TLM

TRANSFORMER-LIFE-MANAGEMENT
CONFERENCE

Appraisal of Transformers using Gas-Monitoring Systems

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

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

Terna

Appraisal of Transformers using Gas-Monitoring Systems

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Liquid Insulation

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

Insulating fluids serve 3 main function:

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

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

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Dissolved Gas Analysis (DGA)

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

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

Some gases are dissolved in oil:

Degassed Trafos ⇒ 0.2% in volume (2000 ppm)

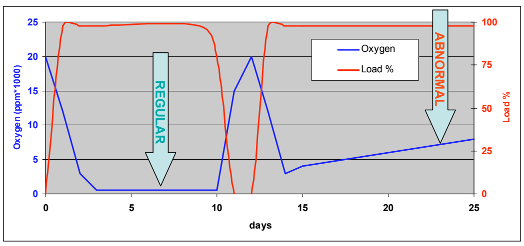
In service Trafos ⇒ 4 – 10% in volume (40.000 ÷ 100.000 ppm)

Dissolved Gas Analysis (DGA)

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

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

Oxygen is consumed due to oxidative reactions.



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Dissolved Gas Analysis (DGA)

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

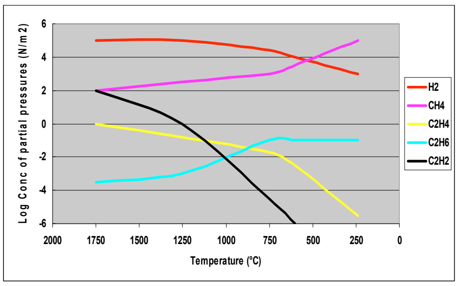
Dissolved Gas Analysis (DGA)

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

Halstead's thermodynamic model:

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

Only theoretical since it is based on unrealistic isothermal equilibrium



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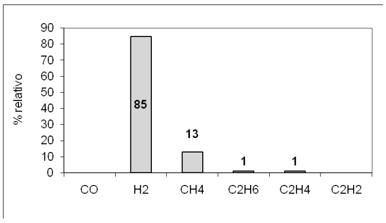
Dissolved Gas Analysis (DGA)

Partial discharge

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

Discharge in oil ⇒ partial discharge (corona) ⇒ H2, C2H6, CH4 and solid paraffin.

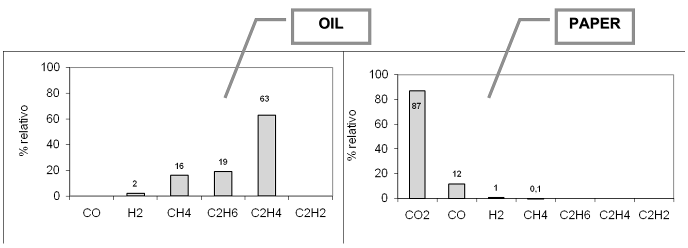
Discharge in cellulose ⇒ high density partial discharge with paper perforation ⇒ C2H2.



Dissolved Gas Analysis (DGA)

Local overheating

Hot spots typically at 300 – 450°C sometimes > 1000°C.
< 450°C ⇒ CH4 and H2
> 450°C ⇒ C2H4 and CH4
> 800°C ⇒ C2H4 only
> 1000°C ⇒ C2H2 also



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Dissolved Gas Analysis (DGA)

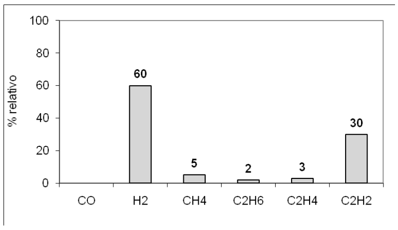
Arcing

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

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

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

0.025 ml gas / Joule

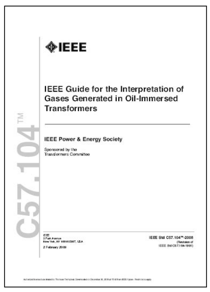


DGA Interpretation

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

Specific Guidelines were developed and published:

- IEC 60599
- IEEE StsC57.104



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Faults

Classified as:

Partial discharges

Electrical defects

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

Thermal defects

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

Interpretation Schemes

Key gas: Dickinson, Potthoff, LCIE

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

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

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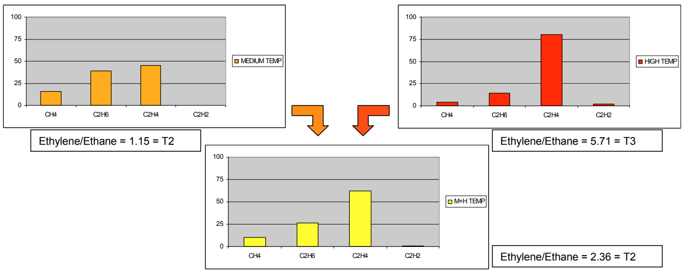
Interpretation Schemes

They are not conflicting.

They can be used together, for diagnostic fine tuning.

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

Interpretation is hard for evolving faults or contemporaneous faults.



Interpretation Schemes

Key gases:

Hydrogen ⇒ Partial discharge (PD)

Hydrogen & Hydrocarbons ⇒ Overheating (in oil)

Acetylene ⇒ Arcing

Carbon Oxide ⇒ Overheating (in paper)

Remark: these gases are always present

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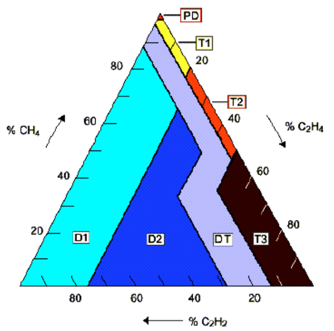
Graphic criteria

Duval's Triangle N°1



PD: partial discharges

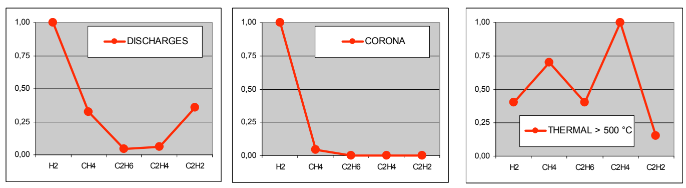
T1: thermal <300°C
T2: thermal 300 – 700°C
T3: thermal >700°C

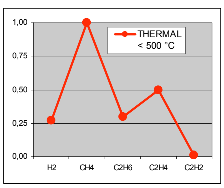
D1: low energy discharges
D2: high energy discharges

DT: thermal & electric fault (mix)

Graphic criteria

Okubo e Tsukioka





In ordinate axis (y) normalized concentrations are displayed.

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

One shape → One defect

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Criteria based on gas ratio

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

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

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

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

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

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

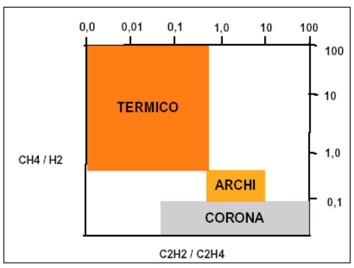
$\frac{N_2}{O_2}$ **Consumption of oxygen; sealing;**

Empirical equation used for estimating hot spot temperature

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

Doernemburg ratios

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



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Rogers ratios

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

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

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

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Rogers ratios

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

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Guide IEEE Std C57.104

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

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

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

Guide IEEE Std C57.104

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

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

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Guide IEEE Std C57.104

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

Guide IEC 60599

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

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

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Guide IEC 60599

Typical values 90%

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

Guide IEC 60599

Additionally others ratio are proposed:

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

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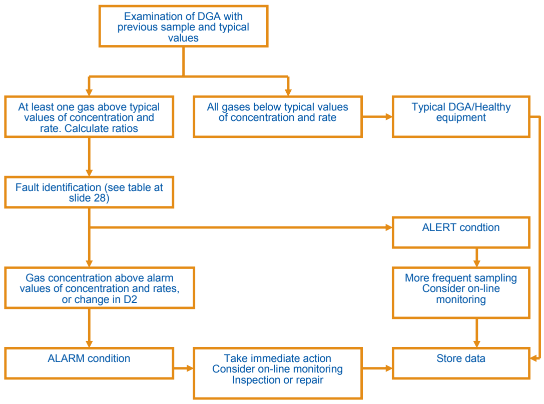
Guide IEC 60599

Flow chart



IEC 61181

Factory Test

Specific for Heat Run Test (Temperature-Rise).

similar to IEEE Std C57.130

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

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

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IEC 61181
Factory Test

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

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

Limitations

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

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

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

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

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

Appraisal of Transformers using Gas-Monitoring Systems

History cases

1) Atmospheric gases

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

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

History cases

1) Atmospheric gases

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

Appraisal of Transformers using Gas-Monitoring Systems

History cases

2) PD

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

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History cases

3) Fake PD

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

STRAY GASS

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Appraisal of Transformers using Gas-Monitoring Systems

History cases

4) Local overheating (hot spots) I

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

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

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Appraisal of Transformers using Gas-Monitoring Systems

History cases

4) Local overheating (hot spots) II

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

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Appraisal of Transformers using Gas-Monitoring Systems

History cases

4) Local overheating (hot spots) III

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

Fault hypothesis (in increasing order of probability):

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

History cases

5) OLTC trans-contamination – False arching

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

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History cases

6) High Energy Discharges (arching)

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

Short circuit between coils and windings displacement

History cases

7) Evolving faults

CORONA

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

HOT SPOT

Appraisal of Transformers using Gas-Monitoring Systems

Dissolved Gas in Oil Analysis (DGA)

4 Steps:

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

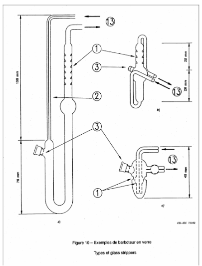
Gas extraction or separation

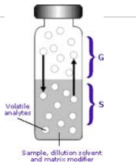
1. Total by mercury Töppler's pump or mercury-free pump.
2. Partial by mercury Töppler's pump or mercury-free pump.
3. Stripping, by the carrier gas (Argon, etc) bubbling itself through a small volume of the oil.
4. Head Space, a glass small vial is partially filled with oil (~ 1\3) and pressurized with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

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

Appraisal of Transformers using Gas-Monitoring Systems

Gas extraction or separation





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

$$K = {}^{C_L}\!\Big/\!_{C_G - \frac{V_G}{V_L}}$$

Table 2: Head-space partition coefficients

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

Gas extraction or separation

IEC 60567 (§ 7.5.1)

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

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

OPERATION AND QUALITY CONTROL BY HIGHLY SKILLED PERSONNEL IS RECOMMENDED.

Appraisal of Transformers using Gas-Monitoring Systems

Total vs. HS vs. Transportable

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

Lab vs. On-Line

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

Appraisal of Transformers using Gas-Monitoring Systems

Thanks for your attention