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A Practical Example of Power Transformer Unit Winding Condition Assessment by Means of Short-Circuit Impedance Measurement

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Abstract--Knowledge of the short-circuit impedance variation is necessary for verifying the observance of the technical conditions (including the design conditions), certain nonconformities in the winding execution, checking the winding behavior in operation, verifying the system and short-circuit calculation (including the correct protection setup), the loading of the same type units, or more importantly, of the different type ones.

The measurement of the short-circuit impedance by means of a three phase low voltage power source can be performed as the value of impedances does not depend on the applied voltage. A modern measurement system has been developed and used for performing a great amount of measurements, the results of which have been compared with those of the manufacturer's, and with those obtained by means of high voltage measurements.

At the end of the paper a case study regarding a short-circuit event on a 250 MVA power transformer unit is presented. A baby hawk landed with his wings spread on the tertiary winding bushings causing a three-phase short-circuit that damaged the power transformer unit. The short-circuit impedance measurements that have been performed clearly indicated the mechanical failure of the power transformer unit.

***Index Terms*—maintenance, power transformer, short-circuit impedance, virtual instrumentation.**

I. INTRODUCTION

THE international standards [1] establish certain conditions for the transformer unit short-circuit impedance measurement on the rated tap, on the first and last taps of the on-load tap changer. In order to perform system calculations and adjust the system protections it is necessary to know the values of the short-circuit impedances on each tap, especially then when the variation range is relatively wide.

This becomes imperative when the operation of two different type transformer units connected in parallel is analyzed.

The short-circuit impedance measurement is a method that has been also used for diagnosing the winding state on site and it is utilized as such in the maintenance activity. It has been included in the norms in force, but it has not been applied until now due to the difficulties encountered due to the measurements at low and highly fluctuating voltages.

As a result of the research that has been carried out so far an operative highly efficient measurement system has been developed. By means of this measurement system a large amount of measurements have been performed whose results have been afterwards compared with those calculated by the designer and with those measured at voltages close to the short-circuit ones by the manufacturer (there, where these measurements have been made on all the on-load tap changer taps – OLTC).

II. LOW VOLTAGE SHORT-CIRCUIT IMPEDANCE MEASUREMENT

The low voltage short-circuit impedance measurements made by means of a low voltage three phase power source can be performed because the value of the impedance does not depend on the applied voltage.

The low voltage short-circuit impedance measurement requires utilization of highly accurate instrumentation on the one side, and elimination of the errors caused by the fluctuations of low voltage power networks due to welding equipment, etc., on the other.

In order to carry out these measurements the diagram presented in Fig. 1 has been developed. The diagram uses a data acquisition and processing system (DAQ) that enables the evaluation of the measured data, the short-circuit impedance variation curve plotting on the spot, Fig.3, as well as the subsequent processing of the data obtained. The processing system also corrects the data with the supply voltage frequency variation.

The measurements are being made between each two transformer windings. One winding is powered from the measurement schema; the second one is short-circuited, while the third winding of the power transformer unit is left open.

In figure 1, A_1, B_1, C_1 are the terminals of the primary winding which, for the power transformer units considered, is the high voltage winding (HV), A_2, B_2, C_2 are the terminals of the secondary winding which, for the considered power transformer units, is the low voltage winding (LV), and a, b, c are the terminals of the tertiary winding (T).

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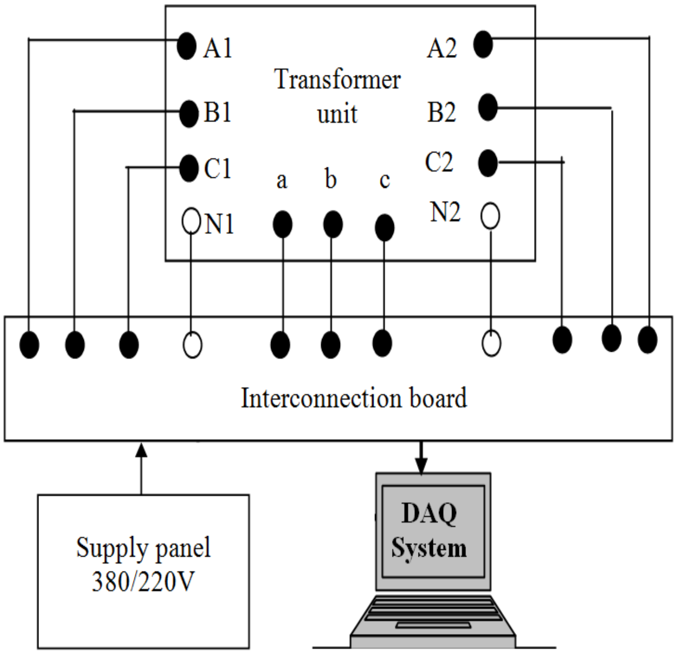


Fig. 1. The block diagram for the short-circuit impedance measurement at low voltages

In this manner the measurements are performed for the following configurations:

- HV-LV which means that the high voltage winding is powered and the low voltage winding is shorted, while the tertiary winding is left open;
- HV-T which means that the high voltage winding is powered and the tertiary winding is shorted, while the low voltage winding is left open;
- LV-T which means that the low voltage winding is powered and the tertiary winding is shorted, while the high voltage winding is left open.

The software application, whose user interface is presented in Fig. 2, has been developed by means of virtual instrumentation using the LabVIEW programming environment [4, 5, and 6].

The user sets the tap from which the measurements start and the direction variation of the taps. Thus, the software application changes the position of the tap automatically after each measurement, according to the selected direction without requiring the user's intervention.

The measured quantities are: the three phase voltages and currents that are displayed both in analogical (gauge) and digital forms to offer complete information on them (both quantitatively and qualitatively). The short-circuit impedance values are displayed for each phase and then their total value is also displayed.

The measurement ranges can be selected from the bottom of the user interface. Thus, the user can choose the measurement by means of the 5A shunts or by means of the current transformers with different types of measurement ranges (5A, 10A, 25A). This gives an accurate measurement of the quantities. If the measured quantities (voltage or current) exceed the measurement range selected by the user, the application warns the latter that he has to switch to a higher range.

This is also the area of the interface where the indicator signaling a possible data saving error can be found.

The table where both the measured and the calculated data are recorded is in the upper right side of the user interface. Below this table a plotting area for the short-circuit impedance (Y axis) graphic representation with the tap position (X axis) is located.

The pushbuttons enabling the table data saving in an EXCEL type file, deletion of certain measurements from the table, insertion of the measured parameter values in the table, as well as the application closing are situated in the lower right side of the user interface.

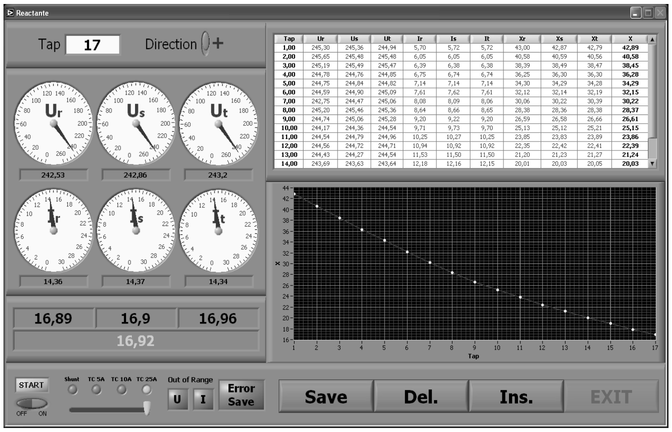
The curves in Fig. 3 point out a good match between the values measured in the factory for a 4000 MVA transformer unit (using a high voltage power source) and the measurements carried out in a substation (using a low voltage power source).

For calculating the short-circuit impedances the designer can use both the analytical formulas and the specially developed calculation programs.

The analytical formulas [7] are more rapid but they consider only two windings through which the current flows. Consequently, the adjustment can be calculated only by coarse approximations.

A more precise method, nevertheless requiring a greater calculation effort, presupposes the determination of the equivalent diagram with the transformer short-circuit parameters concentrated.

The first step consists in determining the own and mutual inductances and winding resistances on the basis of the input data (transformer geometry) [8]. The longitudinal and transversal capacitances can be also calculated although they are not relevant at low frequencies. If the calculation of the ohmic resistances is simple, inductance determination requires the electromagnetic static field calculation in the transformer window. For this there are both analytical solutions and calculation programs utilizing the finite element calculation method.



Tap 17
Direction +

242,53
242,86
243,2

14,36
14,37
14,34

16,89
16,9
16,96
16,92

Tap	Ur	Us	Ut	Ir	Is	It	Xr	Xs	Xt	X
1,00	245,30	245,36	244,94	5,70	5,72	5,72	43,00	42,87	42,79	**42,89**
2,00	245,65	245,48	245,48	6,05	6,05	6,05	40,58	40,59	40,56	**40,58**
3,00	245,19	245,49	245,47	6,39	6,38	6,38	38,39	38,49	38,47	**38,45**
4,00	244,78	244,76	244,85	6,75	6,74	6,74	36,25	36,30	36,30	**36,28**
5,00	244,75	244,84	244,82	7,14	7,14	7,14	34,30	34,29	34,28	**34,29**
6,00	244,59	244,90	245,09	7,61	7,62	7,61	32,12	32,14	32,19	**32,15**
7,00	242,75	244,47	245,06	8,08	8,09	8,06	30,06	30,22	30,39	**30,22**
8,00	245,20	245,46	245,36	8,64	8,66	8,65	28,38	28,36	28,38	**28,37**
9,00	244,74	245,06	245,28	9,20	9,22	9,20	26,59	26,58	26,66	**26,61**
10,00	244,17	244,36	244,54	9,71	9,73	9,70	25,13	25,12	25,21	**25,15**
11,00	244,54	244,79	244,96	10,25	10,27	10,25	23,85	23,83	23,89	**23,86**
12,00	244,56	244,72	244,71	10,94	10,92	10,92	22,35	22,42	22,41	**22,39**
13,00	244,43	244,27	244,54	11,53	11,50	11,50	21,20	21,23	21,27	**21,24**
14,00	243,69	243,63	243,64	12,18	12,16	12,15	20,01	20,03	20,05	**20,03**

Fig. 2. The window application for the short-circuit impedance measurement

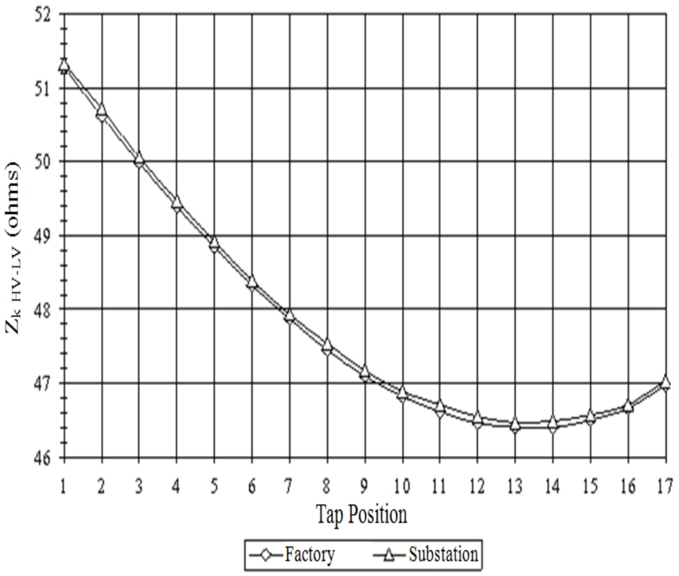


Fig. 3. Comparison between the factory (high voltage) measured values of the short-circuit impedance variation Z_k with the tap position and ones measured

The second step is the generation of the node and side matrices of the equivalent circuit for the tested configuration. In the case of the three phase short-circuit the equivalent diagram can be simplified to a single phase one. In this case, the nodes are earthed, the terminals are connected to the power source and the windings are short-circuited according to the short-circuit diagram. All the circuit elements are correspondingly arranged as matrix and vectors. The system inversion leads to the voltage determination in the circuit nodes, and short-circuit voltage between different pairs of windings (if there are any), respectively, as a function of the on-load tap changer position.

By means of this method the influence of the tap variation on the leakage flow in the transformer window and the short-circuit impedance variation, respectively, are considered.

III. CASE STUDY

The following example presents a case study regarding a short-circuit incident on a 250 MVA power transformer unit.

A baby hawk landed with his wings spread on the tertiary winding bushings causing a three phased short-circuit.

After the event the first investigations that were performed on the power transformer unit condition consisted in the short-circuit impedance measurement. The measurements have been performed according to the schema and configurations presented in this paper. The values that have been obtained were compared with the ones that have been obtained from the same measurements that were performed one year before the event.

The measured values in HV-LV configuration are presented in Fig. 4. From this image there results that the values measured before and after the event on each tap position are almost identical. This proves that there is no mechanical displacement between the primary (HV) winding and the secondary (LV) winding of the power transformer unit.

The values measured in the HV-T configuration are presented in Fig. 5. In this case the difference between the values measured before the event and the ones measured after the event are important (about 50%). This proves that there is a mechanical displacement between the primary (HV) winding and the tertiary (T) winding of the power transformer unit.

The values measured in the LV-T configuration are presented in Fig. 5. In this case the difference between the values measured before the event and the ones measured after the event are even more important than the ones from the HV-T configuration (about 130%). This proves that there is also a mechanical displacement between the secondary (LV) winding and the tertiary (T) winding of the power transformer unit.

From all these measurements a final conclusion can be clearly drawn, namely that the tertiary winding was seriously damaged due to the short-circuit forces. There is no need to further investigate the situation by means of other methods.

The conclusion mentioned above was confirmed when the power transformer unit was opened in the repair shop. The tertiary winding had shrunk and was irreparably damaged.

IV. CONCLUSIONS

The short-circuit impedance measurement between all the winding pairs and by each position of the on-load tap changer is imperiously necessary for:

- verifying the observance of the technical conditions, the designed ones included;
- verifying the possible nonconformities in the winding manufacturing;

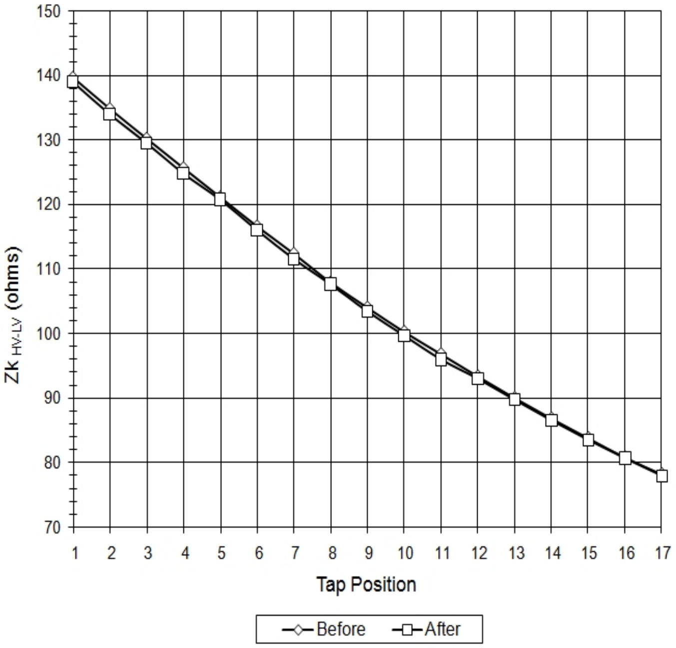


Fig. 4. Comparison between the measured values of the short-circuit impedance variation Z_k with the tap position before and after the event for the HV-LV configuration

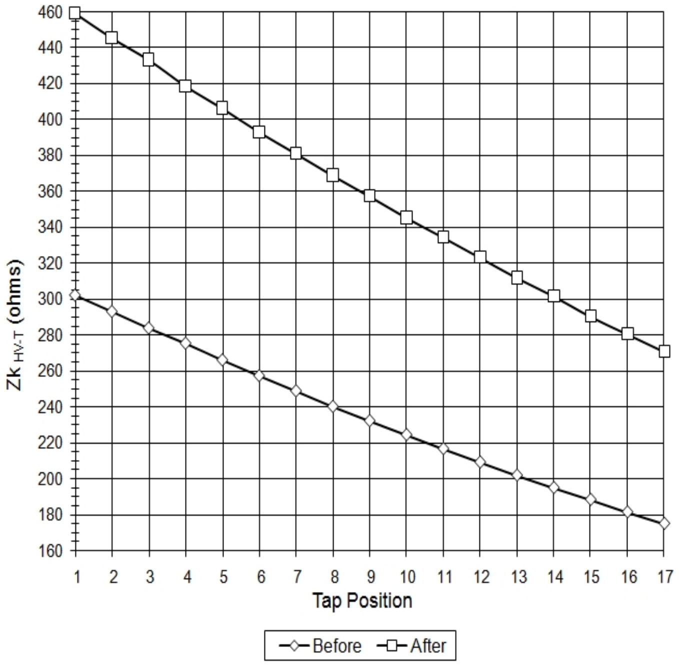


Fig. 5. Comparison between the measured values of the short-circuit impedance variation Z_k with the tap position before and after the event for the HV-T configuration

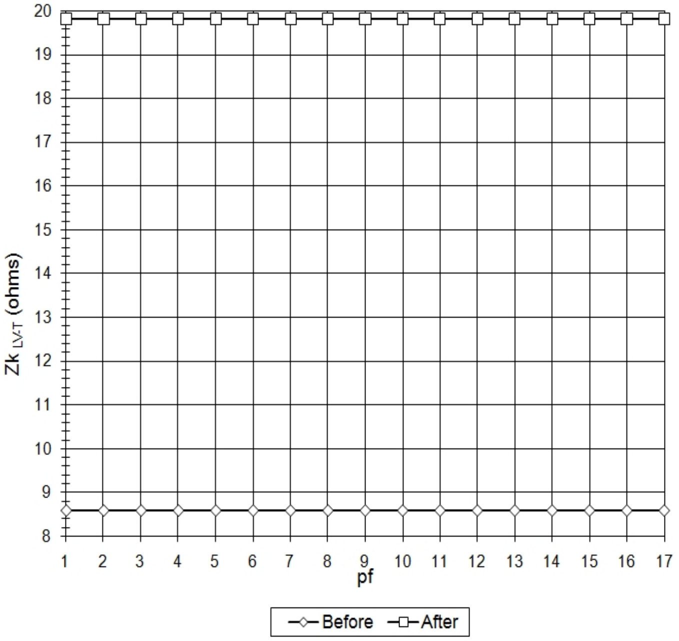


Fig. 6. Comparison between the measured values of the short-circuit impedance variation Z_k with the tap position before and after the event for the LV-T configuration

- verifying the behavior of the winding operation on site (the measurement is performed in agreement with the norms in force);
- carrying out the system calculations and the short-circuit ones (including the correct protection regulation);
- verifying the loading of the same type, as well as of different type transformer units.

The short-circuit impedance measurement can be performed by connecting the measurement installation to a low voltage (380/220V) source provided that highly accurate instrumentation enabling the automatic data processing is used.

The developed measurement installation enables a quick and precise on-site measurement of the short-circuit impedance of the national power system transformer units.

The presented case study proves that this method can be effectively used for the on-site assessment of a possible winding damage due to a short-circuit incident. This method is faster and more cost-effective than other methods, providing a clear result that enables the user to quickly draw a conclusion on the power transformer unit winding condition.

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VI. BIOGRAPHIES

Traian Chiulan received the M. Sc. degree in electrical engineering in 2005, at the Polytechnic University, Bucharest, Romania. He is currently pursuing the Ph. D. degree.

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