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ON LOAD TAP CHANGER TESTING—

DYNAMIC RECORDING

BY RAKA LEVI, *AMforum*

In the past, on load tap changer (OLTC) testing and diagnostics were based on simple resistance measurements at each static tap position to establish whether the tap changer contacts were in good condition. The dynamic recording measurement (DRM) is a new off-line test technique showing its diagnostic power in detecting OLTC operational problems. Sometimes, this test method is incorrectly called a dynamic resistance measurement (same acronym — DRM), but it is not a resistance graph. The product is a current graph versus time, and its analysis is explained in this article.

The AMforum (a European association of asset managers in electric utilities) created a working group to investigate and standardize the methodology, and some of the cases collected are presented here. The IEEE Transformer Committee, through the Power Transformer Subcommittee, is looking into standardizing this method. The IEC and IEEE are coming out with a joint OLTC user guide that includes this test.

The on load tap changer principle was patented in 1927 by Dr. Bernhard Jansen, and its premise is very simple: "Make before break," meaning connect with the next tap before breaking with the previous one. This is still true today, and tap changers are designed following this approach. As this is a tap changer that operates under transformer full-load condition, as opposed to de-energized tap changer (DETC), the circuit should never be broken. Thus, opening the circuit is one of the biggest OLTC problems. It creates gases and can cause transformer tripping or even failure. Detecting this was impossible using old-fashioned static measurement techniques.

TEST METHODS

Tap changers can be visually observed or scanned using thermography. Dissolved gas can be used as a tool to find a problem with excessive heating or arcing. These tests can indicate the existence of a problem. Turns ratio can be measured on each tap, and winding resistance test results for all taps should be consistent. Vibration methods look into signatures collected using vibro-acoustic sensors or accelerometers. Monitoring various on-line parameters can indicate torque, mechanical issues, overcurrent, overheating, etc.

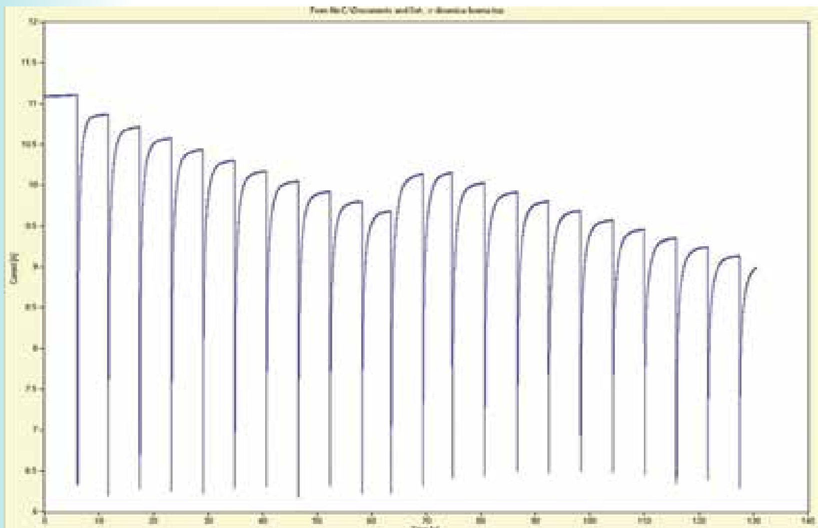


Figure 1: *A Good DRM Graph of a Resistor Tap Changer at Fine-Coarse Regulation*

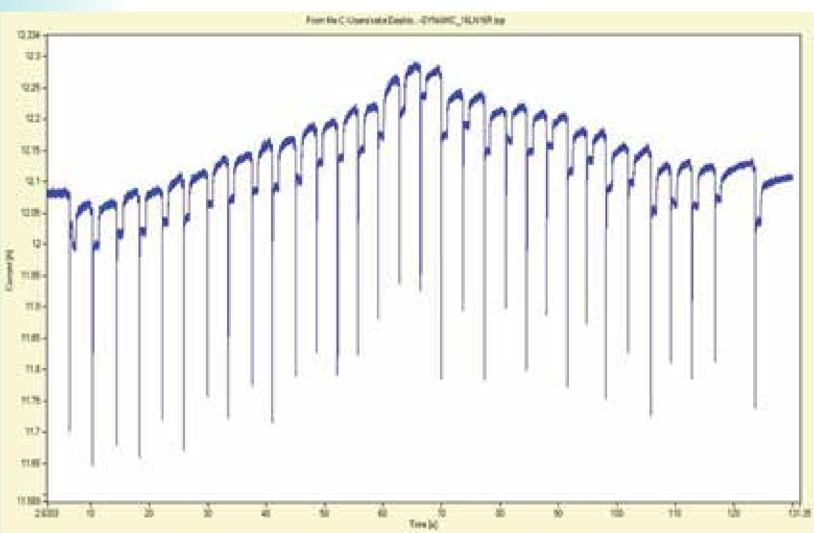


Figure 2: *New Reactor Tap Changer at Plus-Minus Regulation*

In the past, the possibility for a test crew to see the problem off-line with OLTC operation was based on flicker in the test voltage or induced voltage when performing some ac tests such as turns ratio while operating the tap changer. Many times, OLTC was open on these indications, and nothing unusual could be observed.

DRM

With modern electronics, recording of a test current at high frequency allows observing the performance of an OLTC at high speed, providing important information on its mechanical motion as well as contact bouncing, opening, coking, etc. The DRM methodology is only 10 to 15 years old, but it has shown great potential in detecting problems otherwise invisible to repair technicians. Fortunately, this method of analysis does not require great experience when viewing the graph. When the current is stable, it creates a straight horizontal line. Any increase in resistance or reactance makes the current drop, visible as a dip on the graph. Any resistance drop makes the current jump, as with lowering the number of turns the current will go up. A good tap changer makes the graph very smooth, and any discrepancy indicates a problem (Figure 1).

Figure 2 is a graph of a brand new reactor tap changer at plus-minus regulation. These good graphs or benchmarks when the tap changer is new should serve as a base for comparison during maintenance periods.

OLTC

There are many different designs and principles of OLTC operation. They can be in the tank or in a separate compartment attached to the tank. They can use reactors (preventive autotransformers) or resistors to lower the circulating current. The switching can be in oil or contained in the vacuum bottles. For high currents, a booster or a series transformer may be added to lower the current while increasing the voltage dealt with by the OLTC. The current switching and selection of taps can be performed using the same pair of contacts (arcing tap switch) or using two sets of contacts (a selector and a separate transfer or diverter switch). Then, two or three tap changers can operate on the same mechanism in one transformer, and their synchronization needs to be verified. Many variations require the knowledge of exact tap changer type to analyze the result.

REACTOR OLTC

Reactor-type tap changers are predominant in U.S. networks, while European tap changers use resistors for circulating current limitation during the tap transition. These reactor OLTC constructions rely on preventive autotransformers (PA) to limit this current, and provide double the number of tap positions compared with resistor types for the same number of taps brought out from the regulating winding. The PA is a gapped core reactor with dual windings wound in opposite directions; in fact, there is an additional small transformer inside the main transformer tank. As the PA does not permit the current to circulate, a bridging position is allowed with reactor OLTC indefinitely. For resistor types, the bridging position lasts only 10 to 20 msec. It is not really a position, just a quick transition.

DEFINING DRM

Following the idea of dynamic resistance measurement in circuit breakers, the identical procedure is applied to transformers (the reason this method is incorrectly named). However, transformer inductance does not allow calculation of resistance during the transition from tap to tap; thus, only the test current is recorded with high resolution at a frequency of 10 kHz. The connection of the test leads is identical to winding resistance measurement, and the instrument is usually the same. In fact, both can be obtained in the same process; the first one is sometimes called static resistance, as opposed to this dynamic resistance graph. A recommended test current for the measurement is 10A or even 15 to 20A, although there is no special requirement for higher current. The only requisite is that the current is stable, and that is achieved faster if the magnetic core is saturated by applying higher current.

APPLICATION TO DIFFERENT TAP CHANGERS

With the DRM, our dynamic test applies to all types of tap changers. Of course, there are certain modifications to the procedure when testing a series transformer, as the OLTC circuit is electrically isolated from the test circuit. However, the analysis of results and evaluation of the graphs are somewhat different depending on the construction principles.

Each tap changer transition during this DRM test creates a dip in the current graph. These dips are called ripples, and values and shapes of the ripple are analyzed for each transition. The ripple value is expressed in percents, and they all should be consistent. A ripple value of 100 percent (or close to that) indicates the circuit opening, and this is not acceptable for normal OLTC operation. For resistor-type tap changers, ripples are very consistent, while ripples for reactor types alternate — longer and shorter, for bridging and non-bridging position transitions.

GRAPH EXPLAINED

The current trace in Figure 3 shows the key points of a good GE-type LRT200 tap changer operation. Events are identified by these sudden current changes. Six key feature points

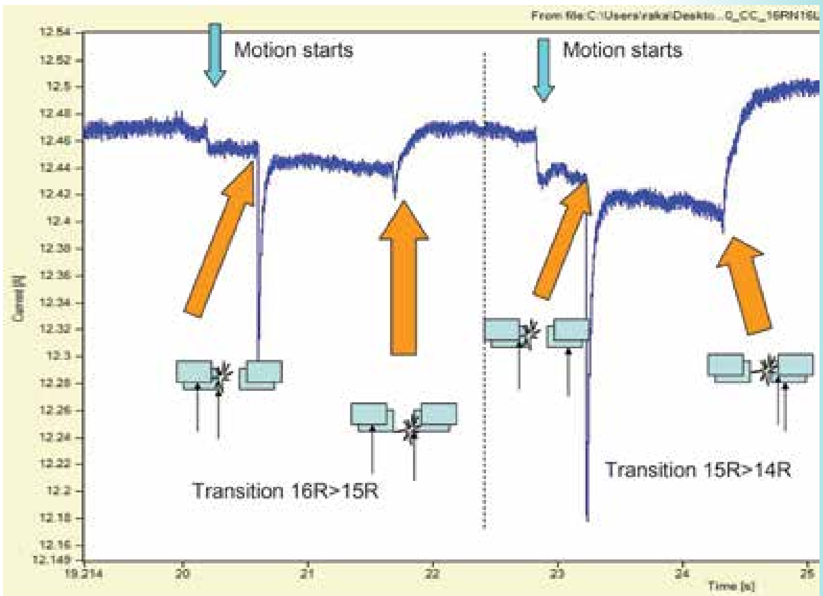


Figure 3: *Key Points of a Good GE-Type LRT200 Tap Changer Operation*

representing two transitions of OLTC are visible in this graph: from non-bridging to bridging, and then from bridging to non-bridging positions (in this example, from 16R to 15R, then 15R to 14R).

The first point in Figure 3 is a small drop pointing to a contact motion start, which creates a small variation in the test current. It points to an increased resistance as the contacts are now sliding over its surface. The next big ripple corresponds to the first contact parting from the initial tap, in this case, the vacuum switch operation. The second ripple, which is somewhat smaller, is where the contact touches the next tap. This is now the bridging position, as two contacts are at two taps — practically bridging them. The bridging positions are odd-numbered positions, while the non-bridging positions are even-numbered positions; a typical U.S. tap changer normally has 33 positions for an eight-tap regulating winding. The reversal switch doubles the eight taps into 16, and the reactor tap changer operating at bridging position makes this double again, creating 32 positions plus the neutral.

The next transition record in Figure 3 shows identical motion and switching points of the tap changer as it moves from the bridging position to the next one, the non-bridging position 14R, where both moving contacts are on the same tap. The difference is in the ripple length, so in a complete graph, ripples alternate long-short to various degrees (where for a resistor OLTC they are almost identical).

SYNCHRONIZATION

When located in the delta winding, tap changers at higher voltages need to be isolated from each other, so two or even three separate tap changers are operated from the same motor and mechanical drive. Their operation coordination needs to be checked, and the synchronization mode is used, where all three phases are tested together. The connection for Wye configuration is with three parallel phases, where for Delta winding, the test is two by two. For a test current of 10A per phase, that would require an instrument with 30A capacity. Figure 4 shows a synchronization graph of a Wye configuration, where one phase is leading the other two by a significant 100 msec difference.

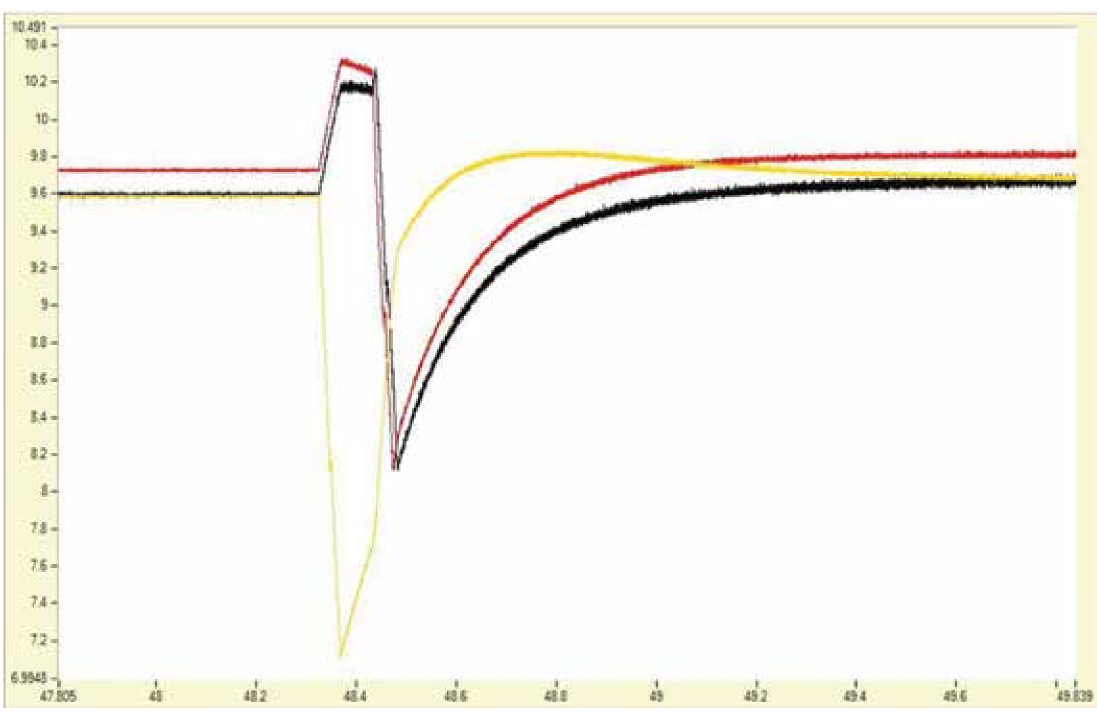


Figure 4: *A Synchronization Graph of a Wye Configuration*

CASES

AMforum has looked into this test method at previous meetings and decided to form a working group to define a procedure and standard method of evaluating test results. The group collected a large number of test graphs from all over the world; some interesting cases are shown here. These are simple cases that saved a number of problems and money to the operator by finding the defect early and requiring an easy fix to rectify it.

On load tap changer model 546, manufactured by Federal Pacific Electric, exhibited a significant difference in the ripple value for the phases X2 compared to X1 and X3. Figure 5 shows an overlay of two graphs with phase X2 in red and X1 in blue. This difference was significant enough to prompt a corrective action, including draining the oil and opening the OLTC tank.

Upon investigation, it was found that the bolt for the feed on phase X2 from the transformer to the collector ring had vibrated loose. The maintenance personnel cleaned and retightened the bolt. Once the transformer was repaired and ready for service, a retest verified that corrective action was successful. Ripple values were normal and compared favorably with the other two phases. This simple and timely correction saved a major problem that could have developed if the bolt was left loose, creating overheating and arcing.

Another example of the problem pinpointed following high DGA results is a VRC-type tap changer, where a reversal switch connection was found loose. Figure 6 shows a correlation of two phases, the good one in blue and bad one in red. It is clearly visible that the red current trace is not a straight line during the stable period of tap changer idling at the neutral position.

The wiggly trace is pointing to a bad contact or connection, in this case the K (+/-) contact. Figure 7 shows the exact position of the loose bolt, which was tightened very easily using the manhole at the selector.

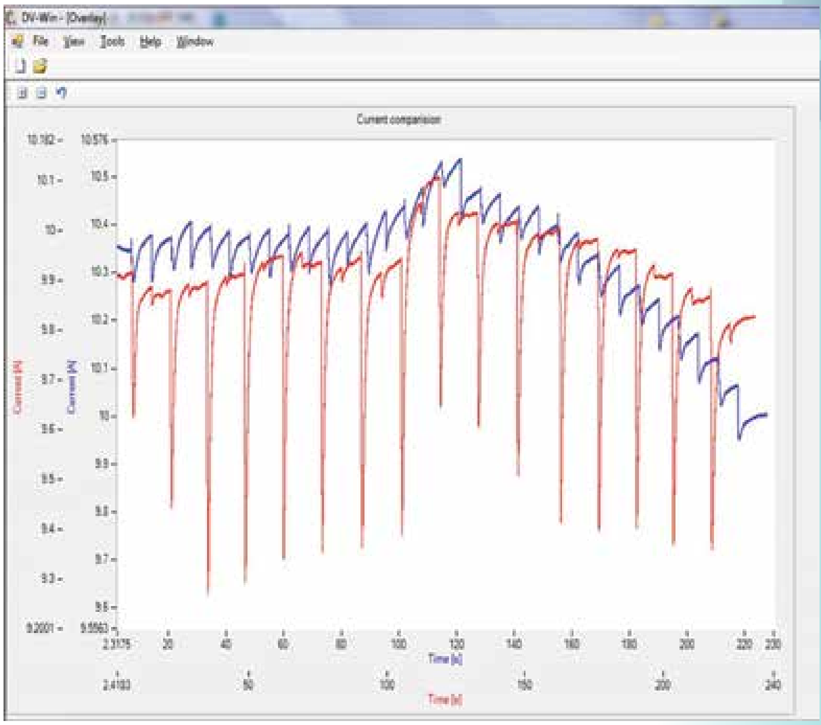


Figure 5: *Overlay of Two Graphs of an On Load Tap Changer with Significant Difference in Ripple Values (Phase X2 in Red and X1 in Blue)*

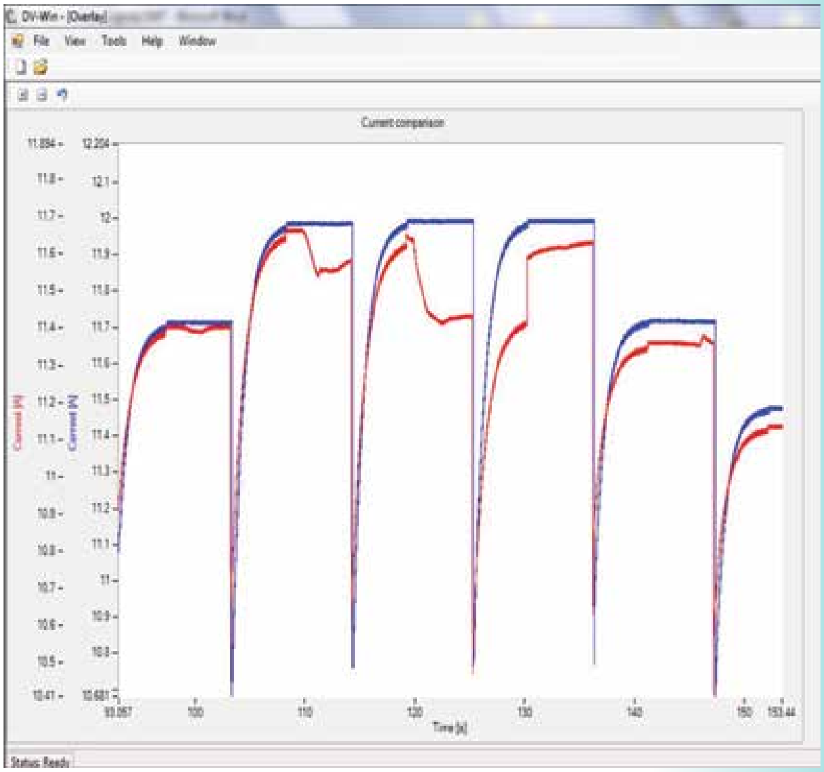


Figure 6: *Correlation of Two Phases in a VRC-Type Tap Changer, Where a Reversal Switch Connection was Found Loose*

Figure 7: *Exact Position of the Loose Bolt*

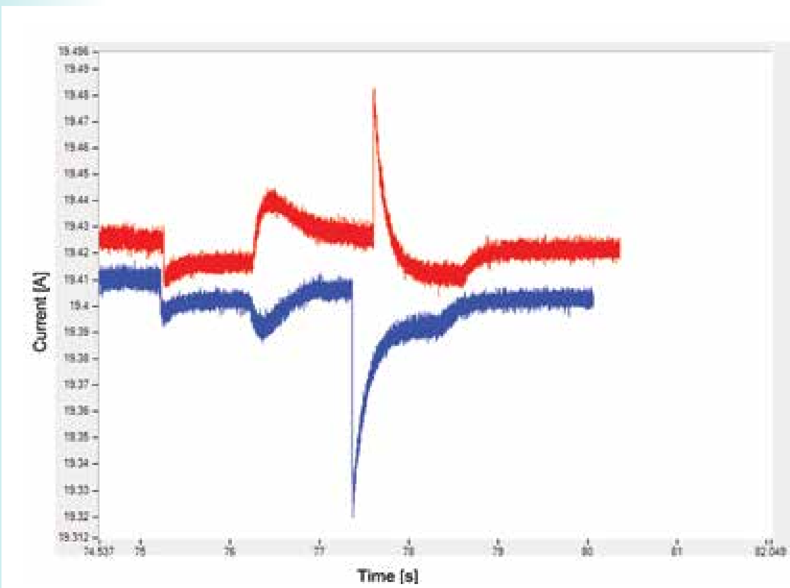


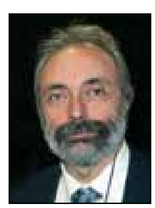
Figure 8: *Two Traces Recorded When a Reactor-Type Tap Changer Switched from One Position to the Next in One Direction and Then in the Other Direction*

The graph in Figure 8 is a good example that proves an important point and makes the necessary procedure very exact. The two traces were recorded when a reactor-type tap changer was switching from one position to the next in one direction and then in the other direction. It is almost a mirror image of the transitions. For that reason, always perform the test in the same direction — either from 16L to 16R or opposite. It would be even better if the tests were performed in both directions so that various switches are investigated in their action regardless of the tap changer direction.

Whenever a dc current is applied to a transformer winding, the core gets magnetized. Remanent magnetism can affect the in-rush current and some other diagnostic test procedures. To eliminate remanent magnetism, an automatic demagnetization process is required from all instruments supplying a dc current for winding resistance tests, no matter whether it is static or dynamic.

CONCLUSION

Service organizations have a new tool in their toolbox with potential to detect and eliminate problems and save big transformers. The DRM is a new method for OLTC condition assessment that has shown great diagnostic power in defining exactly which component is defective, so an early spare part request can be made before the repair. Mechanism defects or maladjustments were detected, and contact bouncing and coking were found. Spring breaking, transfer switch loosening, loose bolts, and circuit opening are some of the problems detected. More important, result analysis defines which phase and which switches were defective. The beauty of the method is the ease with which analysis is visually performed, and no great expertise is required to observe a problem when evaluating the DRM graphs.



***Raka Levi, Ph.D.**, is an Application Expert at DV-Power Sweden and convener of the AMforum association. He has over 30 years of asset performance and condition assessment experience, specializing in apparatus testing, monitoring, and diagnostics. Seven years ago, he started a working group on DRM test methodology for tap changers within the AMforum organization. For 20 years, he has led committees that assemble asset managers, organizing AMforum conferences in Europe, LTC universities in the U.S., and LTC colleges in Asia. His education includes a Ph.D. in HV diagnostics for circuit breakers from University of Belgrade and an M.E. in Electric Power Engineering from Rensselaer Polytechnic Institute.*