Transformer is gassing-What to do

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Abstract

The paper summarizes the experiences with identification of sources of gas generation in Large Power Transformers and Shunt Reactors. The model of Gassing Power Transformer is presented and discussed. Case studies and especially experience with identification of the source of arcing in oil using electrical PD tests will be discussed.

1. Introduction

There have been some typical problems with Power Transformers that require a prompt decision: The most critical problem is "What to do if a transformer is gassing?" DGA is indisputably the best detector of abnormalities. Well-known Guides for Interpretation of Gases [1,2,3] give clear suggestions how to identify defective transformer and what the type of faults could occur. However this information causes another and sometimes more critical problem: Is it serious? How to get the most out of an asset now? What should I do? What are the consequences?

To find a solution for the problem "What to do if the transformer shows clear symptoms of abnormality" it is necessary to answer the questions: is the source of gas generation internal or external? Does the problem associated with thermal or electric faults, with operative voltage or magnetic flux, with main flux or with stray flux? What may happen if the load will be increased?

It is also important to consider the difference in the rate of gas generation in different oils; migration of gases between the oil and cellulose; unusual sources of gas generation.

The goal of this paper is to present some diagnostic techniques and experience with identification of seriousness of a detected abnormality that could be useful in a case of taking decision on the continuing operation of a defective transformer.

2. Diagnostic characteristics of DGA

Concentration of the measured gases

Besides the most commonly measured gases H2 (Hydrogen), CH4 (methane), C2H4 (Ethylene), C2H6 (Ethane), C2H2 (Acetylene), CO (Carbon Monoxide), CO2 (Carbon Dioxide), O2 (Oxygen) and N2 (Nitrogen), ZTZ-Service analyses also C3-C5 hydrocarbons by means of capillary technique [6]. Particularly it was found that isomer C4H8 buten-1 may serve as a key gas to identify a low temperature faults (150-300 °C). The interpretation of the results is carried out if the gases concentrations are above the significant (normal or unusual) level.

Key gases

H_2, C_2H_2, C_2H_4, CH_4, CO and C_4H_8 buten-1 are utilized as key gases to predict a specific problem. Specific gases are used also to assess presence of dangerous by-products:

C_2H_4- symptom of overheating above 500 °C when forming of carbon particles could be expected.

C_2H_2 - Acetylene formation requires temperatures at least 800-1200 °C, gas bubbles generation and metal fusion can accompany dissolved gas generation.

Key Ratios

The following ratios are used $\frac{CH_4}{H_2}$ (PD assessment), $\frac{C_2H_2}{C_2H_4}$ (Arcing), $\frac{C_2H_4}{C_2H_6}$ (oil overheating), $\frac{C_2H_2}{C_2H_6}$ (electrical discharge), $\frac{CO_2}{CO}$ (cellulose overheating), $\frac{C_2H_2}{H_2}$ (oil contamination from divertor switch of LTC), $\frac{N_2}{O_2}$ (consumption of oxygen), $\frac{C_4H_8}{\Sigma C_xH_y + H_2}$ (oil overheating at 150-300 °C).

Ratio $\frac{C_2H_4}{C_2H_6}$ is utilized also to estimate temperature of overheated localized zone by means of empirical equation [8]:

$$t\ °C = 322 \log (C_2H_4/C_2H_6) + 525 \qquad (1)$$

Rate of gas generation

Besides rate of gas generation in ppm/day, corresponding rate of gas generation in ml/hr and ml/hrcm^2 is considered. In case of presumed localized overheating rate of gas generation per day and 1 cm^2 of heated surface is juxtaposed with assumed temperature and possible amount of overheated metal using equation [8]:

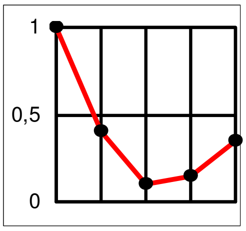
$$\log R = 14.4 - 11800/T, \qquad (2)$$

Where R is the rate of gas generation in ml per hour and 1 cm^2 of heated surface;
T-absolute (Kelvin) temperature

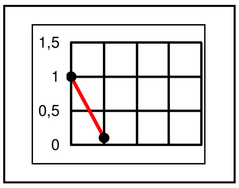
In case of sparking or arcing the rate of gas generation is juxtaposed with estimated PD energy by assumption that 1 kJ energy produces approximately 40-50 ml of gas [10].

Gas patterns

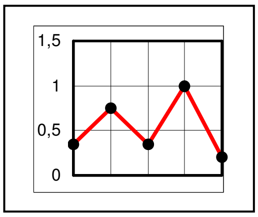
The patterns of typical gas distributions suggested by [4, 8] was found to be a very effective diagnostic characteristics. On the axis of abscissas the maximum value of gas quantity is taken for 1 on the axis of ordinates to plot a ratio in the following sequence: H_2, CH_4, C_2H_6, C_2H_4, C_2H_2. Thereby a pattern of typical fault could be displayed.



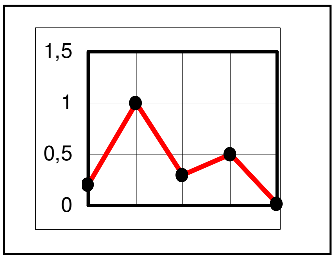
Discharges



Corona



Thermal
> 500 °C



Thermal
< 500 °C

Amount of generated gases

Amount of gases could serve as a rate of material decomposition, particularly of cellulosic insulation. For instance, authors of [12] consider paying attention to the transformers with amount of CO over 15 liter's only. Authors of [4] define warning level of quantity degradation indicator as 0.2 l of (CO+CO2) per 1 kg of heated turn insulation or 20 l per 100 kg of insulation. It is important to consider amount of gases in the transformers having a large volume of oil.

Total dissolved combustible gas

Besides well-known TDCG three other sums of gas concentration are considered as useful diagnostic characteristics

$\Sigma C_x H_y$ (1)= $CH_4+C_2H_6+C_2H_4+C_2H_2$

$\Sigma C_x H_y$ (2) = $CH_4+C_2H_6+C_2H_4+C_2H_2+C_3H_6+C_3H_8$

$\Sigma C_x H_y + H_2$

3. Sources of gas generation in a Power Transformer

Experience has shown that about 70 % of problems with Power Transformers and Shunt Reactors could be detected by means of oil analysis. In principle all the incipient faults that result in decomposition of materials are accompanied with gas generation. However the rate of gases generated by different faults is different and in some cases DGA may detect only advanced fault or even post- failure state.

Possible Diagnostic benefits from DGA technique may be evaluated on the base of the transformer functional failure model suggested by the Cigre WG 12.18 "Life Management" that is presented in Figure 1 in modified view.
The following typical scenarios of the failures progressing are presented on the basis of functional condition – based methodology [5].

Dielectric system

Moisture/particles Contamination $\Rightarrow$Occurrence of moderate PD $\Rightarrow$Occurrence of destructive PD $\Rightarrow$ **Gas generation** $\Rightarrow$Progressing PD, **accompanied with gas** generation $\Rightarrow$ tracking/treeing, accompanied with, critical pre-failure PD and **intensive gas generation** $\Rightarrow$Breakdown.

Electromagnetic system

- Local core overheating/sparking associated with the main magnetic flux. Closed loops in the core (insulated bolts, pressing bolts, pressing metal rings) cause typically an **intensive gas generation.**

- Local core overheating/sparking associated with a stray flux. Faults associated with a stray flux (including short circuit between winding parallels) allow continuing transformer operation on the condition of load limitation. Three failure mechanisms may be advised:

  - *Local overheating due to excessive eddy current losses resulting in **generation of gas**, carbon and other degradation products, and insulation deterioration.*
  - *Close loops between adjacent members linked by stray flux, if accompanied with poor contacts, result in overheating, sparking and arcing, and gas generation.*

- *Sparking due to a floating potential accompanied with gas generation*

Current carrying circuit

A progressive rise of contact resistance results in the progressive rise of temperature, **gas generation**, irreversible degradation of the contacts, coking, open-circuit or short-circuit occurrences.

Mechanical system

- Loosening clamping - Distortion of winding geometry $\Rightarrow$ PD appearance **accompanied with gas generation** $\Rightarrow$ Creeping discharge progressing $\Rightarrow$ Breakdown.

- Distortion of winding geometry + Switching surge $\Rightarrow$ Flashover between coils **accompanied with gas evolution.**

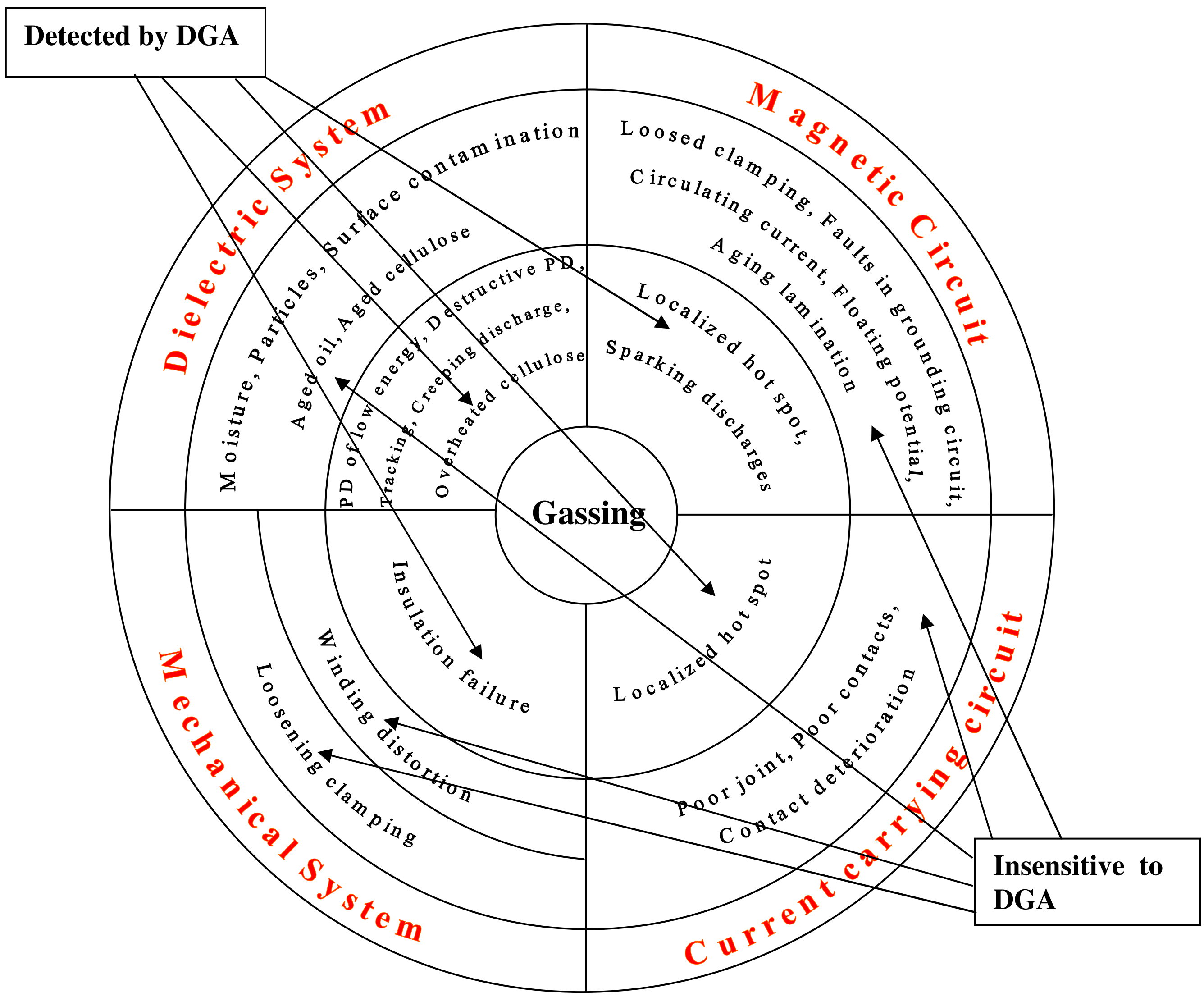


Figure 1
Transformer Functional Failure Model.
Possibility to detect typical defects and faults by means of DGA

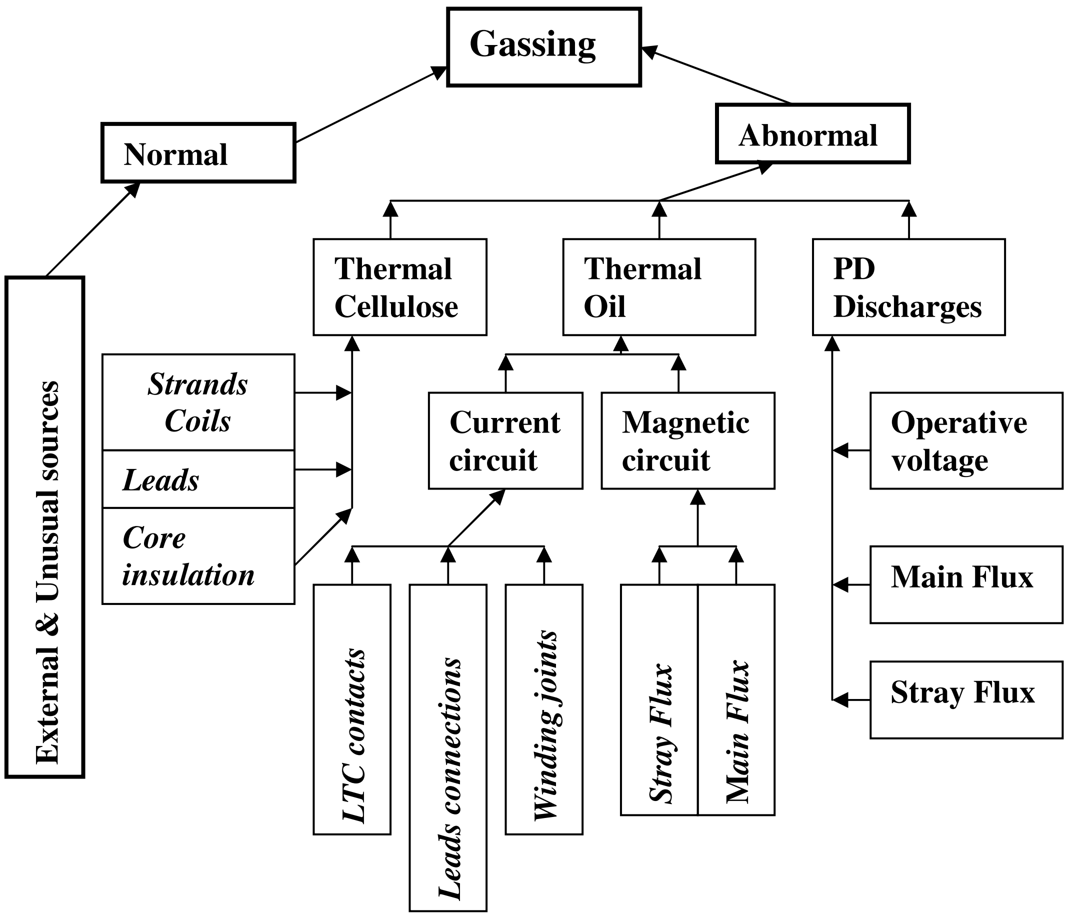


Figure 2
Model of Gassing Transformer

4. What to do if a transformer is gassing. Methodological procedures

To find a solution for the problem "What to do if the transformer is gassing?" it is necessary to answer the questions: are the gas concentrations normal or abnormal? Is the source of gas generation internal or external? What is the type of fault? Does the problem associated with thermal or electric faults, with operative voltage or magnetic flux, with main flux or with stray flux? What may happen if the load/voltage will be increased? The diagnostic model of gassing power transformer in Figure 2 may help to answer these questions in some instances.

ZTZ-Service utilizes the following procedures to identify the problem with gassing transformer:

- Assessment of DGA characteristics (see section 2).
- Identification of the transformer.
- Design review as a vital mean to gain an insight into transformer structural features.

- Identification of the operational conditions.
- Identification of the oil. Assessment of gassing tendency of the oil (if necessary).
- Consideration the possibility of external source of gas generation (LTC divertor switch compartment, burned motor winding in the pump, overheating of oil during processing, presence of residual gas).
- If thermal faults involved:
  - *Verify if the current -flow system involved (LTC contacts, leads contacts, etc). This is the most dangerous case that may result in catastrophic failure. The following diagnostic tools may be used: Design review; Thermo-scanning the zones of leads disposition and LTC compartment; Measurement of winding resistance (transient contact resistance); effect of the variation of current on gas generation.*
  - *Verify if the problem is associated with the main magnetic flux. The following diagnostic tools may be used: magnetizing current and no-load losses, ratio test.*
  - *Assess the effect of load on gas generation if problem associated with stray flux involved. Consider Heat Run Test as a powerful tool to predict the transformer behavior.*
- If electrical discharge faults involved:
  - *Localize the possible source of gas generation by means of PD – acoustic technique and PD electric technique.*
  - *Verify if a problem associated with PD occurrence in winding insulation by means of PD-electrical technique; assess the effect of voltage PD generation.*

- Determination the conditions of possible transformer service continuation, e.g. load limitation. Consider the rate of gas generation and gas patterns. Consider possible contamination of the dielectric system with decomposition by-products: carbons particles, metals, bubbles evolution.

5. Normal and abnormal level of gassing

Defect-free condition of a power transformer is characterized by low (10-50 pC) PD activity, hot spot of the windings lower 105 °C and localized hot spot in the magnetic circuit lower than 130 °C. On such conditions a transformer could be practically free of faulty gases.

Table 1 confirms that defect-free transformers during factory heat run test (maximum load) does not practically show notable faulty gas generation.

Table 1

Interpretation of normal (defect-free) condition of power transformers

Normal rate of gas generation, During factory Heat Run Test			**Normal rate of gas generation, ml/day by IEC 60599-97**
Characteristic	**Criteria of WG12.06 [7]**	**Statistic of 162 tests of (no faulty transformers) average data after test [11]**	
$H_2+CH_4+C_2H_4+$			H2 < 5
$C_2H_6+C_2H_2$	< 2 ppm /hr	0.71 ppm	CH4 <2
CO	< 5 ppm/hr	1.59 ppm	C2H6 <2
CO2	< 20 ppm/hr	8.99 ppm	C2H4 <2
C2H2	< Sa	0.06 ppm	C2H2 <0.1
C2H4/C2H6	< 1	1.59	CO <50
			CO2 <200

Normal concentration values are acceptable quantities below which field experience shows no detectable or possible incipient faults. Accordingly, limited data for normal transformer in service are conditional or agreed quantities that meet different experience in different Guides (Table 2). ZTZ-Service follows the conception that a normal condition of a Large Power Transformer having volume of that tank over 50 m3 should be characterized by absence of C2H2 and concentration of C2H4<10-20 ppm. One should consider also unusual condition of a transformer when concentration values could be less than acceptable gas quantities but still there is a risk of failure. For instance, warning level for 750 kV GSU transformers was established as $\Sigma C_{\text{ч}} H_y$+H2 < 50-100 ppm including absence of C2H2 and concentration of C2H4<20 ppm. Inspection of one the transformer that had concentration values $\Sigma C_{\text{ч}} H_y$+H2=100-150 ppm, C2H4=50 ppm and C2H2=4-8 ppm revealed over one hundred places with shield insulation puncture, burning, and traces of overheating and meting [6].

Table 2

Interpretation of normal condition of Power Transformers in service

Document	Gas concentration, ppm							
	H_2	**CO**	**CO_2**	**CH_4**	**C_2H_6**	**C_2H_4**	**C_2H_2**	**TCG**
IEC 60599-97 No OLTC	60-150	540-900	5100-13000	40-110	50-90	60-280	3-50	
Cigre 15.01.	100	Σ CO+CO2 < 10,000					20	
				$\Sigma C_{ч}H_{y}$ < 500				
IEEE Std C57,104-91	100	350	2500	120	65	50	65	720
Laborelec Belgium	200			$\Sigma C_{ч}H_{y}$ < 300				
Electric Research Association in Japan	400	300		100	150	**10**	**0.5**	500
		CO+CO2 0.2mg/g of heated paper						
CIS Guide 110-500kV	**100**	200	6000 1500	100	50	100	5	
CIS Guide 750 kV	**30**	200		20	20	**10**	5	

6. Gas evolution under normal stresses

ZTZ-Service experience has shown that sometimes elevated level of gas concentrations could be associated with specific behavior of the oil under effect of normal operating temperature. Study of Cigre WG 15.01 has shown that some oils may produce hydrogen even at low temperature (below 130 °C). A possible explanation may be that the catalysts used nowadays may result in producing of "over-hydrogenerated oils". That means that oils contain some molecules where hydrogen atoms occupy unstable position and a mild heating may evolve such atoms. Similarly it has been noted different but substantial production of CO and CO2 and some hydrocarbons at operating temperature of transformer (Table 3). Gas evolution under normal thermal stresses should be considered especially in case of questionable gas generation at early stage of a transformer service.

Table 3

Gas evolution in different oils under effect of temperature
(Tests in ZTZ-Service material Lab)

Type of oil	**Temperature, °C**	**Time, hours**	**H2**	**CH4**	**CO**	**CO2**
			Concentration, ppm			
GK (Russia)		Initial	0	1	0	212
	100	6	5	1	41	408
	120	6	35	42	190	931
	120	+16	78	66	283	1772
Nytro-11GX		Initial	0	0	0	246
	100	6	31	0	55	413
	120	6	79	39	222	833
	120	+16	116	39	227	1068
YPF-64		Initial	0	0	0	297
	100	6	5	1	73	439
	120	6	31	23	282	898
	120	+16	31	39	298	1392
Y-3 (Technol)		Initial	0	0	0	547
	100	6	5	1	16.2	611
	120	6	47	1	63	1076
Diala Ax Shell		Initial	0	0	0	642
	100	6	0	1	26	797
	120	6	0	3.9	130	1471

7. External and unusual sources of gas generation

Experience has shown the following typical sources of occurrence of elevated faulty gases concentration in oil:

- Penetration of gases from LTC divertor switch compartment.
- Overheating while oil processing.
- Desorption from cellulosic insulation.
- Burned motor winding in the pump.

Temperature migration of gases between oil and cellulose may mask real picture of faulty-gas concentration, especially when a unit was de-energized for some while. Special study [16] has shown for instance that cellulose may contain a significant amount of CO and CO2, and change of temperature may result in substantial variation of ratio CO2/CO.

Experience has shown that sampling of oil for DGA test at maximum oil temperature gives more realistic picture of generated gases.

Effect of temperature distribution of gasses

Case #1 Shunt Reactor 110 MVAR, 750 kV.

The reactor with suspected source of localized overheating was tested after storing for 1 year. DGA results showed elevated but not critical values. On recommendation of ZTZ-Service, test was repeated after heating the unit and setting at 60-65 °C for 3 days. A notable increase of gas concentrations was found due to gas desorption from cellulosic insulation.

Table 4

Desorption of gases from cellulose

Test oil temperature	**H2**	**CH4**	**C2H4**	**C2H2**	**C2H6**	**CO**	**CO2**	**O2, %**	**N2, %**
	Concentrations, ppm								
20 °C (before heating)	trace	172	78	not	56	923	1929	0.08	2.9
64 °C (after heating)	56	269	147	1.3	90	1163	2654	0.09	5.5

Therefore to get the most out of an asset of the oil as diagnostic media re-distribution of gases between oil and solid insulation temperature shall be considered.

Burned motor winding in the pump

Burned motor winding in the pump is a typical external-mode source of a high gas generation in transformer oil. Some examples that may give an idea about gas spectrum are shown in the Table 5.One can see that it is not easy to identify the failure mode using traditional gas ratio. Unusual patterns of gases sometimes may suggest the type of problems. There has been only one registered case when acetylene was generated due to the failed motor presuming that sparking between phases was a physical source of gas generation. However the ethylene and methane were the key gases in the case #1,2,3

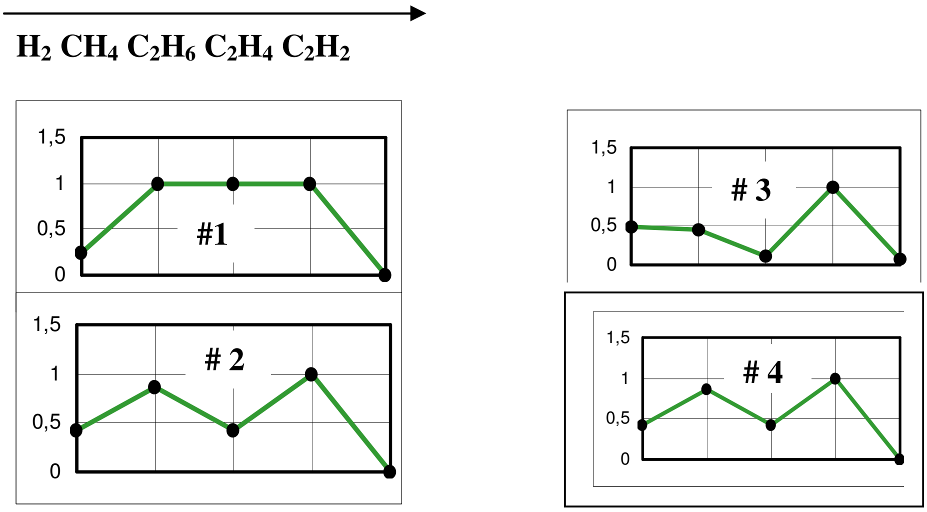


Figure 3
Gas patterns in the cases of burned motor winding in the pump

Table 5

Gas-in-oil concentrations originated from failure of the oil pumps

Transformer	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	CO_2
#1. 150MVA, 400 kV	220	1660	1880	1140	ND	410	2430
#2. 200 MVA, 330 kV	100-180	204-360	110-175	240-420	ND	60-90	350-500
#3. 125MVA, 220/110kV	90-150	360-630	360-630	360-628	0.01-0.10	170-200	2300-2500
#4. 333 MVA, 750/330 kV	40-92	50-87	6.0-20	80-190	6.0-14.0	170-570	370-1400

8. Thermal Faults

8.1 Identification of seriousness of gas generation

The critical step in order to identify the seriousness of the problem that causes localized oil overheating is to answer the question whether current-flow circuit or magnetic circuit involved. That is easier to define for transformers rated less than 100 MVA due to those comparatively low values of stray losses in and accordingly more less probability of overheating. However, special procedures are necessary to verify the state of lead contacts, LTC contacts, and other connection that may result in open-circuit and catastrophic failure. Winding (transient) resistance test is typically most appropriate sometimes.

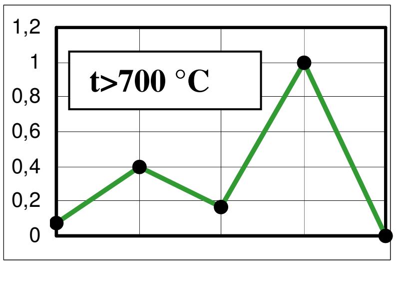
Case #2. Gassing of the transformer caused by dangerous overheating of the lead contacts.

An auxiliary transformer of a 1000 MW nuclear power plant unit 63 MVA 24/6.3/6.3 kV, 1515.5/2887/2887 A, was in the service since 1984. In December 1997 DGA analysis revealed a clear symptoms of thermal decomposition (6). Localized oil overheating with local temperature over 700 °C was suggested. Rate of gas generation was estimated as 239 ppm/day or 590 ml/day. ZTZ-Service advised to check the influence of load on gas generation. After load decreasing gas generation practically stopped. It was suggested that the problem is associated with bad contact in the current flow circuit. The winding resistance test was advised to identify the problem. The unit was left in operation for another two weeks until the planned de-energizing. The test of LV2 winding showed increasing contact resistance in phase" b" by 212 μΩ The operating current of 1440 A could produce localized "heater" of 440 W. Inspection revealed severe overheating of LV2 lead connection.

Table 6

DGA results for the 63 MVA transformer, ppm

Test	H_2	CH_4	C_2H_2	C_2H_4	C_2H_6	CO	CO_2	C_3H_6+ C_3H_8	ΣC_xH_y (C1-C3)
Problem detected	78	259	<0.1	640	117	219	1827	276	1292
After 3 days	64	347	1.4	883	147	266	2402	610	1988
After decrease load	37	247	<1	798	35	190	1837	644	1724



Winding	Resistance, μΩ			Difference between phases
	a-b	b-c	c-a	
LV1	2582	2626	2610	1.7 %
LV2	**2992**	**2840**	2780	**7.6 %** or **212** μΩ

Figure 4

Gas Pattern in 63 MVA Transformer

8.2 Continuation of the transformer operation on the basis of In-Field Heat Run Test

Experience has shown that temporal increase of load for 8-12 hours might be an effective means to predict seriousness of localized overheating associated with magnetic stray flux.

Case # 3. Selection of possible level of load to continue operation.

250 MVA, 330/150 kV autotransformer after 20 years of service has shown symptoms of oil overheating. Localized oil overheating with estimated temperature about 800C was suggested (Figure 5, Table 7). Based on the test program, that incorporated checking the condition of pumps, leads and OLTC contacts, and possible loops associated with the main magnetic flux, the problem associated with stray magnetic flux was suggested . The Heat Run Test was advised to determine the serviceability of the unit. Load was increased from 60 % up to 100 % for 8 hours. Increasing of load results (Table 7) in rise of gas generation up to 4100 ml/hour and appearance of acetylene. The unit was left in operation with limited load.

Table 7

Gas generation during Heat Run Test

Load	Gas concentrations, ppm							
	CO2	CO	H2	CH4	C2H4	C2H2	C2H6	$\Sigma C_x H_y$
60 % of rated	1329	152	695	1274	2820	Trace	297	4391
Rated	1298	127	534	1518	3034	33	354	4939

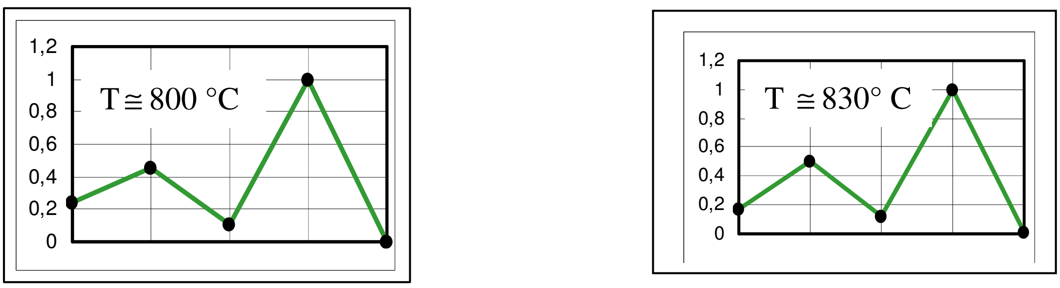


Figure 5
Gas patterns prior and after Heat Run Test

9. Identification of sparking and arcing in oil

On the other hand the sources of PD can be associated with operative voltage, with voltage induced by main magnetic flux, and with voltage induced by stray flux.

Statistics has shown that the problems associated with sparking and arcing within a transformer could be roughly distributed as the following:

PD associated with main magnetic flux	31 %
PD associated with stray flux	41 %
PD associated with operative voltage	
Conductor under floating potential, bad contacts	14 %
Creeping discharge	14 %

The most dangerous cases with PD activity in major insulation spaces make up less than 15 % of the total problems associated with arcing inside a transformer. In such case the unit has to been taken from operation immediately.

Case # 4. Assessment of seriousness of gas generation in 300 MVA, 500 kV transformer.

One of two sister's – type shell-form autotransformers showed clear generation of faulty gases, likely associated with combination of PD activity, localized oil heating, and cellulose decomposition. Continuing of operation of the both units was very critical. The problem arose how serious was the symptom of abnormality? Will it progress to affect the insulation system? ZTZ-Service advised and performed PD-electrical test [13] to verify whether gas generation is associated with PD activity in the major insulation.

Table 8

DGA data , ppm for the 300 MVA autotransformer T1RS

Test date	H2	CH4	C2H6	C2H4	C2H2	CO	CO2
07.23.98	557	155	45	156	<1	588	1720
09.02.98	674	204	70	217	<1	722	2174

Table 9

PD Test report, 300 MVA, 500kV Autotransformer T1RS

Sensor	**noise, [pC]**	**Maximum Pulse Magnitude [pC]**	**Repetition Rate [ppc]**	**PD Power [mW]**
Bush U	127	**1,270**	**100**	**10.7**
Bush V	127	225	1000	47.1
Bush W	142	252	1800	8.06
Neutral	37.8	0	0.759	0.00046

PD characteristics pointed out presence of the source of PD on the phase U close to the HV terminal. However, the level of ionization could not cause destruction of insulating material and explain the observed rate of gas generation. It was suggested that the problem is not attributed to PD in the major insulation and the unit may be left in operation. This suggestion was accepted by the Utility and the Autotransformer is still in operation.

Case #5. Seriousness of gas evolution in the Shunt Reactor 750 kV.

The Shunt Reactor 110 MVAR, 750/$\sqrt{3}$ exhibited both symptoms of arcing and localized overheating with estimated temperature about 800 °C. Continuing of its operation was critical, and decision was taken to verify whether the winding insulation involved. PD electrical test was performed using PD Analyzer and 6 sensors connected to the Bushing's Tap, electrostatic shields and grounding leads (see Figure 6).

Table 10

DGA data for the Shunt Reactor 750 kV

Date	**H_2**	**CH_4**	**C_2H_6**	**C_2H_4**	**C_2H_2**	$\sum C_3$	**C_4H_8**
05.27.99	60	1	0.1	100	0	36	0
11.22.99	155	241	64	429	6	722	100

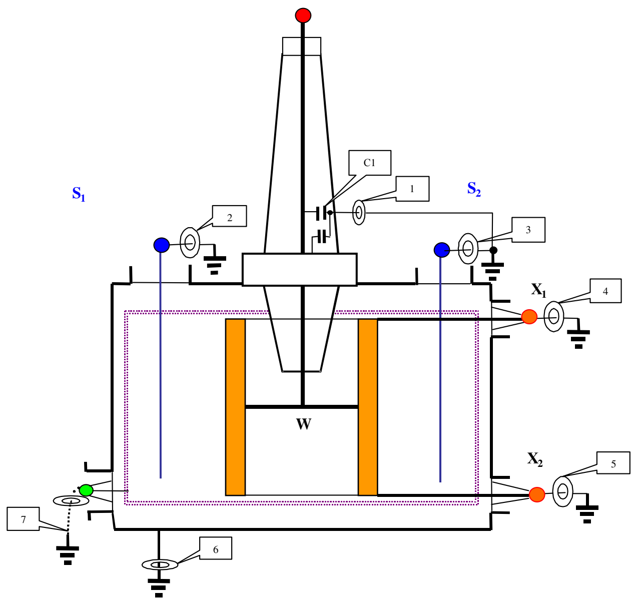


Figure 6
General View of the 750 kV Shunt Reactor and Sensors Location

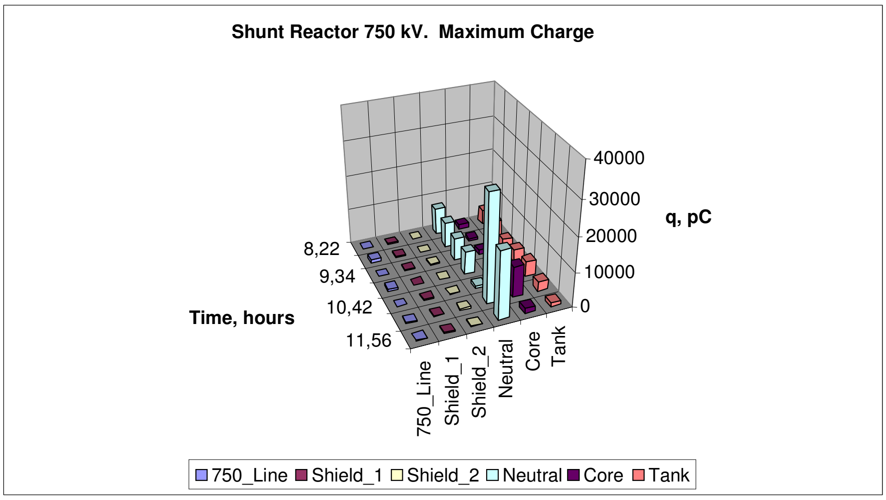


Figure 7
Distribution of PD Signals

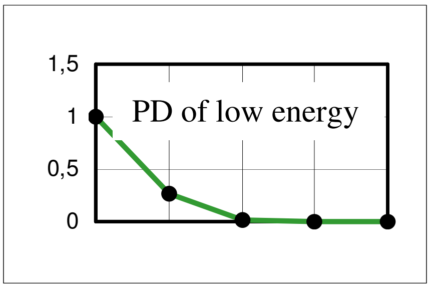
Case # 6. Identification of gassing seriousness in 750 kV Autotransformer.

Single phase 417 MVA, $750/\sqrt{3}/525/\sqrt{3}$ autotransformer exhibited gas generation after 11 years of service. DGA analysis showed clear symptoms of PD – in-oil activity.

Table 11

DGA data for the 750/500 kV autotransformer

Test date	**H2**	**CH4**	**C2H6**	**C2H4**	**C2H2**	**CO**	**CO2**	**Rate of H2 Generation in 1999-2000**
03.26.93	6.7	1.3	4,5	4	ND	620	150	5-12 ppm/day or 300-720 ml/day
08.01.00	950	260	16	5	0.5	3000	240	



Rate of Hydrogen generation constituted 300-720 ml per day that corresponds to 6-14.4 kJ of dissipated energy or about 70-170 mW of average PD energy

Figure 8
Gas Pattern in 750/500 kV Unit

PD-electrical tests were suggested to identify whether a source of gas generation relates to PD activity in a critical insulation zone. Results are presented in the Table 12. A source of PD with maximum pulse magnitude about 1600 pC and average power about 4 mW was suggested near the 750 kV line terminal. However this power was not sufficient to cause oil decomposition and gas generation. Results of combined electrical and acoustic PD tests suggested that more likely source of gas generation could be associated with floating potential and located in the zone of magnetic shields disposition on the tank wall. The autotransformer was left in service until repair that appointed for summer 2001.

Table 12

PD test report for 417 MVA, 750/500 kV autotransformer

Sensor location	Residual noise nC	Maximum pulse magnitude, MV/ pC	Repetition Rate, ppc	PD Power mW
Tap 750kV	0.229	0.19/1640	50.9	3.87
Tap500 kV	0.744	0.047/1600	146	21.4
Neutral	0.012	0.04/410	124	0.327
Tank ground	0.059	0.05/250	30	0.417

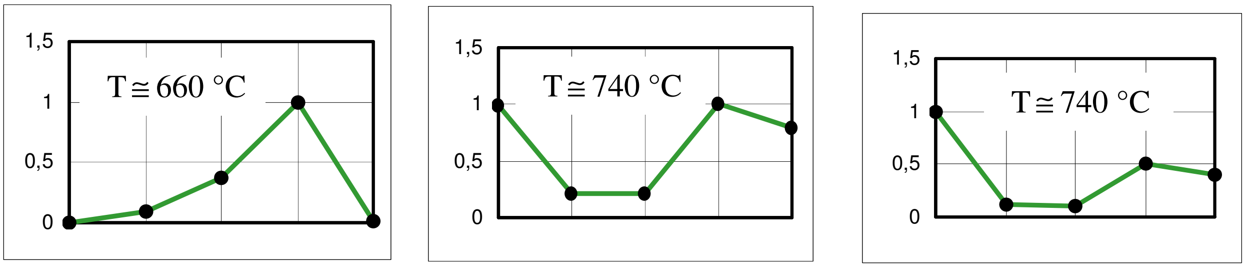
Case # 7. Identification of double discharges-mode and thermal faults in 500 kV GSU autotransformer.

167 MVA, 500/√3, 230/√3, 15,8 kV, GSU autotransformer after 28 years of service exhibited gas evolution. Continuing of the unit operation was very critical and only short time outage was accepted to identify and fix the problem. DGA analysis showed that the unit exhibited symptoms of thermal fault until October 1999 and clear symptom of intensive PD activity since the middle of October. Reduction of load for a day on request of the ZTZ-Service resulted in clear mitigation of gas generation. Thus, it was found that source of gas generation is associated with load. Based on the design review two problems in the autotransformer were suggested: occurrence of a closed loop linked by stray flux (a source of arcing) and a thermal fault likely due to contacts overheating. Internal inspection was advised with the goal to fix the problem.

Table 13

DGA test data for 167 MVA autotransformer

Test date	**H_2**	**CO_2**	**CO**	**CH_4**	**C_2H_4**	**C_2H_2**	**C_2H_4**	**$\Sigma C_{ч} H_{y}$ +H2**
	Concentration, ppm							
10.12.98	-	2250	220	41	464	7	174	683
10.18.99	500	3730	190	52	220	240	65	1077
11.18.99	525	5568	825	109	527	420	113	1694 20.5 ppm/day
12.01.99 reduction load	320	4500	660	70	320	300	88	1098
12.16.99 increasing load	630	1900	160	120	530	540	100	1920
12.24.99	1040	1790	370	103	450	630	107	2330 51.2 ppm/day
01.01.00 after fixing	ND	1900	<30	4.5	22	22	5	



10.12.98
Thermal

11.18.99
Thermal +Discharges

12.24.99
Discharges

Figure 9
Gas Patterns in the 167 MVA Autotransformer

A closed loop between the core frame and the tank was found as a possible source of arcing. Moreover severe overheating of the selector contacts that practically operated only on the odd tap position was revealed. A terminal solution was advised to continue operation of the unit: to limit the current in the closed loop by means of resistance introduction and changing position of the selector. Gas generation was stopped (see the Table 13) and in summer 2000 the problem was completely fixed during in-field repair of the autotransformer.

Case # 8. Identification of gas generation in the place of buckling of the HV2 (inner) winding in the GSU transformer.

After asynchronous switching on of the generator single evolution of free gas into 400 MVA, 347/20 kV GSU transformer gas-relay occurred.
DGA- in- oil analysis showed clear symptom of arcing:

Table 14

DGA data for 400 MVA transformer

	GAS concentration, ppm				
	H2	**CH4**	**C2H4**	**C2H6**	**C2H2**
DGA test after evolution of Gas into relay	245	30.5	35.3	5.1	245

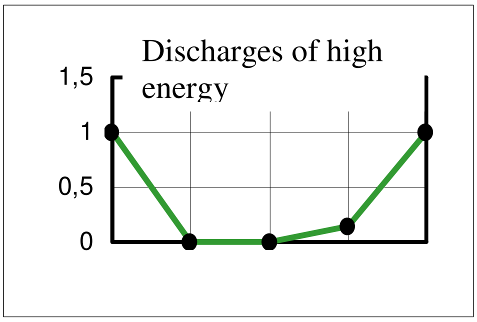
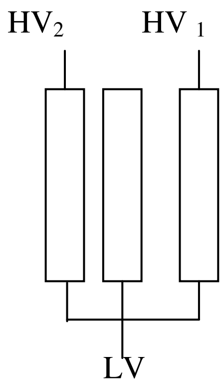


Figure 10
Gas Patterns in the 400 MVA transformer

Subsequent oil analysis showed the decreasing of gas concentrations.
Leakage Impedance Test was advised to verify mechanical state of the winding.
Test results are given in the Table 15.

Table 15

Leakage Impedance tests in the 400 MVA gassing GSU transformer

Winding arrangement	**Test circuit**	**Phase**	**Leakage Impedance, Ohm**		ε_{Np-S} **% relative to nameplate**	ε_{ABC} **% between phases**
			Name plate	**In-service**		
	Predictive test	A	35.3	35.39	0.25	0.28
		B		35.08	-0.62	
		C		35.39	0.25	0.28
	HV-LV Test after Asynchronous Switching on the unit	A	35.3	36.23	2.63	3.28
		B		35.08	-0.62	
		C		35.33	0.08	

In such a transformer design practically only buckling of the inner HV2 winding could be expected. Relative change of the leakage impedance on the phase **A** increased by 2.63 % relative to the nameplate (average) data and by 2.37 % relative to the per phase reference test. However design review shown that due to dividing the

HV into two parts winding sensitivity of LR to the buckling of HV_2 winding is limited and “Yellow zone”(characteristic of marked buckling- $5 \geq \Delta x \leq 10$ mm) corresponds to relative change of LR 2% only. The difference between LR tested on different phases also pointed to defective condition of phase **A.** It was advised removing the transformer from operation. After disassembling the active part two waves of deformation was revealed on the HV_2 winding phase A. Trace of overflashing between the coils was found along the supported lath due to distortion of insulation space.

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