On-Load Tap Changer Testing Methods

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Introduction

As the only moving parts in a typical power transformer, on-load tap changers (OLTCs) are among the most vulnerable components, and their regular testing and maintenance is an important part of transformer asset management. Visual inspection can be used to detect degradation of accessible OLTC parts at regular intervals. However, many mechanical parts are not easily accessible for inspection, and it is recommended to perform additional tests to establish the OLTC condition.

There are several diagnostic methods used today, that can be divided into:

1. Oil and insulation analysis
   - Dissolved gas analysis (DGA)
   - Particle profiling
2. Analysis of tap changer contacts
   - Static resistance measurement
   - Dynamic resistance measurement (DVtest)
   - Dynamic resistance calculation
3. Mechanical analysis
   - Vibro-acoustic diagnostic method
   - Motor current measurement

Dissolved Gas Analysis (DGA) Method

The DGA method is the most common analysis method and it has been in use for many years. Around one million DGA analyses are performed every year in laboratories all over the world [1]. After an oil sample has been taken, the gases are extracted, separated, individually identified and quantified. Special laboratory equipment is used for this purpose. One of the recent developments in the DGA method is on-line monitoring for several key gasses. This method provides a good indication of problems in their early stages.

Several different methods are used to interpret the DGA results [2]:
- the method recommended by IEC 60599-199 (IEC99) and IEC 599-1978 (IEC78);
- the Duval triangle method;
- the methods recommended by IEEE C57-104 1991, which includes the refined Rogers ratio method, the Doernenburg method and the key gas method;
- the logarithmic nomograph method

The application of DGA method for the OLTC testing are both similar to and different from its application for the testing of other oil-filled equipment. [3] The similarity comes from the fact that same processes will create the same gasses in the oil. However, OLTCs are much more complex in this regard than power transformers, since they may (or may not) produce so-called "bad gasses" during their normal operation.

The major disadvantage of the DGA method comes from the fact that it cannot locate which part of the tap changer is creating the critical results. Visual inspection of all tap changer contacts after its disassembly is a long and difficult process with uncertain results. If the same oil is used for both the power transformer and the OLTC, it is difficult to locate the source of the problem, which means that other methods should be used to supplement it.

Particle Profiling

Fluid assessment tests are used in conjunction with the 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 a particle production. This includes information about in-service processes such as fluid degradation, contact deterioration, 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. [4]

Static Winding Resistance Measurement

The OLTC contact degradation can be detected by using winding resistance measurement in all tap positions. The winding resistance measurement is performed by passing a DC current through the transformer winding and reading the voltage drop across that winding.

The winding resistance is measured in all OLTC positions in all three windings. A static resistance graph can be created from the measured values in each tap position for easier analysis as in the Figure 1. The graph can be analyzed in several different ways: by comparing the result values with earlier results obtained on the same OLTC, by comparing the results obtained on different phases, by analyzing the graph shape, as explained in [5]. Changes in the winding material temperature may cause significant deviations in resistance values, which means that results obtained under different conditions should be recalculated to the common reference value.

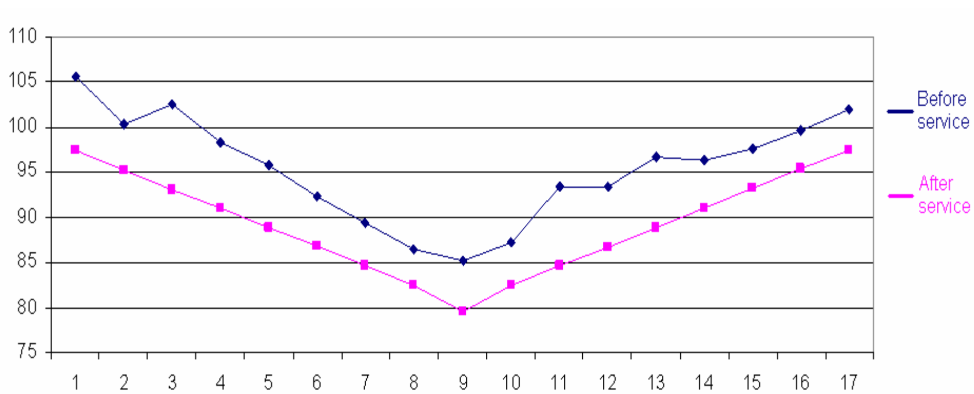

Figure 1. Static resistance graph for all tap changer positions before and after maintenance

This type of test is very useful for detecting winding damages as well as the state of the static contacts in each tap position. With this method, it is possible to precisely locate any high-resistance contacts. Also, different types of contact problems result in specific graph shapes, which make the diagnostic process easier. However, the static resistance measurement neither provides any information about the moving OLTC parts, nor about any faults which occur during the tap changer operation.

Dynamic Resistance Measurement (DVtest)

The DVtest is a new method that conducts the DC current through the winding, similar to the winding resistance measurement. A constant output voltage is maintained. This means the total output current will be inversely proportional to the resistance in the circuit. Increase of resistance during a tap transition will cause a sharp drop of the current, known as the transition ripple.

The DC current flowing through the winding is measured by the instrument at a high-frequency sampling rate (0,1 ms or 10 kHz). This information is transferred to the PC software, which creates a DVtest graph from the recorded data. The high sampling rate enables precise timing measurement of various stages of transition, as well as detection of OLTC problems that cannot be detected using other methods.

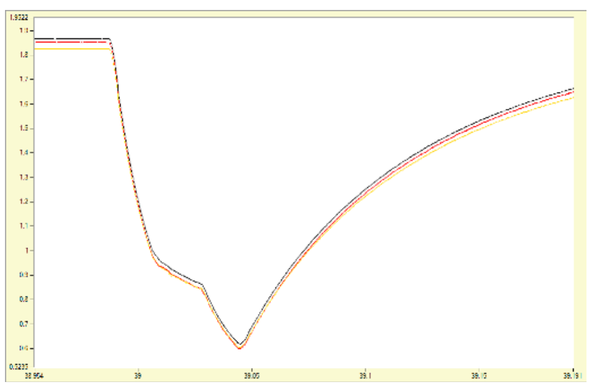

Figure 2. An example of three-phase DRM graph – one transition

Three important parameters can be used for the DVtest graph analysis:

- Transition ripple
- Transition time
- Shape of the graph

The instrument checks whether the OLTC performs switching without an interruption. The moment a tap position is changed from one tap to another, the device detects a sudden, very short drop of the test current. These drops, called transition ripples, should be consistent, where any drop out-of-line should be investigated. Their magnitude is measured in percentage points of the starting current (before the transition has started). Defective "make before break" tap changer performance results in a 100% transition ripple value, which is easy to observe. This is an indication of an interruption during the change. [6]

Transition time is defined as time necessary for the OLTC to change a position. It depends on the construction of the tap changer. Different stages of transition can be measured on the DVtest graph using the graphical analysis tools provided by the software.

The graph obtained by the software can have different shapes for different types of tap changers and voltage regulation method. It can be affected by the number and size of resistors used during the change of tap positions – there could be 1, 2, 4, or 6 resistors. Also, a tap changer mechanism, contact construction and condition, transformer parameters can influence the results.

One can easily observe and diagnose bad contacts by zooming the graph, like in the Figure 4, where before- and after-repair results are compared.

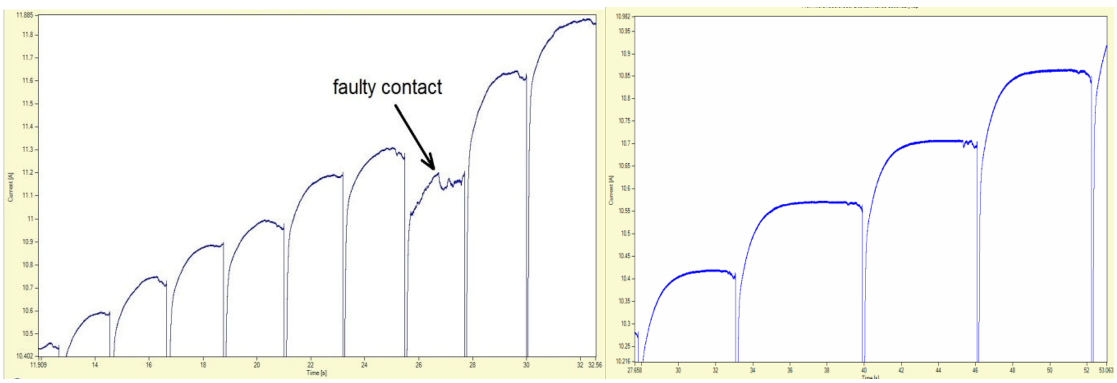

Figure 4. DVtest graph before and after repairs

The DVtest method has one important advantage – it can be applied to all types of tap changers: resistance, reactance and those with series transformer.

As the recording measures the current proportional to the circuit parameter variation, one can easily observe feature points of the tap changer operation – the moment when the contacts separate, when they connect, when their resistors are in the circuit, when the preventive autotransformer is connected and disconnected. The difference between transitions from bridging to non-bridging and vice versa at reactance tap changers is easily observable.

The series transformer arrangement (the booster transformer) requires a special test procedure which is performed using the current recording procedure. [7]

Dynamic Resistance Calculation

Many common OLTC designs include transition resistors that carry the load during transitions. The number and placement of these resistors may vary according to the manufacturer and the tap changer type. However, one thing they have in common is that, over time, their condition deteriorates. One of the common methods of determining their state is by measuring their resistance.

Direct resistance measurement of these resistors involves taking the transformer offline and disassembling the OLTC, which creates a major inconvenience for the operators. Standard static resistance measurement method cannot be used to measure these values, since these resistors are within a current circuit for a very short period of time. New methods have been introduced to obtain these results in a non-intrusive manner.

Feasibility of performing this test is limited by the transformer inductance. Even with the secondary winding short-circuited, the transformer inductance is still significant. Changes of the resistance will cause the change of DC test current with the time constant of L/R.

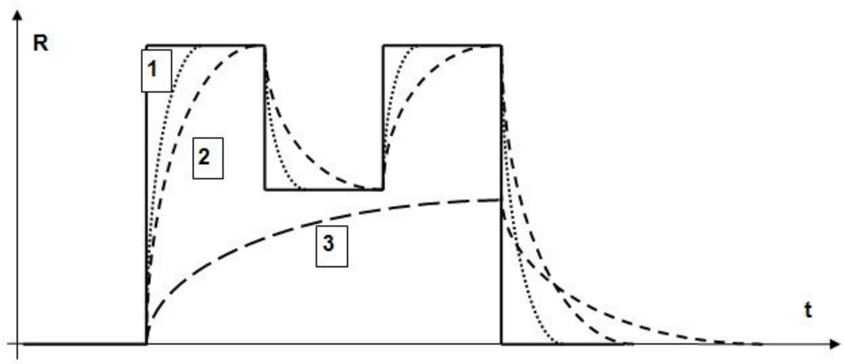

Figure 5. Dynamic resistance graph recorded with different time constants

It has been attempted to overcome the measurement problems caused by the presence of transformer inductance by using the voltage values measured on the transformer secondary side to eliminate the influence of the inductance mathematically. This method enables obtaining the transition time values for different stages for the transition (similar to the DVtest), as well as the calculation of the resistance values. [9]

The application of this method is limited to resistive OLTCs, and it cannot be used to measure reactive OLTCs and OLTCs with a series transformer arrangement. The large number of factors that are used to calculate the resistance values may affect the result accuracy.

Vibro-Acoustic Analysis

The vibro-acoustic analysis is a new method which enables detection of various OLTC problems by analyzing the vibro-acoustic waveform which is transferred from the OLTC mechanism through the structural elements. The results obtained in one measurement are compared to the previously obtained reference results in order to detect the tap changer problems during its operation.

It is very important to place the sensors correctly, since measurements with incorrect placement will produce results which cannot be properly analyzed. It is recommended to place them close to firm structural elements, to avoid gas-filled areas and to look for a spot beneath the transformer oil level. Also, it is recommended to avoid central parts of large lids or hatches, since such surfaces generate their own vibrations which may affect the results.

The vibro-acoustic analysis provides another tool to asset managers looking for more information about their OLTCs, which can be used to supplement the results obtained by other methods. However, a lot of skill is necessary to draw useful conclusions from the obtained results, and the result accuracy can be negatively affected by many outside factors.

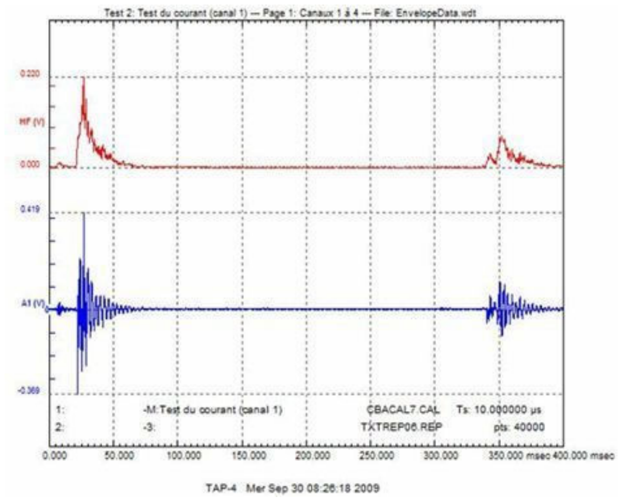

Figure 6. Vibro-acoustic signal graph [9]

OLTC Motor Current Measurement

The AC or DC current of the OLTC motor drive can be measured during the tap transition using current clamps. Failures or friction in the mechanism can be detected by analyzing the obtained current graph and by comparing it for different moments of the OLTC operation. This type of test is best performed simultaneously with the DVtest or dynamic resistance calculation. Overlaying the two obtained graphs with a common time axis enables comparing the mechanical problems detected on the motor current graph with different transition stages shown on the dynamic resistance calculation graph, which helps the operator detects part of the mechanism causing the problem.

Figure 7. OLTC motor drive

Conclusion

The DGA method is a good way of detecting incorrect contact operation caused by burning or overheating. However, oil samples should be obtained from the tap changer compartment as those collected from the main transformer tank will contain information about all the components submerged in the oil. This would make it impossible to precisely determine the exact location of the problem. Also, the DGA method cannot be used to detect mechanical failures. Although this method is the most common method of OLTC diagnostic used today, it does not provide a full picture of the OLTC condition and other methods should be used to supplement it.

The static and dynamic resistance measurements can be used to determine the contact condition. Both of these methods are off-line measurements. The winding resistance measurement is a standard test and its results can be easily analyzed. When it is combined with the DVtest method, problems with transition resistors, mechanical and motor problems, contact bouncing and many other types of issues can be detected in their early stages. DVtest and dynamic resistance calculation also provide transition time measurements. Of these two tests, the DVtest can be used on a greater variety of OLTC types and can be easily combined with the static resistance test and the motor current test.

Mechanical analysis is another useful part of the OLTC analysis. The two commonly used methods of analysis, vibro-acoustic and the motor current recording can provide valuable information about the tap changer condition. However, the motor current measurement graph is much easier to analyze, especially when combined with one of the dynamic resistance methods for transition time measurement. It is also less susceptible to the ambient noise and measurement errors.

In general, each method provides an additional tool in the asset manager's" toolbox". Since they all have their drawbacks and limitations, the best method of analysis is to use the results obtained by different methods to supplement each other. By combining the results of DGA, static resistance measurement, DVtest and motor current measurement, it is possible to obtain a good picture of the overall condition of an OLTC and to make informed decisions about it.

Literature

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Biography

Nada Cincar, is a Senior Assistant at the University of Eastern Sarajevo in Bosnia and Herzegovina at the College of Electrical Engineering. Her MSc thesis was written about the methods of on-load tap changer testing. She has authored several papers on this and other subjects.

Goran Milojevic is an application engineer at IBEKO Power AB, Sweden, working as a technical support engineer for North America and Western Europe. After receiving his MSc, he has worked as a product manager for the high-current transformer testing instruments, including the TWA40D, the most advanced three-phase winding ohmmeter in the market. He is a member of AM Forum On-Load Tap Changer Dynamic Resistance Measurement working group. He has lead a DRM research project in cooperation with ESBI, Ireland.