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.

CIGRE TB 939 - Analysis of AC transformer reliability shows the failure location for all 848 analysed failures (Worldwide) were predominantly winding (37 %), bushings (25 %), and tap changer (19 %) related (See Figure 1), with the South Africa current failure data obtained from the Eskom's distribution division showing a similar failure rate for tap changers at 16 % (See Figure 2)

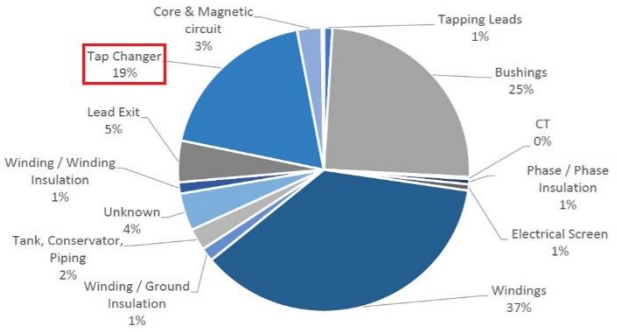


Figure 1: Failure location analysis for 848 failures.

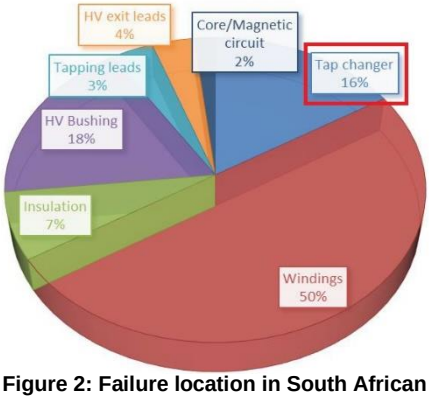


Figure 2: Failure location in South African failures.

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.

On-load tap-changers (OLTC) can be divided into two groups according to the type of current limiting impedance used:

1. **Resistor type OLTCs** are suited to high voltage power transformers but require a high speed mechanism to limit time the resistors are inserted to typically 50 – 150 ms. These spring-operated mechanisms can be sophisticated and require more skills for maintenance. HV applications are more susceptible to dielectric failure. Therefore, oil quality is also a maintenance issue for most resistor type OLTCs.

2. **Reactor type OLTCs** are limited to lower voltage (less than 138 kV) power transformers but they can typically carry higher loads and have no limitation in transition time. The reactor type OLTCs all feature the use of a reactor that provides the OLTC with twice as many voltage positions when compared to a resistor type OLTC that uses the same number of steps in the tapping winding.
High load applications make them more susceptible to coking, but most are equipped with slower motor-driven mechanisms that are easier to maintain. The reactor usually brings additional transformer cost, size and, occasionally, testing issues.
The OLTC incorporates one or more of the following components:

- Diverter Switches are always used in conjunction with a tap selector that comprises two sets of moving and stationary contacts that alternately carry the load. The operation of the Resistor Type OLTC involves two steps. First, the target tap is preselected with the unloaded moving contact.

Then the Diverter Switch transfers the load to the pre-selected tap. This contrasts with the Reactor Type OLTC where the Diverter Switch has to first interrupt the load on one set of moving contacts before that set can be used to pre-select the next tap. Diverter Switches that are the Resistor Type must have high speed mechanisms (usually

spring operated) in order to limit contact wear from arcing and to limit the temperature rise of their transition resistors.

- Selector Switches effectively carry out the two-step operation described above, but with only a single motion. This is achieved with an arrangement of auxiliary moving contacts that can bridge across the two taps for the necessary make-before-break transition. Selector Switches that are Resistor Type must also have high speed mechanisms for the same reasons outlined for the Diverter Switches. Selector Switches are usually spring-operated for high-speed action when used on Resistor Type OLTCs, and motor-driven with slow action on Reactor Types. These devices are usually limited to equipment voltages up to 138 kV and having less than 33 tap positions.
- Change-over Selectors (coarse or reversing) are designed to carry, but not to make or break, through-current. They are used in conjunction with the tap selector or selector switch to enable its contacts and the connected taps to be used more than once, thus increasing (doubling) the number of operation positions for the same number of taps.
- Vacuum type tap-changers can use all principles described above, but in most cases through the addition of a number steps in the sequence and by-pass or auxiliary transfer switches.
- Motor Drive Mechanism and External Drive Shafts are used for the operation and control of the OLTC.

For more details on the different switching technologies and applications, refer to IEC 60214 Parts 1 and Part 2.
Unlike the active part of the transformer, OLTCs could theoretically be kept in working conditions indefinitely by maintaining, repairing or replacing parts (including complete components). End of life decision is therefore not typically based on a simple condition criterion but rather occurs in the following situations:

- Failure beyond economical repair
- Maintenance costs vs new technologies
- Sustainability i.e. availability of maintenance skills or parts

DGA 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

Insulation Fluid Tests

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.

IEC 60422 Edition 5.0 2013-01 INTERNATIONAL STANDARD
Mineral insulating oils in electrical equipment – Supervision and maintenance guidance.

Table-Tap-changers – Application and interpretation of tests

Property	Category[a]	Conditions, limits & recommended actions [b, c] Good	Fair	Poor	Notes
Breakdown voltage (kV)	F star point (Y)	Limits >>	≥ 30 kV	< 30	If OLTC configuration is not known, then delta/line end guidance should be applied.
	F delta (Δ) or line-end	Limits >>	≥ 40 kV	< 40	
		Actions >>	No action required, continue normal sampling	Non-vacuum type– initiate maintenance including oil replacement. Vacuum type - Check the source of water or particulate contamination, resample. If high values are confirmed, recondition or replace oil.	
Water content (mg/kg at transformer operating temperature)	F star point (Y)	Limits >>	<15 / 15-40	>40	The value of water content shall be regarded together with the value for breakdown voltage. The value of breakdown voltage is of overriding importance. When reconditioning the oil, consider residual humidity in the solid insulation which may require multiple drying process or repeated oil replacement.
	F delta (Δ) or line-end	Limits >>	<15 / 15-30	>30	
		Actions >>	No action required, continue normal sampling / No action required, continue normal sampling. For vacuum tap-changers, consider more frequent sampling.	Check source of water. Non-vacuum type – Initiate maintenance including oil replacement. Vacuum type – Recondition or replace the oil.	

Category of equipment (see Table 1).
[b] Ensure sampling was properly done, sampling valve was properly cleaned before sampling (Clause 6) and transportation and storage periods in the laboratory were short.
[c] No action should be taken on the basis of one result and one property. All results shall be confirmed by a repeat sample especially if the result appears abnormal compared to the trend of the previous results obtained.

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 4
Diagnostic Gas Ratios

Heating to Arcing Ratios			
Ratio1	**Ratio 2**	**Ratio 3**	**Ratio 4**
Temperature Dependent Ratios			
Ratio 5		**Ratio 6**	

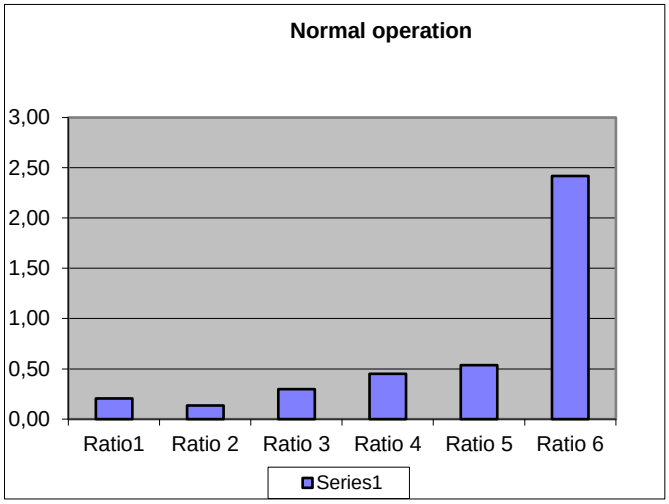
The primary test for OLTC diagnostics and condition assessment is that for dissolved gas-in-oil as this detects most of the problems. There are three main types of OLTC's, reactive with arcing contacts in oil, resistive with arcing contacts in oil and arcing contacts in a vacuum bottle. There should 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.

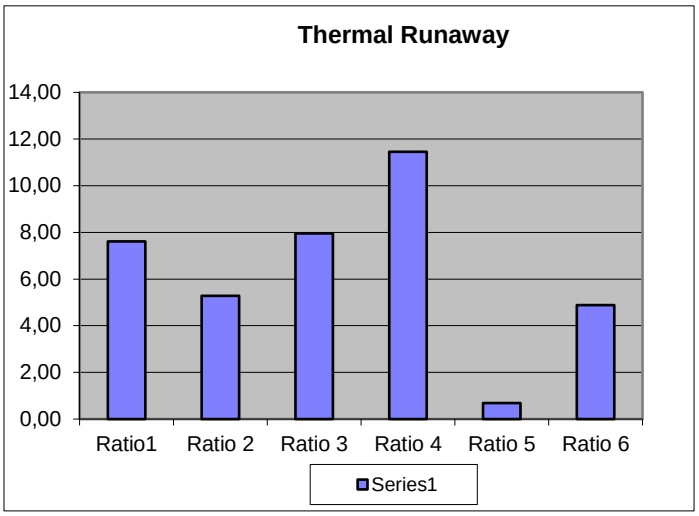
NEW DGA INTERPRETATION SCHEME

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.

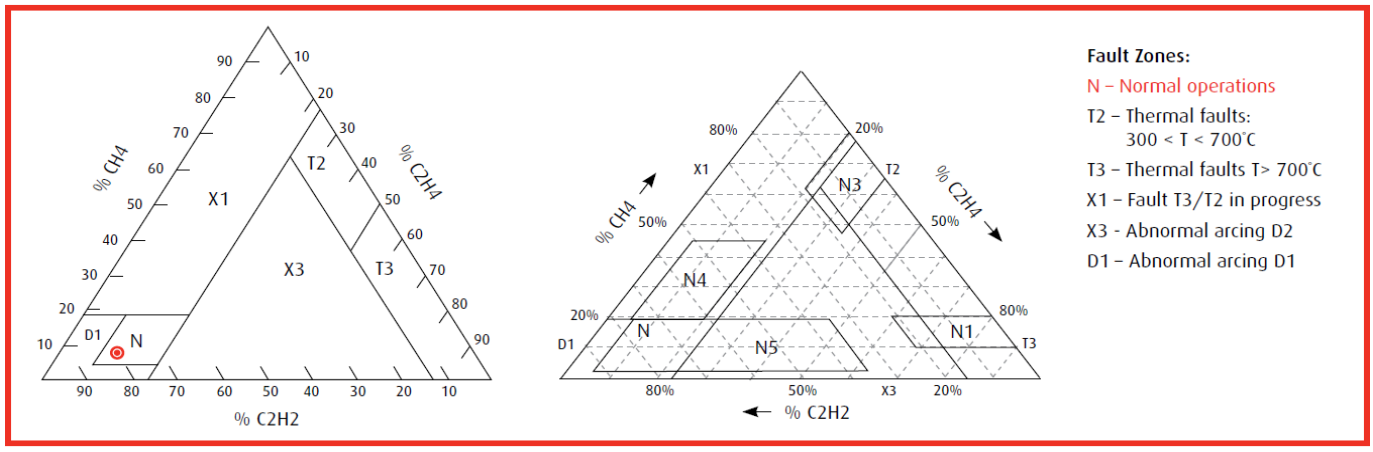




DUVAL TRIANGLE FOR THE INTERPRETATION OF DGA IN LTC'S

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.
N1 for oil types M,D: N3 for oil vacuum types VR,VV : N4 for oil types R,V : N5 for oil types G and UZD's
Note: A few resistive type LTC's (eg UZB's) may have their normal operation in X3 zone.

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.

Limitations and cautions

A suitably trained and experienced person should perform the interpretation of DGA data. Computer assistance including utilization of spreadsheets, databases, analytical software, maintenance management systems, etc. is useful. Additional information about the LTC and the transformer on which it is mounted, including operation, maintenance, test, and environmental history, may be needed for a detailed interpretation. The nature of the interpretation also depends upon the context or application of the DGA.

For various reasons, DGA results can sometimes be false or misleading, and sometimes DGA can fail to identify a fault which may be present. Diagnostic and repair decisions should not be made based on DGA results only, particularly not on an isolated DGA sample.
Results should be confirmed by additional DGA and other tests and expert consultation before inspection and/or repair operations are performed. All due regard to local operating conditions, requirements, and safety issues should be undertaken.

Appropriate caution limits depend on the LTC model and the operating conditions. If limits generated by another LTC population are adopted in lieu of limits derived from the user's own LTC population's DGA data, those limits must be treated with extra suspicion and adjusted in light of actual experience.
The gas concentrations themselves do not give any useful information since the concentrations are dependent on a large number of factors, such as load, number of operations, piping, breathing, temperature variations, oil volumes, type of connection, OLTC type, etc.
Therefore IEEE and IEC have refrained from publishing typical concentration values.
However, the table below gives an idea of what levels are considered typical by a certain OEM.(all values in ppm v/v):

Gas	**Low current/few operations**	**"Normal operation"**	**Industrial service**
Hydrogen	1000-5000	1000-15000	<35000
Acetylene	500-5000	2000-30000	30000-150000
Methane	<300	300-2000	<20000
Ethane	<100	<500	<30000
Ethylene	50-300	300-5000	<70000
Propene	<100	100-1000	<15000[1]
Propane	<10	10-200	
Carbon monoxide	<700	<700	<700
Carbon dioxide	500-3500	500-3500	1000-3500
Oxygen	15000-35000	10000-35000	1000-35000
Nitrogen	40000-70000	40000-70000	40000-70000
[1] The sum of propene and propane			

Note: As can be seen the levels can vary significantly.

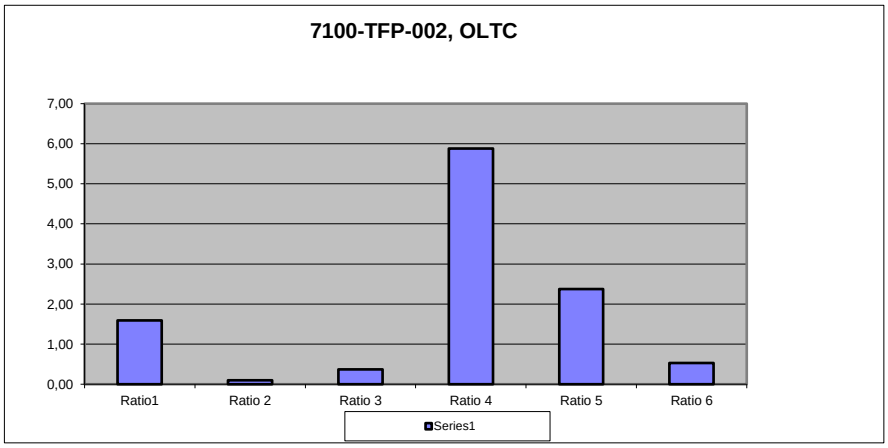
Case Study 1

Client: MOZAL SMELTER
Substation: 132kV AIS, AUX NO.2
Sample Point: TAP CHANGER S
Primary Voltage: 132 kV
Vector Group: Dyn1
Make: M.R.G
Breather Size:SA2

Region: MOZAMBIQUE
Transformer No:7100-TFP-002, T/C
Sample Date:05-05-2004
Secondary Voltage: 22 kV
Impedence:11.92%
Year Manufactured: 1999
Oil Volume Litres:400

District: BOANE
Serial No: AID69222T21TC
Analyses Date: 21-05-2004
VA Rating: 31.5 MVA
Tap Changer: On Load
Conservator: Yes
Report Number:MOZAL-8988

Dissolved Gas (DGA)	***µ L/L (ppm^v)***
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
Stenestam ratio	**7.4**



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.

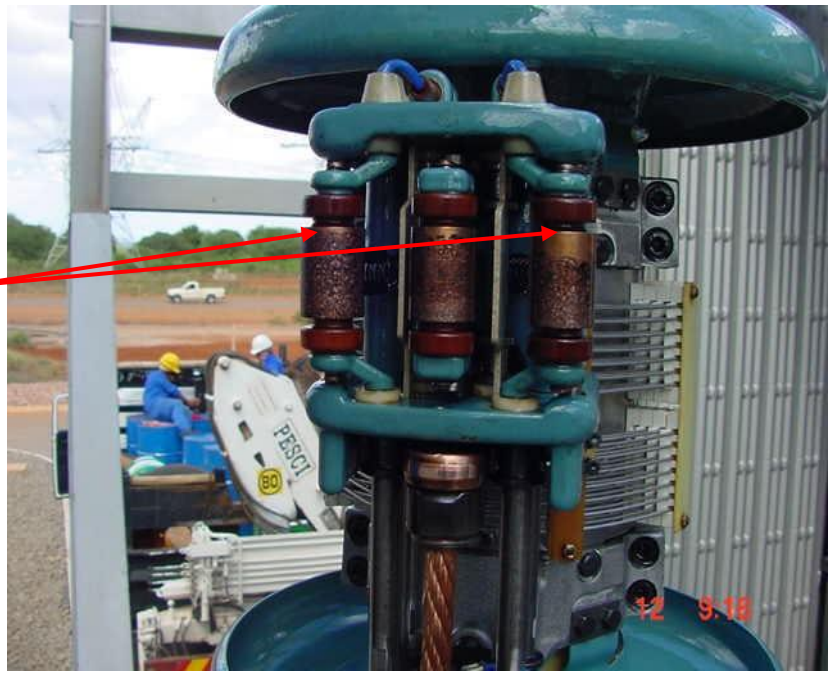
Stensestam Ratio	Interpreting
7,4	>5 Overheating has occurred. The unit should be taken out of service and be repaired as soon as possible

RECOMMEND: **Contact manufacturer(OEM)/Plan Outage for Inspection/Repairs.**

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

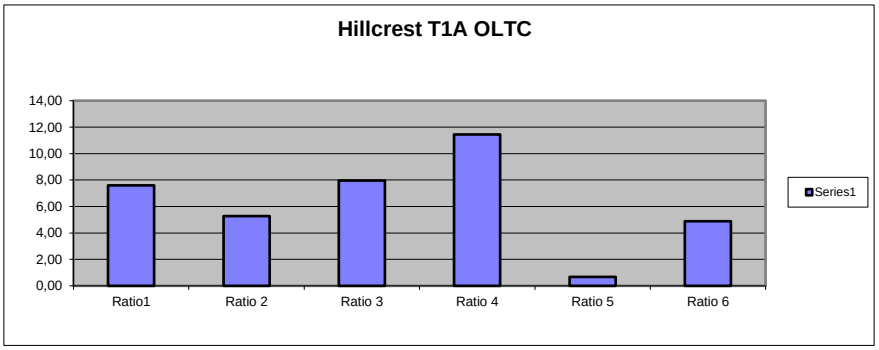


Case Study 2

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

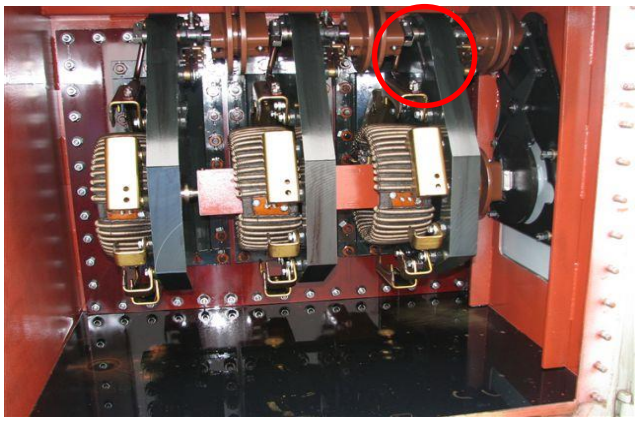


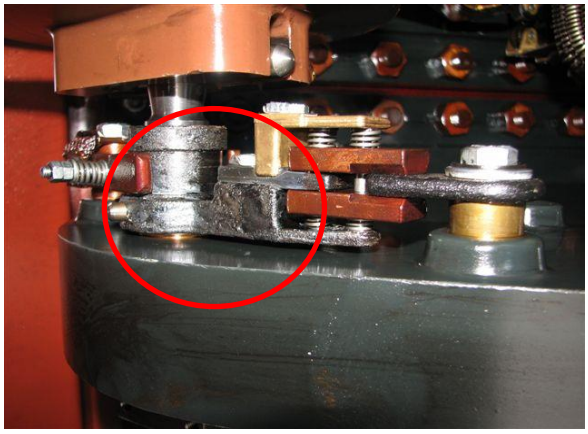
REPORT: **The DGA indicates a Thermal Fault. (Hot Metal gases-Thermal runaway.) See diagnosis Ratios**.
Note-The sample was taken following a Fault trip. (Buchholz surge relay operation on the OLTC)

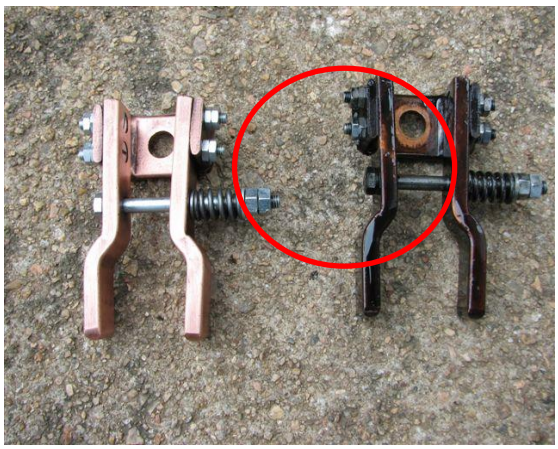
RECOMMEND: Remove from service for Inspection/Repairs. Resample after treatment.

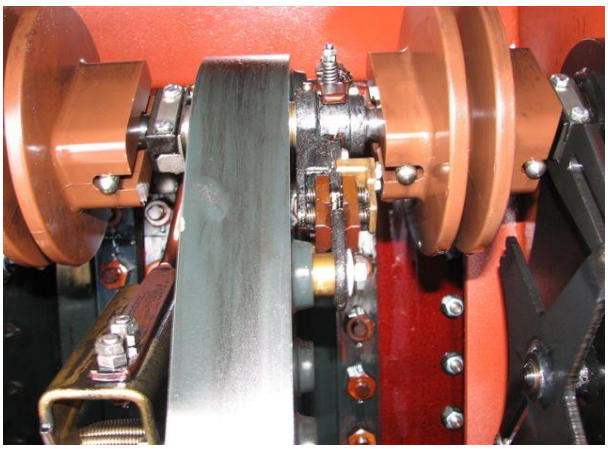
RESULTS OF INVESTIGATION

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.





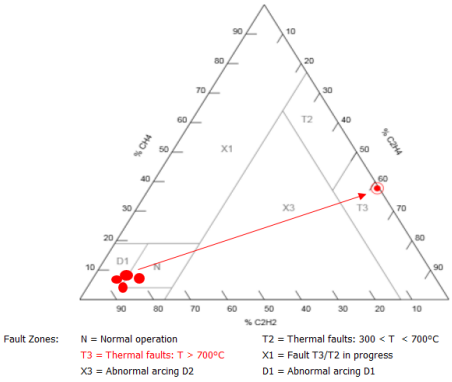




Case Study 3

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

Diagnosis: Thermal Runaway T>700ºC /Burnt Contacts(See Table below DGA results)
Scoring matrix/Risk Assessment : F- Indications of extreme degradation or ageing, or excessive maintenance delays have occurred. A failure is likely to occur in the short term.
RECOMMENDED : Remove from service immediately for Inspection/repairs.



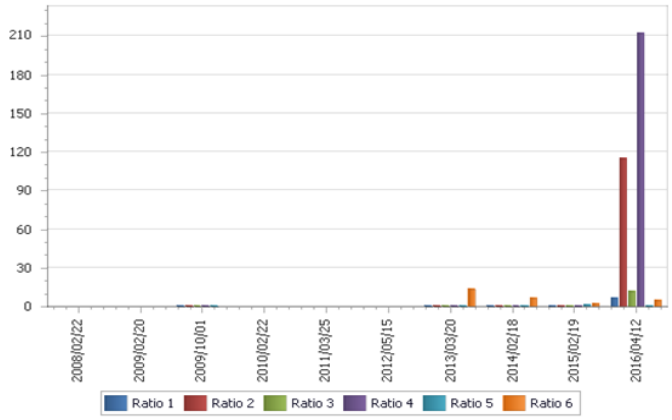


Table DGA Results

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

Failure detection capabilities of different OLTC tests

A number of on-line diagnostic tools have emerged recently for the condition assessment of OLTCs.
The Table below gives an overview of the detection capabilities of the main diagnostic methods available.

DIAGNOSTIC METHOD	OLTC TYPE
VIBRO-ACOUSTIC	Vacuum
	Reactor
	Resistor
MOTOR TORQUE	All
DISSOLVED GAS ANALYSIS	Vacuum
	Reactor
	Resistor
IR THERMOGRAPHY	In-Tank
	Compartment
DYNAMIC RESISTANCE	All

PROBLEMS										
Linkage/Gears							G	G	G	G
Timing/Sequence	G							E	E	E
Control/Relays							E			
Motor							G			
Brake							E			
Lubrication							E			
Contacts alignment							G	G	G	G
Arcing				M	G	E		E	E	E
Overheating/Coking		G	L	M	E	E		L	M	L
Contact wear	M							E	M	L
Transition	E							E	E	E

L-Low
M-Moderate
G-Good
E-Excellent

It appears that any Condition Assessment program for OLTCs would have to rely on the implementation of more than one technique to cover the widest possible range of failures. Although these tests can provide valuable information for the operation of an OLTC, especially those that can be performed on-line, a comprehensive condition assessment can only be achieved by a detailed visual inspection of the internal parts.

Regular (systematic) maintenance consists as a major part in all these visual checks in addition to cleaning and oil filtering.
Also, when regular maintenance is performed in compliance with the OEM recommendations, many failure modes can simply be eliminated by preventive replacement of parts and timely implementation of design upgrades. Accordingly, the maintenance policies and practices of an OLTC operator should also be considered as a possible root failure causes.

Failure mode assessment

Tap-changer condition can be assessed using the tests listed above, supplemented by family history, results of inspections and inductive reasoning as appropriate and in conjunction with the assessment scoring matrix. The tables in Annex A(CIGRE TB 761) can also be used as a starting point when assessing a transformer but users should consider if the values are suitable for their fleet of transformers, operating conditions, maintenance practices, and the time scales used in their scoring matrix. User should refer to Chapters 1 to 7(CIGRE TB 761) before assessing their transformers.
The following data should be considered to be available and relevant for the condition assessment of OLTCs:
1. OLTC Manufacturer, model and age
This information is key in pinpointing vintages that have identified issues such as known design weaknesses, lower service reliability or unavailability of some parts. Also, when the OEM is still supporting the model, all released critical modifications or upgrades can be checked.
Age alone is not an adequate indicator of the general condition of the OLTC, but it can be correlated to the reliability of some components such as the motor drive.

2. Review maintenance records and policies including:
- Last date of service and observations from the inspection
- List of critical modifications and upgrades performed
- List and type of alarms/trip during service
- Qualification of the service technician
- Maintenance practices and more particularly deviations from the OEM’s recommendations (time,
- operations, replacement/repair criteria).

3. Accumulated number of operations and operating range
The number of operations is normally not a relevant indicator of the expected reliability provided that the OEM maintenance recommendations are applied and that the accumulated number stays within the maximum lifetime number rated by the OEMs. This evaluates the overall wear of the OLTC and gives a reference criterion above which the unit’s reliability starts to be affected and its condition is considered to be beyond cost-effective repair.

For modern products, typical ranges of values issued by OEMs are:
- Diverter switch : 800,000 to 1,200,000 operations.
- Selector switch: 1,000,000 to 4,000,000 operations.
- Vacuum interrupters: 600,000 to 1,000,000 operations.
- Motor drive unit: 1,000,000 to 4,000,000 operations.

For older OLTC vintages, different OEM limits (typically lower) may apply. For a normal network transformer with approximately 5,000 yearly operations, it is clear that this criterion will more likely not impact the transformer assessment index significantly.

4. Load history

Load deviations from the rated load can affect ageing and wear mechanisms. Main components that can be affected are insulating material degradation and contact wear. For this purpose, the average load factor and general characteristics of overload occurrences (peak and yearly frequency) should normally be available.

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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