Condition Based Assessment of On Load Tap Changers

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INTRODUCTION

Load tap changers (OLTCs) are a crucial element of utility networks, as they must operate in a precise fashion in order to maintain a constant voltage output. This must be achieved regardless of variation on input or load. OLTC's have been a weak link in many networks as they deteriorate over time due to mechanical problems or contact wear from repeated operation. Erosion of the contacts over time is expected due to the nature of their function. Coking of the contacts causes overheating, which can cause thermal runaway. Regular maintenance is necessary to ensure continued proper functioning

Oil testing has long been recognized as an important tool for detecting incipient faults in the main tanks of transformers and is being applied to load tap changers. Some of the advantages of oil test are.

- can usually be performed while equipment remains in service
- can detect a wide range of problems in the early stages
- can be used to ascertain a reasonable sense of the severity of the problem
- have been shown to be very cost effective

This testing is used to provide one of the most important early warning diagnostics for load tap changers and because of its effectiveness is making condition based maintenance a reality

Abstract

DGA has been applied successfully for many years to non-current switching oil-filled power equipment. The application of dissolved gas analysis to load tap changers (OLTC's) has both similarities and differences to the use of DGA in other oil-filled power equipment. It is similar in that the same processes produce the same gases. However, in terms of gas production, OLTC's are far more complex than transformers. OLTC's may or may not produce all of the so-called 'fault gasses' in normal operation and the gases that are produced may or may not be lost through venting.

The first applications of DGA to evaluate load tap changer condition were based on experiences with transformers. Threshold limits were developed for the gasses produced by overheating both individually and in combination. Many factors such as design, operations, ventilation, and on-line filtration affect gas levels. Consequently, this gas threshold approach offered limited success but proved the potential usefulness of fluid testing for OLTC condition assessment. Since gas data alone cannot provide sufficient information to fully assess OLTC condition, new approaches were required for OLTC evaluations. The search for this new approach led to the development of Condition Codes, which provides a condition assessment of the load path components.

In addition to providing useful information for the maintenance of insulating fluid, fluid assessment tests are used in conjunction with LTC gas data to provide diagnostic information about the condition of load tap changers. Keeping the oil free of water, arc decomposition products and other contaminants is essential for proper operation of the load tap changer. Particle profiling provides important information about the deterioration of materials that result in particle production. This includes information about in-service processes such as fluid degradation, contact deterioration and mechanical wear of moving parts and rust formation. Two of the most important fluid degradation processes to be evaluated are charring of the oil and coke formation.

Table 1 shows the gas producing process that occur in oil filled electrical equipment. The gases that are produced by these process are listed in Table 2. Recognition of these differences between normal and abnormal gassing patterns paved the way to diagnostic assessment of On Load Tap Changers OLTC's

Table 1
Gas producing Process

Equipment	**Normal**	**Abnormal**
Transformers	Heating	Excessive Heating, partial Discharge and Arcing
OLTC's	Arcing	Excessive heating and Partial Discharge

Table 2	
Gasses	**Indication**
Hydrogen	Partial Discharge, Heating Arcing
Ethylene, Ethane, Methane	“Hot Metal” gasses (Heating)
Acetylene	Arcing
Carbon Oxides	Cellulose insulation degradation

DGA and other non-invasive tests can be combined to assess the OLTC condition. Diagnostic programs have been successfully developed to achieve the goal of condition-based maintenance with the consequent saving in costs.

Table 3 Diagnostic Tools		
Diagnostic Tool	**Problem detected**	**Result**
DGA	Coking, Contact misalignment	Overheating (Thermal run-away)
Oil Quality	Coking, Contact Wear, Change in Arcing characteristics, Oil sludgeing	Conducting particles in oil, Sludge
Metal Analysis	Contact wear, misalignment	Contact wear

Dielectric Breakdown Voltage: The oil in an OLTC should maintain a minimum dielectric breakdown voltage. In recent years on-line filters have been used for compartments containing arcing contacts in oil to better maintain the dielectric breakdown strength of the insulating materials. This approach has been effective in pushing out maintenance cycles and reducing the rate of contact wear. The dielectric breakdown voltage is a function of the relative saturation of water in oil and the amount, size, and type (conductivity) of particles

Water Content: Excessive water reduces the dielectric breakdown strength of the oil and can accelerate the aging of the contacts.

Neutralization Number: As oils and cellulosic materials age they will deteriorate and form aging byproducts, including acids. Eventually the aging byproducts will begin to polymerize and form sludge’s. Increasing acidity can be used as a guide to the aging rate of the oil. When high values are reached the oil should be replaced or reclaimed. Acid byproducts, particularly in the presence of water are corrosive.

Total Metals in Oil: The metals test, consisting of both particulate metals and those dissolved in the oil is an extremely meaningful test. It provides as indication of the amount of material that has been worn or sublimated from the moving and/or stationary contacts and is now present in the oil. It also provides a quantitative analysis as to composition of the metals found in the oil.

Particle Count and Qualitative Analysis: The total number of particles by size groupings is used to detect abnormal quantities of byproducts and wear materials. The ratio(s) of the size groupings provides information as to the extent that a detrimental condition has progressed.

DGA Diagnostics

It is obvious that DGA plays a primary diagnostic role. The interpretation protocol for applying DGA is empirical in nature. In the case of OLTC’s it is generally accepted that fault gas interpretation will be most useful if it is model specific.
Individual gas concentrations based diagnostics for OLTC’s are not useful as they are operation count and breathing configuration dependent. DGA ratios of fault gases are fairly independent of operation count.
The various gas ratios are excellent diagnostic tools.
Table 4 lists the gas ratios proposed by Weidmann-ACTI (F.Jakob: K. Jakob: S.Jones)

<table>
<tr><td colspan="4">Table 4
Diagnostic Gas Ratios</td></tr>
<tr><td colspan="4">Heating to Arcing Ratios</td></tr>
<tr><td>Ratio1</td><td>Ratio 2</td><td>Ratio 3</td><td>Ratio 4</td></tr>
<tr><td colspan="4">Temperature Dependent Ratios</td></tr>
<tr><td colspan="2">Ratio 5</td><td colspan="2">Ratio 6</td></tr>
</table>

The primary test for OLTC diagnostics and condition assessment is that for dissolved gas-in-oil as this detects most of the problems. There are three main types of OLTC's, reactive with arcing contacts in oil, resistive with arcing contacts in oil and arcing contacts in a vacuum bottle. There should be differences in the gassing behavior between resistive and reactive types as the shorter time of arc extinction of the resistive type (5-6 ms after contact separation) should lower the concentrations of gases generated. However the gassing behavior of different models of LTCs are so different that generic rules for reactive and resistive OLTC's are not adequate.

The primary diagnostic gases used to develop condition codes are methane, ethylene and acetylene. In addition three ratios are used:

- ethylene/acetylene: distinguishes between thermal and electrical discharge activity in oil
- methane/acetylene: distinguishes between thermal and electrical discharge activity in oil and can also detect partial discharge activity as a predominant gassing pattern.

For example, localized overheating of contacts or the reversing switch will generally show increasing combustible gas generation with ratios of gassing going from an arcing pattern to characteristics of high temperature overheating of oil. Excessive arcing between contacts is most likely to develop high gas concentrations until the later stages when heating occurs (causing the combustible gas ratios to change). Examples of causes of overheating include:

- excessive contact resistance due to the formation of organic films and carbon deposits
- metal fatigue causing poor contact pressure
- loss of direct contact surface area from misalignment or loss of contact material

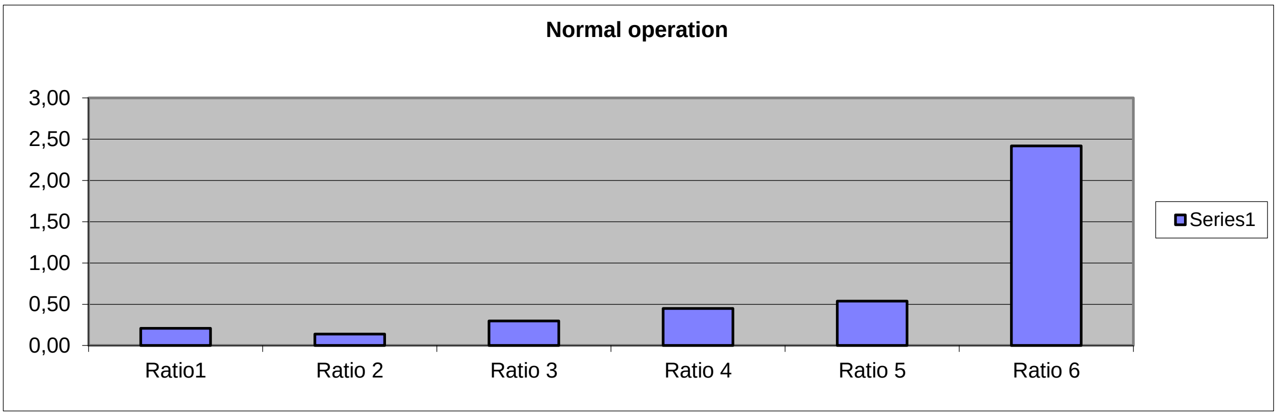
Excessive combustible gas buildup can result when the vent becomes plugged. This eventually leads to low oxygen contents as it is consumed in oxidation reactions and is not replenished. Typically the ratios will remain normal unless another problem is present at the same time. Various other thermal and electrical problems can also be detected depending upon the model of LTC.

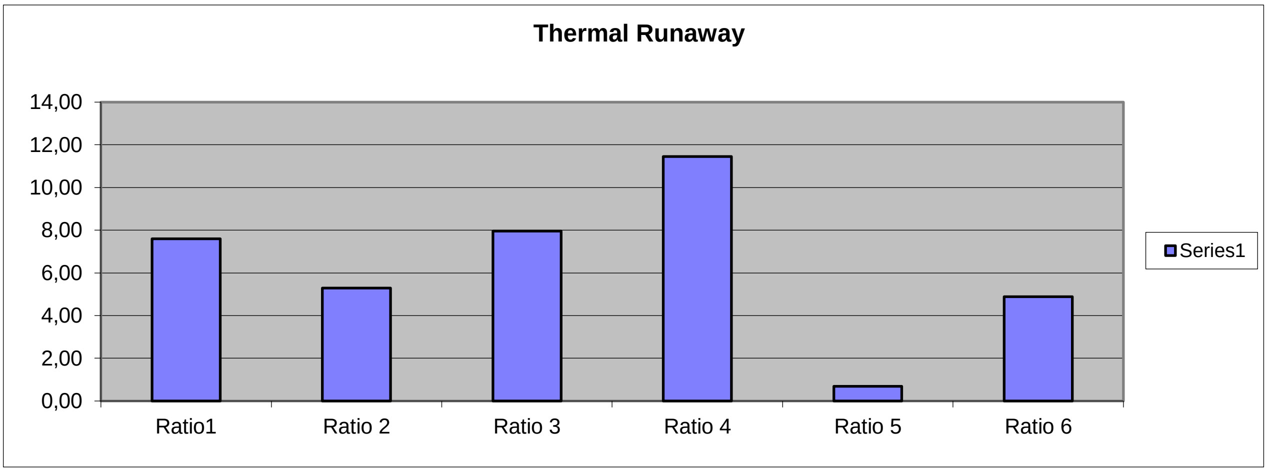
NEW DGA INTERPRETATION SCHEME

In an attempt to improve the understanding of the significance of DGA results the 'Kohonen net' cluster analysis technique has been relatively successful in grouping together DGA results of an apparently similar significance and identifying when a result appears to move to a different state. Although such techniques can be argued to provide a better basis for identifying an unusual condition than the purely statistical approach, they still rely very much on the human expert to ascribe some significance to the clusters identified.

The new approach proposed makes use of the relative proportions of the six combustible gases H_2, CH_4, C_2H_4, C_2H_6 and C_2H_2 are displayed as a bar chart to illustrate the gas signature. The novel aspect of the approach proposed here is that this method is used to investigate and illustrate the clear difference that exists between 'normal and 'abnormal' results.

The graphical plotting of these ratios gives a clear indication of a heating problem (Thermal runaway) when compared to the normal arcing process.

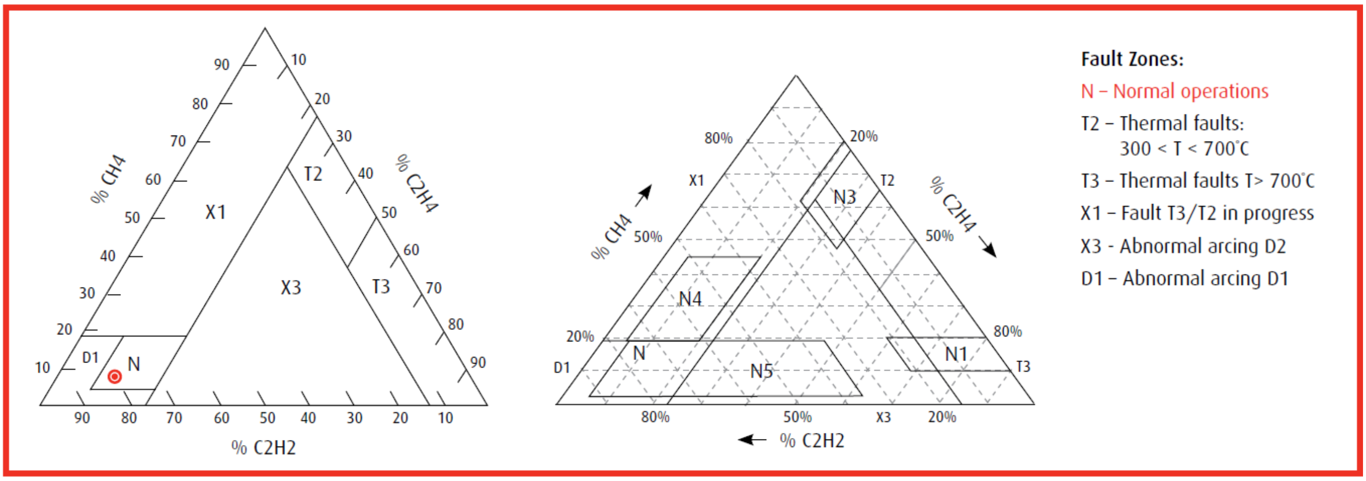




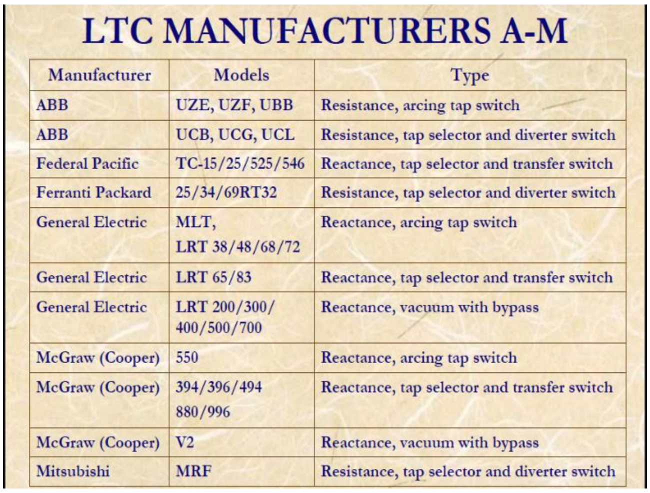
DUVAL TRIANGLE FOR THE INTERPRETATION OF DGA IN LTC'S

Duval Triangle using CH_4, C_2H_4 and C_2H_2 gases in a single graphical representation has been developed for tap changers, the basic Duval Triangle can be used to detect faults in compartment type OLTC's.

When DGA points move with time from the normal to a fault zone, this means a fault is appearing.
What makes the use of DGA in LTCs different from its use in transformers is that during the normal switching operation of OLTC's arcs in oil or hot spots in various OLTC components are produced, generating gases such as C_2H_2 and C_2H_4 which may interfere with the detection of abnormal faults.
The "normal" gas formation of OLTC's must therefore be identified first as precisely as possible in order to use DGA for the detection of faults in OLTC's.
Triangle 2 has been developed to distinguish between normal and abnormal gas formation in OLTC's of the compartment and in-tank resistive-type OLTC's, without any fault, generate large amounts of heating gas, especially ethylene.

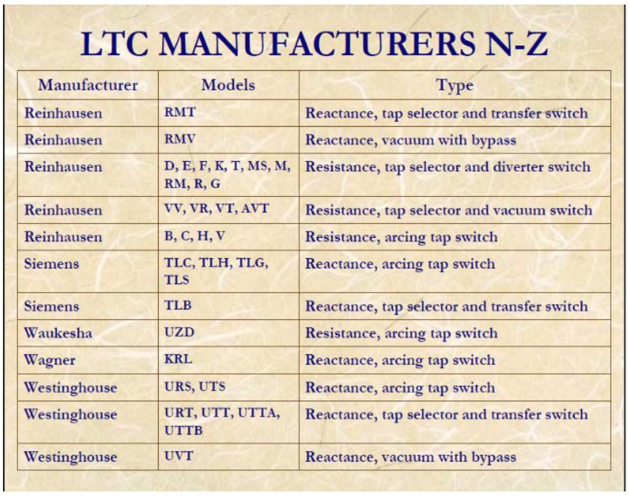


Different Zones(N1: N3: N4: N5) of Triangle 2 have been identified for various types of LTCs,(indicating the normal zone(s) of operation depending on power operating conditions: OEM Models and Type.



LTC MANUFACTURERS A-M

Manufacturer	Models	Type
ABB	UZE, UZF, UBB	Resistance, arcing tap switch
ABB	UCB, UCG, UCL	Resistance, tap selector and diverter switch
Federal Pacific	TC-15/25/525/546	Reactance, tap selector and transfer switch
Ferranti Packard	25/34/69RT32	Resistance, tap selector and diverter switch
General Electric	MLT, LRT 38/48/68/72	Reactance, arcing tap switch
General Electric	LRT 65/83	Reactance, tap selector and transfer switch
General Electric	LRT 200/300/ 400/500/700	Reactance, vacuum with bypass
McGraw (Cooper)	550	Reactance, arcing tap switch
McGraw (Cooper)	394/396/494 880/996	Reactance, tap selector and transfer switch
McGraw (Cooper)	V2	Reactance, vacuum with bypass
Mitsubishi	MRF	Resistance, tap selector and diverter switch



LTC MANUFACTURERS N-Z

Manufacturer	Models	Type
Reinhausen	RMT	Reactance, tap selector and transfer switch
Reinhausen	RMV	Reactance, vacuum with bypass
Reinhausen	D, E, F, K, T, MS, M, RM, R, G	Resistance, tap selector and diverter switch
Reinhausen	VV, VR, VT, AVT	Resistance, tap selector and vacuum switch
Reinhausen	B, C, H, V	Resistance, arcing tap switch
Siemens	TLC, TLH, TLG, TLS	Reactance, arcing tap switch
Siemens	TLB	Reactance, tap selector and transfer switch
Waukesha	UZD	Resistance, arcing tap switch
Wagner	KRL	Reactance, arcing tap switch
Westinghouse	URS, UTS	Reactance, arcing tap switch
Westinghouse	URT, UTT, UTTA, UTTB	Reactance, tap selector and transfer switch
Westinghouse	UVT	Reactance, vacuum with bypass

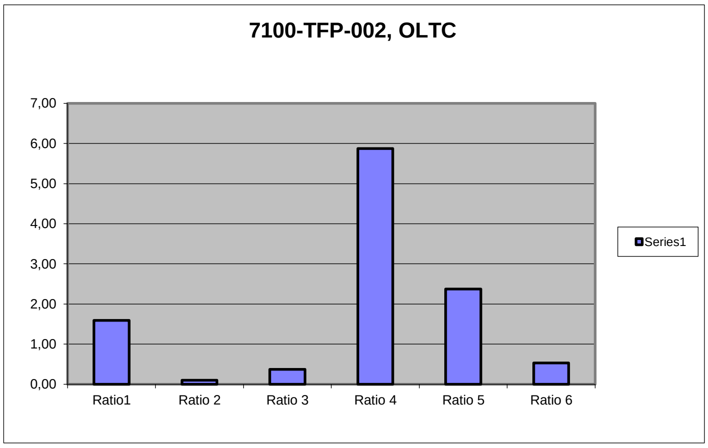
Note-CIGRE WG D1.32 [B4] indicates that resistive-type LTCs sometimes, without any fault, generate large amounts of heating gas, especially ethylene. This behavior is usually associated with high operation frequency and/or high load.

Case1

Client: MOZAL SMELTER Region: MOZAMBIQUE District: BOANE
Substation: 132kV AIS, AUX NO.2 Transformer No:7100-TFP-002, T/C
Serial No: AID69222T21TC
Sample Point: TAP CHANGER Sample Date:05-05-2004 Analyses Date: 21-05-2004
Primary Voltage: 132 kV Secondary Voltage: 22 kV VA Rating: 31.5 MVA
Vector Group: Dyn1 Impedence:11.92% Tap Changer:On Load
Make: M.R.G Year Manufactured: 1999 Conservator: Yes
Breather Size:SA2 Oil Volume Litres:400 Report Number:MOZAL-8988

Dissolved Gas (DGA) vpm @ NTP

Hydrogen	H_2	**7465**
Oxygen	O_2	1165
Nitrogen	N_2	73197
Methane	CH_4	690
Carbon Monoxide	CO	128
Carbon Dioxide	CO_2	66
Ethylene	C_2H_4	727
Ethane	C_2H_6	1468
Acetylene	C_2H_2	390
Total % Gas		8.48
Total Gas Combustibles		10868



REPORT: **The DGA indicates a Partial Discharge of low energy (Corona).**

The Ratio profile indicates abnormal operation.

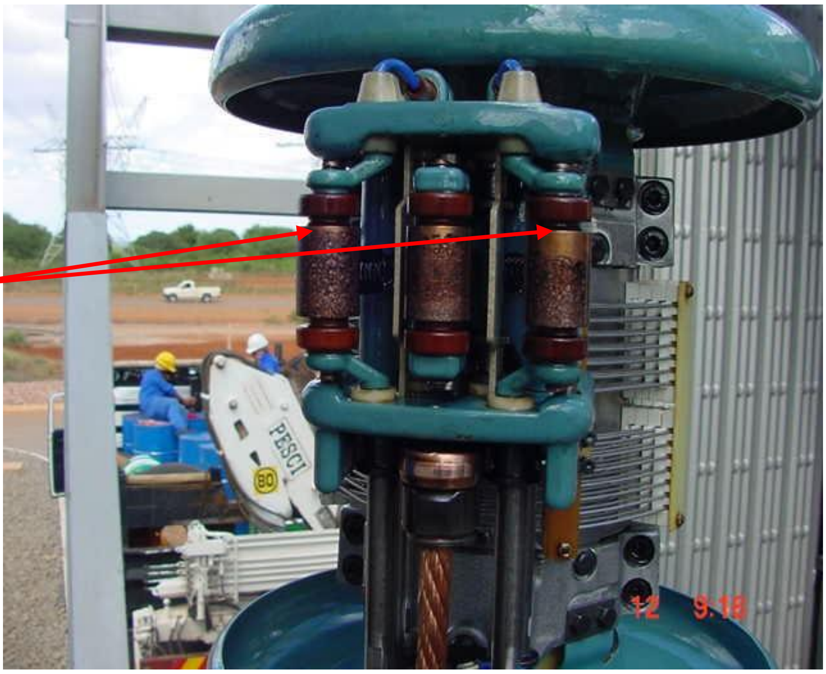
Note-This is not normal for an OLTC.

RECOMMEND: **Contact manufacturer.**

RESULTS OF INVESTIGATION

The amount and ratios of gasses revealed the approaching failure. The unit was serviced-reversing switch contacts were cleaned, tightened and tightened, and placed back in service. The DGA now shows normal operation of the OLTC.

Uneven and excessive wear

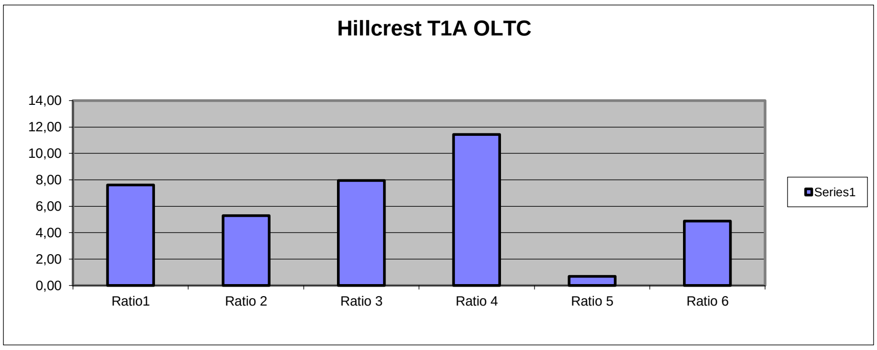


Case 2

Client:	DURBAN ELECTRICITY	Region:	KZN	District:	DURBAN
Substation:	HILLCREST	Transformer No:	T 1A, T/C	Serial No:	2206328
Sample Point:	TAP CHANGER	Sample Date:	09/12/2008	Analyses Date:	10/12/2008
Primary Voltage:	132 kV	Secondary Voltage:	11 kV	VA Rating:	30 MVA
Vector Group:	YNyn0	Impedence:		Tap Changer:	On Load
Make:	ASEA	Year Manufactured:	1975	Conservator:	Yes

Dissolved Gas (DGA) vpm @ NTP

Hydrogen	H_2	797
Oxygen	O_2	13257
Nitrogen	N_2	32073
Methane	CH_4	**4145**
Carbon Monoxide	CO	866
Carbon Dioxide	CO_2	5068
Ethylene	C_2H_4	**13797**
Ethane	C_2H_6	**2823**
Acetylene	C_2H_2	1814
Total % Gas		7.46
Total Gas Combustibles		24242

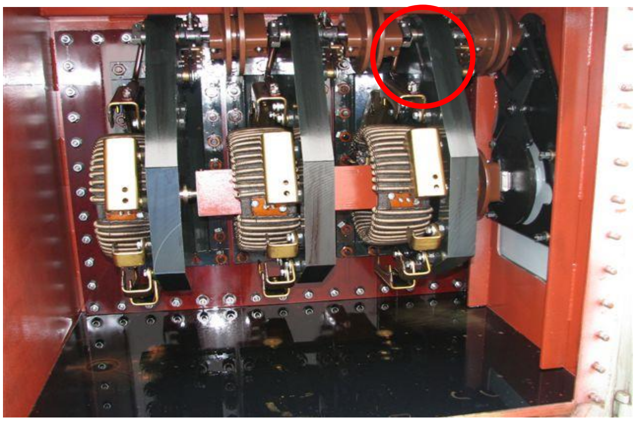


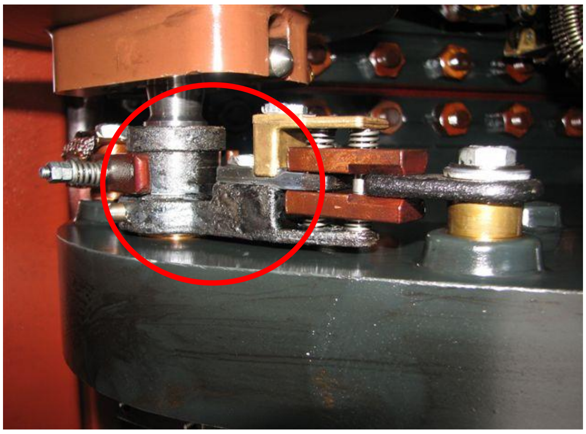
REPORT: **The DGA indicates a Thermal Fault. (Hot Metal gases-Thermal runaway.) See diagnosis Ratios**.
Note-The sample was taken following a Fault trip. (Buchholz surge relay operation on the OLTC)

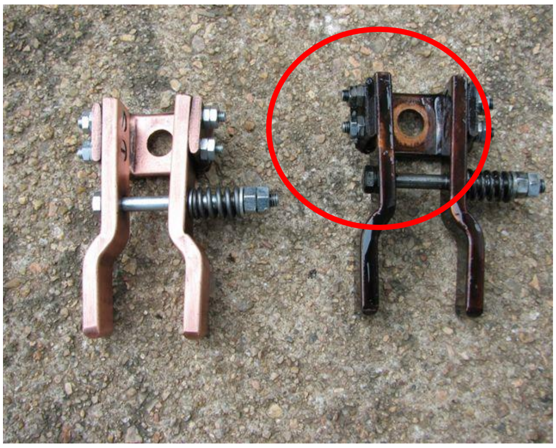
RECOMMEND: Remove from service for Inspection/Repairs. Resample after treatment.

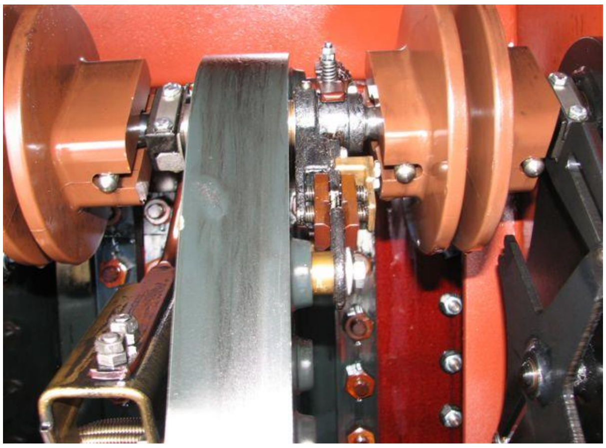
RESULTS OF INVESTIGATION

The internal investigation found severe burning and coking on the forward/reversing moving arm contacts and springs of the red phase. The fixed contacts were coked and slightly burnt. The other phase contact were also coked and with time would have developed into a similar condition. All the forward/reverse fixed and moving contacts were replaced.





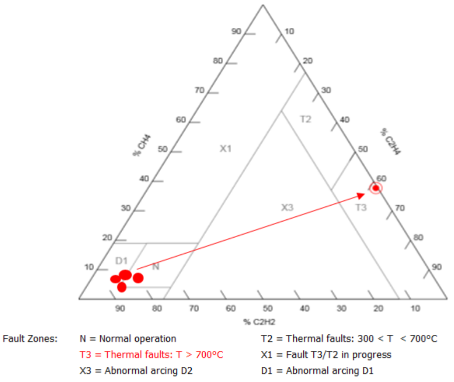


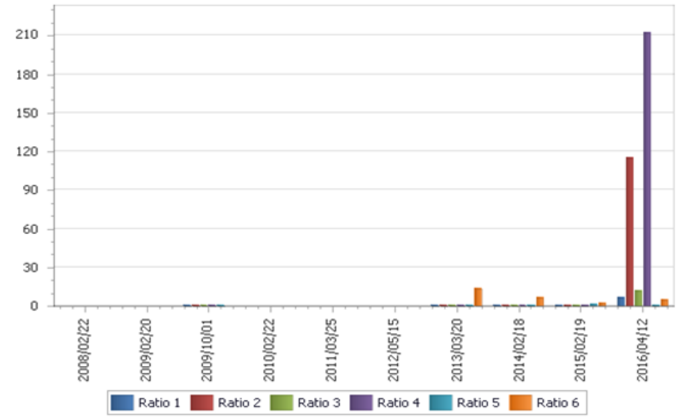


Case 3

Client: SASOL Synfuels Generator Step Transformer (GSU)
Manufacturer of OLTC: ASEA 132 kV : 60 MVA
Year of manufacturer : 1981

Diagnosis: Thermal Runaway T>700°C /Burnt Contacts





Date	H2	CH4	CO	CO2	C2H4	C2H6	C2H2	Ratio 1	Ratio 2	Ratio 3	Ratio 4	Ratio 5	Ratio 6	Stensestam Ratio	Diagnosis
2016/04/12	1896	7533	238	1226	12329	2814	107	6,16	115,22	11,32	**211,93**	0,37	4,38	**211,93**	**Overheating - contact the manufacturer for advice**
2015/02/19	34	6	22	546	6	4	66	0,06	0,09	0,16	0,24	0,67	1,50	0,24	No overheating present
2014/02/18	46	9	15	509	13	2	88	0,10	0,15	0,18	0,27	0,22	6,50	0,27	No overheating present
2013/03/20	0	10	44	1133	13	1	120	0,11	0,11	0,20	0,20	0,10	13,00	0,20	No overheating present

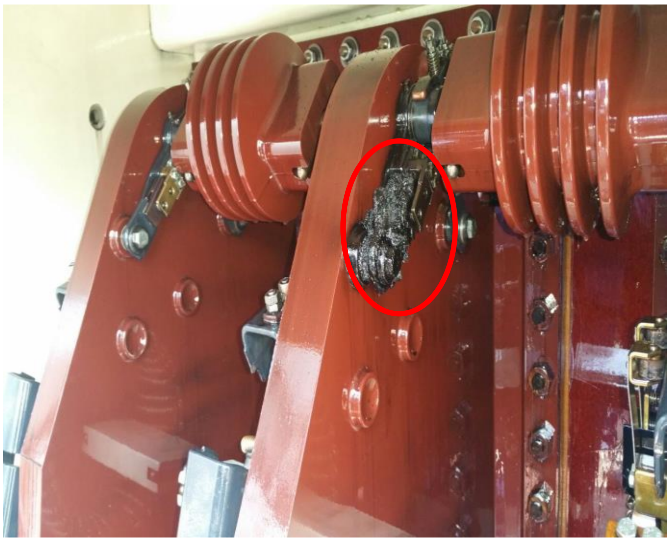
RESULTS OF INVESTIGATION

This case provides an example where the DGA was an indicator of a Thermal Runaway condition prior to failure.

Note: The amount and ratios of gases revealed the approaching failure. The problem in this unit was found to be a Burnt Contact switch.

Remedial action taken avoided Catastrophic failure which was estimated at 2 weeks. If left undetected the resulting Catastrophic failure would have resulted in at least 6 weeks to 6 months of a forced outage.

Savings in Millions Rands range due the Strategic importance of this Generator Step-up unit(GSU)



CONFIRMATION AND COMPLIMENTARY TEST

There are a number of non-oil tests that have been employed to confirm or identify OLTC problems. These include the following:

Infrared thermography and temperature differential: A frequently used method to detect or confirm overheating of contacts or the reversing switch in OLTC's is to determine the temperature difference between the main tank and the OLTC. Normally the main tank should be operating at a higher temperature than the OLTC compartment except for the occasional transient such as when the pumps initially come on to cool the main insulation. As thermal problems develop in the LTC compartment the oil temperature will consistently be higher than the main tank. This difference in temperature can be detected using continuous temperature monitors mounted to the tank wall or by periodic inspections using infrared thermography.

Electrical tests: There are a number of electrical tests that can be used to confirm or help identify the source of OLTC problems before entering for visual inspection.

- Exciting current tests on all OLTC tap positions can be used to detect shorted turns and core problems in the preventive autotransformer, contact problems and connection problems in the preventive autotransformer or in taps.

- Turns ratio can detect shorted turns in the preventive autotransformer.

- Power factor tests are used to detect insulation deterioration such as from moisture and partial discharge activity, including tracking and carbonization of solid insulation structures.
- Contact resistance is used to detect excessive contact wear, poor contact pressure, and coking and polymeric films on contact surfaces.

- Sweep Frequency Response Analysis (SFRA) and leakage reactance (short circuit impedance) are both used to detect winding movement or deformation and contact problems.
-

  Tap changer Diverter Resistor and Contact Analysis provides a means for condition assessment of tap changers using dynamic contact resistance measurement techniques. A signal is injected into the phase under test with the secondary and tertiary windings shorted. The tap changer is tapped through its sequence and a trace is produced of the complete sequence. The detail of each tap can be viewed, allowing the timing of the transition to be measured. The test results provide the necessary information to establish the state of the tap changer to make planned decisions or take corrective actions minimizing the need for intrusive inspections.

Acoustic and vibration analysis: Some investigators have developed a database of OLTC signatures using acoustic analysis to complement diagnostic programs for OLTC's

The advantages of the Tap changer Analysis program are:

- Units that require maintenance are identified.
- Units that do not currently require maintenance are identified
- Maintenance activities can be better focused.
- Operators and planners can assess loading capabilities.
- Failures and collateral damage to transformers can be reduced.
- Reliability is enhanced.
- Costs are reduced.
- Safety is not compromised.

Percent Savings in Maintenance

		Fixed - Year Maintenance Interval (Years)				
		2	3	4	5	6
% of Units Requiring Maintenance Based on Condition Code	12%	76	64	52	40	32
	14%	72	58	44	30	20
	17%	66	49	32	15	20
	20%	60	40	20		
	25%	50	25			

Percent savings are based on a comparison of the percentage of units requiring maintenance as given by the condition code versus the number that would be maintained on a fixed-time interval.

CONCLUSIONS

The ability of utilities and other power transformer operators to convert from time-based maintenance to condition-based maintenance for load tap changers has been greatly enhanced by the advancement of oil diagnostic test. These test have gained acceptance in the industry and will be standard practice in the near future. We have found that once oil diagnostics program are started for OLTC’s, problem that were not detected by other methods are revealed and there is acceptance of this approach. After using oil diagnostics for all the OLTC’s in a system, the number of problems found the second time around is reduced showing the effectiveness of the program.

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