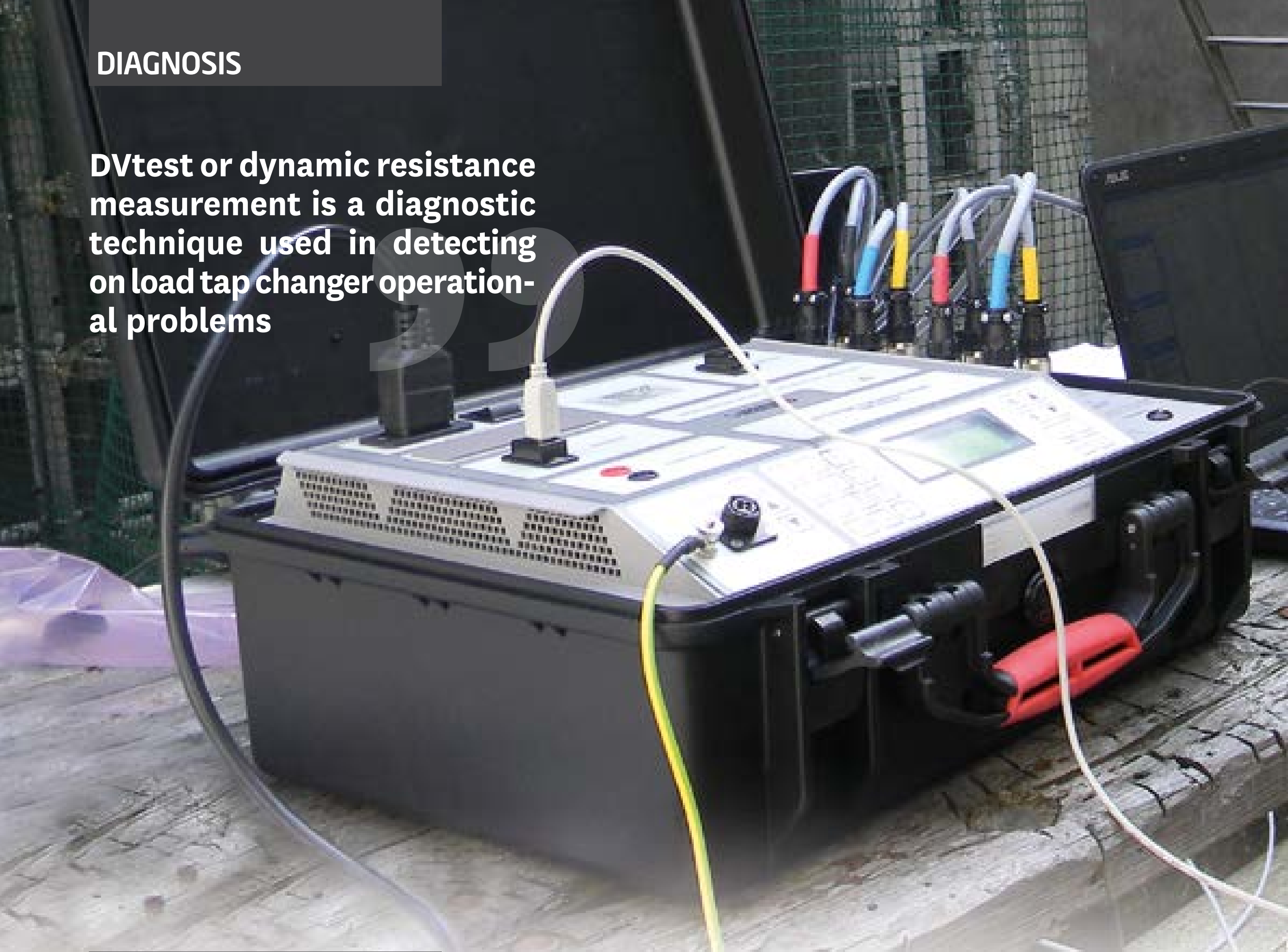

DVtest or dynamic resistance measurement is a diagnostic technique used in detecting on load tap changer operational problems

Reactor-type tap changers testing

Dynamic resistance measurement for on load tap changers

ABSTRACT

This paper discusses DVtest or Dynamic Resistance Measurement, a new diagnostic method used in detecting on load tap changer (OLTC) operational problems, as applied to reactor-type tap changers. Several cases of tap changer problems are presented, which were detected using the DVtest method – a high speed recording of a DC test current as the OLTC goes from tap to tap. The focus of the article is on the reactor-type tap changers. These reactor OLTC constructions apply Preventive Autotransformers (PA) for current control instead of resistors. Specific features in the current traces due to this particularity are explained. Finally, the article presents a discussion of the principles, DVtest features and defect cases for tap changers in a series transformer/booster arrangement.

KEYWORDS

tap changer, DRM, DVtest, reactor, transformer, booster

1. Introduction

On Load Tap Changer (OLTC) testing and diagnostics used to be based on simple resistance measurement at each tap position to establish if the tap changer contacts are in good condition. Possibility to see the problem with its operation, if any, was based only on flicker in the test voltage or induced voltage when performing some AC tests, such as turns ratio while operating the changer. With modern electronics, recording of a test current at high frequency allows us to see the performance of an OLTC at high speed, providing the important information of its mechanical motion, and contact bouncing, opening, coking, etc. The DVtest methodology is only 10 years old, but it has shown a great potential in detecting problems, otherwise invisible to repair technicians.

The reactor-type tap changers are predominant in the USA networks, while European tap changers use resistors for circulating current limitation during the tap transition.

2. The DVtest or Dynamic Resistance Measurement (DRM)

Winding resistance measurement is a well-known method in the transformer maintenance procedure.

The measurement is performed with a low DC current through the winding to make sure losses are as expected on a new transformer, and to check if the values have not changed due to defects when measuring units already in service. This measurement can also be called static resistance measurement.

The dynamic measurement is the same test where, in addition, the current during the tap change operation from one position to the other is recorded. This can be done through the whole range of positions. A current drop (the graph ripple) when transition resistors or reactors are connected can be observed and analyzed. The operation time for each transition of the OLTC is measured.

The test should be performed applying a DC current value that exceeds the knee point of the magnetization current to keep the core saturated during the complete measurement, in order to reduce the inductance as much as possible. If appropriate, windings not measured should be short-circuited in order to reduce the inductance even further. An example of graphs showing difference when the inductance is minimized, with a much larger trace inherent resolution, is provided further in the paper (Figure 2) as compared with the one where it is left unchanged.

3. Reactor-type tap changers

Almost all of the European tap changers are of the resistor type. In contrast to this, US transformers use reactor tap changers for voltage regulation. A reactor-type tap changer is a special design where circulating current is limited by application of preventive auto-transformer PA (a reactor), in contrast to the resistor tap changers where this task is given to plain resistors. Due to its configuration requirements, most of these tap changers are in the low voltage windings, or secondary side. This makes them switch higher currents in normal operation, but they are located in the neutral area of the wye connected (star connection) winding. In this way, they see lower phase to phase voltage, and clearances required between phases of the OLTC are small; thus, one unit can do the task. In case of high voltages between phases, such as putting them in the Delta configuration, two or three separate OLTC units may be required, one for each phase (3), or in two corners of the delta winding (2). Some lower current rated tap changers would require a booster winding (series transformer) to boost the voltage and lower the current the OLTC switches.

Most of the OLTCs in the USA have 33 positions, going from 16 Lower (16L) to 16 Raise (16R), with the neutral position marked as "N" – having total of 32 tran-

By recording a test current at high frequency, DVtest allows us to see the performance of an OLTC at high speed, providing the important information about its mechanical motion, contact bouncing, opening, coking, etc.

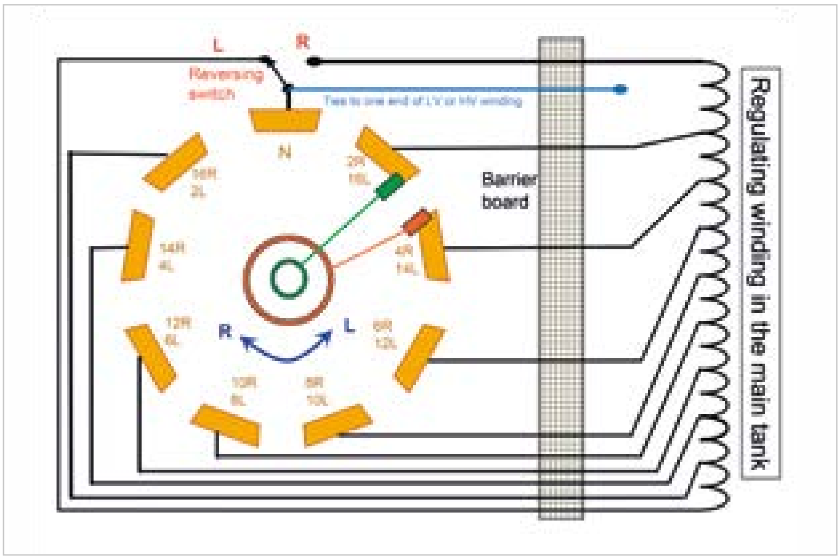

Figure 1. Reactor OLTC design schematic – showing contacts in a bridging position

> **DVtest is a good tool for diagnostics of reactor tap changers and it can be used as a prioritization tool for maintenance, upgrade, or OLTC overhaul**

sition operations from one extreme to the other. They are located in the secondary, star-connected winding of a common "Dyn" configuration. Three different design models of OLTC exist. First, arcing tap switch, where switching and selecting the tap position is done with the same contacts. The second one is with selector and separate transfer switches, usually two for current interruption, while the selector selects the tap without carrying any current. Finally, the third one is the vacuum interrupter design with two bypass switches. These vacuum type OLTCs have all the current switching and arc interruption done by the vacuum interrupter, without any arc quenching in the insulating oil. The bypass switch operates while being short-circuited by the vacuum interrupter, and thus no arcing is present.

Reactor tap changers can operate in the bridging position on the regulating winding. This is due to the inherent PA capability of limiting the circulating current when two taps are connected together to create one "middle" position. The contact of one arm is connecting with tap A, while the other is connecting with tap A+1. The resulting voltage output is the half-way of voltages at position A and A+1, providing finer regulation. For the bridging position, the PA as a reactor with two opposing windings allows the load current to flow, as the flux in each winding is opposing each other. The circulating current of the shorted taps A and A+1 is restricted as the two windings create the flux in the same direction and significant impedance exists that limits this component of the current.

The methodology presented in this paper is a very good tool for diagnostics of these reactor tap changers due to the high speed of current recording at 10 kHz, and it can be used as a prioritization tool for maintenance, upgrade, or OLTC overhaul. Additionally, the test current value of 10-15 A or even 25 A, together with special motor trigger algorithm, allows detection of tap changer "ripples", which are extremely small for these OLTC constructions. Each ripple is a drop in the test current, observed in the graph, due to the fact that the circuit configuration has changed while transferring connection from one tap to the other. Figure 2 shows 32 blue vertical lines as "ripples", due to 32 transitions from position 16L to position 16R. The x-axis is time in seconds, while the y-axis is the test current in amperes. The Figure 2 also shows the difference of the test result trace when the HV winding is short circuited (the trace in blue), and the corresponding one where the HV winding is open, the red trace. Lowered inductance by shorting the winding allows for much faster test-current change, and thus the ripple gets bigger.

4. Testing reactor tap changers

Over the last years, the DRM test method has been used [1, 2, 3] exclusively on resistor tap changers. Our experience with testing reactor tap changers is not very long. The method was introduced in the USA only six years ago [4] and named DVtest.

The DVtest current trace in the graph plotted in Figure 3 shows the key points of a good GE type LRT200 tap changer operation, identified by the sudden current change. Six key feature points are visible in this graph that represents two transitions

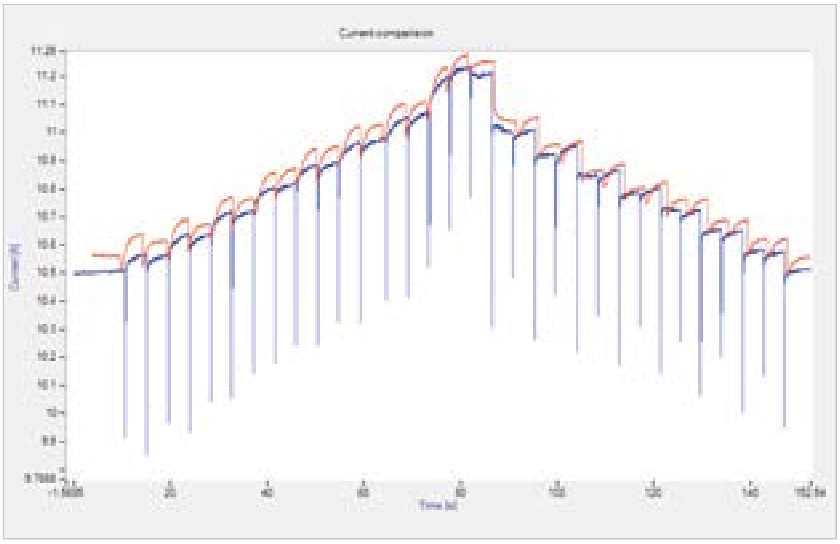

Figure 2. Two graphs of a reactor tap changer overlaid: with open HV winding (red trace) and shorted (blue trace)

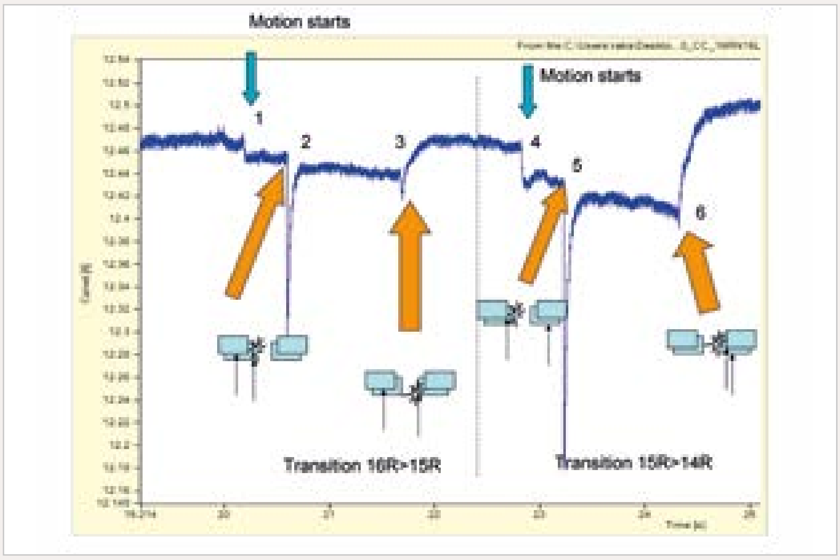

Figure 3. The main features of the reactor DVtest graph

Shorting the winding lowers inductance and allows for much faster test-current change, leading to a bigger ripple

of OLTC: from non-bridging to bridging, and then from bridging to non-bridging positions (in this example: from 16R to 15R, then from 15R to 14R).

The point 1 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 (point 2) corresponds to the first contact parting from the initial tap, or the vacuum switch operation. The second ripple, being somewhat smaller (the point 3) 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 of a typical USA tap changer that normally has 33 tap changer positions for an eight-tap regulating winding. The reversal switch doubles the eight taps into 16, and reactor tap changer operating at bridging position makes this double again to 32 positions, plus the neutral.

The next transition record in the same figure (points 4-5-6) show identical motion and switching points of 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 next winding tap. The difference is in the ripple length, so in a complete graph ripples alternate between long and short to various degrees (where for a resistor OLTC they are very consistent).

Let us investigate a couple of cases where the DVtest pointed to the defective component of a tap changer. The first sign of a problem may be an OLTC DGA (dissolved gas analysis) indication of excessive heating or undesired arcing in a vacuum tap changer [5]. The DVtest requires taking the transformer out of service, but does not require opening the tap changer.

Case 1

One case of a Federal Pacific FPE 546 tap changer defective reversal switch was detected in a 67 kV substation in California that indicated overheating condition and contact problem based on OLTC DGA. The graph of the DVtest on phase 2 of this transformer (plotted in Figure 4) showed a big difference in the performance of the tap changer through positions 16L (Low) to N, while from N (Neutral) to 16R (Raise) the trace followed expected pattern for a normally-operating tap changer. In order to confirm the findings, a test was performed in the opposite direction, where the problem was detected again on the same side. This conclusion was sufficient for the crew to get into the unit and find that the tap changer was in a bad condition. Reversal switch was creating this problem on phase 2, but also to a smaller degree on phase 1. Figure 4 shows the four graphs obtained in two directions of the tap changer motion for phase 2, as well as comparable graphs for phases 1 and 3.

The first sign of a problem may be an OLTC DGA indication of excessive heating or undesired arcing in a vacuum tap changer

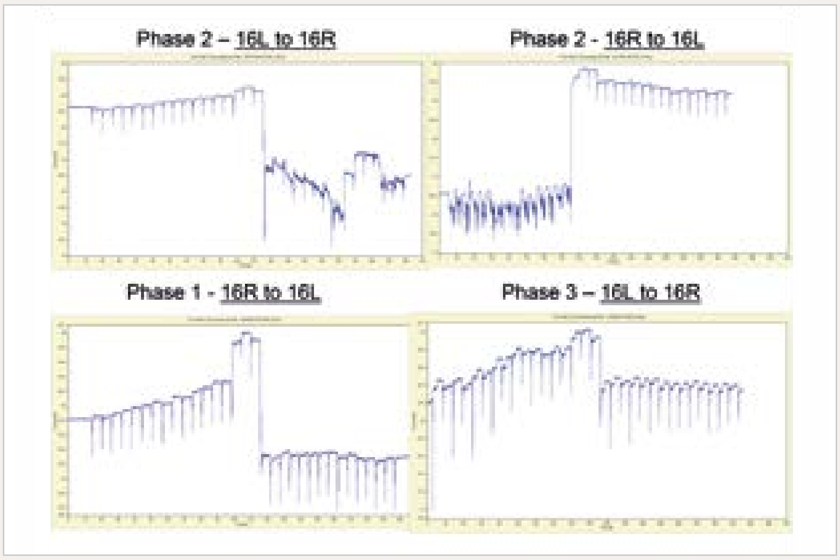

Figure 4. Reversal switch problem detected by DVtest method

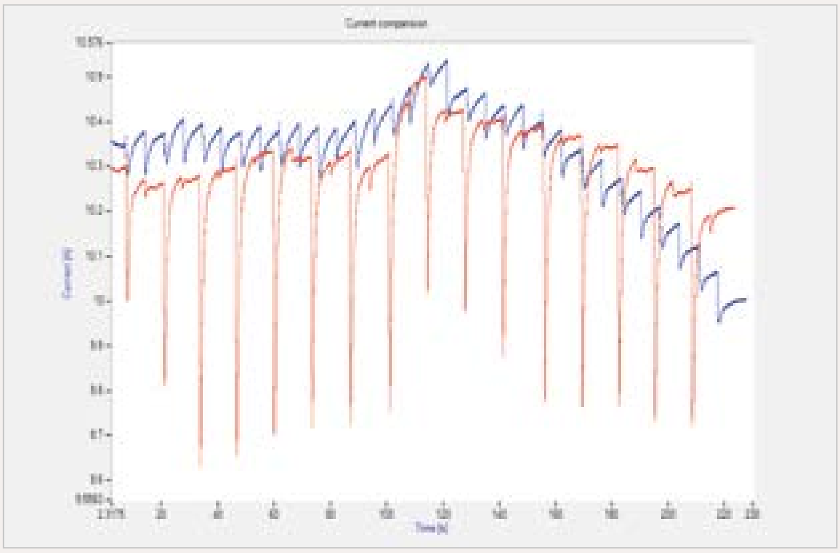

Figure 5. Overlay of two phases – good (blue) and bad (red)

The DVtest requires taking the transformer out of service, but does not require opening the tap changer

Case 2

On Load Tap Changer type 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 DVtest graphs – phase X2 shown 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 was performed to verify that corrective action was successful. Ripple values were normal and compared favourably with the other two phases. The graph in Figure 6 shows the comparison of the phase X2 graphs before and after the repair. This simple and timely correction saved a major problem that could have developed if the bolt was left loose, creating overheating and arcing.

Case 3

Heavy coking on the lower stationary transfer switch of the McGraw OLTC type 394 was found on the phase X1. The problem was indicated by increased OLTC DGA result ratios of ethylene to acetylene, as proposed by analysis given in [6]. That was the starting point – the knowledge that something was burning inside the OLTC. The exact position of the troublesome switch was detected by carefully analyzing the DVtest graphs of all three phases. The overlay of the phase X1 and X3 in the graph of Figure 7 shows the deviation of the blue current line (in the red circle), pin-pointing the defect to the particular phase and operation of exact transfer switch. While the red trace shows a clear transition when the switch of X3 phase operates, the blue trace with the wiggle at alternating transitions pointed to this particular problem.

The tap changer repair required replacing the transfer switch as it was completely coked and the switch repair was not possible.

5. Series transformer

Power transformers with an OLTC using a series transformer or booster for voltage increase and current decrease cannot be tested using any conventional methods. This is because the OLTC is electrically isolated from any external points, e.g. bushings. DV Power has developed a method for the OLTC basic condition assessment. Applying this special procedure enables the operator to check the tap changer timing, and for any contact bouncing.

An OLTC which uses a series transformer is electrically isolated from any external points, which is why it was not possible to test it with conventional methods

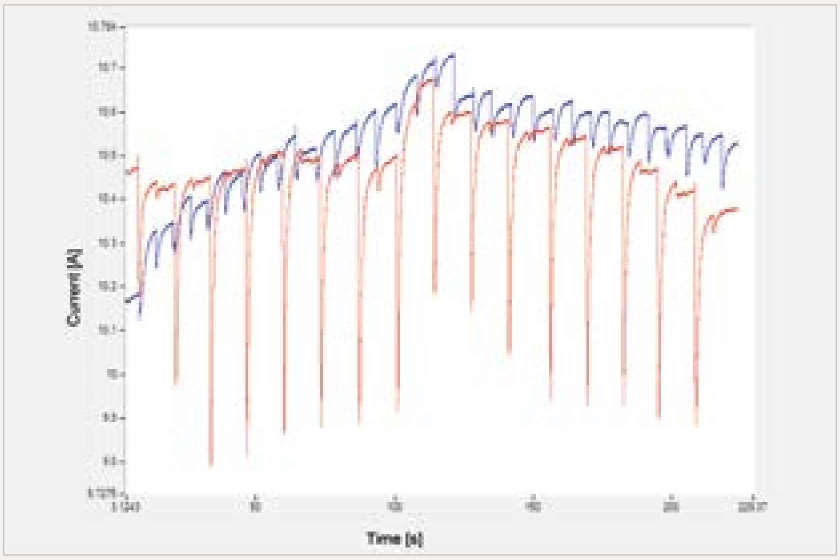

Figure 6. DVtest graph traces before (red) and after repair (blue)

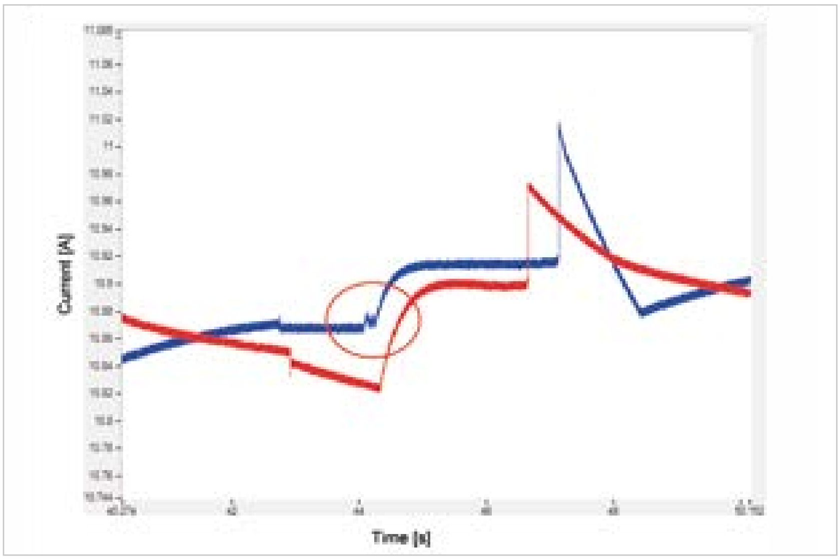

Figure 7. DVtest trace indicating coking on transfer switch

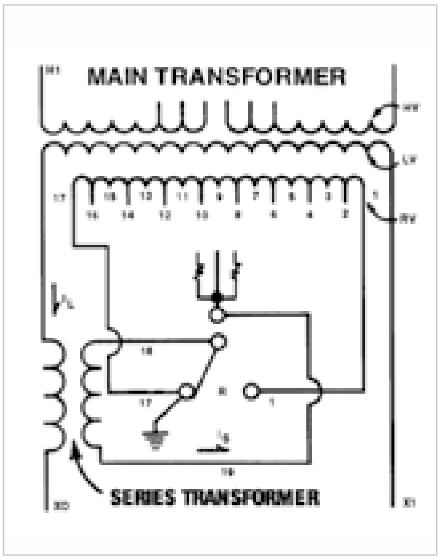

Figure 8. Schematic of a tap changer with a series transformer

DV Power has developed a method for basic condition assessment of OLTC which uses a series transformer

Since the tap changer is only magnetically coupled with the secondary winding, a steady DC test current through the winding under test will neither create any variable flux, nor induce a current through the tap changer circuit. To create a current flow through the tap changer, it is necessary to provide a variable DC current value through the secondary winding. This creates changes of magnetic flux and generates a current in the tap changer circuit. Any change in this current, such as a ripple during tap changer transition, will be reflected through the series transformer into the secondary winding test current that is being recorded.

A nice case of a test on a tap changer equipped with series transformer follows. Figure 9 shows two traces of the DVtest graphs obtained on the tap changer with the series transformer using this proprietary algorithm, a good one and a bad one.

The figure shows two ripples, in red and in blue, where one is a clean trace of a good contact tap changer, and the other (blue) shows disturbances symptomatic of a bad contact – wear, bouncing or even coking. Seeing this on a tap changer that is only magnetically coupled to the winding resistance test circuit through the series transformer adds a big advantage to test crews in diagnosing problems with all kinds of tap changer designs.

6. Finding a problem

As DVtest (DRM) is a new methodology, a small database of signature graphs exists. For that reason the evaluation is based on comparison of ripples between transitions and phases. This is done on a resistor-type tap changer between all ripples, while for the reactor tap changer odd ripples are compared to odd ones, and even ripples are compared to even ones. This is due to the inherent bridging and non-bridging tap positions in the reactor tap changer.

Conclusion

The DVtest or a high-speed dynamic test current recording on reactor tap changers presents a powerful diagnostic tool for detection of component defects. Various constructions of tap changers create different traces, or fingerprints of its operation. This is much emphasized for reactor types, as inductance of the PA introduces current drops or jumps depending on the direction of the tap changer motion, as shown in Figure 10. It is obvious that these two graphs look like mirror images. The understanding of the tap changer construction/type as well as the exact knowledge of the test procedure is a must for proper diagnostics.

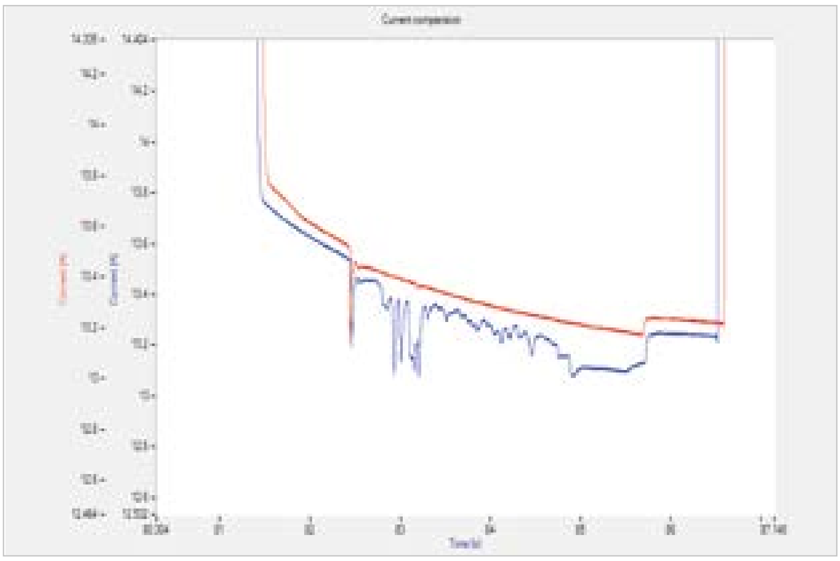

Figure 9. Series transformer test graphs: bad (blue) and good (red) traces

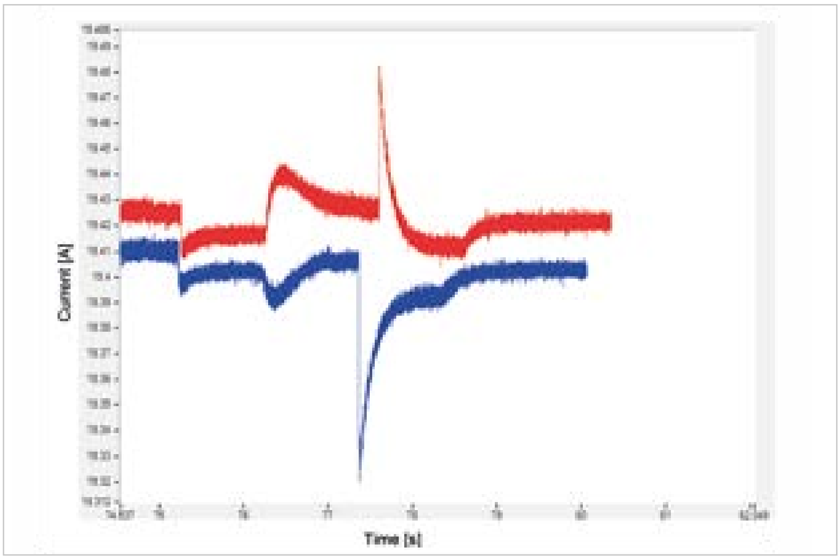

Figure 10. DVtest graphs of two reactor OLTC transitions, one UP and the other DOWN

For reactor types ripple can drop-down or spike-up depending on the direction of the tap changer motion

In view of the complexity of analysis [7] for extreme number of types and manufacturers of existing tap changers, a working group was formed by the AMforum association to collaborate and exchange experience and data in order to better understand, and if possible standardize the test procedure. Certain conclusions and recommendations of the working group were implemented here [8]. The IEEE Transformer Committee has also discussed at the last meeting creation of a task force to standardize this test procedure as a part of C57-152 IEEE Guide for Diagnostic Field Testing of Fluid-Filled Power Transformers, Regulators, and Reactors.

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