DYNAMIC TAP-CHANGER TESTING, REACTORS AND REACTANCE

Gunnar ANDERSSON
ABB Components – Sweden
gunnar.l.andersson@se.abb.com

Raka LEVI
AMforum – USA
raka@amforum.org

Edis OSMANBASIC
DV Power - Sweden
eddie@dv-power.com

ABSTRACT

Dynamic resistance measurement (DRM) – a diagnostic technique that has recently been attracting a lot of attention due to its capability to detect On-load tap-changers (OLTC) problems – is discussed in this paper as applied to variable shunt reactors (VSR). Specific features in the current traces are explained. In addition, there is discussion of principles and DRM features as well as presentation of defect cases for reactance type of tap-changers tested using DRM methodology.

INTRODUCTION

A shunt reactor consists of one winding only and is connected between a high voltage line and ground. It can be three phase or single phase. It is built to have a certain inductance. Its duty is normally to stabilize line voltage by compensating for reactive power generated by capacitances to ground. It can be seen as a no-load transformer with a high magnetization current. By having the reactor equipped with a regulating winding and an on-load tap-changer (OLTC), the reactance can be varied in small steps and with considerable range. In this way, the reactance can be smoothly adapted to the variations in load and the voltage can be adjusted more precisely. Variable Shunt Reactors (VSR) [1] are seeing increasing use in networks to stabilize line voltages. So far, DRM has only been used on transformers as a diagnostic technique and as a priority tool for maintenance, upgrades or overhauls of these essential network components. This paper shows that the DRM test methodology in additional can be used also on OLTCs in VSR application.

Dynamic Resistance Measurement

Winding resistance measurement is a well-known method in the trade. It is a measurement performed with a low DC current through a winding to ensure that losses are as expected on a new transformer, and to check that the values have not changed due to defects when measuring on units in service. This measurement could be called static resistance measurement.

Dynamic measurement entails measuring in the same way but in addition, it also records the current during tap change operations from one position to the other through the entire range of positions. By analyzing the recordings it is possible to draw a number of different conclusions related to the condition on the windings as well as on the OLTC. In general it is possible to see the time for the electrical load commutation of the OLTC and for specific types of OLTC it is even possible to see the connection and disconnection of the transition impedance (resistance or reactance).

The measurement should be performed with a DC current exceeding the knee point of the magnetization current so as to keep the core saturated during the complete measurement. This is done to reduce the inductance as much as possible. If practical, one of the windings not measured should be short circuited to reduce the inductance even more [6].
The inductance causes slow current reaction during measurement and high impedances make the interpretation of the resulting curves difficult and limit the value of the measurement.

DRM and different OLTC types

Before starting the measurements it is worth considering the different responses that different OLTC types give to the measurement. DRM measures the current through the winding. The current that changes is thus only what corresponds to the load current in actual service. The circulating current that is caused by the step voltage in actual service is not seen.

Without getting into the details, the so-called flag cycle types, which include most of the non-vacuum types of OLTCs, will produce the complete operating cycle that is seen on the DRM. However, all pennant cycle types, a principle used by most of the vacuum-type OLTCs outside of the US, will only show the main contact operations and nothing from the transition contacts since these are only switching circulating current. In addition, the vacuum types have auxiliary contacts that are not seen either.

Almost all non-US tap-changers are of the resistance type. In contrast to this, many transformers in the US use reactance tap-changers for voltage regulation. A reactance tap-changer is a special design where circulating current is limited by use of a preventive auto-transformer (reactor), in contrast to the resistance tap-changers where this task is handled by conventional resistors.

For information about the different OLTC operating cycles, please see IEC 60214-1 2003-02, Annex A for resistive type OLTC, and IEEE Std C57.131-1995, Annex B for reactance type OLTC.

TESTING VARIABLE SHUNT REACTORS

Since no experience of such measurements existed before our measurements, we had only expectations. As a recommended procedure, the measuring current should be kept higher than the magnetization current and preferably, another winding should be short circuited.
In a reactor, the magnetization current is equal to the load current and the measuring current can thus not exceed it. The primary reason is that it would require a huge

instrument since the currents often are in the range of 100–300 A. Moreover, running full DC current through a winding is normally not allowed for thermal reasons. Consequently, the impedance cannot be reduced by keeping the measuring current higher than the peak of the magnetization current.
The second task is to reduce inductance. Short circuiting windings are normally not possible either since there is no other winding. The expected problem was thus, that the impedance could be so high that evaluation of the results could be difficult.

The following measurements (1 and 2) are performed on a VSR with a vacuum OLTC of resistive type working according to the asymmetrical pennant cycle, more specifically the ABB VUCG model.

The VUCG used on the VSR in the tests described operates according to the asymmetrical pennant cycle but with the exception that it operates with the main contacts first in both directions. This is achieved by a mechanical rectifier in the mechanism and provides such electrical advantages as lower breaking stresses and longer contact life.

Measurement 1

The actual VSR tested is a 127-209 MVAr at 420 kV with inductance of 4.4–2.7 H and transition resistance of 11.2 ohms. Since we could not rely on any previous experiences, we started with a measurement from position 1 to position 2, which connects more turns. The DRM trace was as shown in the graph in Figure 1. The response is surprisingly fast when the resistors are connected, and slow when they are disconnected.

The graph in Figure 2 is a magnification and shows the connection of the resistors only. First there is a slow decrease in current in the graph, remaining for approximately 6–7 ms. This is the arcing time of the main vacuum interrupter. The arc has a voltage drop of about 17 V, corresponding to a resistance of 17 V/10 A=1.7 Ω (winding resistance ignored). The time constant (L/R) is thus 2.7/1.7=1.6 seconds.
The second part, between this initial time and the larger slope within the circle, remains for about 37 ms. This is the time when the transition resistors are connected. This time added to the arcing time is the true mechanical time when the main vacuum interrupter is open and is present for about (7+37=) 44 ms, which is as expected.

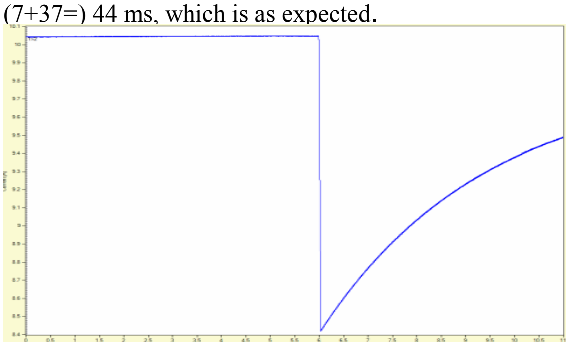

Figure 1. Transition from position 1 to position 2

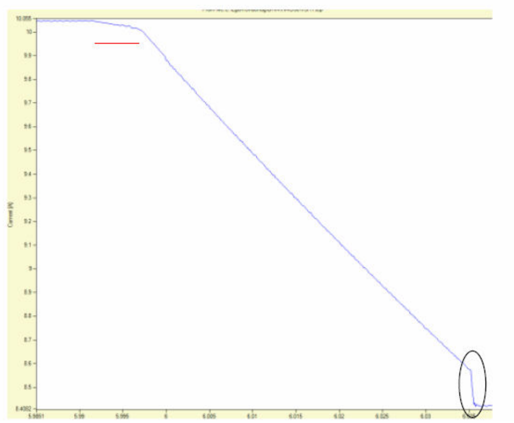

Figure 2. Magnified transition from position 1 to position 2

The time constant when the resistors are connected is 2.7/11.2=0,24 seconds, which is 6.6 times faster than with the arc alone. This explains the faster slope in the second part of the curve.
The third part, which is within the right-most circle in the curve, is when the next tap is connected. This is connected by the main contact without any resistance other than that of the test loop itself. The inductance increases by 4% and the current decreases. The time constant is low since the inductance in one loop is low and the transition resistance is high.
After this, the current increases again but now slowly since the resistance now decreases by a factor of approximately 10 and the time constant increases correspondingly. It is seen however, that the expectation of a slow curve is not correct; at least not for the decrease in current. As we saw above, the operation time for the main vacuum interrupter was clearly seen, and since this is a pennant cycle operation, only the main vacuum interrupter operation is visible.

Measurement 2

This measurement is from position 4 to 3, which is in the opposite direction compared to Measurement 1 and winding turns are now disconnected; see Figure 3.

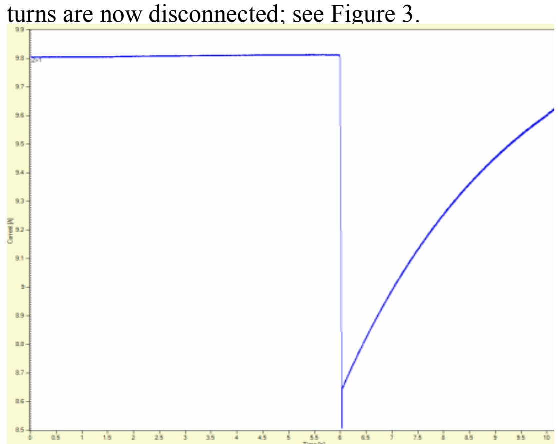

Figure 3. DRM of a tap change from position 4 to 3

The graph in Figure 4 is a magnified view of Figure 3 and shows the connection of the resistors only. Initially, as

before, there is a slow decrease in current above the red line in the graph, remaining for approximately 6-7 ms. This is the arcing time of the main vacuum interrupter. The arc has a voltage drop of about 17 V corresponding to a resistance of 17 V/10 A=1.7 Ω (winding resistance ignored). The time constant (L/R) is thus approximately 2.7/1.7=1.6 seconds. The second part, between this first time and the larger slope within the circle, remains for about 37 ms. This is the time when the transition resistors are connected. That time added to the arcing time is the true mechanical time when the main vacuum interrupter is open and here it is about (7+37=) 44 ms, which is same as in Measurement 1.
The time constant when the resistors are connected is 2.7/11.2=0.24 seconds, which is 6.6 times faster than with the arc alone. This explains the faster slope in the second part of the curve.
The third part, the one within the right-most circle in the curve, is when the next tap is connected. That is connected by the main contact without any resistance other than that of the test loop itself. The inductance now decreases by approximately 4% and the current increases.

The time constant is low since the inductance in one loop is low and the transition resistance is high.
After this, the current increases again but now slowly since the resistance now decreases by a factor of approximately 10 and the time constant increases correspondingly.
It is again seen that the expectation of a slow curve is not correct. At least not for the decrease in current. As we saw above, the operation time for the main vacuum interrupter was clearly seen, and since this is a pennant cycle operation, only the main vacuum interrupter operation is visible.

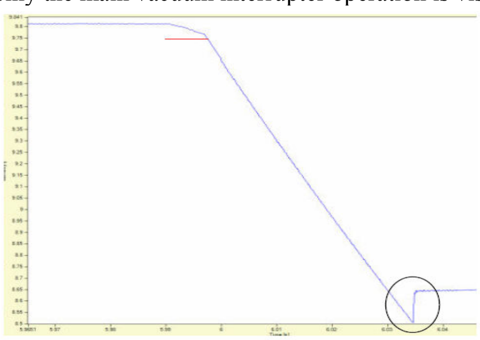

Figure 4. Magnified transition from position 4 to 3

Three-phase test
A three-phase graph of the tap-changer transition on this particular tap-changer operating on a VSR is shown in Figure 5. It was obtained with the new generation of the test instruments recording three-phase DRM simultaneously.

Testing reactance tap-changers in transformers

Over the past 18 years, the DRM method has been used [2,3,4] exclusively on resistance tap-changers. Our experience with testing reactance tap-changers is limited. The method was introduced in the US only in the past couple of years [5]. The DRM current trace on the graph in Figure 6 shows key points of tap-changer operation, for two tap transitions, identified by the sudden current change, i.e. breaking and making of fixed- and moving-contacts.

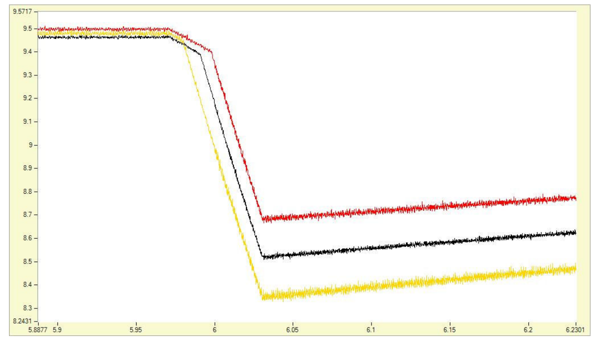

Figure 5 Three-phase transitions

The measurements are made on non-ABB OLTC and the type is therefore not specified in the paper.

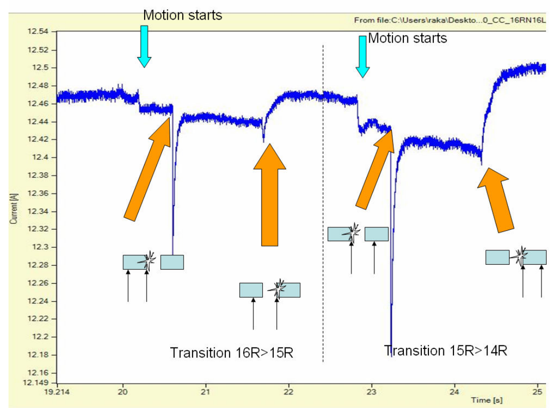

Figure 6 Reactance DRM graph main features

Case 1
A case of a defective reversal switch was detected in a 67-kV substation in California that indicated an overheating condition and contact problem based on DGA. The graph for the DRM on phase 2 of this transformer showed a substantial difference in the performance of the tap-changer through position 16Low to N, while from N (neutral) to 16Raise the trace followed the expected pattern for a normally operating tap-changer. In order to confirm the findings, a test was performed in the opposite direction. The side with the original problem indicated a problem again. This was enough reason for the crew to open the unit. They found that the tap-changer was in poor condition. Figure 7 shows the four graphs obtained in two directions of the tap-changer motion for phase 2, as well as phases 1 and 3.

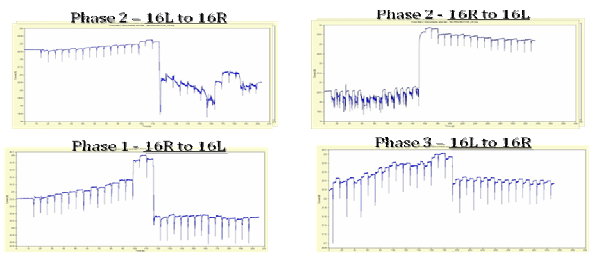

Figure 7 Reversal switch problem seen by DRM

Case 2

Heavy coking on the lower stationary transfer switch of phase X1 was detected by increased DGA results. The exact position of the faulty switch was detected by carefully analyzing the DRM graphs of all three phases. The overlay of phases X1 and X3 on the graph in Figure 8 below shows the deviation of the current line (in the red circle), pin-pointing the defect to the particular phase and operation of the particular transfer switch.

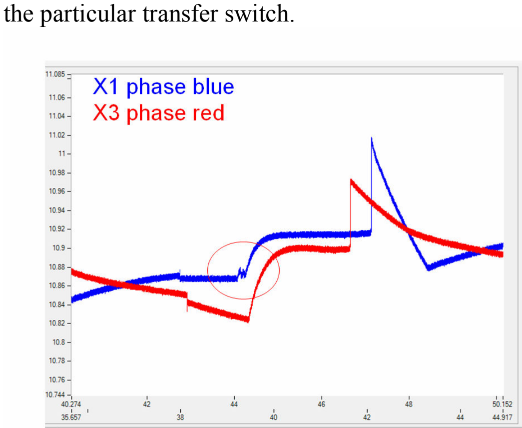

Figure 8. DRM trace indicating coking on transfer switch

CONCLUSION

Dynamic resistance measurement on variable shunt reactors can be performed without any problems. The response when changing resistances will be fast enough to clearly show ripple as well as transition times.

The results for an OLTC operating according to the flag cycle can be assumed to be about the same. Although the measurements in this paper were made on a large shunt reactor, it can be safe to say that the same conditions will apply even to smaller shunt reactors. In other words, the DRM can be seen as an additional tool to asses the condition of the windings and the OLTC in VSR application.

In view of the complexity of analysis [6] for the extreme number of types and manufacturers of existing tap-changers, a working group was formed by the AMforum to collaborate and exchange experience and data in order to better understand, and if possible, standardize the test procedure. Certain conclusions and recommendations from the working group were implemented here [7].

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