Complementary Analysis of DVtest and Vibroacoustic Method for OLTC

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COMPLEMENTARY ANALYSIS OF DVTEST AND VIBROACOUSTIC METHOD FOR OLTC

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Abstract

DVtest and vibro-acoustic measurement are both valuable non-invasive techniques of on-load tap changer (OLTC) condition assessment. Vibro-acoustic measurement is based on the comparison of signals obtained on the same transformer or transformer of the same type using external accelerometers. The dynamic recording measurement, also known as DVtest, establishes the tap changer condition by applying and recording a DC test current through the winding and the tap changer as it moves through all tap positions. While DVtest can recognize the resistance change, vibro-acoustic measurement can identify mechanical events not influencing the test current. The aim of this paper is to compare the tap changer analysis results produced by the two methods and to analyze the types of tap changer faults which can be detected in this manner.

Introduction

A typical on-load tap changer (OLTC) consists of two parts: a diverter switch which carries the load during the transition, and tap selector which selects the active tap position. Both parts are placed in transformer oil, and the diverter is usually in a dedicated compartment which is physically separated from the transformer main tank. Figure 1 shows the schematic of an OLTC with two transition resistors which carry the load during its operation.

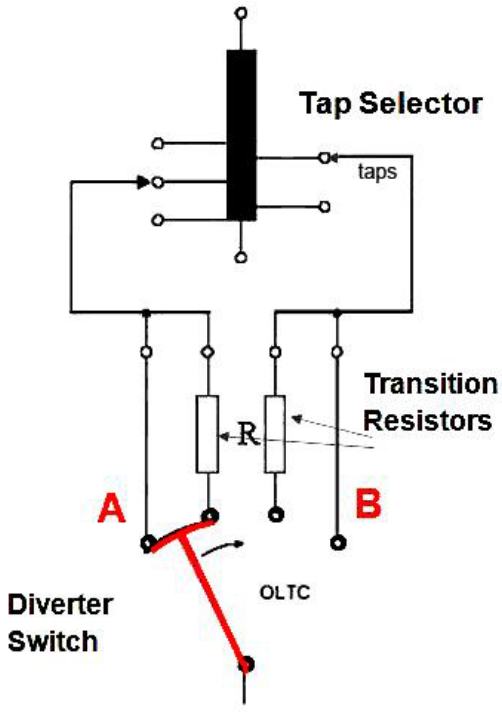


Figure 2.
An OLTC Schematic [1]

OLTCs are the only moving part in a typical power transformer, which makes them especially vulnerable. The statistical analysis of transformer problems shows that the faults located on OLTCs represent a significant number of total transformer faults, and that, in average, 1 in 20 tap changer faults lead to the transformer main tank failure [2]. Problems may occur for various reasons, such as poor design, poor maintenance, overloading, contact wear, mechanism failure, etc. Since OLTCs are very complex mechanical systems, a significant number of OLTC faults are also caused by incorrect maintenance and bad assembly. Also, a study has shown that 12% of OLTCs require maintenance before the manufacturer's suggested period [3].

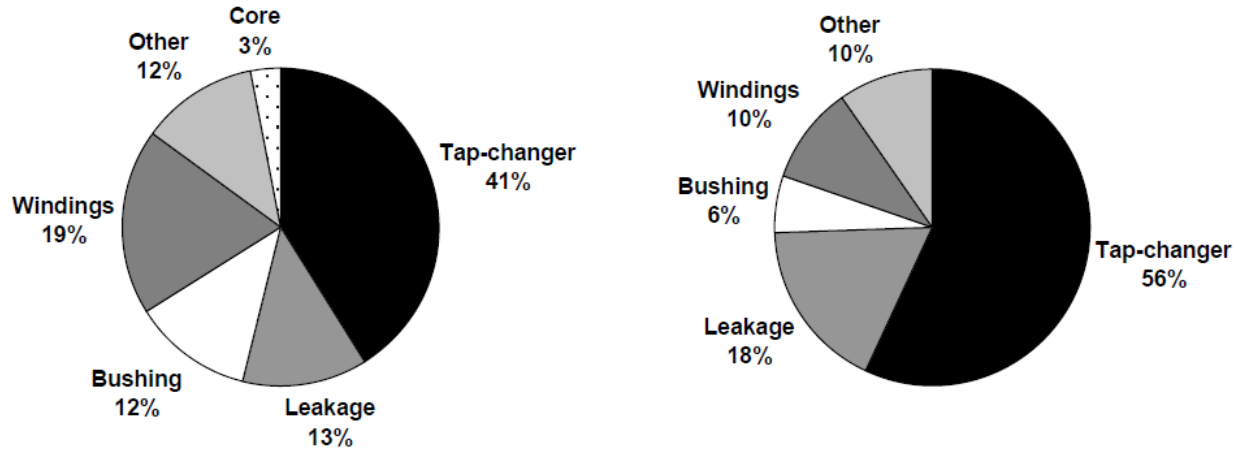


Figure 2.
Failure Distribution of an International Population (Left) and a Population of 50-150 kV Power Transformers in Netherlands (Right) [4]

For these reasons, the regular testing and maintenance of on-load tap changers is an important part of transformer asset management. Visual inspection is one of the frequently used methods of checking the condition of accessible OLTC parts. However, it is often impossible to detect many faults in this manner, either due to inaccessibility of damaged parts, or because the damage cannot be visually detected. Another drawback is the need for taking the transformer offline for an extended period and draining and disassembling it. Non-intrusive inspection and testing methods are preferable from a practical standpoint.

There are several diagnostic methods which are used for this purpose today. The most commonly used method is dissolved gas analysis (DGA), which is also used on power transformers. TJH2b has developed TASA method in order to interpret the DGA results for OLTCs. The subject of DGA results interpretation has been covered in detail in previously published work [5-10]. However, unlike a power transformer, OLTC may create "bad gasses" even during its regular operation due to arcing. Once a fault is detected, an additional investigation is required to locate which part of the tap changer is causing the critical results, which creates the need for additional testing.

Another frequently used method is winding resistance measurement, which detects the tap changer contact degradation by measuring the winding resistance in all tap positions and in all three phases of a three-phase transformer. It is performed by injecting a DC current through the transformer winding and measuring the voltage across the winding. High-resistance contacts can be easily and accurately detected with this test. However, it does not provide any information about the moving tap changer parts, which are not part of the circuit during the measurement, and it also does not detect the faults which occur during the tap changer operation.

Complementary analysis tools are required to provide additional data about the tap changer condition, and also to diagnose motor and mechanical problems, as well as problems with moving parts. The two most promising methods for this purpose are DVtest, also known as the dynamic recording measurement, and vibro-acoustic diagnostic method, which are covered in more detail in this paper.

DVtest Method of Tap Changer Analysis

DVtest is an off-line, non-destructive test during which a DC current is continuously injected through the winding and the tap changer contacts as the OLTC moves through the tap changer positions. The test setup is similar to the winding resistance test, and these two tests are complementary since they provide information about different OLTC components. The current reflects the change of resistance in the circuit during the tap changer operation. It is an inverse to the total resistance of the circuit (winding resistance + OLTC contacts resistance), and it is continuously recorded during the change of tap position. When the tap changer operates, the current will change accordingly due to the change in the total circuit resistance during different stages of the transition. The current is recorded with a high 10 kHz sampling rate.

Different stages of the diverter switch operation can be observed on the graph. The exact shape of the graph will depend on the tap changer design – whether it uses resistors or reactors to carry the load, how many transition resistors are used, etc. All types of tap changers can be tested with DVtest, but detailed graph analysis requires familiarity with the operational stages of the tested tap changer. If the test is performed on a tap changer from Fig.1, the graph will have different characteristic points which correspond to specific stages of diverter switch operation. This is shown in the Fig.3.

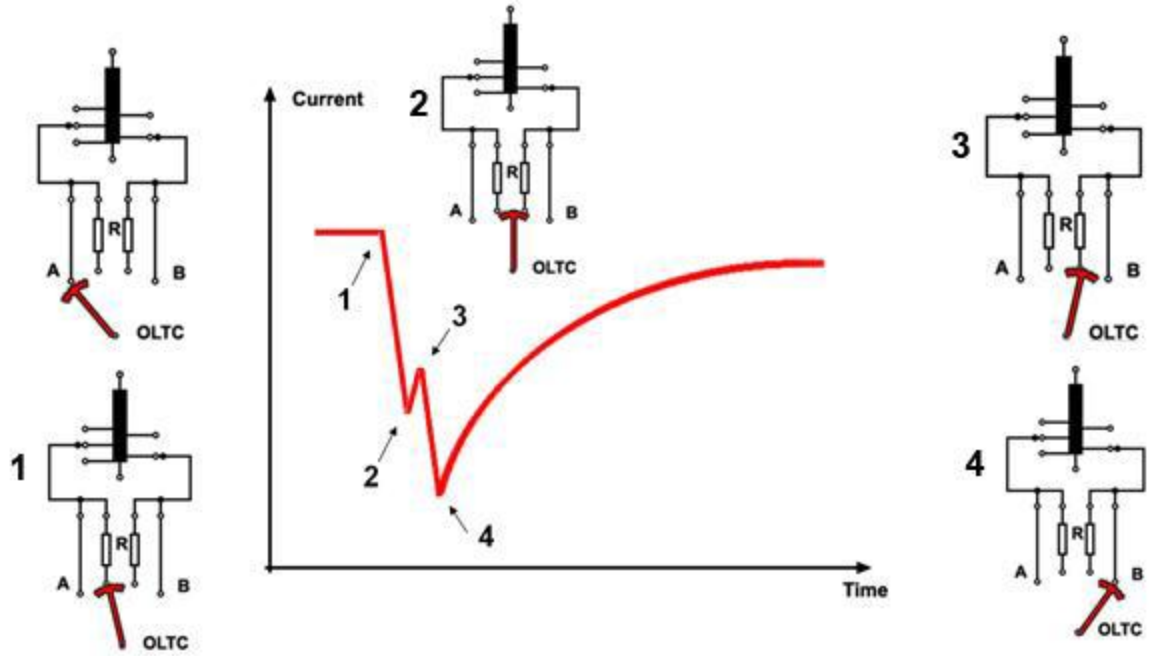


Figure 3.
Dynamic Behavior of the Diverter Switch [1]

The connection of three-phase test instrument TWA40D to the test object for the DVtest measurement is shown in the Fig.4.

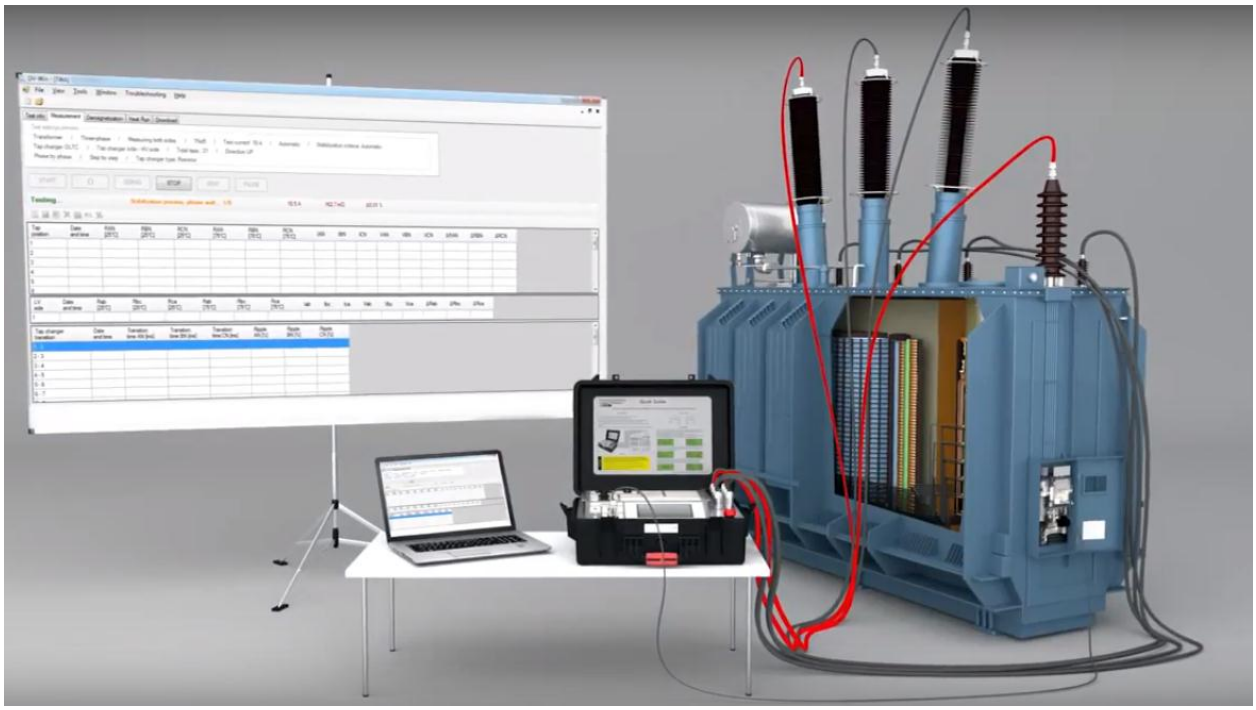


Figure 4.
Three-Phase Connection for Performing DVtest on a Power Transformer with OLTC

It is possible to perform either single-phase or three-phase DVtest, and each method has its own advantages. Single-phase DVtest is easier to analyze, since the graph will not be affected by the other two transformer phases. Three-phase DVtest saves time and enables checking the synchronization between the three phases with a high degree of precision. Any delay in tap changer operation in any of the three phases can be easily noticed on a three-phase DVtest graph, as shown in Fig.5.

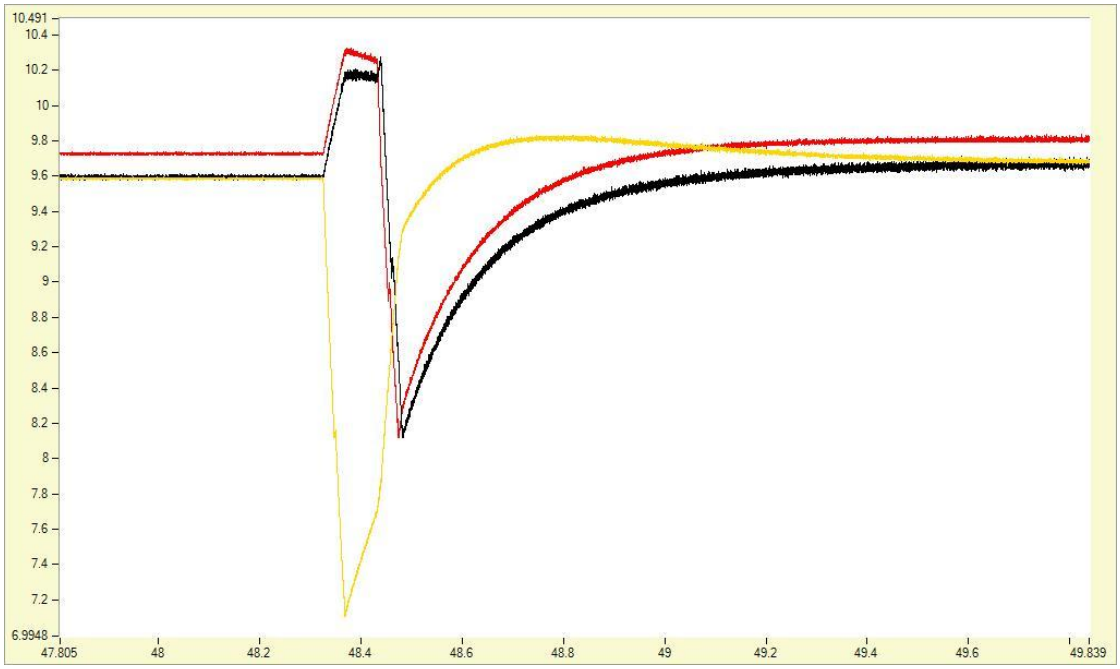


Figure 5.
A Three-Phase DVtest Graph Showing Synchronization Differences –
Phase C Operates 100 ms Earlier than A and B [13]

Three important parameters can be observed on the DVtest graph:

- Current ripple.
- Transition time.
- Shape of the graph.

The current ripple is the test current drop (in percentage points) during the transition. It depends on the construction of the transformer/OLTC and there is no strictly defined value for comparison or pass/fail criteria. However, a 100% ripple value can reliably indicate an open circuit during tap changer operation. During the results analysis, the results of one phase are compared with the other two phases, and complete results are compared with the results obtained from previous test.

The transition time is the period necessary for the change of the OLTC position. It also depends on the OLTC construction and it usually lasts between 30 and 50 milliseconds for resistive type OLTC.

The easiest way to analyze the graph shape of DVtest is by comparing the graphs recorded on the three phases, or with the results previously recorded on the same test object. Results recorded on different transformers with the same tap changer type will have the same characteristic points, but may differ in shape due to differences in winding resistance and transformer inductance values. Graph linearity and regularity may be used to detect various contact problems.

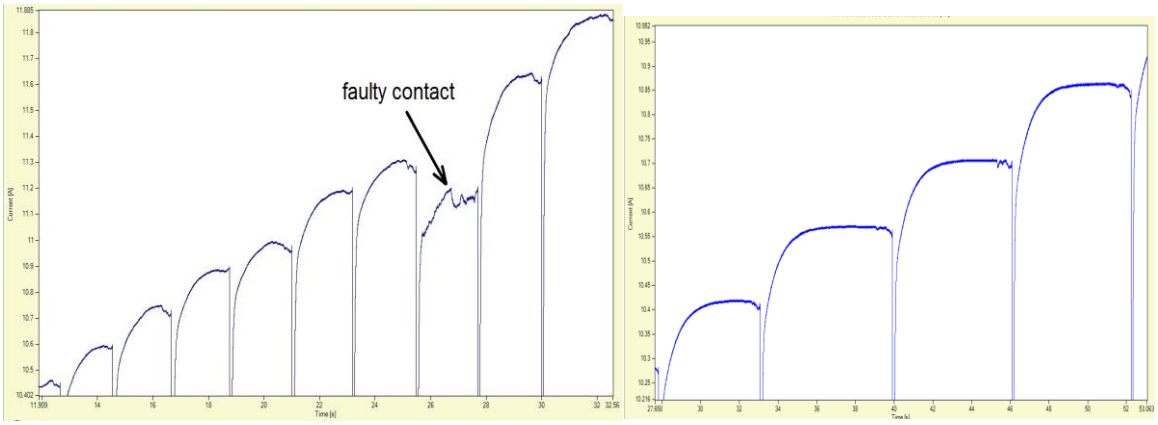


Figure 6.
DVtest Graph Before (Left) and After Repairs (Right) [12]

The DVtest can be performed together with the winding resistance measurement, by recording the resistances while the tap changer is stationary, and the DVtest graph while the tap changer operates, using the same instrument and the same software. This can be done automatically, with the tap changer mechanism fully controlled by the software. It is also possible to record it as a standalone test, where the software continuously records the current graph from the first tap position to the last. Tap changer motor current recording is a complementary measurement to DVtest, since it provides additional information about the tap changer motor mechanism. Most instruments used for DVtest recording have a dedicated measurement channel for recording the motor current graph simultaneously with the DVtest graph. This enables comparing the timing of the motor operation with the operation of the tap changer diverter switch. In addition, motor current signature analysis enables condition estimation of the tap changer moving parts.

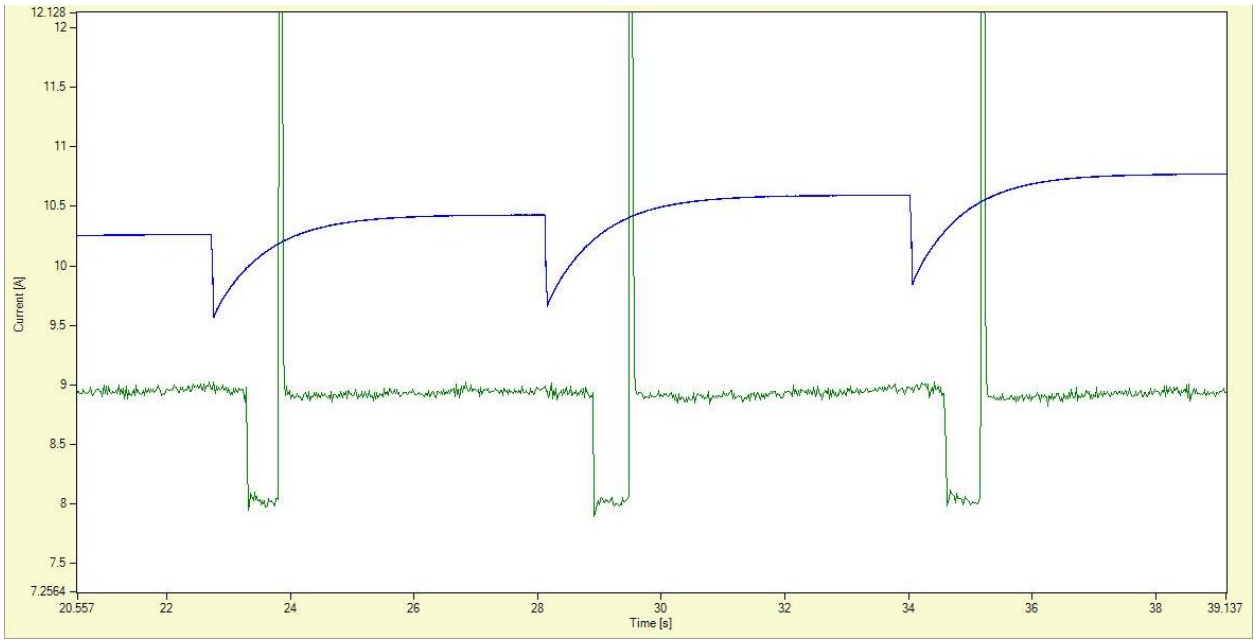


Figure 7.
Tap Changer Motor Current Graph Recorded Together with the DVtest Graph

Vibro-Acoustic Measurement on OLTCs

This testing method is based on the analysis of the vibro-acoustic waveform which is transferred from the OLTC mechanism through the structural elements. The measured signal waveform is analyzed for characteristic points which correspond to the specific stages in tap changer operation. Tap changers with mechanical problems will produce a different waveform from healthy tap changers. This method has been in use for many years [13].

The measurement is performed using accelerometers placed on the external tap changer tank. The measured signal is processed by the instrument and displayed by the software. Similar to the DVtest, the obtained results is a graph which can be used to detect mechanical problems and to measure timing.

Correct placement of sensors is crucial in order to obtain useful results. 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 positioning of sensors should be noted for future reference, since the results recorded with different sensor positioning might not be comparable to each other and may result in incorrect conclusions about the tap changer condition. Sensors are connected to the external tank using screws, wax or magnets. However, the magnetic mounting base reduces the signal's frequency response.



Figure 8.
Connecting an Accelerometer to the OLTC Tank

The shape of the produced graph will depend on the method of operating the tap changer – whether it is manual or motor-operated. The graph needs to be recorded with a high sampling rate, and the system needs to be have a range of ±50g in order to fully capture the signal extremes.

A major advantage of vibro-acoustic test over other tap changer testing methods lies in the fact that it can be performed while the transformer is on-line [14]. However, safety considerations need to be

taken into account in case of on-line testing, and all relevant safety procedures need to be observed. In case of on-line testing, the position is only raised or lowered by one tap, while in case of off-line testing the full range of tap positions can be tested. Similar to DVtest, the vibration graph can also be recorded together with the tap changer motor current graph in order to provide additional information.

Tap Changer Analysis using DVtest and Vibro-Acoustic method

DVtest can be used to detect problems in the condition of contacts which form a part of electric circuit during the tap changer operation. It enables open circuit detection, by sensing the interruption of test current flowing through the contacts. It can be used to detect damage to transition resistors, which affects the slope and ripple of the test current during the transition. Worn or pitted contacts can be detected from the shape of the graph, and a lot of problems can be detected in their early stages. The DVtest method has been used to detect various tap changer problems on many different OLTC types, and it has become one of the most powerful tools used for tap changer analysis by asset managers worldwide [1, 11, 12, 15 - 24].

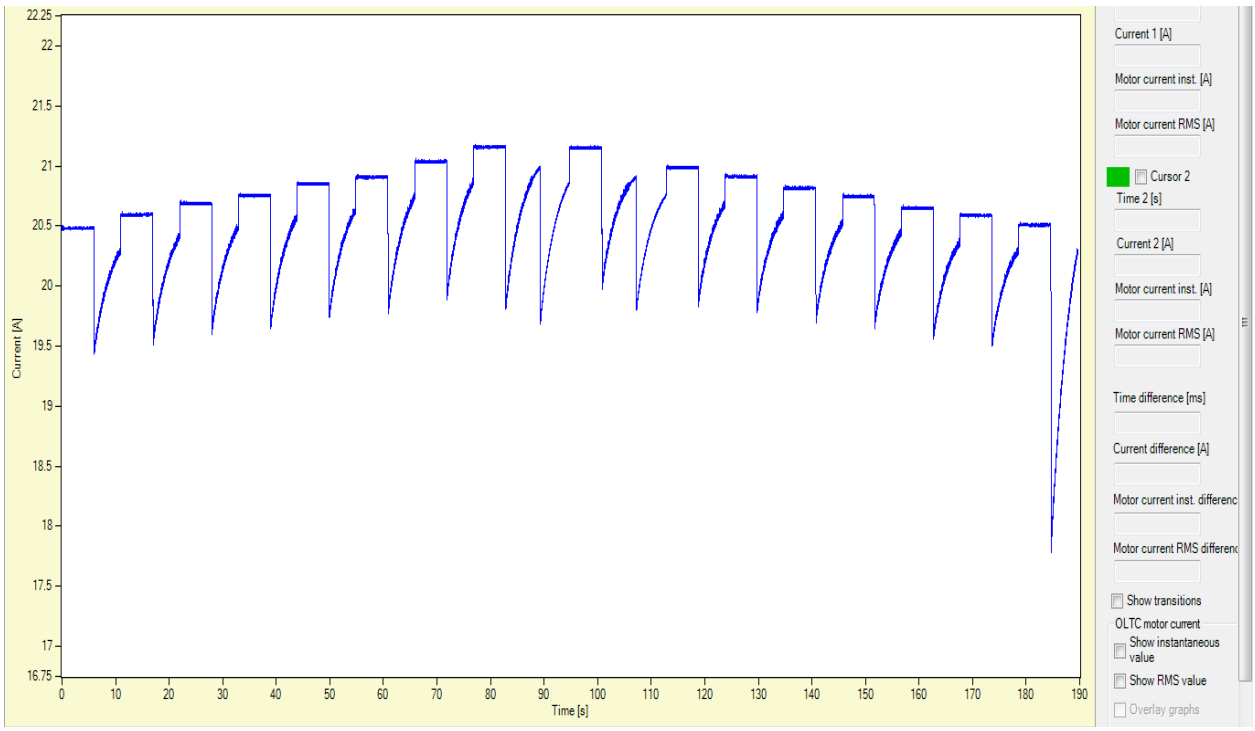


Figure 9.
An example of Incorrect Tap Connection Detected by DVtest –
All Contacts are Shifted by One, and the Reversal Switch Operates between Positions 16 and 17

However, the DVtest cannot be considered as the only tool for establishing the tap changer condition. Not every tap changer fault is as immediately apparent from the graph as the one in Fig.9, and many faults are in the “gray area” where additional investigation is needed before any firm conclusions can be made. The vibro-acoustic method provides an additional source of data for this purpose. It can also be used to detect the specific moments in tap changer operation which cannot be detected from the DVtest graph due to the fact that they do not affect the total resistance in the test current circuit. Finally, the vibro-acoustic method can be used in the on-line mode, in cases where offline testing is not possible or desirable.

The best way to analyze the vibro-acoustic waveform graph is by focusing on the timing of the various stages of tap changer operation. While the amplitude or the shape of the signal can be affected by the placement of sensors or the method of mounting them on the tap changer tank, the timing of specific impacts is not affected. Fig.10 shows an example of vibro-acoustic graph recorded simultaneously with the tap changer motor current, where the spikes in the signal correspond to specific points of the transition. The recording was performed on a reactance-type OLTC, which has significantly longer transition times than resistive OLTCs.

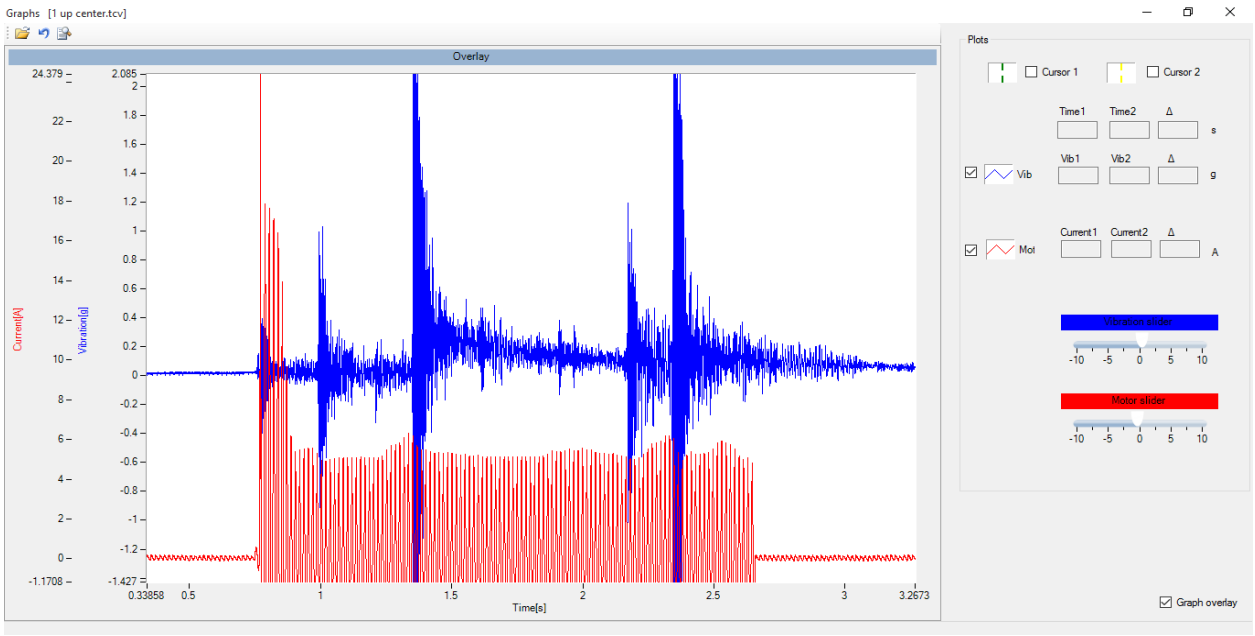


Figure 10.
Vibro-Acoustic Waveform Recorded Together with the Tap Changer Motor Current

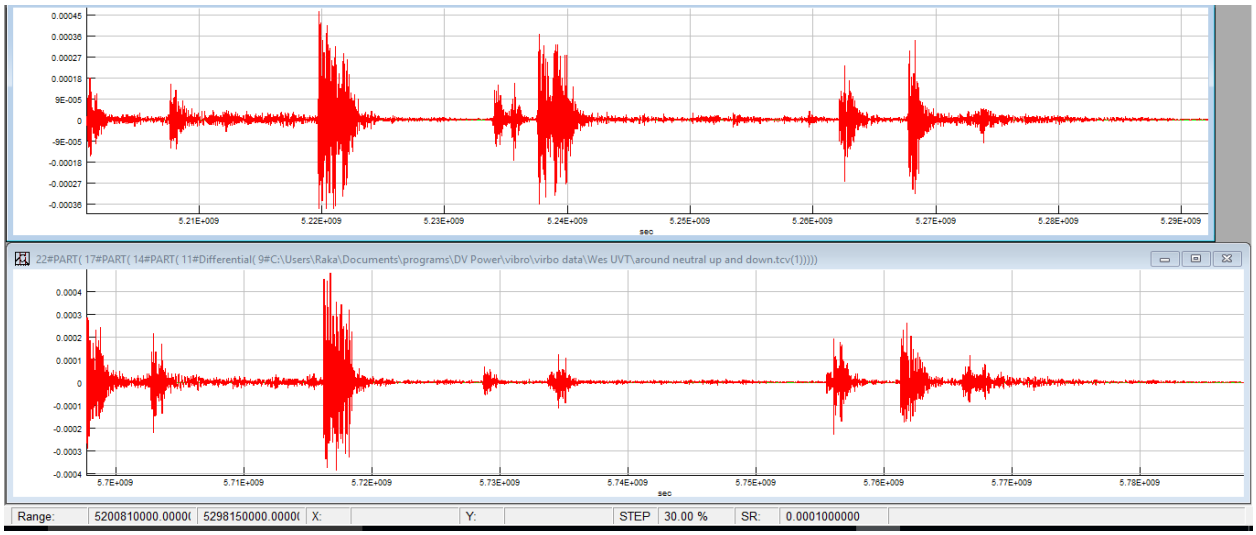


Figure 11.
Difference in Vibro-Acoustic Signal in Case of
Reversal Switch Operation (Above) and Normal Transition (Below)

Similar to the DVtest, the vibro-acoustic method can also be used to check the synchronization between the three-phases, especially in cases where two or three separate tap changer mechanisms are used on the same transformer. Fig.12 shows an example where 200 ms de-synchronization was detected between two tap changer operating on the same power transformer. After the repairs, the synchronization was improved to a 40 ms value (Fig.13).

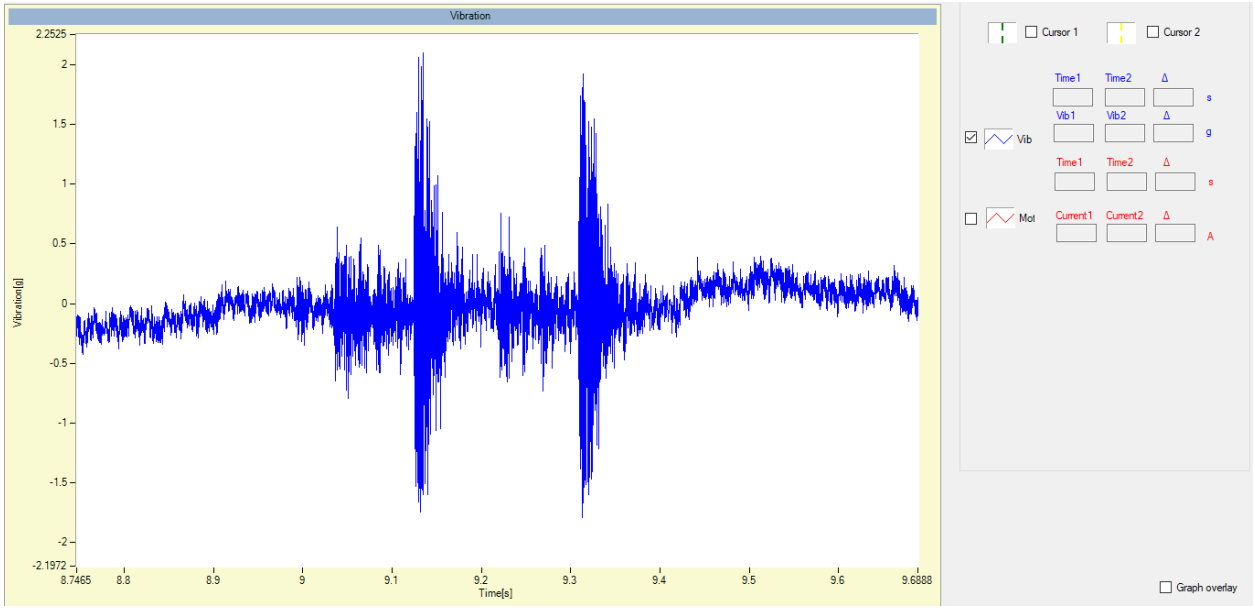


Figure 12.
A 200 ms Desynchronization Between Two Tap Changers, Detected by Vibro-Acoustic Measurement

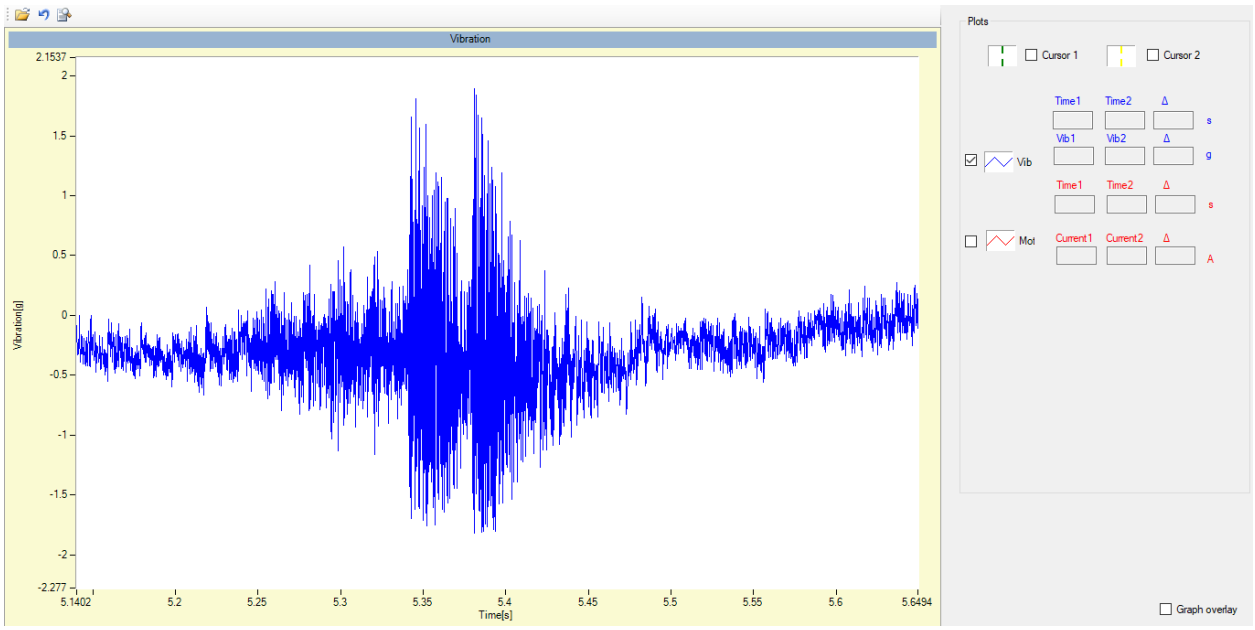


Figure 13.
Synchronization Between Two Tap Changers After the Repair

Fig.14 shows an example of events which can be identified with the combination of DVtest and vibro-acoustic measurement methods in case of OLTC with two transition resistors. The full orange lines show the events which can be detected with the DVtest, since they affect the electric circuit. The full

green lines show the events which can be detected with the vibro-acoustic analysis, since they cause vibrations in the tap changer mechanism. Finally, the full red lines show the events which can be detected from the combination of the two tests. This example demonstrates how a combination of these two methods can be a powerful tool in order to provide full tap changer analysis.

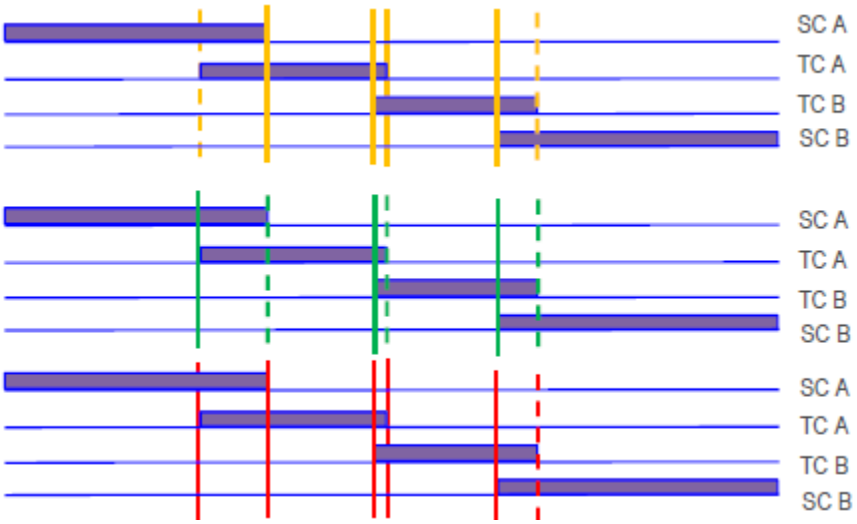


Figure 14.
A combination of DVtest and Vibro-Acoustic Measurement
and the Events Which Can Be Detected with Each ,ethod [25]

Conclusion

It is often necessary to perform a number of different tests on an OLTC in order to get an accurate estimate of its condition and to determine if any maintenance is needed. There are several diagnostic methods used today, and some of the major methods can be divided into:

1. Oil and insulation analysis (DGA)
2. Analysis of tap changer contacts
   - Winding resistance measurement
   - DVtest
3. Mechanical analysis
   - Vibro-acoustic diagnostic method
   - Motor current measurement

None of these individual methods can be considered as the perfect method for tap changer analysis by itself. Instead, each of them is an additional tool in the asset manager's "toolbox". The best method of analysis is to use the results obtained by different methods to supplement each other. Combining the results of DGA, winding resistance measurement, DVtest, vibro-acoustic measurement and motor current measurement may be necessary to perform full tap changer analysis.

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Biography

Goran Milojevic is an application engineer at DV Power since 2011, working as a technical support engineer for North America, Australia and UK. 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.

He holds the B.S. and M.S. degrees in electrical engineering, both from the University of Sarajevo.

Srdjan Jokic was born in 1977 in Sarajevo, Bosnia and Herzegovina. Since 2008 he has been working as a Teaching Assistant and Senior Teaching Assistant at the Faculty of Electrical Engineering, University of East Sarajevo. Additionally, he has been cooperating with DV Power since 2006.

He holds the B.S. and M.S. degrees in electrical engineering (2008 and 2013), both from the University of East Sarajevo.