DGA: from theoretical Aspect to practical Application

Fabio Scatiggio
Trasmissione Elettricità Rete Nazionale S.p.A

Fabio Scatiggio was born in Venezia, Italy, in 1957. He is with Terna Rete Italia where he is in charge as Chemical Laboratory Manager.

He is the Italian representative in many IEC TC 10 and CIGRE A2&D1 working groups. Mr. Scatiggio has published many papers on transformers diagnosis by DGA and on problems related with presence of corrosive sulphur in oil.

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

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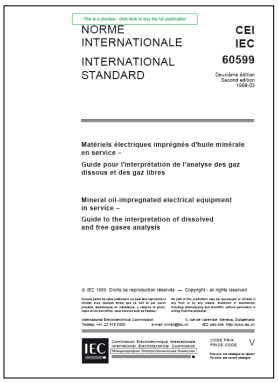
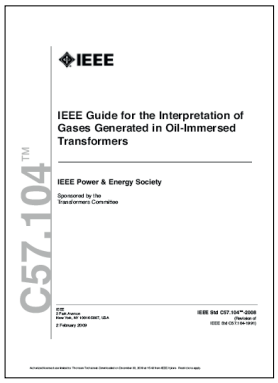
DGA Interpretation

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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Interpretation Schemes

Key gas: Dickinson, Potthoff, LCIE

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

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

… 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)

Criteria based on gas ratio

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

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

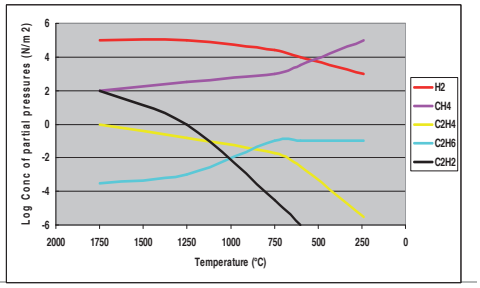
$\frac{C_2H_2}{C_2H_4}$ **Arcing;**

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

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

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

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



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History cases

1) Atmospheric gases

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

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

Transformer Life Management 2014
DGA: from theoretical Aspect to practical Application

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

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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

Case	Typical Fault	C2H6/C2H4	CH4/H2	C2H4/C2H6
PD	Partial discharge	ns	< 0,1	< 0,2
D1	Low energy d.	>1	0,1 - 0,5	>1
D2	High energy d.	0,6 - 0,25	0,1 - 1	>2
T1	Thermal fault <300	ns	>1	<1
T2	Thermal fault 300-700	<0,1	>1	1 - 4
T3	Thermal fault >700	<0,2	>1	>4

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

Case	Typical Fault	C2H6/C2H4	CH4/H2	C2H4/C2H6
PD	Partial discharge	ns	< 0,1	< 0,2
D1	Low energy d.	>1	0,1 - 0,5	>1
D2	High energy d.	0,6 - 0,25	0,1 - 1	>2
T1	Thermal fault <300	ns	>1	<1
T2	Thermal fault 300-700	<0,1	>1	1 - 4
T3	Thermal fault >700	<0,2	>1	>4

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History cases

4) Local overheating (hot spots) I

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

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	

Case	Typical Fault	C2H6/C2H4	CH4/H2	C2H4/C2H6
PD	Partial discharge	ns	< 0,1	< 0,2
D1	Low energy d.	>1	0,1 - 0,5	>1
D2	High energy d.	0,6 - 0,25	0,1 - 1	>2
T1	Thermal fault <300	ns	>1	<1
T2	Thermal fault 300-700	<0,1	>1	1 - 4
T3	Thermal fault >700	<0,2	>1	>4

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	

Case	Typical Fault	C2H6/C2H4	CH4/H2	C2H4/C2H6
PD	Partial discharge	ns	< 0,1	< 0,2
D1	Low energy d.	>1	0,1 - 0,5	>1
D2	High energy d.	0,6 - 0,25	0,1 - 1	>2
T1	Thermal fault <300	ns	>1	<1
T2	Thermal fault 300-700	<0,1	>1	1 - 4
T3	Thermal fault >700	<0,2	>1	>4

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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

Case	Typical Fault	C2H6/C2H4	CH4/H2	C2H4/C2H6
PD	Partial discharge	ns	< 0,1	< 0,2
D1	Low energy d.	>1	0,1 - 0,5	>1
D2	High energy d.	0,6 - 0,25	0,1 - 1	>2
T1	Thermal fault <300	ns	>1	<1
T2	Thermal fault 300-700	<0,1	>1	1 - 4
T3	Thermal fault >700	<0,2	>1	>4

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	

Case	Typical Fault	C2H6/C2H4	CH4/H2	C2H4/C2H6
PD	Partial discharge	ns	< 0,1	< 0,2
D1	Low energy d.	>1	0,1 - 0,5	>1
D2	High energy d.	0,6 - 0,25	0,1 - 1	>2
T1	Thermal fault <300	ns	>1	<1
T2	Thermal fault 300-700	<0,1	>1	1 - 4
T3	Thermal fault >700	<0,2	>1	>4

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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	8500	2200	5040	10200	22800	-	-	-	If in equilibrium

Short circuit between coils and windings displacement

Case	Typical Fault	C2H6/C2H4	CH4/H2	C2H4/C2H6
PD	Partial discharge	ns	< 0,1	< 0,2
D1	Low energy d.	>1	0,1 - 0,5	>1
D2	High energy d.	0,6 - 0,25	0,1 - 1	>2
T1	Thermal fault <300	ns	>1	<1
T2	Thermal fault 300-700	<0,1	>1	1 - 4
T3	Thermal fault >700	<0,2	>1	>4

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

Case	Typical Fault	C2H6/C2H4	CH4/H2	C2H4/C2H6
PD	Partial discharge	ns	< 0,1	< 0,2
D1	Low energy d.	>1	0,1 - 0,5	>1
D2	High energy d.	0,6 - 0,25	0,1 - 1	>2
T1	Thermal fault <300	ns	>1	<1
T2	Thermal fault 300-700	<0,1	>1	1 - 4
T3	Thermal fault >700	<0,2	>1	>4

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History cases

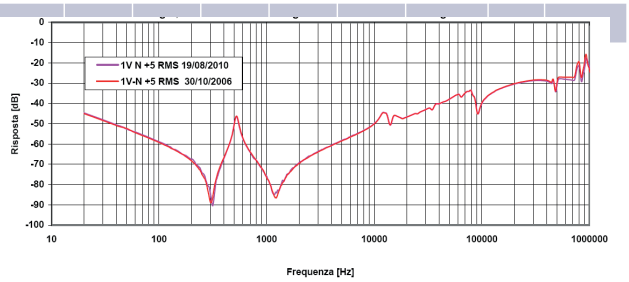
8) Tricky cases

1

H2	CH4	CO	CO2	C2H4	C2H6	C2H2	C2H2/C2H4	CH4/H2	C2H4/C2H6
2159	6935	193	3870	9448	1395	114	0,01	3,21	6,77

2

H2	CH4	CO	CO2	C2H4	C2H6	C2H2	C2H2/C2H4	CH4/H2	C2H4/C2H6
23									



The first is still regularly in service.

The second exploded 2 months later.

Dissolved Gas in Oil Analysis (DGA)

4 Steps:

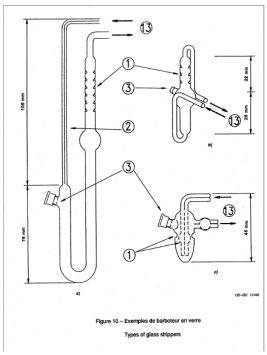
- Sampling
- Gas extraction from oil by Töppler's pump or mercury-free pump (TOGA), by stripping or by head-space
- Analysis by GC (in according with IEC and IEEE) or by PAS (not in according with IEC and IEEE)
- Interpretation

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 (~ 2\3) and pressurized with carrier gas (~ 1\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.

Gas extraction or separation



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

$$K = \frac{C_L}{C_G - \frac{V_G}{V_L}}$$

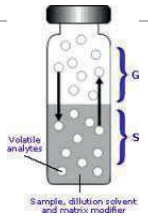


Table 2: Head-space partition coefficients

	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.

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, air, H2	Ar, air, H2	ambient air
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

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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

Thanks for your attention