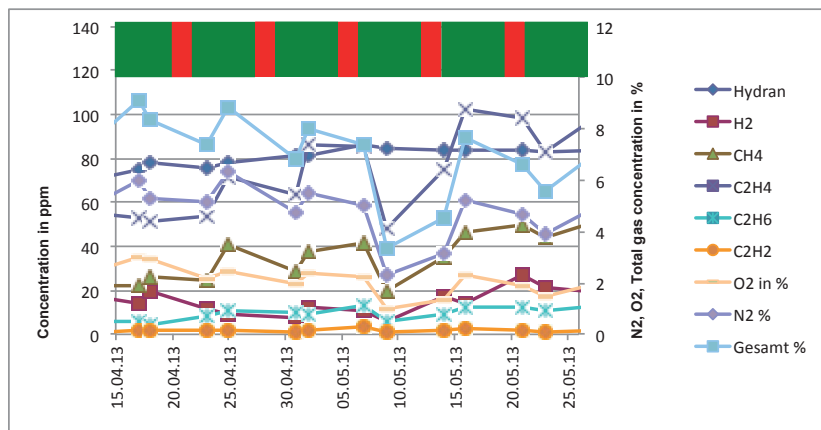




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Example 2  
DGA Trend, zoom with operation profile of the transformer



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Example 2  
Results of the DGA (07/2013)

Test	Result
H <sub>2</sub> [ppm]	10
O <sub>2</sub> [ppm]	28354
N <sub>2</sub> [ppm]	64150
CO <sub>2</sub> [ppm]	502
CO [ppm]	64
CH <sub>4</sub> [ppm]	35
C <sub>2</sub> H <sub>6</sub> [ppm]	6
C <sub>2</sub> H <sub>4</sub> [ppm]	57
C <sub>2</sub> H <sub>2</sub> [ppm]	1
C <sub>3</sub> H <sub>8</sub> [ppm]	2
C <sub>3</sub> H <sub>6</sub> [ppm]	20
Total Gas Content [%]	9,6

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## Transformer Diagnose on practical Samples

### Example 2 Evaluation of the DGA

- On site performed electrical measurements:

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

- No gas limit was exceeded – gases are stable
- Strong changes of O<sub>2</sub>, and N<sub>2</sub> concentration which are expected to be stable (DGA provided by the customer)

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### Example 3 Shunt Reactor

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## Transformer Diagnose on practical Samples

### Example 3 Description and Background

- Technical data of the shunt reactor

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

- History:
  - Abnormal DGA results in 2012

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### Example 3 Results of the SOT (07/2012)

Test	Result
Breakdown voltage	71 kV
Dielectric dissip. factor	2,4 ‰
Acidity	<0,03 mg <sub>KOH</sub> /g <sub>Oil</sub>
Moisture content	8,8 mg/kg
Interfacial Tension	39,1 mN/m

- No abnormalities

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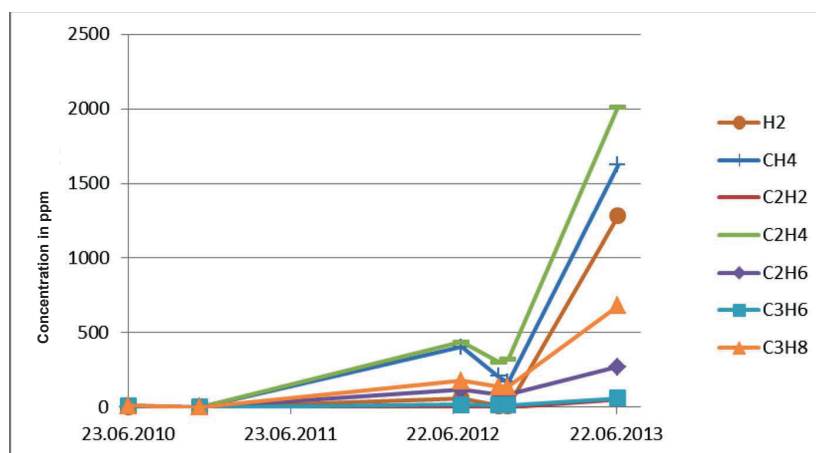




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Beispiel 2  
Evaluation of the DGA: DGA Trend



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Example 3  
Results of the DGA (07/2012)

Test	Result
H <sub>2</sub> [ppm]	60
O <sub>2</sub> [ppm]	19460
N <sub>2</sub> [ppm]	54872
CO <sub>2</sub> [ppm]	5229
CO [ppm]	769
CH <sub>4</sub> [ppm]	406
C <sub>2</sub> H <sub>6</sub> [ppm]	116
C <sub>2</sub> H <sub>4</sub> [ppm]	439
C <sub>2</sub> H <sub>2</sub> [ppm]	1
C <sub>3</sub> H <sub>8</sub> [ppm]	16
C <sub>3</sub> H <sub>6</sub> [ppm]	177
Total Gas Content [%]	8,1

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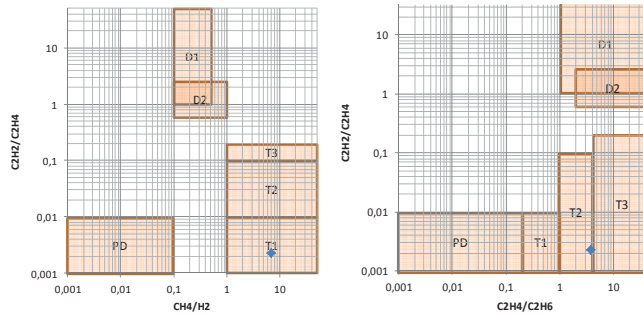


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Example 3  
Evaluation of the DGA

- Limit was exceeded at Methane and Ethylene concentrations
- IEC 60599 Quotients:
  - C<sub>2</sub>H<sub>2</sub>/C<sub>2</sub>H<sub>4</sub>: 0,0; CH<sub>4</sub>/H<sub>2</sub>: 6,8; C<sub>2</sub>H<sub>4</sub>/C<sub>2</sub>H<sub>6</sub>: 3,8
  - Indication: Thermal fault between 300°C and 700°C
- Graphical interpretation acc. to Dörnenburg

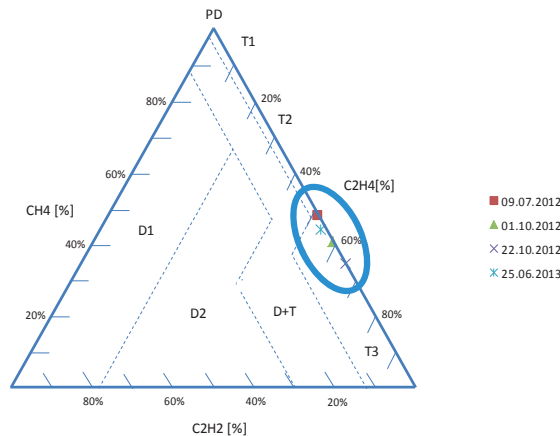


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Example 3  
Evaluation of the DGA

- Trend in Duval triangle



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## Transformer Diagnose on practical Samples

### Example 3 Results of the DGA (07/2012)

Test	Result
H <sub>2</sub> [ppm]	60
O <sub>2</sub> [ppm]	19460
N <sub>2</sub> [ppm]	54872
CO <sub>2</sub> [ppm]	5229
CO [ppm]	769
CH <sub>4</sub> [ppm]	406
C <sub>2</sub> H <sub>6</sub> [ppm]	116
C <sub>2</sub> H <sub>4</sub> [ppm]	439
C <sub>2</sub> H <sub>2</sub> [ppm]	1
C <sub>3</sub> H <sub>8</sub> [ppm]	16
C <sub>3</sub> H <sub>6</sub> [ppm]	177
Total Gas Content [%]	8,1

Experience ABB

C<sub>2</sub>H<sub>4</sub>/C<sub>3</sub>H<sub>6</sub> >=2-3  
-> Core Problem

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### Example 3 What was the problem?

- Transportation to ABB Service Center
- Visual inspection of the active part:
  - Hot spot at the core



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## Transformer Diagnose on practical Samples

### Conclusion Oil Analysis

- Oil Analysis is the most important tool for a first diagnostic on a liquid filled transformer
  - Statement on Ageing and Failure existence can be given
- Samples must be taken and analysed correctly !
- Rating plate data, basic design information and history has to be taken into account for the interpretation
- Experience and know-how is needed in order to draw the right conclusions using the oil analysis results
- Additional condition assessment methods can be used in order to find the root cause of a problem

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