COMPARATIVE ANALYSIS OF THREE-PHASE AND SINGLE-PHASE DYNAMIC RESISTANCE MEASUREMENT RESULTS

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ABSTRACT

Dynamic resistance measurement (DRM) has been proven to be a very effective method in detecting possible faults in on-load tap changers (OLTC). This article gives an overview of the correlation between the three-phase DRM results and the single-phase DRM results. The measurement of OLTC synchronization is also explained. In addition, the demagnetization, which is necessary after any DC test on a transformer, is also described in the second part of this paper.

INTRODUCTION

DRM method is recording a DC current through the OLTC while a DC voltage has been applied. Getting three DC currents of approximately the same value through all three primary or secondary windings of a transformer is not a problem if these windings are connected in a wye configuration with neutral point accessible. However, if the OLTC is on a delta or wye without accessible neutral, injecting the three DC currents of the same value through the windings at the same time is impossible. In those cases, two or three single-phase measurements have to be performed in order to obtain DRM graphs of all three phases. The major advantage of a dynamic resistance measurement is the relatively low amount of time and effort required. [1]

DRM parameters

During field tests it was observed that DRM results of degraded contacts are highly dependant on the test circuit and test parameters. [2] The important issue that should be considered when performing DRM is the value of the test current and short circuiting the transformer secondary side, as recommended by the working group on DRM. [3]
A low value of the test current can indicate a false problem presented by interruption of the current due to the thin oil film. The higher value of the test current will break this surface film.

SHORT CIRCUITING THE SECONDARY SIDE

The secondary side short circuit provides important benefits when carrying out a DRM test where a tap changer is located on the primary side. As the current flows through the secondary short circuit the main inductance has no significant effect and the current is allowed to change relatively fast. [2] With this fast time constant, short changes in the contact resistance can be detected. Thereby, shorted secondary transformer side during DRM test

provides more details on the DRM graph such as short irregularities, contact bouncing, etc. The Figures 1 and 2 show the example of the DRM graph for open and shorted transformer secondary side. The DC current recovery after transition (tap change) is much faster in case when the secondary side is shorted.
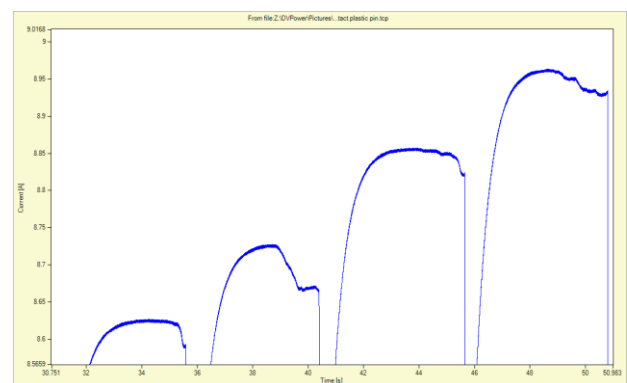

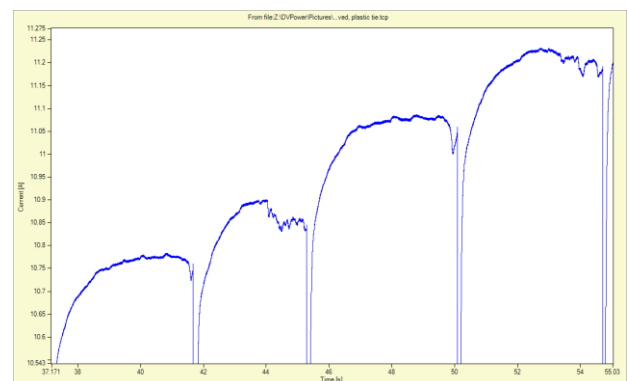**Figure 1.** DRM graph when the secondary side is open

Figure 2. DRM graph when the secondary side is shorted

Also, the ripple values (the current drop during tap change, expressed in percents) are higher when the secondary is shorted, which is important for DRM graph analysis. Below is a comparison when the secondary transformer side is open and when it is shorted. The table 1 shows the ripple value (%) in both cases, for open and shorted secondary sides for different test currents. The test object in this case was Getra power transformer, YN yn0 d11, 30/30/10 MVA, 130/46 /16 kV, 133,2/376,5/1079,2 A.
Note that shorted secondary transformer side is recommended for DRM test, and not for the static resistance test (measurement of winding resistance). If there is shorted secondary transformer side, the stabilization time of static resistance measurement can be very long.

Table 1. Comparison of ripple values when the secondary side is open and shorted

TAP	Ripple (%) Open secondary side				Ripple (%) Shorted secondary side			
	Test current				Test current			
	1 A	5 A	10 A	20 A	1 A	5 A	10 A	20 A
2	4,2	14,3	28,3	38,7	46,2	62,5	62,3	61,7
3	4	14	27,8	37,6	46,8	61,8	61,3	58,7
4	2,3	12,7	27	37,6	-	62,5	62,1	61,5

THREE-PHASE DRM

Getting three DC currents of approximately the same value through all three primary or secondary windings of a transformer is possible if these windings are connected in a wye configuration with neutral point accessible. This kind of DRM will be called three-phase DRM hereinafter.
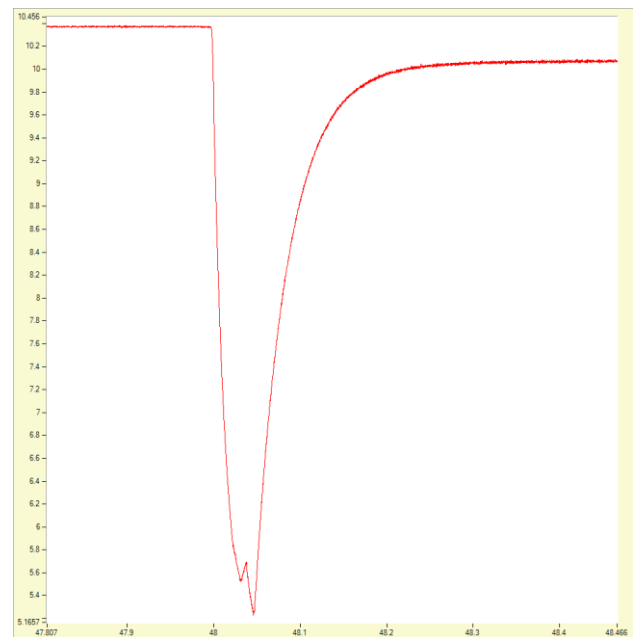

Figure 3. Single-phase DRM when the secondary is open

Comparison with single-phase DRM

Three-phase DRM test (DC current flows through all three phases in parallel) has very similar effects as the single-phase DRM with the shorted secondary side. The single phase DRM methodology was reported in [4,5,6]. The ripple value is significantly higher, compared with single-phase DRM for open secondary transformer side. The Figures 3 and 4 show transitions for both cases, single-phase DRM test (open secondary side) and three-phase DRM test (open secondary side), respectively. The ripple value for single-phase DRM test is 10%, while the value for three-phase DRM test is 40%. Comparing these values with the ones from the table 1, we can see a very important

relationship: the single-phase DRM results obtained with another windings short-circuited are comparable with the three-phase DRM results. This means that the appropriate single-phase DRM results obtained on a "healthy" OLTC can be used as a fingerprint for future three-phase DRM test results comparison.

It is easy to observe that the DC current recovery after transition is much faster for three-phase DRM test.

Figure 4. One phase of a three-phase DRM when the secondary is open

Tracing synchronization between phases

Another very useful feature of three-phase DRM test is measuring synchronization of the OLTC mechanism between phases. Any desynchronization between phases is easily visible on the DRM graph. The graph of a good OLTC synchronization is shown on the Figure 5. When there is a loss of synchronism, the transition resistor is introduced in one phase earlier than in another phase. The measurement current during an OLTC operation will then briefly increase in the path with the lowest resistance (i.e. the phase without transition resistors). [7] The Figure 6 gives an example: the current through the three phases is

shown at the moment when desynchronized OLTC operates. One phase switch prematurely, causing the current through the other two to increase. The Figure 6 shows that the phase C mechanism (yellow line) operates much earlier (around 100 ms) than other two phases, A (red line) and B (black line).
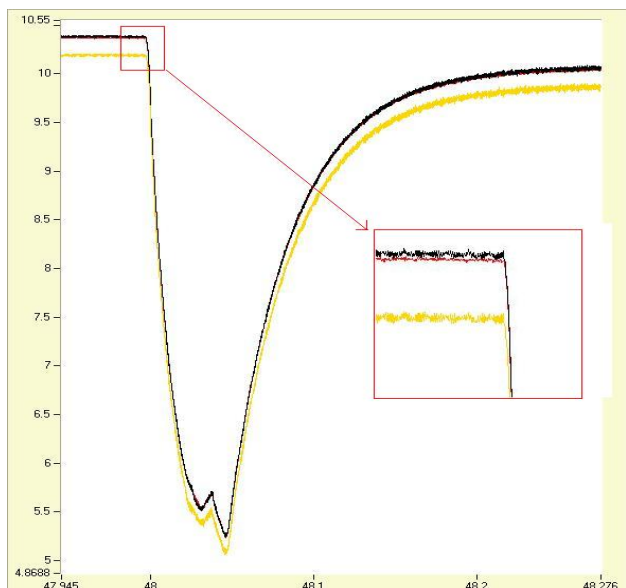

Figure 5. Example of a good synchronization

For the information about allowed delay time between phases, the recommendation is to contact the OLTC manufacturer.

DEMAGNETIZATION

It was shown [8] that inrush currents at power transformer start-up, calculated at the head of the feeder were reduced by about 60% when a transformer was previously demagnetized.

There are several methods which are used for the transformer core demagnetization. In general, to eliminate residual magnetism the opposite direction magnetic flux should be applied to the iron core. The flux is established by applying DC current through the winding. [9] In this way, static magnetic flux in the core is being added or subtracted (depending on the transformer previous state). By changing polarity and decreasing magnitude of the current, the static magnetic flux is reduced step by step. In other words, the operating point is being moved to the center of the B-H hysteresis loop, independent of the initial residual magnetic flux magnitude. [8]

One excellent way to verify that transformer is demagnetized is comparing the single-phase excitation current values for all three phases before and after the demagnetization. The demagnetization is considered successful if measured excitation currents are symmetrical and significantly lower than before demagnetization.

Aimed to identify the optimal three-phase transformer

demagnetization algorithm, three cases are considered: single-phase demagnetization of all three-phases, single-phase demagnetization of the middle phase only, and simultaneous three-phase demagnetization. The measurements were performed on 700 MVA, 410/17,5 kV, YNd11 power transformer. The referent excitation currents, recorded in demagnetized state, are shown in the Table 2.
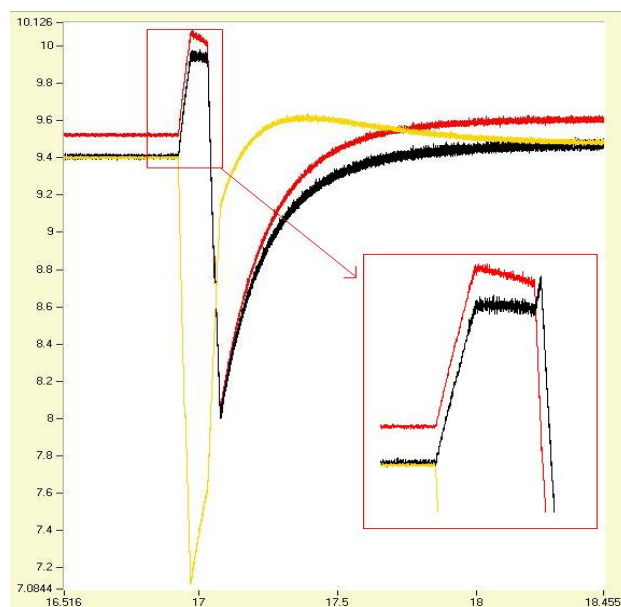

Figure 6. Example of a bad synchronization of phase C

Table 2. Excitation currents in demagnetized state

Phase	Excitation current
A	4,6 mA
B	2,7 mA
C	4,6 mA

Case 1 - Single-phase demagnetization of all phases

After the DC current test, the excitation current measurement was performed again. Increased and non symmetrical excitation current values indicated that the magnetic core resistance is also increased (Table 3). Therefore, the test confirmed the presence of residual magnetism.

Table 3. Excitation currents before and after demagnetization of all phases

Phase	Magnetized state	After demagnetization
A	6,4 mA	4,5 mA
B	5,3 mA	3,2 mA
C	6,2 mA	4,5 mA

All three phases are separately demagnetized. The excitation current (Table 3) showed successful demagnetization.

The confirmation of the method efficiency was in repeated tests; no matter how the core was magnetized, separate demagnetization of the transformer legs led to demagnetized transformer.

Case 2 - Single-phase demagnetization of middle phase only

In theory, it is expected that by injecting alternating current into the middle phase winding, the middle leg and outer legs should be affected by the alternating magnetic flux.

The transformer has been magnetized again with the DC current (Table 4).

Table 4. Excitation currents before and after demagnetization of middle phase only

Phase	Magnetized state	After demagnetization
A	7,0 mA	4,8 mA
B	3,3 mA	3,2 mA
C	4,2 mA	4,9 mA

The excitation currents, measured after the middle phase demagnetization, are shown in the Table 4. We can see that the outer phases are not completely symmetrical. The conclusion is that the middle phase demagnetization might not be sufficient to demagnetize the entire core, especially if only one outer phase has been magnetized.

Case 3 - Simultaneous three-phase demagnetization

The analysis and on-site testing showed that simultaneous three-phase demagnetization does not provide benefits in time or efficiency regarding the demagnetization process. On the contrary, generating three currents simultaneously through the windings can lead to unequal distribution of currents which could lead to unequal demagnetization levels for the core legs and, finally, inefficient demagnetization.

CONCLUSION

The reported new DRM method provides a great tool for diagnosing condition of OLTCs. So far, only single-phase DRMs have been performed on OLTCs. [4,5,6] Along the methods to detect various OLTC defects, like discontinuity, problems with diverter switch etc., the need for simultaneous three-phase DRM arose. Tracing synchronization of all three phases in all tap changer positions is a great advantage. That way one can make a complete OLTC condition assessment. Because a DRM graph is interpreted based on the fingerprint of similar units or previous test, it is important to establish a relation between single-phase DRM and a new three-phase result. Various field tests have shown that the relation between these two exists: a three-phase graph is comparable with

single-phase DRM recorded while another transformer winding is shorted.

The DRM leaves the iron core magnetized. The transformer needs to be properly demagnetized after any DC tests. The measurements of excitation currents showed that the most efficient process is to demagnetize all phases applying the single-phase method.

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