A NEW METHOD OF WINDING TURN DETERMINATION FOR WINDINGS OF POWER TRANSFORMERS

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Abstract: The number of turns of windings is one of the most important properties of transformers but can currently not be measured without using a magnetic core. To enable measurements in the production process of transformers a method is necessary which enables to determine this value without such a core. Therefore a new device was developed which is easy to handle, transportable and enables fast measurements with a sufficient accuracy. The functional principle of this technique is to inject a defined current in the device under test. The resulting magnetic field can be detected by an optical measuring device using the Faraday Effect. Thus the number of turns can be calculated, because the magnetic field strength is depending on the injected current and the number of winding turns. The properties of this method are documented and discussed using measurements on different types of windings and winding blocks with different sizes

1 INTRODUCTION

The number of winding turns is an essential property of windings, because this number defines the transformer turns ratio. Measuring the number of turns can be necessary in several situations during the production or/and the repairing of transformer. If a new transformer is under construction the number of turns should be measured before the winding is mounted on the core. When a transformer is being repaired, the number of turns has to be measured in the case the winding has to be rebuilt and the design drawings are not available. Today, the winding turn number can be measured only by the complex measuring methods like a test core. This method provides some disadvantages like its big size or the demand to put the device under test on the test core. Furthermore the accuracy is less due to the fact that the magnetic flux is not only in the magnetic core but also in the outside and can not be detected by the secondary winding. Therefore in this paper a new measuring device is presented which enables to decrease measuring time and increase the accuracy. [1]

2 FUNCTIONAL PRINCIPLE

According to the Ampere's circuital law, an electric current I_1 flowing through an electrical conductor causes a magnetic field H. This magnetic field can be analysed in an integral way as shown (1). If a current is flowing through a closed loop of length s, then the line integral of the magnetic density is equal to the total induction Θ which is simply the sum of all surrounded currents I_n – called total current I_{total}, like shown in (1).

$$\oint H ds = \Theta = \Sigma I_n = I_{total} = N I_1 \qquad (1)$$

Where:
- H — *Magnetic field intensity*
- ds — *Infinitesimal element of length*
- Θ — *Magneto motive force*
- I_n — *Current in a certain turns*
- I_{total} — *Total current*
- N — *Number of turns*

This is what can be done also with a transformer winding. If an electric current is injected in a winding with N turns, this current will flow through every turn of the winding and a magnetic field will be created. In case of the way of the line integral surrounds every turn one time then the measured magnetic field is proportional to the injected current and the number of turns.

If this magnetic field is expressed in term of total current the total current will be the product of the injected current and the number of turns. That is why the number of turns N can be calculated according to (2) by knowing the magnetic field, expressed as total current divided by the injected current I_1.

$$N = \frac{I_{total}}{I_1} \qquad (2)$$

Where: I_1 — *Injected current*

In order to find the number of turns in this way, a measuring device is needed which analyses the magnetic field and expresses it in term of total current. One possible measuring device for this application is the fibre optic current sensor – FOCS [2, 3].

The main part of this sensor is the fibre optic which surrounds an electrical conductor in an open loop [2]. This sensor has a high accuracy up to 0.1% and is available in dimensions needed to surround a transformer winding. Therefore, the FOCS fulfils the requirements, needed by the described application. Originally the sensor was developed to measure high DC currents up to 500kA [2]. The use of the sensor leads to the measuring set up shown in Figure 1. A known DC current is injected into the device under test and the optical fibre must surround every turn of the winding. The measurements of the total current and the injected current enable to calculate the number of turns according to (2).

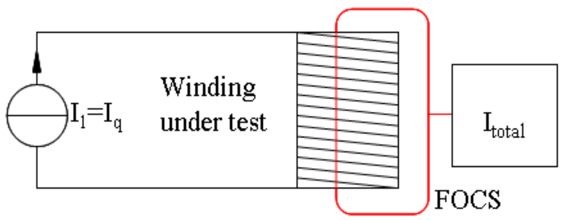

Figure 1: Measurement set up for winding turn measurements.

As discussed before that the total current is proportional to the injected current and the number of turns, so the turns ratio of an winding block can be measured as well. Therefore, a certain amount of known current is injected equally in the two windings and the resulting total current of both windings is measured. The turns ratio *TR* of these two windings with the numbers of turns N_1 and N_2 will be equal to the ratio of the measured total currents I_{total_1} and I_{total_2} as shown in (3).

$$TR = \frac{N_1}{N_2} = \frac{I_{total\_N1}}{I_{total\_N2}} \qquad (3)$$

Where: *TR*

I_{total_N1}	*Total current in reference coil*
I_{total_N2}	*Total current in winding under test*
N_1	*Number of turns of reference coil*
N_2	*Number of turns, winding under test*

Another application for this method is to verify an equal number of turns at windings with middle exits or parallel cables. An identical number of turns on such windings are important to avoid magnetic flux differences in both parts which would lead to additional currents in the winding.

To verify this, a separate measurement and comparison of parts is possible. The total current can be measured according to the blue loops in Figure 2. The results of both individual measurements can be compared – identical results are expected.

Due to the measurement principle, a second method can be applied. As shown in Figure 2, a current can be injected in a way that the magnetic field of both parts will be orientated in opposite direction. If the total current is measured as demonstrated by the red loop in Figure 2 the total current will be equal to 0. This second method is easier because only one measurement is needed.

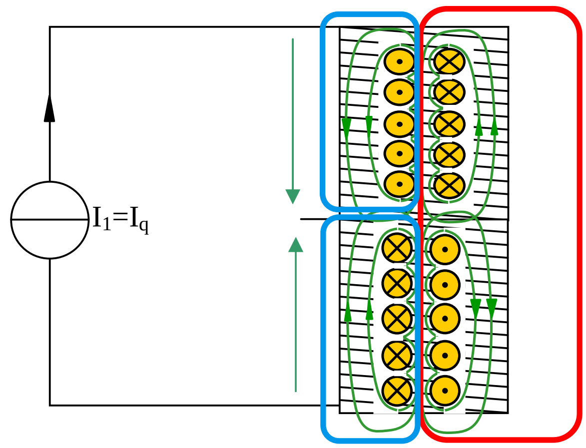

Figure 2: Measurement set up at windings with middle exits.

3 MEASURING RESULTS

To investigate the properties of the described measuring principle, a first measurement set up according to Figure 1 was built up. The setup included a winding block with several windings. The numbers of turns of each winding was known. The high voltage winding had 1120 turns, the low voltage winding had 200 turns. Furthermore, the FOCS for the measurement of the total current and the DC power source for the injection of known current were necessary.

First, the number of turns of the low voltage winding was measured several times. The error of every measurement must be smaller than 0.5 turns to detect the right number. It was observed that all the results were verified in these defined tolerances. This shows that the method is well practical to measure the number of turns.

As shown in Figure 3, also the measurement at the high voltage winding which had 1120 turns showed that the results are equal. However, in most cases the measured number of turns was 0.5 turns less than the rated one. Which is a small difference compared to the absolute rated value.

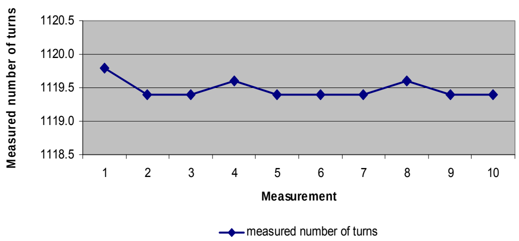

Figure 3: Measuring results: Number of turns of the high voltage winding.

Secondly, the turns ratio between high- and low voltage winding which is 1120 turns to 200 turns respectively 5.6 was measured several times. As shown in Figure 4, the nominal ratio of 5.6 was measured in every case with an error less than 0.05%. That shows that the turns ratio can be measured also very well.

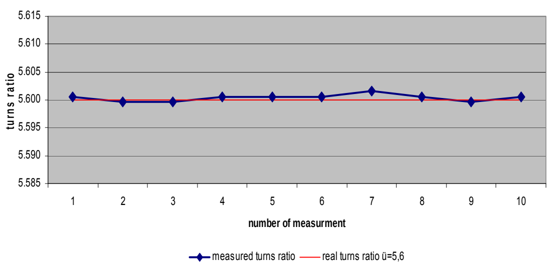

Figure 4: Measuring results: turns ratio between low- and high voltage winding.

By knowing this, the number of turns of a winding can be calculated by measuring the turns ratio of two windings, if the number of turns of one of the two winding is known and the same current is injected in both windings according to (4). Therefore a second winding in the optical way is needed. This can be other winding in a winding block or a special reference winding with a known number of turns. Knowing this a new advanced method is available if the accuracy of the measured value has to be improved.

$$N_1 = \frac{I_{total\_N1} * N_2}{I_{total\_N2}} \tag{4}$$

These both methods are compared in Figure 5. The blue curve shows the results which have been achieved by the normal calculation method according to (2) and the green ones by using the comparative method explained in (4). It can be observed, that the measurement values taken by using the normal method are approximately one winding less compared to the nominal number of turns. This high accuracy of better than 0.1% is because of the high nominal value of 1120 turns. But even this can be improved by the advanced method. Every result shows the right number of turns. [1]

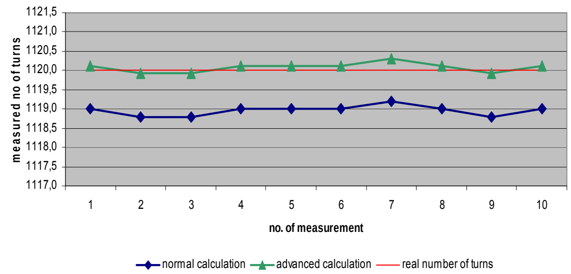

Figure 5: Comparison of the normal and advanced calculation method.

4 SET UP OF A MEASUREMENT DEVICE

By using the measurement principle, a device was developed to perform the measurements fast and easily. This device, shown in Figure 6, consists of a control cabinet including the DC power source -1- and a panel pc to control the measurement. Additionally a reference coil -2- is included to enable the advanced method also at single windings. The main part is the sensor fibre -3- which is protected against mechanical destruction by the sensor housing -4-. Using this device the sensor housing has to be put around the winding, the sensor fibre can be injected in its housing and the measurements itself can be controlled via the panel pc. The device is easy to handle and can be transported to the device under test easily. It is in use to check the right number of turns at windings of new power transformers as well as before delivering spare parts. Also it was used to measure the number of turns of windings which have to be replaced.

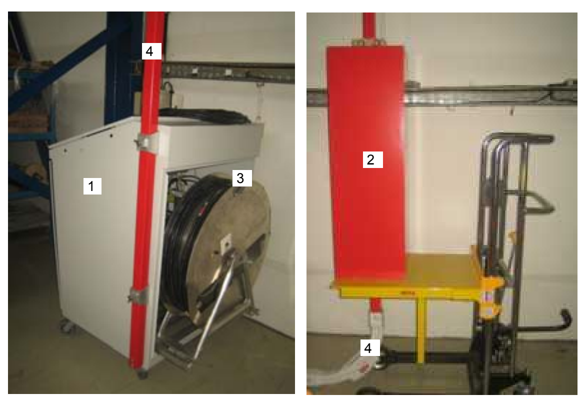

Figure 6: Measuring device

5 APPLICATIONS

The presented measuring device is currently in operation to measure the number of turns in all three described applications. The device is fully included in the production process of new winding in a transformer plant. It is also in use to measure the number of turns of windings which must be rebuilt. In one case a 250 MVA transformer with two active parts was in a transformer service plant not only to rebuild the windings but also to do a power upgrade. Thereby it was elementary necessary to know the number of turns of every winding to design an exact copy. It took only one day for two persons to determine the number of turns of all windings. The several numbers of turns were in a range between 125 and 800 turns. Also to verify the accuracy of windings as spare parts the device was used in the past. It is common to document the properties of such a kind of windings before transportation to the customer's plant or on site. Therefore the new device is in use, as it is shown below in the Figure 7. The set up can be done easily: After the sensor housing -1- is mounted on the winding -2- and the sensor fibre was injected the test can be done. For each measurement the reference coil -3- is included in the set up. [1]

Figure 7: Measuring device in use

In many cases the winding turns measurement is performed for whole winding and for all different taps e.g. tapings for the OLTC. In case of windings with middle exits a measurement of the total current is always performed to ensure an equal number of turns.

6 CONCLUSION

The use of the presented measuring device enables to measure the number of turns of transformer windings with the high accuracy.

Additionally the ratio of a winding block can be estimated with the accuracy as discussed in 3 which enable to fulfil the requirements regarding the transformer ratio of IEC 60076-1 [4].

Therefore it is possible to avoid additional work in the case of wrong number of turns of new windings.

The use of the presented technique makes it possible to improve the design process in a transformer repair shop by detecting the numbers of turns of windings which have to be remanufactured.

Because of the dimensions of the sensor almost every size and kind of winding can be investigated. It is also possible to save space in the work-floor compared to other methods of winding turn measurements because of its small size and the possibility to bring the measuring device to the test object.

The described method was successfully applied in more than 50 measurements at different windings and winding types. The numbers of turns varied in a range between 14 and more than 1600 turns. By comparing the measured value to the rated one it was observed that in almost every case both values were similar. Also windings with a measured value of more than 1600 turns show a difference smaller than 0.2%. Therefore the presented new method can be used for different applications in the new production for the quality issues and especially for the repair purposes on power transformers.

7 REFERENCES

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[4] IEC 60076-1 (2.1) 2000-04: Power Transformers: Part 1: General