SFRA, transformer, diagnostic, loss factor, insulation resistance, capacity

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DIAGNOSTIC MEASUREMENTS OF 3-PHASE 25MVA TRANSFORMER AND THEIR ANALYSIS

This paper describes measurements of 25 MVA transformer, which is operated by company SSE a.s. in substation Handlova, by diagnostic methods like Sweep frequency response analysis (SFRA), measurement of capacity and loss factor tanδ, and insulation resistance measurement.

1. INTRODUCTION

The transformer, which is described in this paper has been problematic since the beginning of its operation. During periodic tests performed by SSE a.s., the transformer oil samples have been withdrawn and measurements of windings resistance, insulation resistance, loss factor, capacity and transformer ratio have been made as well. In comparison with other transformers, values of insulation resistance are very low, but still in range given by the standard STN 35 1090. According to this norm, minimal insulation resistance for 110 kV transformer should be 330 MΩ, for 220 kV it should be 660 MΩ, and so on. In this paper, the results of following measurements are stated as follows:

- SFRA – Sweep Frequency Response Analysis by DOBLE M5100.
- Measurement of insulation resistance by MEGGER MIT 520.
- Measurement of loss factor tanδ and capacity by MIDAS 2880.

Parameters of measured transformer are stated in following table.

Tab. 1. Label data of transformer

Substation, title of transformer	SSE a.s. Handlová, T101
Manufacturer	Škoda
Year	2001
Type, connection	ER 31M-0, YNyn0/d5
Frequency	50 Hz
Nominal voltages	110 / 23 / 6,3 kV
Nominal power	25 / 25 / 8 MVA
Position of tap switch	13
Temperature of transformer	58 °C
Date of measurement	August 24, 2011

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2. MEASUREMENT OF TRANSFORMER BY SFRA METHOD

Sweep frequency response analysis (SFRA) is a method which can indicate a damage or change in the winding or in the core of transformer. The fundamentals of this type of measurements is to supply input winding of transformer by low voltage frequency impulses and the response in output winding is figured as an amplitude frequency characteristic. The responses to change of frequency depend on total impedance of transformer. The impedance of transformer depends on the resistivity of windings, its own, mutual and leakage inductance and the capacity of windings given by transformer design. The changes of frequency responses measured by SFRA determine if any mechanical changes in the windings occurred and the need of defect investigation. The most significant defects in the windings occur during often short-circuit operation and high current stress, which can lead to axial or radial deformation. The forces in the winding can cause a radial shift and consequently axial deformation of winding. In the case of higher forces in the winding the radial or axial shift can occur. We have to respect forces in radial direction during the design of core of transformer. It is needed to consider the importance of the radial forces, which act towards the tank in the axial direction and are most important for the type of transformer distortion determination.

It is possible to detect he changes or deformations in the windings of transformer which lead to changes in internal inductance and capacitance by external low-voltage impulse method (FRA – frequency response analysis).

FRA (SFRA) methods are useful to detect:

- Deformation or shift in internal winding
- Damage in interconnect structure
- Problem in connection between core and ground wire
- State of tap changer.

Measurement methodology results from Tab. 2.

Tab. 2. Table of SFRA measurements

1. Open Circuit Tests						
110 kV			**23 kV**			**6,3 kV tert. winding**
Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
1U-1N	1V-1N	1W-1N	2U-2N	2V-2N	2W-2N	3U2-3W1
2. Short Circuit Tests						
Shorted 2U-2V-2W (ssek)			**Shorted 1U-1V-1W (spri)**			
Test 8	Test 9	Test 10	Test 11	Test12	Test13	
1U-1N	1V-1N	1W-1N	2U-2N	2V-2N	2W-2N	

Following picture illustrates measured frequency characteristics in case of Open circuit tests.

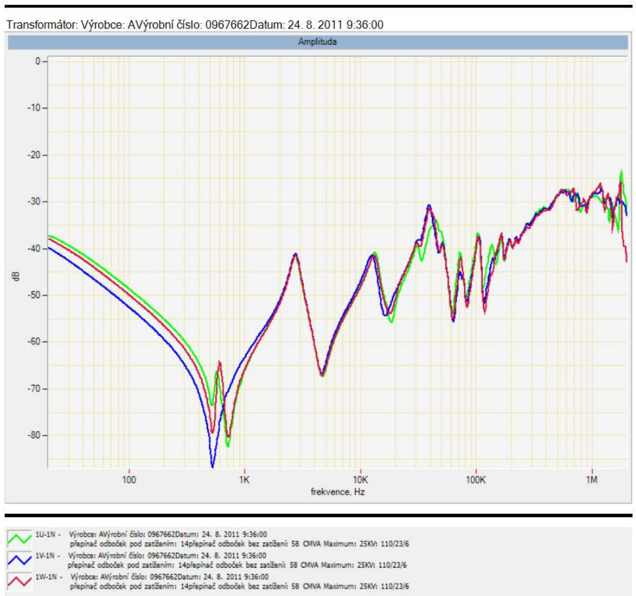

Fig. 1. Frequency characteristics of primary windings – open circuit test

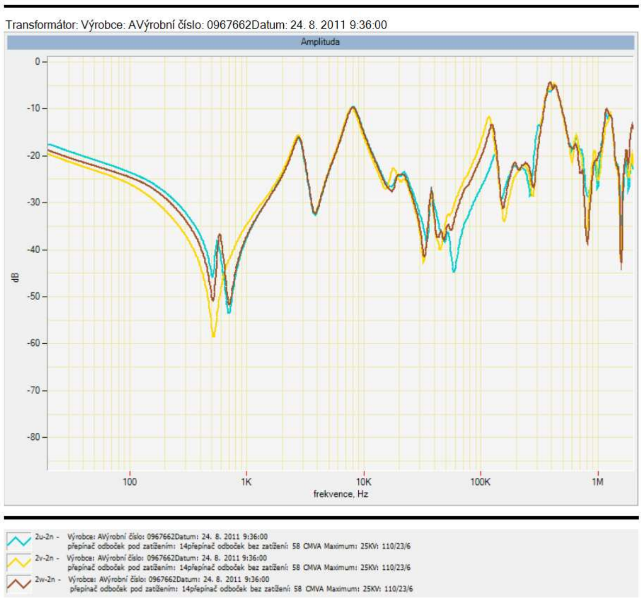

Fig. 2. Frequency characteristics of secondary winding – open circuit test.

We consider the measured frequency characteristics to be a reference one, and future measurements will be compared by cross correlation coefficients analysis [1].

3. INSULATION RESISTANCE MEASUREMENT

The insulation resistance describes a basic properties of whole insulation system, which is in this case created by transformer oil ITO 100 and by insulation paper. The deterioration of insulation properties is for example caused by: temperature, time, oxygenation, humidity, and so on. These factors are also related to the operation of transformer (its loading). One of the basic prophylactic diagnostic method is measurement of insulation resistance. It is performed according to the standard STN 35 1090. We used a Megger MIT520 for insulation resistance measurements. Measured values are in Tab. 3, and for polarization index p_i calculation we used following equation:

$$p_i = \frac{R_{60}}{R_{15}} \tag{1.1}$$

where: R_{60} is insulation resistance after 60 s at test voltage,
R_{15} is insulation resistance after 15 s at test voltage.

Since measured transformer was in operation before measurement, its temperature was 56°C, thus i tis necessary to recalculate values for temperature 25°C. According to the table, which is referred in the standard STN 35 1090 for insulation resistance recalculation, we used the coefficient K1=3.55. By using coefficient K_1 the recalculation is done as follows:

$$R_{25} = K_1 \cdot R_{60} \tag{1.2}$$

Test voltage was 2500 VDC. The negative pole of measurement equipment was connected to the cord body.

Tab. 3. Measured and recalculated values of insulation resistances of transformer T101.

Winding	R_15/R_60 [MΩ]	pi	R_25 [MΩ]
110-23+6,3+k	280/414	1,47	1469,7
23-110+6,3+k	250/413	1,65	1466,15
6,3-110+23+k	252/519	2,05	1816,5
110+23-6,3+k	200/290	1,45	1029,5
110+23+6,3-k	190/283	1,48	1004,65

The values of insulation resistance for each individual combination of connection during measurement, after recalculation, are in accordance with standard. However, in comparison of this type transformer with other transformers, values are much smaller. The insulation resistance values of these types of transformers are in the range from 4GΩ to 9GΩ. The values of insulation resistance are shown in Tab. 4. and are obtained from measurement database of SSE Inc.

Tab. 4. Measured and recalculated values of insulation resistances of transformer T101, date: June 4, 2007

Winding	R_15/R_60 [MΩ]	pi	R_25 [MΩ]
110-23+6,3+k	304/500	1,64	1440
23-110+6,3+k	290/700	2,41	2016
6,3-110+23+k	304/975	3,2	2808
110+23-6,3+k	270/372	1,37	1071
110+23+6,3-k	183/292	1,59	840

There are some changes in insulation resistance values R_{25} in comparison with values obtained 4 years ago, they are caused by degradation of transformer insulation parameters.

By measuring of loss factor tanδ and capacity we can find out more about insulation state of this transformer.

4. MEASUREMENT OF LOSS FACTOR TANδ AND CAPACITY BY MIDAS 2880

Factors like temperature, humidity, time, power loading of transformer, which affecting insulation system, causes its aging. These impacts increase working temperature of transformer and this fact causes chemical reactions in insulation increasing, and thus also degradation of insulation electrical characteristics. The loss factor gives information about overall condition of insulation. Humidity is affected by solid and liquid portion of the dielectric and it indicates whether the insulation system is aged or wet.

The measurement of capacity and loss factor is relatively simple way of repeatable condition of insulation state monitoring. The defined limits of loss factor, related to a specific type of electrical equipment, have been based on a number of statistical data. The loss factor was calculated and the results were adjusted by comparing the energy values at voltage10 kV and temperature 20 ° C.

The loss factor tanδ is total energy, which is lost by current flowing through resistive component of insulation

$$\tan\delta = \frac{1}{\omega . C . R} \tag{1.3}$$

It is possible by measuring of loss factor to monitor: chemical degradation, contamination by water, oil condition, leakage through cracks and on surface and ionization.

Our measurement was made by measurement system MIDAS 2880 which is owned by SSE Inc. The measurement system MIDAS 2880 is based on method of double vector-motor, where two currents are measured. The current I_N is flowing through reference capacitor C_N and the current I_X is flowing through measured object which is understood like capacitor C_X (Fig. 3) [2].

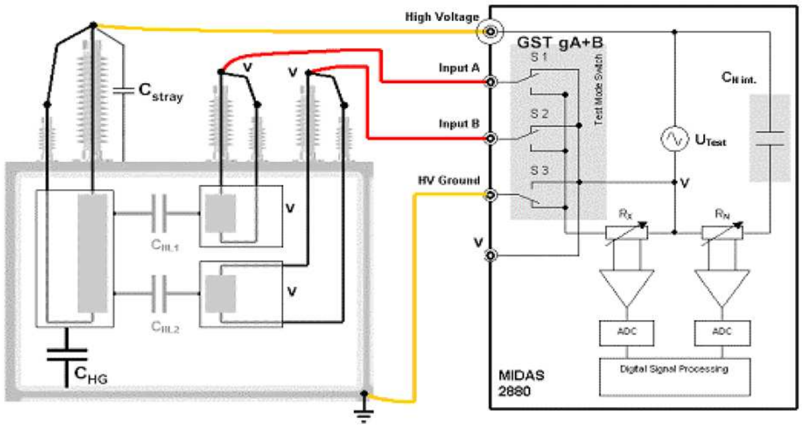

Fig. 3. The principle scheme of 3-phase, 3-windings transformer YNynd . [2]

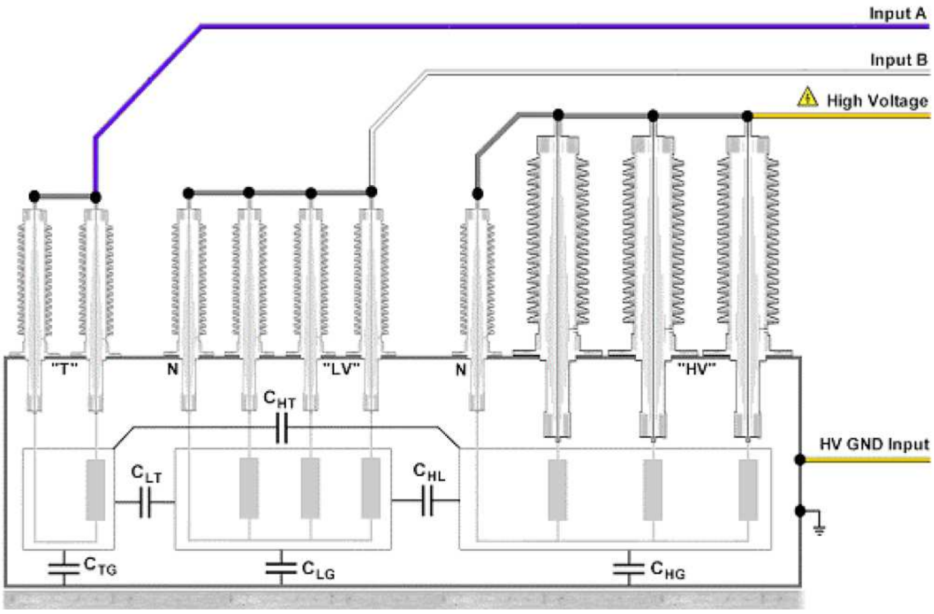

Fig 4. The scheme of measured transformer with figuration of individual measured capacity. [2]

The results of measurements are stated in Tab. 5, and measured individual capacities are shown in Fig 4.

Tab. 5. The values measured by MIDAS 2880

Seq.	Measured	INPUT A	INPUT B	INPUT HV GND	Test Mode	VN
1.	C_{HT}	T	LV	GND Transformer tank	UST A	HV
2.	C_{HG}	T	LV	GND Transformer tank	GST gA+B	HV
3.	C_{HL}	T	LV	GND Transformer tank	UST B	HV
4.	C_{LG}	T	H	GND Transformer tank	GST gA+B	LV
5.	C_{TG}	HV	LV	GND Transformer tank	GST gA+B	T
6.	C_{LT}	HV	LV	GND Transformer tank	UST B	T
7.	$C_{HG}+C_{LG}+C_{TG}$	-	-	GND Transformer tank	GST gA+B	HV+LV +T

Seq.	U rms	DF (tan δ)	DF%(tan δ)@20°C	Cp(Zx=Cp//Rp)	Frequency
1.	10,2 kV	-0,0072	-0,15 %	58,84 pF	49,99 Hz
2.	10,0 kV	+0,0124	+0,26 %	2,863 nF	49,99 Hz
3.	9,96 kV	+0,0058	+0,12 %	5,957 nF	49,99 Hz
4.	9,97 kV	+0,0174	+0,37 %	1,125 nF	50,00 Hz
5.	10,0 kV	+0,0082	+0,17 %	9,656 nF	49,99 Hz
6.	9,97 kV	+0,0064	+0,13 %	10,42 nF	50,02 Hz
7.	10,1 kV	+0,0100	+0,21 %	13,65 nF	50,02 Hz

5. CONCLUSIONS

Referred to the low values of insulation resistances for different combinations of winding connections (phase U in Tab. 3, at U-ground measurement, the value is the lowest) measurements, and by comparison of SFRA characteristics for open circuit methodology (Fig. 1), we can assume that there could be an axial displacement of the primary winding because of the small differences between the waveform of the first and third phase (U, W). According to the past experience and measured SFRA characteristics of about 30 110/23 kV transformers, these waveforms should theoretically be equal. But these are only assumptions, since each transformer has its unique geometric arrangement, given by its production. We can conclude, based on capacity and loss factor measurements that insulation system has little humidity and the measured values conform to the standards for operation. However, one value of the measured capacity is lower by about half, compared with the capacities of other transformers of the same type. It is capacity between primary and tertiary windings C_{HT}. The values of this capacity are in most cases higher than 120 pF. Also the value of the loss factor tan δ has negative value. The same negative value of the loss factor we get at the repeated measurements, which lead us to question why the results of measurements are the same. The issue is complex and unable to answer it clearly, either measurement system poorly evaluated measured value (even if the measurement was repeated with the same result), or there is a hidden fault in the vicinity of transformer primary winding. Based on the measured results, we recommend the repeating of insulation resistance and loss factor detailed measurements. We will recommend this transformer stand off and to put it to detail control and revision in the case of repeatedly measured values.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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