Load Tap Changers:

Diagnostics and Fault Identification – A Key to Condition-Based Maintenance

by **Corne Dames**

Corné Dames is the Managing Director of Independent Transformer Consultants, always striving to keep on top of new developments and research. She has expertise as Laboratory Manager in the analysis of transformer oils and as diagnostician identifying problem areas in transformers, as well as profiling of transformers according to available results thus empowering the customer to take preventative steps in maintenance. Corné has vast practical and theoretical knowledge on reliability maintenance programs. Coming from a strong chemical background she has insight in all the chemical processes that is part of the transformer system coupled with technical insight helps customers optimise their reliability maintenance and electrical asset lifetime.

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Load tap changers (LTCs) are an extremely important element in the reliability of any transformer in the utility network and in many industrial applications. This part of the transformer is the only actively moving mechanism, which must operate continuously to ensure a constant voltage output. LTCs have been reported to be accountable for approximately 22% of failures in transformers [1]. Their dominant failure modes are found to be contact wear, weak springs and breakage of components in the driving mechanism [2]. This article will look at the different types of condition monitoring methods of LTCs and their practical application in the field as well as the accuracy in fault identification and ease of use for the types of monitoring.

As the only actively moving mechanism in a transformer, load top changers are an extremely important element in the reliability of transformers which must operate continuously to ensure a constant voltage output.

Diagnostic and Monitoring Methods

The load tap changers diagnostic and monitoring methods that will be discussed in the following are:

1. Infra-red (IR) scanning
2. Differential temperature measurements
3. Oil and insulation analysis – DGA (Dissolved gas in oil analysis) and particle profiling
4. Electrical testing (ET)
5. Mechanical analysis – Vibration signatures (Vibro-acoustic diagnostic method)

IR Scanning to Assess LTC Health

LTC failure will cause the transformer to shut down, causing loss in revenue and in the case of industrial applications, severe potential failure of mission critical systems.

Thermal imaging will identify any parts that have increased operating temperatures. Under normal circumstances the tap changer functions at approximately the same temperature as the transformer tank, unless certain start-up of high energy consuming processes in the plant are present. When a problem is developing in the tap changer an increased operating temperature would be noted, with this increase continuing up to the critical point of failure.

A thermal image sensor can record or monitor temperatures in real-time, which can help us to understand the temperature trends of the LTC and assist the end user in making critical decisions before the transformer/tap changer fails. This continuous monitoring will warn us as soon as the problem arises and will give ample time to address the problem.

This method warns you that there is a problem but won't pinpoint the problem. The tap changer unit needs to be opened, an inspection needs to be done to identify and rectify the problem, but it won't give you an indication of the severity of the problem [3].

Differential Temperature Measurements

Thermal and electrical faults dissipate energy. The normal operating temperature of the LTC is lower than the operating temperature of the transformer main tank. This will change if there is an electrical problem in the tap changer unit, if this unit is separate from the main tank. If incorporated in the main tank this change in temperature might not be as significant since the body of oil is much larger and the increase in oil temperature around the tap changer will be distributed throughout the main tank. A sudden increase in operating temperature of the tap changer tank will indicate that a problem has begun, and a visual inspection might be needed. Since this testing method is not able to diagnose the problem, but merely signal that there is a problem, thermal imaging should not be the only option in reliability maintenance testing protocols for LTCs.

Thermal imaging is not able to diagnose the problem, but only signal that there is a problem. So, this method should not be the only option in reliability maintenance testing protocols for LTCs.

Oil and Insulation Analysis – DGA and Particle Profiling

Oil tests that can be performed on LTCs include the following measurements:

Dielectric Breakdown – The oil in the LTC should maintain a minimum breakdown voltage [4]. Online filters are used to contain the particles discharged during arcing in order to maintain a better breakdown strength. This application ensures that the maintenance cycle interval is further apart and reduces contact wear in the tap changer.

Water Content – Excessive water accelerates aging of contacts. Compartments with arcing contacts will be vented to ensure that there is no build-up of combustible gases in the chamber, as the formation of combustible gases during the tap changing cycle is normal. An oil temperature that is higher than ambient temperature will ensure relatively less saturation of the oil with water. Sealed LTC chambers with desiccant breathers will display standard ppm concentration levels in the compartment and a relative saturation in percent (%) can be applied.

Dissolved Gases in Oil – This is the most important diagnostic test for LTCs. The gassing behavior of the LTC changes as problems arise, and the amount and relative concentrations of the gases change as problems develop and escalate. Localized overheating and excessive arcing are some of the problems that might arise when a problem occurs in the LTC. Carbonization and byproduct polymeric films can form on conductors, which can lead to a thermal runaway condition, which leads to failure if not stopped. The hydrocarbons generated during this process are methane, ethane, ethylene and acetylene – the ratios between these gases enables the diagnostician to identify the problem area as well as the severity (Table 1).

Dissolved Gases in Oil is the most important diagnostic test for LTCs

The ratio of ethylene over acetylene is important to consider in order to predict when inspection on the load tap changer should occur. Low, moderate and severe heating conditions can be detected based on the ratio of ethylene to acetylene. These ratios are independent of the number of operations in the tap changer and are also resistant to changes due to loss of gasses to the atmosphere. For vacuum type LTCs, tracking of the total combustible gas over time can give some indication of when the unit needs to be inspected. Also please consider the diagram in Table 2 as an indication of sampling frequency needed to ensure safe operation [5].

Table 1.

	Arcing Type LTCs (Resisitve & Reactive)*	
Ethylene / Acetylene	<5	Normal. Continue annual sampling.
	0.5<X<1	Warning. Sample more frequently; trend.
	>1	Severe heating/coking probable. Inspect.
		** Ethylene & Acetylene >50 ppm*
	Vacuum Type LTCs	
Total Combustible Gases	<10 ppm	Normal. Continue annual sampling.
	10<X<25 ppm	Warning. Sample more frequently; trend.
	>25 ppm	Heating/coking probable. Inspect.

Table 2.

$$\frac{\text{Methane } (CH_4) + \text{Ethane } (C_2H_4) + \text{Ethylene } (C_2H_6)}{\text{Acetylene* } (C_2H_2)}$$

**Acetylene >500 ppm*

Ratio	Diagnosis	Recommended Sampling Frequency
<0.5	Normal	Sample annualy.
0.5 to 1	Possible heating	Sample every 3-6 months.
1 to 3	Possible heating	Sample every 1-3 months.
3 to 5	Possible heating	Sample weekly to monthly.
>5	Heating probable	Remove from service and inspect.

Particle count – Larger particles indicate advanced deterioration. The particles are formed from three main mechanisms: wear, arcing and overheating. These wear metal particles are formed when two metal surfaces are in contact with each other - the size, morphology and types give an indication of the source of the problem as well as the severity.
The main advantages of oil testing in LTCs include:

- Early detection of problems arising
- The severity of the problem can be determined with relatively high accuracy
- Cost-effective and nonintrusive

Electrical Tests

There are a number of electrical tests available to identify LTC faults.

- **Exciting current tests on all tap positions** detect contact or connection problems in the taps, as well as shorted turns and core problems in the autotransformer.
- **Turns ratio** tests detect shorted turns in the autotransformer.
- **Power factor** tests are used to identify insulation deterioration and carbonization of solid insulation.
- **Contact resistance** tests detect excessive contact wear, poor contact pressure (worn out springs) and coking or polymeric films on contact surfaces.
- **Sweep Frequency Response Analysis (SFRA) and leakage reactance measurements** detect winding movement/deformation and contact problems.
- **Tap changer divertor resistor and contact analysis** is a condition assessment test of tap changers, providing results necessary to establish the state of the tap changer to make informed decisions on planned maintenance or corrective action minimizing the need for intrusive inspections [6].

Oil testing of LTCs has many advantages, including early detection of faults with a relatively high accuracy in determining the severity of the problem.

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Vibration Analysis

The OLTC monitoring system consists of various modules connected to a PC. The system simultaneously captures high and low frequency signals and can be triggered manually or automatically, depending on customer requirements. Automatic triggering allows online data acquisition. Noninvasive transducers minimize the cost of installation and are essential in the measurement of essential parameters. The whole system can be installed while the transformer is online.

Condition monitoring

If there is a significant degree of variation in the "normal" signatures, this is due to variation in load conditions which cause bursts in amplitude and shifts in time between individual vibration events. The shifts in time are caused by data acquisition system delays. The alignment of the burst envelopes can be acquired by normalized auto-correlation functions – manipulation of the data to line up.

Any out of bounds deviation is then labelled as an abnormality and an alarm is sent out.

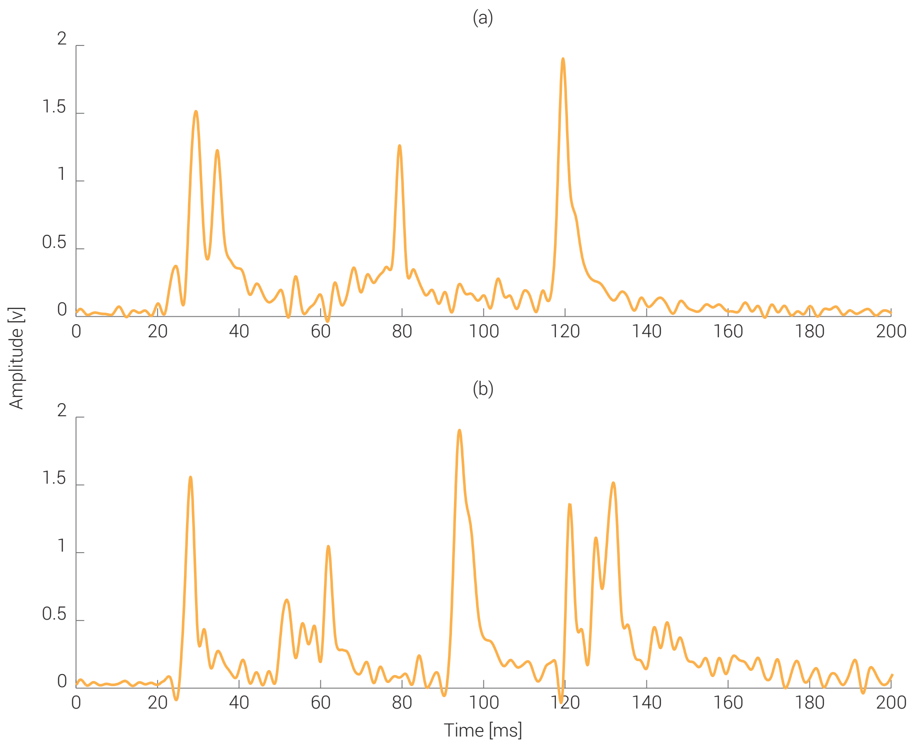
A database of OLTC signatures needs to be established to determine normal operating conditions. The vibration signal is acquired by monitoring the contact movements, and there should be various signatures for different transformer loads. The change in the OLTC condition is a gradual series of steps, sometimes with shorter increments depending on the severity of the abnormality.

Field Application

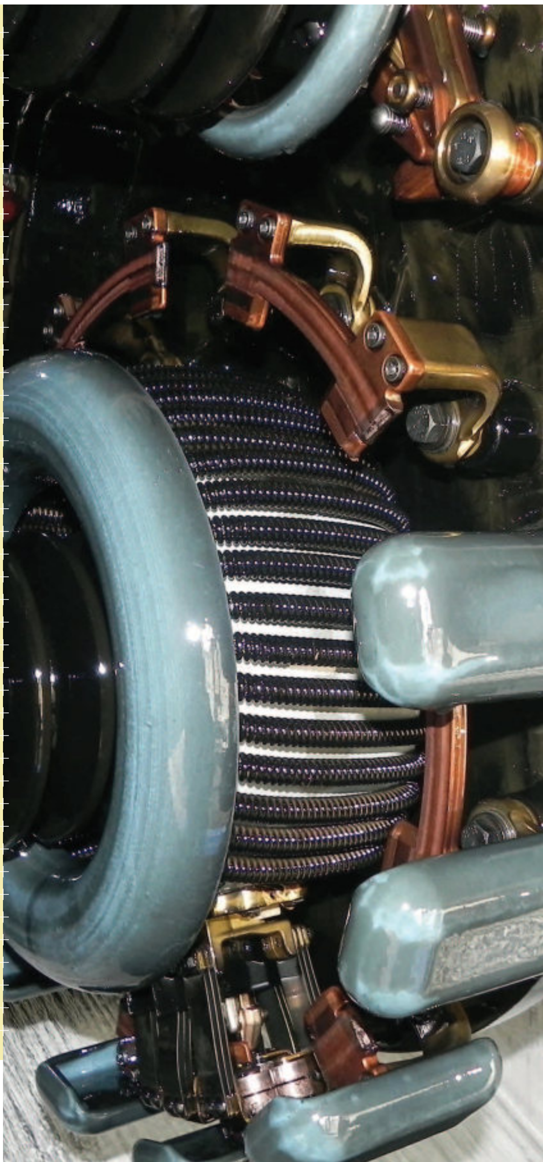
Abruptly occurring faults

In the following example, the maintenance was completed on September 14. A year later, in early October, the monitoring system gave a warning that a fault had suddenly occurred. Figure 1 (a) shows that one of the bursts that normally appears in Figure 1 (b) is missing,

Figure 1. (a) The signature of the tap operation from 7 to 8 of a faulty condition, (b) the signature of the tap operation from 7 to 8 of the normal condition



A reliable OLTC condition monitoring system, which can be readily used or applied by maintenance and reliability engineers, will not only assess the current condition of the equipment but will also help to make informed decisions for future applications.



indicating that a set of contacts was not making contact, causing improper contact positioning. This could have been caused by a missing contact or by problems in the driving mechanism. As this faulty signature only appears on occasion between the normal signature, this could be due to slipping of the drive shaft. The concern was that the abnormal contact sequence could lead to early catastrophic failure, so inspection was recommended.

Upon inspection the slippage on the shaft was identified. There was an approximate 1-2 mm of play within the keyway, which, if unchecked, could have resulted in a catastrophic failure [7].

Delay of maintenance

An OLTC of the same type displayed a normal signature during inspection, so it was decided not to perform maintenance as all the key indicators on the signature indicated a "healthy" OLTC. The maintenance was thus deferred by 1.5 years for this unit.

This method of monitoring is very accurate, nonintrusive and ongoing.

Conclusion

In conclusion, it is necessary to identify the type of monitoring that would suit the profile of your company, your budget and the outcome you require. A reliable OLTC condition monitoring system, which can be readily used or applied by maintenance and reliability engineers, will not only assess the current condition of the equipment but will also help to make informed decisions for future applications. The method used should enable maintenance engineers to check the quality of maintenance already performed, ensuring peak performance and value for money. The method should also ensure immediate identification of a problem at the onset point, so they can effectively identify source of the problem and decide on the action needed to rectify the problem, avoiding production loss or equipment damage.

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