LOAD TAP CHANGER DIAGNOSTICS USING OIL TESTS – A KEY TO CONDITION-BASED MAINTENANCE

by

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INTRODUCTION

Load tap changers (LTCs) are a crucial element of utility networks, as they must operate repeatedly in a precise fashion in order to maintain a constant voltage output. This must be achieved regardless of variations on input or load. LTCs have been a weak link in many networks as they deteriorate over time due to mechanical problems or contact wear from repeated operations. 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.

The electric power industry has been undergoing changes in the past decade in their approach for maintaining electric apparatus in a reliable state. More emphasis is being placed on reducing out of service time by having equipment be more reliable, minimizing down time, and minimizing maintenance activities. Making this more difficult is that the demands on these apparatus are increasing, as is the average age of the population as capital replacement is deferred. There are a number of strategies to maintain the equipment, including periodic, time-based maintenance, condition-based maintenance, or some combination of both. Periodic maintenance can work if sufficient resources are utilized such that these activities occur at shorter time intervals than the gestation time of expected excessive wear and tear or development of problems into failures. To do this well, the time period much be conservative enough to catch most problems which increases cost of maintenance. Condition-based maintenance relies on tools which can detect most problems early enough that maintenance can be scheduled and performed. The quality of these “tools” or diagnostic tests will to a large degree determine the successfulness of a condition-based maintenance program. The diagnostic tests must be performed at a short enough time interval to catch most of the problems while they can be maintained. In some cases, there may be a need to perform some functions on a time-basis cycle (or operation basis) with a frequency that is as long as possible. At the same time condition-based assessment would be used to catch problems that are developing that would not be detected early enough on a time or operation basis. Current day practices for maintenance of electric apparatus are migrating towards condition-based maintenance in order to best protect valuable assets, extending their life in a cost-effective manner.

Oil testing has long been recognized as an important tool for detecting incipient-fault conditions in the main tanks of transformers and is being applied to load tap changers (LTCs) [1-9]. Some of the advantages of oil tests are that they:

- can usually be performed while the 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.

OIL TESTS FOR LTCs

Traditionally, oil tests for LTCs were used to determine if the dielectric breakdown voltage and water content were acceptable and that the oil was not excessively acidic or prone to sludge formation. These tests are important and continue to be performed. They can detect some equipment problems such as poor seals or wet cellulosic materials, but are mostly an indicator of oil quality. In recent years, diagnostics tests such as dissolved gases in oil, particle analysis and metals in oil have been used to assess the condition of LTCs. Although these tests are performed the same way as for the oil from the main tank of the transformer, the diagnostics schemes are different. Condition codes, which will be discussed in a later section, are a means to prioritize the need for further testing and/or remedial action as needed for condition-based management.

Doble as part of its studies on bulk oil circuit breakers and LTCs determined a minimum set of tests that would provide the necessary information for condition assessment of these devices [10]. The tests and their significance are as follows:

Dielectric Breakdown Voltage: The oil in an LTC 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 [11-13]. This approach has been effective in pushing out maintenance cycles and reducing the rate of contact wear. Two test methods are often used in the U.S. for measurement of dielectric breakdown voltage, ASTM Methods D 877 and D 1816. The D 877 test method was developed in the 1920's and is most appropriate to low-voltage equipment, especially where the requirements for dielectric breakdown voltage are not very stringent. More recently Method D 1816 is being used, particularly for filling these devices and for higher voltage equipment. 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. Excessive water in the solid insulation can result in tracking and ultimately an insulation failure. The water content will vary depending if the compartment is sealed to the air, free breathing to air or has a desiccant tube between the air and the LTC compartment. Compartments with arcing contacts in oil will often be vented to reduce the combustible gas concentration generated in the operation of the device. For those LTC compartments that are free breathing, the relative saturation of the water in oil will be driven by the ambient humidity and altered by the difference in the temperature of the ambient air and the oil. Increasing the temperature of the oil above that of the ambient air lowers the relative saturation of water in oil. Under equilibrium conditions, expected amounts of water in oil can be quantified and therefore it is possible to estimate what are excessive amounts of water in oil. For sealed LTCs and those with desiccant breathers standard values for concentration in parts per million (ppm) and relative saturation in percent (%) can be applied. As there can be cellulosic materials present in LTCs, temperature dependent moisture migration between cellulosic materials and oil need to be taken into consideration. As there often is not a temperature gauge on the LTC compartment, the top oil temperature of the transformer can be used for estimating temperature effects.

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 sludges. 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.

Dissolved Gases in Oil: This is the most important test for LTC diagnostics using oil testing. As the insulating materials deteriorate byproduct gases are generated. Normal deterioration produces gassing patterns which are typical for a specific family which includes the model, type of breathing, and compartment. As problems arise the gassing behavior changes which includes both the amount and most often the pattern or relative composition of gases in oil. Problems include localized overheating and or excessive arcing and other abnormalities. Localized overheating of conductors and surrounding insulation may lead to carbonization and byproduct polymeric films forming on conductors, which creates a thermal runaway condition. Carbonization and polymeric films increases the surface resistance of the contacts, thereby causing increased heating and further byproduct formation and accumulation which causes more heating and eventually leads to failure unless the cycle is interrupted by maintenance. This can be detected by observing the generation of hydrocarbon gases such as methane, ethane, ethylene, and acetylene. It has been determined that as an overheating event develops into a thermal runaway condition, the ratio of the hydrocarbon gases change. Dissolved gas analysis (DGA) has become a reliable tool in helping to detect, and identify problems and their severity in LTCs.

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. Larger particles are especially important as the dielectric strength of the insulating oil is more adversely affected by these particles. Formation of larger particles are an indicator of advanced deterioration.

Particle typing has been used successfully in other fields such as lubrication and hydraulic systems for quite some time. In LTCs, particles are formed from three main mechanisms: wear, arcing and overheating. Wear metal particles are formed as two metallic surfaces move against each other. The size, morphology and types of particles are dependent upon the severity of the pressure applied to the surface and the angle at which the surfaces intercept [14]. Some components such as bearings can wear excessively without the formation of combustible gases, and hence the need for a separate test. Arcing can also form metal particles but these particles are quite different in morphology and topography, as they are not wear induced. Arc produced metal particles are formed from molten metal being quenched by the cooler surrounding oil and thus producing a somewhat teardrop shaped particle. Arcing will also produce organic particles such as carbon fines and larger conglomerations from the breakdown of the oil. Overheating increases the rate of decay of other materials and induces the formation of byproducts such as polymerized oil films. The examination of the filter provides a qualitative identification of the types of particles. In the process of particle typing there is an attempt to relate the particles to specific materials of construction. Along with microscopic examination of the particles trapped on a filter, a Doble carbon coding process has been introduced to aid in quantifying the carbon loading in the sample.

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.

SAMPLING FOR LTCs

As the oils from LTCs can contain considerable byproducts from the deterioration process, it is very important to take care in sampling to avoid cross contamination and obtain a representative sample. Doble recommends the follow flushing guidelines to remove condensation in the valve and excessive carbon and debris that has formed as sediment on the bottom of the LTC:

LTCs with <300 gallons of oil flush 1 quart before sampling
LTCs with >= 300 gallons of oil flush 2 quarts of oil before sampling

Generally, plastic tubing is used to connect the valve or the reducing fitting from the valve to the sampling device such as a syringe or bottle. It is critical to use new tubing each time as plastic materials have a "memory effect" where some of the gases dissolved in the oil will adsorb and /or absorb in the plastic only to desorb in the next sample that contains less of the gas. This can be particularly troublesome as the gases are not visible and different types of LTCs have very different normal gas concentrations.

Similarly it is important to use clean sample containers as again cross contamination is of concern when taking samples from LTCs.

For DGA samples taken in syringes there should not be any bubbles immediately after sampling but bubbles that form during storage should be included in the analysis.

Another precaution is to make sure the LTC is under positive pressure. This can be done by introducing a bubble of air in an otherwise oil filled piece of tubing attached to the valve. Open the valve slowly and watch the movement of the bubble. If it moves away from the valve then there is positive pressure and flushing can continue. If the bubble moves towards the valve, the value should be immediately closed and the LTC should be brought back to positive pressure. This may mean opening a plugged vent for a desiccant breather or adding nitrogen to a sealed compartment.

Other precautions include standard practices for safety clearances around energized equipment, and making sure the oil level is adequate. LTCs are fairly low volume equipment so makeup oil should be added periodically, preferably during an outage.

There can be an explosion hazard involving the gas space above oil containing high concentrations of combustible gases. Normal sampling activities would not be expected to create an explosion hazard. However, when handling the oil from LTCs such as moving the oil to a drum or other storage vessel, care should be take to avoid an explosion from ignition of combustible gases. Compartments with arcing contacts in oil can form concentrations of combustible above the explosion limits. Estimating the flammability of the gases in the gas space and safe handling of oils containing high combustible gas contents have been described in other papers [14-16].

NOMENCLATURE FOR LTCs

As with any sample from electric apparatus, it is necessary to have sufficient identification that the test data can be linked to the equipment. This would include information from the nameplate such as manufacturer and serial number. For diagnostic purposes the minimum information that should be supplied with LTC samples is:

Manufacturer of LTC
Year of manufacturer
Model
Type – Vacuum or break in oil (this is often evident from the model information but not always)
Compartment – selector, diverter, transfer
Tank type – sealed, free breathing, desiccant breathing
Filter – yes/no

It is also useful to let those doing the interpretation of results know if the LTC has been maintained or the oil handled since the last test.

An example of a sample identification form is given in the Appendix

DIAGNOSTICS AND RANKINGS (CONDITION CODES)

The goal of diagnostics is to provide equipment owners with a ranking that prioritizes maintenance activities. This goes beyond the simple good/bad distinction, to provide some grading to permit different management options.

The primary test for LTC diagnostics and condition assessment is that for dissolved gas-in-oil as this detects most of the problems. There are three main types of LTCs, 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 [3]. However, it has been our experience that the gassing behavior of different models of LTCs are so different that generic rules for reactive and resistive LTCs are not adequate. This is highlighted in the Doble Client Transformer Subcommittee Report on Transformer Load Tap Changer Dissolved Gas Analysis of September 24, 2001 [1]. This model specific criteria has been further refined by Doble using statistical analysis, field experience of problems and failures, and careful review of model specific data.

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
- (hydrogen + acetylene)/(TCG – carbon monoxide): Ratio of gases associated with discharges to those associated with overheating of oil. This is similar to a ratio proposed previously which included the carbon monoxide in the TCG [4].

A matrix has been developed for each model that includes concentration limits for each of the three diagnostic gases plus the three ratios. Points are assigned for each limit and then summed, with there being a minimum of 0 and a maximum of 15. Condition codes are then determined from the points as shown in Table 1. A Condition Code of 1 indicates a LTC in the worst possible condition that should be the number one priority. A Condition Code of 5 would indicate an apparatus in good condition and the lowest possible on the list for sample frequency. Condition codes 3-5 have a range for sample frequency. This is based upon the experience that the time from inception to complete failure, particularly for thermal runaway conditions, is shortened considerably if overloading significantly beyond nameplate on a regular basis.

The matrix is setup to find a variety of problems which may be detected by excessive gassing rate, change in gas ratios or both. 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.

The diagnostic matrix for selector compartments and vacuum type models that break under vacuum is different. The ratios do not apply in the same way for vacuum type LTCs and therefore, absolute concentration limits for the gases are relied upon to determine the condition codes. Condition codes are generated with the same type of ranking as for arcing contacts-in-oil compartments.

TABLE 1
Condition Codes and Maintenance Assessment

Condition Code	Assessment
1	Remedial action needed
2	INVESTIGATE to determine problem
3	Monitor – Resample in 3 months if loaded below nameplate or 1 month if loaded above nameplate
4	Monitor – Resample in 6 months if loaded below nameplate or 2-3 months if loaded above nameplate
5	Of No Concern – Resample in 1 years if loaded below nameplate or 4-6 months if loaded above nameplate

The Doble diagnostic scheme has been exercised against published data and problems detected from testing where an internal investigation has been found, with good success.

On-line filters can change the relative composition and quantities of gases that are generated [2]. To date the presence of on-line filters has not been added to the matrix to determine the condition codes.

Other diagnostic tests serve as modifiers to the condition code determined by the DGA results. The reason for setting up the analytical scheme this way is to allow for tolerance in the interpretation of results when different sets of tests are used. Oil quality, particle count, particle analysis and metals are not always requested. However these tests can be important. For example, excessive contact wear that requires attention can cause vaporization and dissolving of metals in oil in detectable and diagnostically significant amounts. In some cases this will not be fully indicated in the DGA results.

CONFIRMATION AND COMPLIMENTARY TEST

There are a number of non-oil tests that have been employed to confirm or identify LTC 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 LTCs is to determine the temperature difference between the main tank and the LTC. Normally the main tank should be operating at a higher temperature than the LTC 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 [18-20] or by periodic inspections using infrared thermography [9, 21].

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

Exciting current tests on all LTC 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, 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.

Acoustic and vibration analysis: Some investigators have developed a database of LTC signatures using acoustic analysis to complement diagnostic programs for LTCs [22].

CASE STUDIES OF LTCs

To illustrate the LTC diagnostic program several case studies are presented.

CASE 1

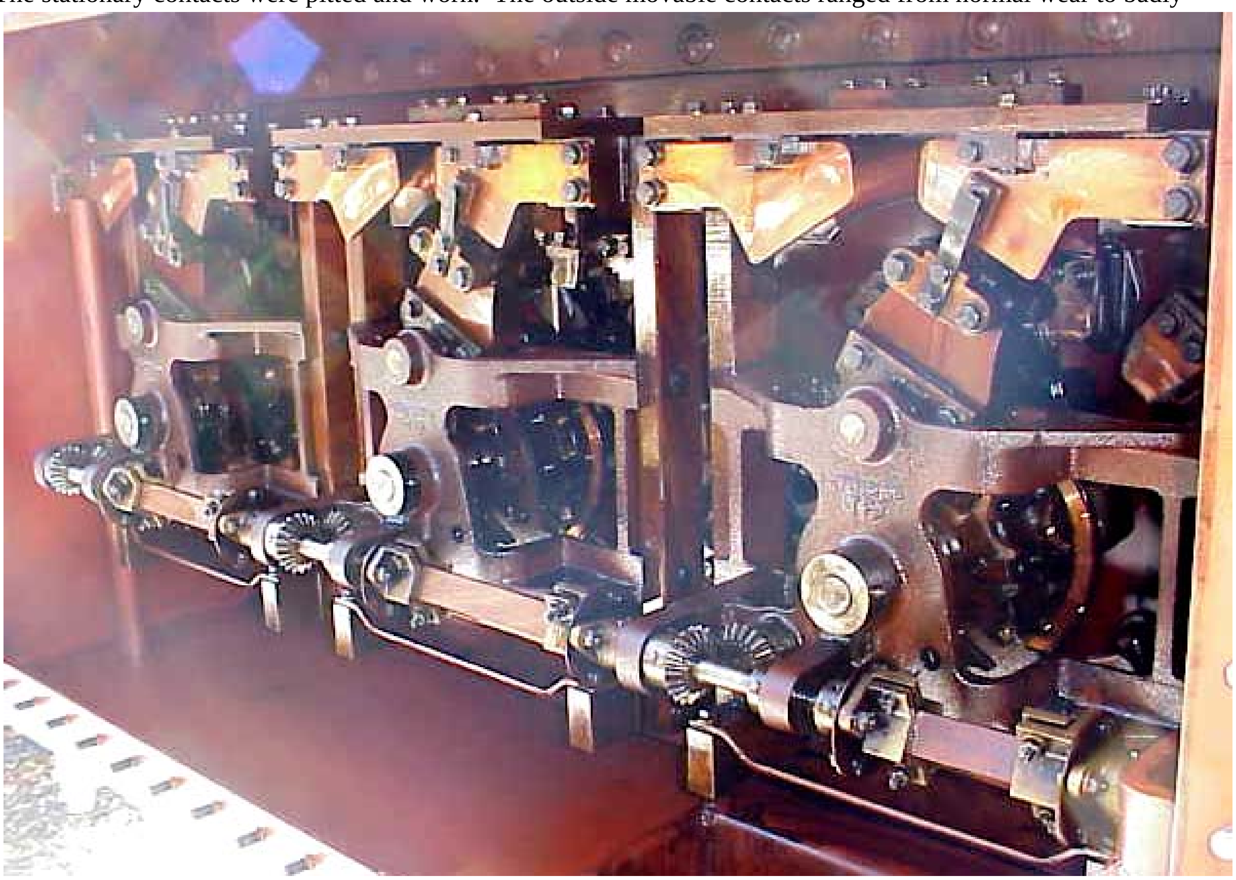
Manufacturer of LTC: Westinghouse
Year of manufacturer: 1958
Model: URS
Type – Break in oil
Compartment – Arcing Selector
Tank type: Free breathing
Filter: No

TABLE 2
Case 1 Dissolved Gas-in-Oil Results (ppm vol/vol at STP)

Gas	**6/10/2004**
Hydrogen	7,611
Ethane	2,982
Methane	5,234
Ethylene	32,123
Acetylene	3,601
Carbon Monoxide	211
Carbon Dioxide	4,380
Oxygen	6,610
Nitrogen	50,700
TCG	51,762
Methane/Acetylene	1.5
Ethylene/Acetylene	8.9
(H_2+Acet)/TCG-CO	0.22
Doble Condition Code	1

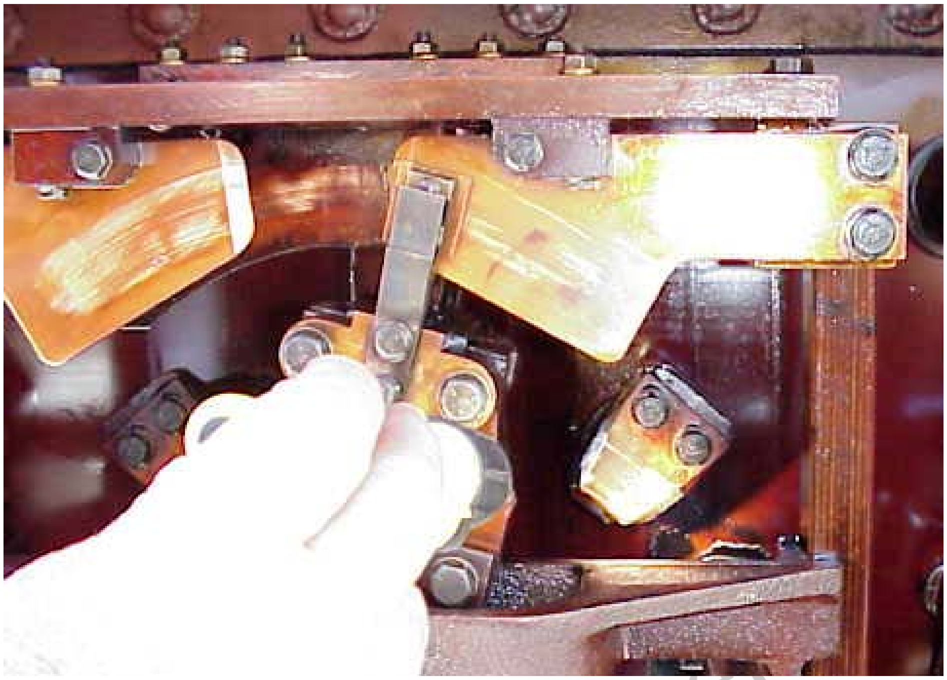
RESULTS OF INVESTIGATION

Connecticut Light and Power had started a new program using oil testing for diagnostics on LTCs. This was the first case where a Condition Code of 1 had been obtained. The DGA results show the values were high and the ratios indicative of a developing problem in the late stages. An investigation was performed. One of the problems that was found was that the free breather valve was not working properly, therefore allowing the combustible gas concentration to build up. This can also be seen in the gas composition as hydrogen will tend to be proportionally higher in units that are not free breathing and the oxygen, which is consumed in oxidation reactions, is lower than normal. The internal investigation revealed a small amount of carbon sediment, about 0.25 inches (0.64 cm) in depth below the active components. Figure 1 shows the internal condition of the three-phase LTC. The reversing switches were in good condition with normal contact wear as can be seen in greater detain in Figure 2. The stationary contacts were pitted and worn. The outside movable contacts ranged from normal wear to badly



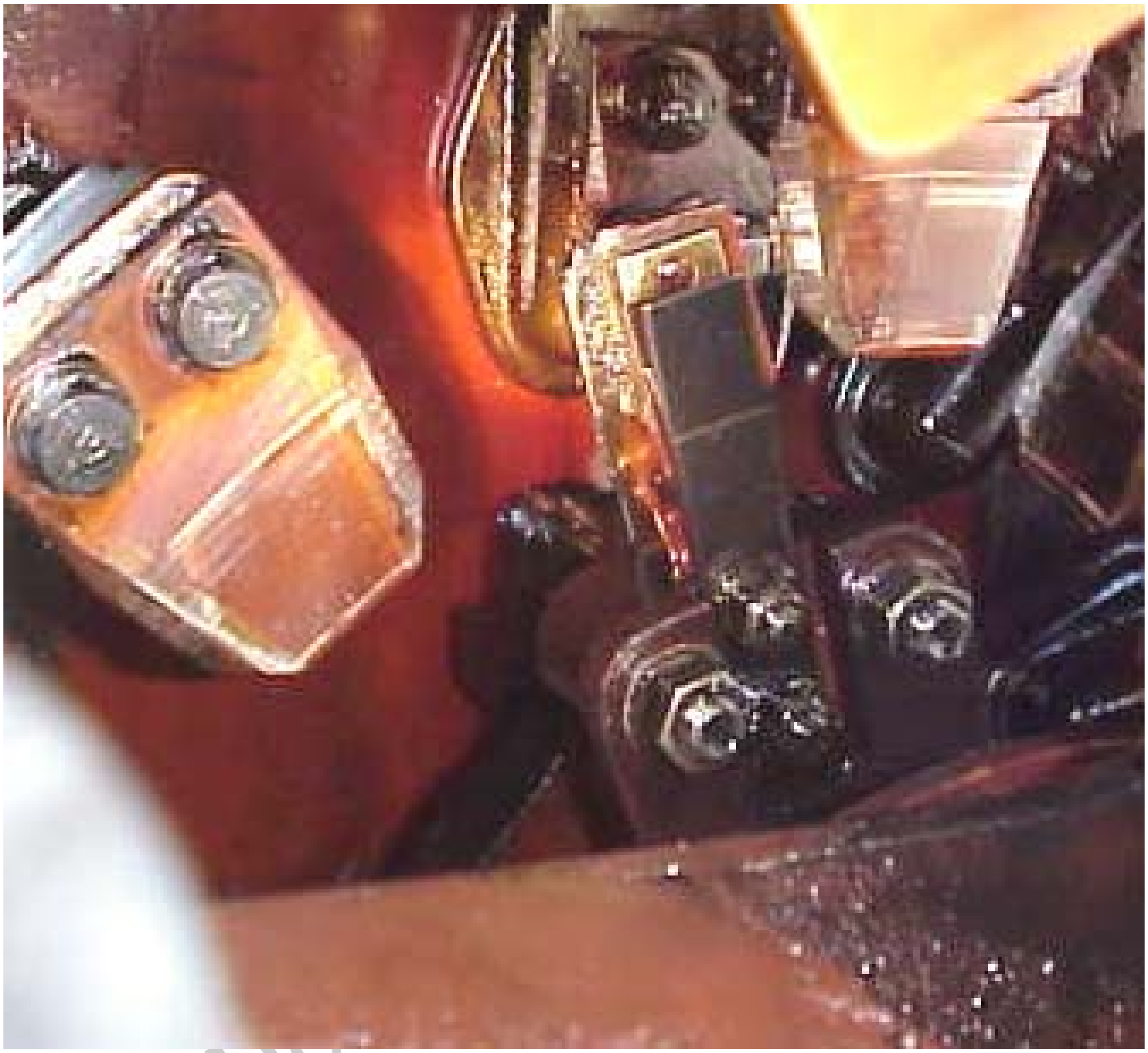
worn, while the inside movable contacts had normal wear. One of the movable contacts showing normal wear is given in Figure 3, while Figure 4 reveals a badly worn moving contact.

Westinghouse URS LTC
FIGURE 1



Normal Wear on Reversing Switch
FIGURE 2

Normal Wear on Moving Contacts
FIGURE 3



Badly Worn Moving Contact
FIGURE 4

CASE 2

Manufacturer of LTC: Westinghouse
Year of manufacturer: 1962
Model: URS
Type: Break in oil
Compartment: Arcing Selector
Tank type: Sealed
Filter: No

TABLE 3
Case 2 Dissolved Gas-in-Oil Results (ppm vol/vol at STP)

Gas	9/28/04
Hydrogen	8,789
Ethane	1,026
Methane	3,214
Ethylene	11,365
Acetylene	8,575
Carbon Monoxide	298
Carbon Dioxide	3,620
Oxygen	3,790
Nitrogen	49,600
TCG	36,891
Methane/Acetylene	0.37
Ethylene/Acetylene	1.3
(H_2+Acet)/TCG-CO	0.47
Doble Condition Code	2

RESULTS OF INVESTIGATION

The gas in oil data for this URS tap changer showed the combustible gases were high but the ratios indicated that the LTC was not in as bad of a condition as for Case 1. This is the reason for the Condition Code of 2 for this case. The results of the investigation showed that the reversing switch was badly worn and needed replacement.

CASE 3

Manufacturer of LTC: McGraw Edison
Year of manufacturer:
Model: 550C
Type: Break in oil
Compartment: Arcing Selector
Tank type: Free breathing
Filter: No

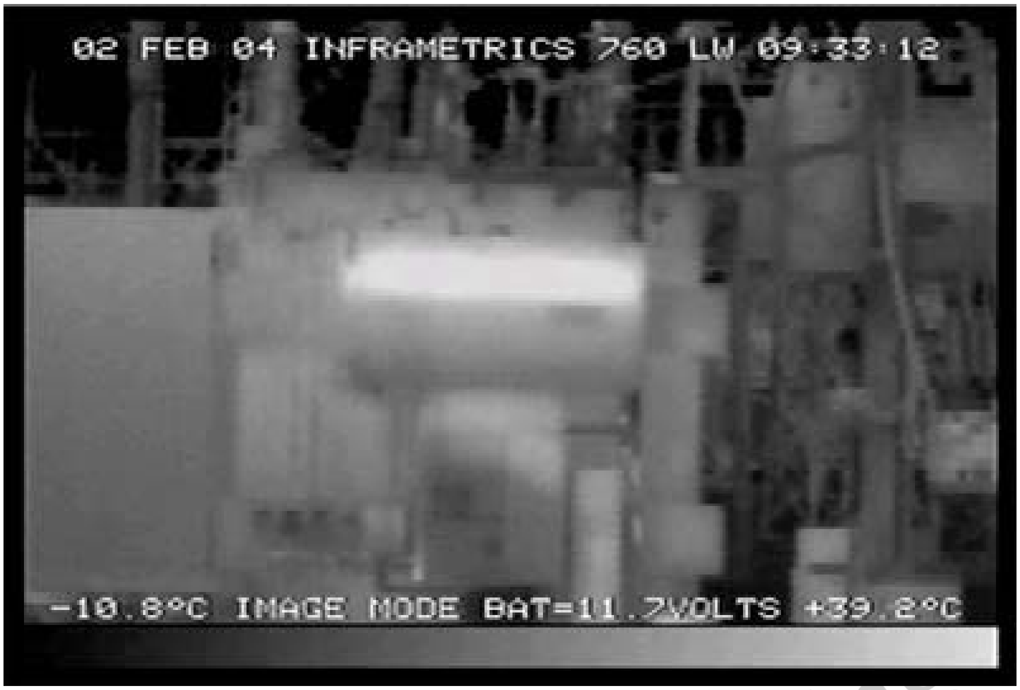
TABLE 4
Case 3 Dissolved Gas-in-Oil Results (ppm vol/vol at STP)

Gas	1/19/2005
Hydrogen	177
Ethane	1,454
Methane	1,800
Ethylene	3,295
Acetylene	14.6
Carbon Monoxide	178
Carbon Dioxide	750
Oxygen	25,490
Nitrogen	67,800
TCG	6,919
Methane/Acetylene	123
Ethylene/Acetylene	226
(H_2+Acet)/TCG-CO	0.03
Doble Condition Code	1

RESULTS OF INVESTIGATION

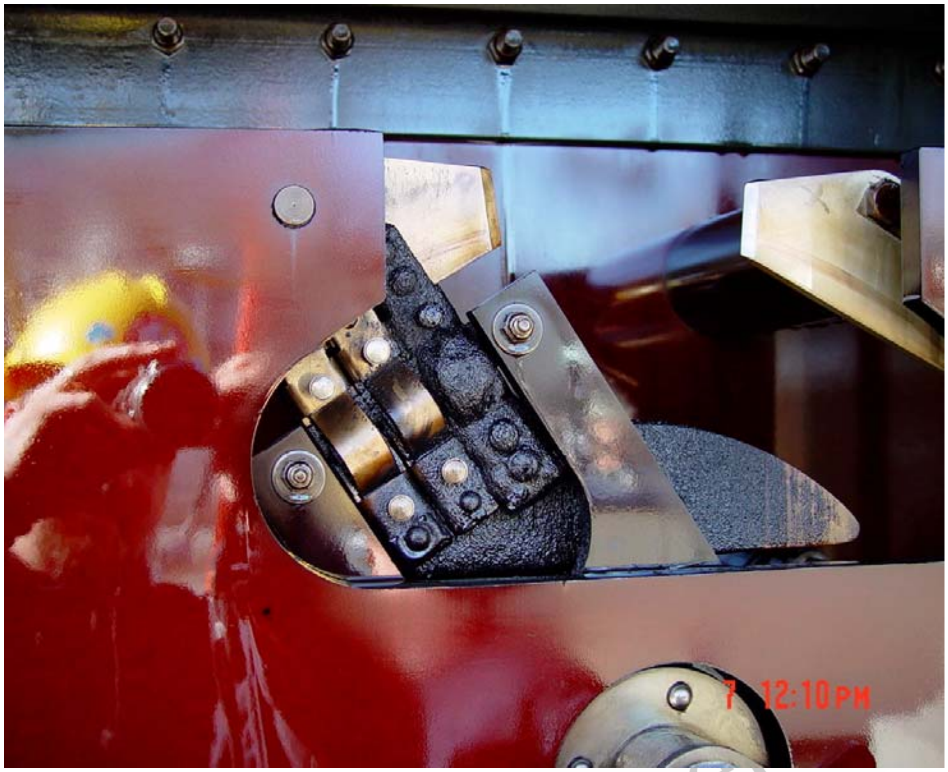
After the oil tests diagnostics indicated that this unit needed immediate attention, an infrared scan was performed to determine the difference in temperature between the LTC compartment and the main tank. Figure 6 shows the transformer and location of the LTC compartment. The infrared thermal scan given in Figure 7 clearly shows the extent of the overheating and the seriousness of the condition of this unit as the LTC temperature was quite a bit higher than the main tank (33ºC higher). Normally for this LTC the temperature is 8-12ºC lower than for the main tank. This provided a confirmation of the conclusions from the DGA results and an internal investigation was performed. Figures 8 and 9 shows that the reversing switch was coking on the fingers of the contact, with one of the fingers being very seriously deteriorated. The internal investigation report noted that two phases on the reversing switch movable contacts and neutral reversing stationary contacts were coked and burned and one of the phases was not too bad. All of the contacts were replaced. The importance of using model specific information and the ratios can be observed by comparison with Case 2, which had a higher combustible gas content, but a lower Condition Code of 2.

Photograph of Transformer with Problem McGraw Edison 550C LTC
FIGURE 6



Infrared Image of Transformer with Problem McGraw Edison 550C LTC
FIGURE 7

McGraw Edison 550C LTC with Coking on Reversing Switch
FIGURE 8



Close up of McGraw Edison 550C LTC with Coking on Reversing Switch
FIGURE 9

CASE 4

Manufacturer of LTC: Pennsylvania
Year of manufacturer:
Model: 550
Type: Break in oil
Compartment: Arcing Selector
Tank type: Desiccant breathing
Filter: No

TABLE 5
Case 4 Dissolved Gas-in-Oil Results (ppm vol/vol at STP)

Gas	12/6/2004	6/24/2004
Hydrogen	161	386
Ethane	441	96
Methane	163	123
Ethylene	1,750	490
Acetylene	487	677
Carbon Monoxide	96	268
Carbon Dioxide	3,330	4,090
Oxygen	16,600	136
Nitrogen	54,500	70,880
TCG	3,098	2040
Methane/Acetylene	0.33	0.18
Ethylene/Acetylene	3.6	0.72
(H_2+Acet)/TCG-CO	0.22	0.59
Doble Condition Code	1	3

TABLE 6
Case 4 Oil Quality Results

Test	12/6/2004	6/24/2004
Dielectric Breakdown Voltage, D1816, kV	16	12
Water Content, ppm	52	59
Relative Saturation of Water in Oil, %	56	41
Equilibrium Water Content, ppm	36	No temp. given
Color	L1.5	L1.5
Interfacial Tension, dynes/cm	20	24
Neutralization Number, mg KOH/g	0.15	0.12
Power factor at 25ºC, %	0.032	0.023

RESULTS OF INVESTIGATION

The DGA results for this unit revealed a change in several things. First it would appear from the oxygen (lower than expected) and hydrogen content (higher than in subsequent sample) that the LTC vent was plugged when the sample was taken on 6/24/2004. For the next sample the vent appears to be working properly as seen by the decreasing hydrogen content and increasing oxygen content. The trend showed that the key combustible gases associated with overheating of oil, methane and ethylene (ethane also increases from overheating of oil) are increasing while the acetylene is decreasing. This was clearly indicated in the ratios which were in the normal range for the 6/24/2004 samples but with the ethylene/acetylene and (hydrogen + acetylene)/(TCG-CO) ratios both revealing a trend indicative of the early stages of deterioration. The second sample, about five and one half months later, showed these two same ratios indicating a serious overheating condition and the methane/acetylene ratio trend beginning to indicate deterioration. The resulting condition code went from a 3 which is of moderate concern (with a recommendation to resample in 3 months if loaded below nameplate and 1 month if loaded above nameplate) to a condition code of 1, which suggests remedial action is needed.

Infrared thermograph was performed on this unit and did not detect a problem. The LTC for this unit runs in the 1 and 2 raised position almost all of the time. As these contact were the only two in bad condition and replacement contacts were not readily available, the 1and 2 raised contacts were replaced with the 16 raised and 16 lowered contacts. The LTC was limited to 14 raised to 14 lowered through controls.

It is interesting to note the importance of model specific information. If this same unit was a FPE TC-25 LTC, the June 24th sample would have received a condition code of 5 which indicates no problem and the December 6th sample would have been a condition code of 3 indicating an advancing problem of moderate concern.

CASE 5

Manufacturer of LTC: Westinghouse
Year of manufacturer: 1972
Model: UTT
Type: Break in oil
Compartment: Transfer
Tank type: Free breathing
Filter: No

TABLE 7
Case 5 Dissolved Gas-in-Oil Results (ppm vol/vol at STP)

Gas	6/25/2004
Hydrogen	7,240
Ethane	48,647
Methane	45,426
Ethylene	197,303
Acetylene	18,774
Carbon Monoxide	0
Carbon Dioxide	2,080
Oxygen	2,670
Nitrogen	8,900
TCG	317,390
Methane/Acetylene	2.4
Ethylene/Acetylene	10.5
$(H_2$+Acet)/TCG-CO	0.08
Doble Condition Code	1

RESULTS OF INVESTIGATION

The results of the investigation found a worn contact which was replaced. Both the amounts and ratios of the key gases provided a clear indication of the problem.

CASE 6

Manufacturer of LTC: Westinghouse
Year of manufacturer: 1957
Model: UTT
Type: Break in oil
Compartment: Transfer
Tank type: Free breathing
Filter: No

TABLE 8
Case 6 Dissolved Gas-in-Oil Results (ppm vol/vol at STP)

Gas	6/6/2004
Hydrogen	5,358
Ethane	2,174
Methane	3,621
Ethylene	22,575
Acetylene	5,124
Carbon Monoxide	276
Carbon Dioxide	4,620
Oxygen	9,540
Nitrogen	60,400
TCG	39,128
Methane/Acetylene	0.7
Ethylene/Acetylene	4.4
$(H_2$+Acet)/TCG-CO	0.27
Doble Condition Code	1

RESULTS OF INVESTIGATION

In this case the concentrations of gases were high and the ratios were indicative of an LTC in the later stages of deterioration. The results of the investigation found badly worn contact which were replaced.

CASE 7

Manufacturer of LTC: Westinghouse
Year of manufacturer:
Model: UTT
Type: Break in oil
Compartment: Transfer
Tank type: Sealed
Filter: No

TABLE 9
Case 7 Dissolved Gas-in-Oil Results (ppm vol/vol at STP)

Gas	9/28/2004	8/2/2004
Hydrogen	19,910	4,415
Ethane	2,732	2,310
Methane	7,268	1,137
Ethylene	32,628	13,089
Acetylene	273	176
Carbon Monoxide	332	65
Carbon Dioxide	6,670	2,260
Oxygen	4,920	1,640
Nitrogen	40,900	12,800
TCG	63,143	37,892
Methane/Acetylene	27	6.5
Ethylene/Acetylene	120	74
(H_2+Acet)/TCG-CO	0.32	0.12
Doble Condition Code	1	1

RESULTS OF INVESTIGATION

This case provides an example where the DGA was an indicator of the rapid rate of deterioration of the LTC when it was in the later stages leading towards failure. Note both the amount and ratios of gases revealed the approaching failure. The problem in this unit was found with the transfer switch which was replaced. Remedial action taken in the earlier stages might have been less extensive.

CASE 8

Manufacturer of LTC: Moloney
Year of manufacturer: 1973
Model: TC-MJ-2
Type: Break in oil
Compartment: Arcing selector
Tank type: Free breathing
Filter: No

TABLE 10
Case 8 Dissolved Gas-in-Oil Results (ppm vol/vol at STP)

Gas	8/03/2004
Hydrogen	11,500
Ethane	36,800
Methane	72,300
Ethylene	162,000
Acetylene	870
Carbon Monoxide	327
Carbon Dioxide	6,210
Oxygen	629
Nitrogen	21,200
TCG	283,797
Methane/Acetylene	83
Ethylene/Acetylene	186
(H_2+Acet)/TCG-CO	0.04
Doble Condition Code	1

TABLE 11
Case 8 Oil Quality Results

Test	12/6/2004
Dielectric Breakdown Voltage, D1816, kV	14
Water Content, ppm	56
Relative Saturation of Water in Oil, %	No temp. given
Color	L2.5
Interfacial Tension, dynes/cm	34
Neutralization Number, mg KOH/g	<0.01
Power factor at 25ºC, %	0.097 (erratic)

RESULTS OF INVESTIGATION

This transformer is loaded 80-85% of nameplate rating most of the time. When the dissolved gas-in-oil results indicated a problem, infrared thermography was performed. The results confirmed there was an overheating problem. The internal investigation found the reversing switch was loose and out of alignment and therefore making poor contact. The reversing switch contacts were cleaned, the reversing switch tightened and adjusted, and placed back in service.

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 tests. These tests have gained wide acceptance in the industry and will be standard practice in the near future. We have found that once oil diagnostic programs are started for LTCs, problems that were not being detected by other methods are revealed and there is acceptance of this approach. After using oil diagnostics for all the LTCs in a system, the number of problems found the second time around is reduced showing the effectiveness of the program. A number of case studies for several types of LTCs were shown along with the condition codes to provide examples of how the diagnostics work.

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BIOGRAPHIES

Paul J. Griffin

Mr. Griffin has been with Doble since 1979 and held the position of Laboratory Manager before becoming Vice President of Laboratory Services. Since joining Doble, Mr. Griffin has published over 50 technical papers pertaining to testing of electrical insulating materials and laboratory diagnostics. He is a Fellow of ASTM and a member of Committee D-27 on Electrical Insulating Liquids and Gases. He was formerly ASTM Subcommittee Chairman on Physical Test, ASTM Section Chairman on Gases in Oil, and the Technical Advisor to the U.S. National Committee for participation in the International Electrotechnical Commission, Technical Committee 10, Fluids for Electrotechnical Applications. Mr. Griffin is a member of the IEEE Insulating Fluid Subcommittee of the Transformer Committee, and the American Chemical Society. He is the U.S. Representative on CIGRE Working Group 15.01 Fluid Impregnated Insulating Systems. Mr. Griffin has received the ASTM Committee D-27 Charlie Johnson Award and the ASTM Award of Merit.

Lance R. Lewand

Lance Lewand is the Laboratory Manager for the Doble Materials Laboratory and is also the Product Manager for the Doble ***DOMINO***, which is a moisture-in-oil sensor. The Materials Laboratory is responsible for routine and investigative analyses of liquid and solid dielectrics for electric apparatus. Since joining Doble in 1992, Mr. Lewand has published numerous technical papers pertaining to testing and sampling of electrical insulating materials and laboratory diagnostics.

Mr. Lewand was formerly Manager of Transformer Fluid Test Laboratory and PCB and Oil Field Services at MET Electrical Testing Company in Baltimore, MD for seven years. His years of field service experience in this capacity provide a unique perspective, coupling laboratory analysis and field service work.

Mr. Lewand received his Bachelor of Science degree from St. Mary's College of Maryland. He is actively involved in professional organizations such as ASTM D-27 since 1989 and is a sub-committee chair. He is also the secretary of the Doble Committee on Insulating Materials.

Richard C. Peck

Mr. Peck is the Supervisor of Laboratory Services at Connecticut Light & Power Company, in Berlin Connecticut. Rich earned his Bachelors Degree in Electrical Engineering from Worcester Polytechnic Institute in 1973 and has managed the Connecticut Light & Power Chemistry Laboratory for 23 years. He has worked in Connecticut Light &Powers Electric Distribution Operations for a total of 31 years.

Norman A. Letendre

Mr. Letendre is the Test Coordinator for Laboratory Services at Connecticut Light & Power Company, in Berlin Connecticut. Norm earned his Bachelors Degree in Chemistry from Charter Oak College in 1989 and has worked in the CL&P Chemistry Laboratory for 28 years. He has been with Connecticut Light & Power for a total of 34 years.

Denny Frieze

Mr. Frieze is a Manager of Relays and Substation Maintenance, Western Division, at Empire District Electric Company. He was Manager of Line Operations for 17 years before becoming Manager of Substation Maintenance for the Western Division. He has 35 years of experience in the utility industry

Joseph L. Johnson

Mr. Johnson is a Manager of Substation Maintenance at Empire District Electric Company. He has 25 years of experience in substation maintenance and transformer testing.

APPENDIX

Doble Sample Identification Information

Transformer Information	
Serial Number:	Equipment Number:
Substation Name:	Transformer Name:
Manufacturer:	Maximum kV:
MFR.	Maximum MVA:
Year:	Phase:
Sample information	
Container Id:	Ambient Temp °C:
Miscellaneous Id:	Ambient Humidity:
Sample Date/By:	Top Oil Temp °C:
Sample point: ☐ Diverter/Interrupter ☐ Selector ☐ Transfer/contacter ☐Other, specify ________________	
LTC Information	
LTC MFR.:	Fluid Type:
LTC Model:	Reference #:
LTC Type: ☐ Reactive ☐ Resistive ☐ Vacuum	LTC Oil Capacity:
LTC Tank Type: ☐ Sealed ☐ Free breathing ☐Desiccant breathing	Filter LTC: ☐ yes ☐ No
Testing Requested: Select package or individual test	
☐ **LTCare (all the tests listed below)**	
☐ DGA	
☐ Water	
☐ Neutralization number (acidity)	
☐ Dielectric breakdown voltage ☐D 1816 or ☐D 877	
☐ Particle count	
☐ Filter and microscopic particle examination	
☐ Doble Carbon Code	
☐ **LTCare+ add total metals**	
☐ Other	
☐ Rush ☐ Routine	