IDENTIFICATION OF THE BREAKDOWN AND ANALYSIS OF TRANSFORMER 22/0.4 KV

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Resume

The paper deals with the identification of the breakdown of the transformer withdrawn from operation because of repeated reaction of transformer protections. Successively the transformer was put of operation, removed from the distribution and put to diagnostic measurements. For identification of the failure were used diagnostic methods, e.g. Sweep Frequency Response Analysis (according to IEC 60076-18), measurement of winding resistances, measurement of isolation resistances and capacitances. The results were compared with reference measurements.

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1. Introduction

Distribution transformers are equipments used in the long term in the uninterrupted 24 hours operation. Such transformers are dismounted only at a planed service operation, or at a fault condition. The possibility of measurement of parameters by prophylaxis measuring, as insulation resistance, turn ratio, and transformer winding resistance arrive only in these two cases. Back into operation is put only the transformer qualified for operation standards. We have performed on such transformer withdrawn from operation for reaction of protections the mentioned diagnostic measurements, which showed small differences in values at the winding resistance and turn ratio. These measurements have pointed out on the defect in the tap switch. On the basis of these assertions the transformer was put to measurement and analysis by SFRA (Sweep Frequency Response Analysis).

SFRA theory is a method which can indicate some damage or change in the winding or in the core of the 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 displayed as an amplitude frequency characteristic. The frequency response change depends on total transformer impedance, which depends on the equivalent circuit parameters of transformer: primary and secondary resistances of windings, magnetizing, leakage inductance and the capacity of windings given by transformer design. The changes in frequency responses measured with SFRA determine if any of mechanical changes in the windings occurred and if investigation of defect is needed. The most significant defects in the windings can occur during often short-circuit operation and high current stress, which can lead to axial or radial deformation. The forces in the windings can cause radial shift and consequently axial deformation of windings. During the design of transformer core have to be respect forces in radial direction, but considering the case of the forces position in axial way are more important. [2, 3] This difference is the most useful to identify a defect of transformer.

2. Measured Transformer

As it was mentioned in the introduction, the transformer (Nameplate Data in Tab. 1, Fig. 1) was withdrawn from operation for the reason of repeated transformer switch - off by over - current and differential protection.

Table 1

Nameplate Data.

Manufacturer	BEZ, v.č. 212875
Year of manufacture	1981
Type	aT0354/22
Connection	Dyn1
Frequency	50 Hz
Nominal voltage	22/0,4 kV
Nominal power	400/400 kVA
Position of tap switch	1
Temperature of transformer	21 °C

Fig. 1. Tested Transformer.
(full colour version available online)

The transformer was in 2011 subject to the planed repair work, when the bushings, conductor leads to bushings on it were exchanged, and the insulation between the transformer container and bushings conductors was made complete for reason of electric strength rising. The mechanic tap changer was cleaned and the transformer was filled up with the new transformer oil ITO 100. The transformer passed tests through the applied voltage 35 kV, and values of insulation and winding resistance met all requirements for approval and introduction the transformer into operation. After approximately annual operation the protections on the transformer reacted and successively the operator shut it down and transferred it to the testing workplace in Sučany. Here repeatedly the values of the insulation resistances were measured with the measuring instrument MEGGER MIT520, of the effective winding resistance with the measuring instrument MEGGER 830280 and the test with the applied voltage by means of portable testing apparatus High Voltage model ALT-120/60F 50 Hz. The measured values of the isolation resistance are given in Tab. 2 and the values of the effective resistances in Tab. 3.

Table 2

Measured values of the isolation resistance after the transformer withdraw from operation.

Connection	R_{iz}[GΩ]
VN-NN+k	10,10
NN-VN+k	7,20
VN+NN-k	8,24
VN-NN	12,60

Table 3

Resistance of windigs – tap position 3 (centre) after the transformer withdraw from operation.

Primary winding			**Secondary winding**		
A-B	**B-C**	**C-A**	**a-n**	**b-n**	**c-n**
9,66 Ω	9,63 Ω	8,67 Ω	2,26m Ω	2,29m Ω	2,39m Ω

It emerges from the measured values that the transformer satisfies the conditions for operation, but after finishing the test with applied voltage 35 kV, the transformer has not satisfied the best because at voltage 18.5 kV it so happened that a spark occurred and the test was finished.

On the basis of the measured values the results were compared and small differences were shown in values of gear and effective resistance for the third phase of the primary winding C. On the basic of these findings the measurement SFRA with the apparatus DOBLE M5100 was done according to the Tab. 4.

Table 4

Table of measuring for SFRA analysis

1. Open circuit tests					
22 kV			**400 V**		
Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
A – B	B – C	C – A	a – n	b – n	c – n

2. Short circuit tests					
Shorted a –b –c (ssek)			**Shorted A – B – C (sprim)**		
Test 7	Test 8	Test 9	Test 10	Test 11	Test 12
A – B	B – C	C – A	a – n	b – n	c – n

3. Interturn tests		
Test 13	Test 14	Test 15
A – a	B – b	C – c

3. Measured frequency responses with the detecting interturn short circuit

By means of the analysis of the measured frequency responses the interturn short circuit was found on the primary winding of the third phase C. The frequency responses represented on Fig. 2 and 3 show the difference in their forms. They are caused by impedance change, capacitances, and scattering inductances of the transformer winding. In the Fig. 4 there are for comparison represented reference courses of windings connected in delta connection of the new transformer.

4. Measurement of permittivity and loss tangent with microwave resonator technique.

For the measurement of permittivity and loss tangent a microwave resonator technique was used with regard to the dimensions of the sample, which dielectric properties were measured. Resonance methods belong to the most exact ones at permittivity and loss tangent measurement and from more method of this type we have adopted for our measurements the method using the cylindrical resonator [4].

It is necessary at this type of measurement to take into account the circumstance that the cavity resonator has many resonant frequencies. On the other hand at high frequency lines the resonance on a certain harmonic standing wave, which are layed down along the line, but at cavity resonators a different number of standing waves can be layed down along all three dimensions. This property is taken into account also at the location of samples in the resonator volume in the case when dielectric properties of investigated sample are measured. From the point of view of the laying out of electromagnetic field it is possible to look at the resonator as a short waveguide on both ends closed by conducting walls, in which travelling waves cannot propagate. Thus for the oscillations in the resonator can be used markings for waveguides with adding the third number giving a number of standing waves in the resonator axis direction.

The resonator used in our experiment is in this wave characterized through figures E010, what can be schematically represented as it in Fig. 5.

For such resonator filled by measured sample Maxwell equations in cylindrical coordinates can be written in the form

$$j\omega\mu H_{\vartheta} = \frac{\partial E_z}{\partial r} \qquad (1)$$

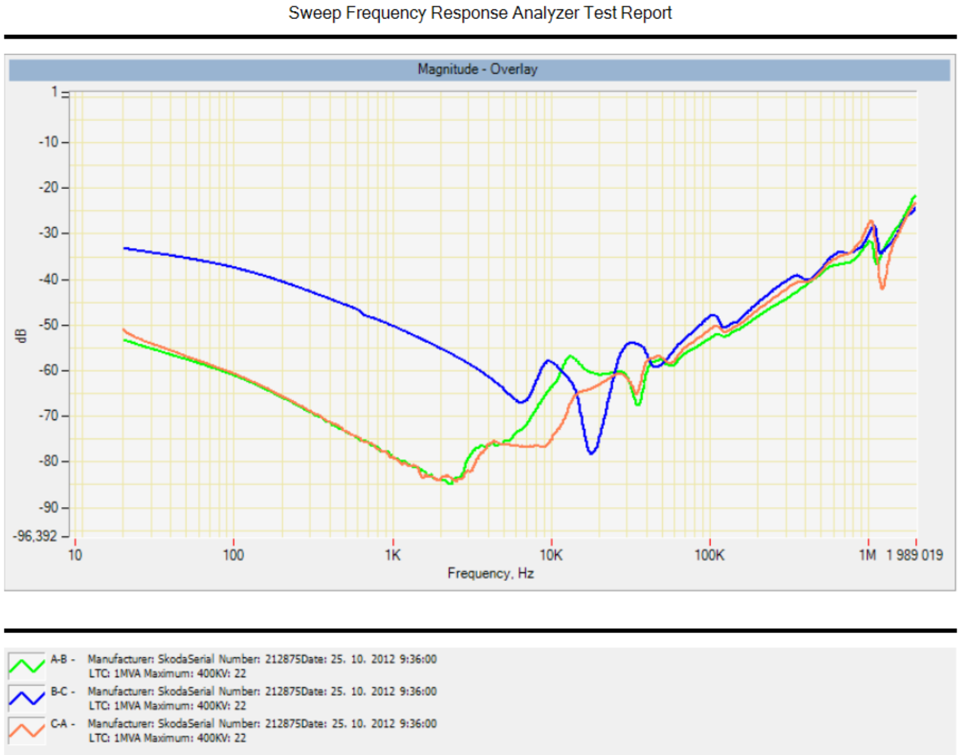

Fig. 2. Measured frequency responses of the primary winding, Open circuit tests.
(full colour version available online)

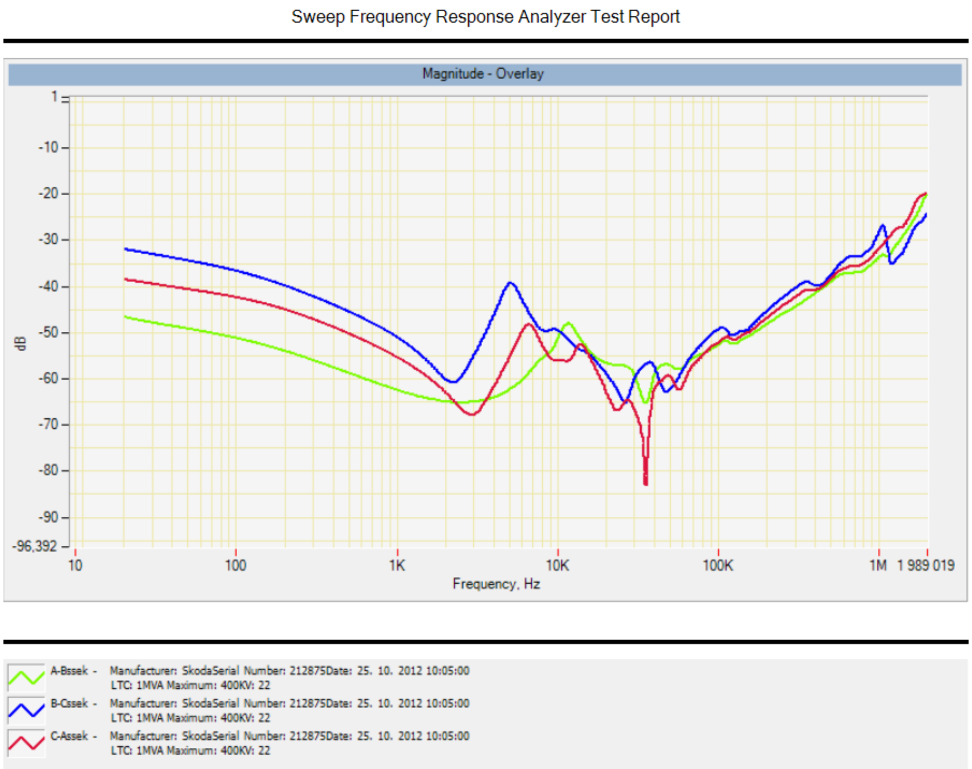

Fig. 3. Measured frequency responses of the primary winding, short circuit tests.
(full colour version available online)

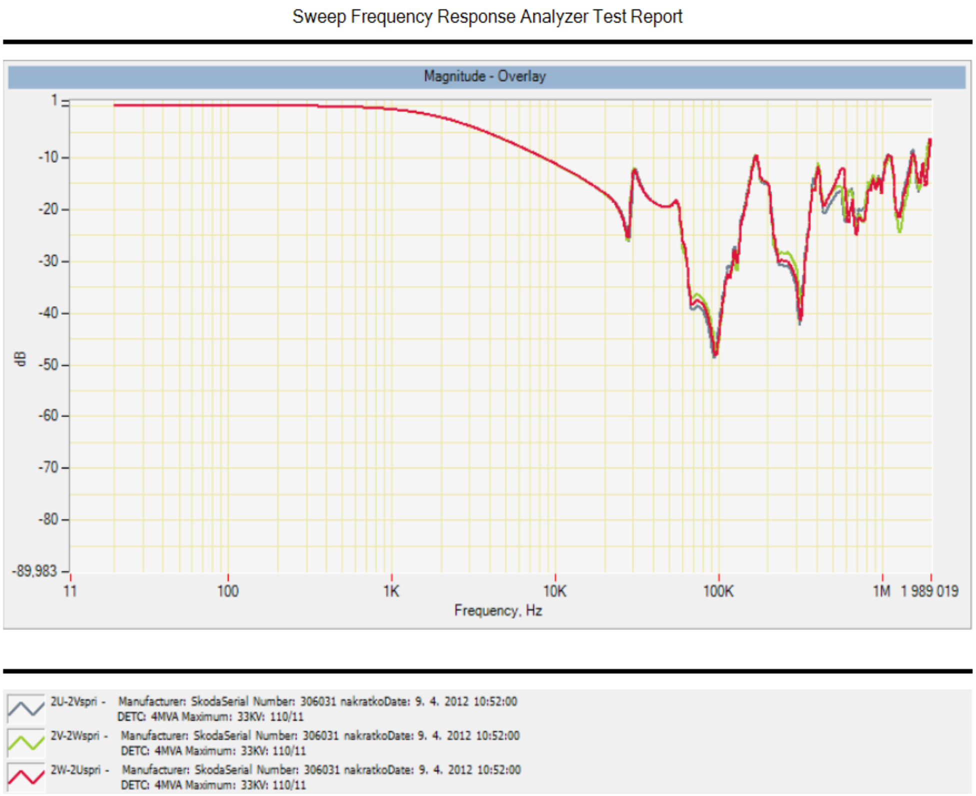

Fig. 4. The display of reference frequency responses for the delta connected winding – short circuit tests.
(full colour version available online)

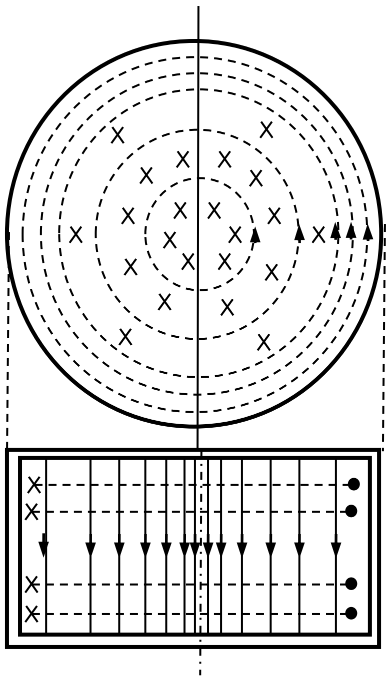

Fig. 5. The electric (crossline) and magnetic field (broken lines) distribution in the cylindrical cavity resonator E_{010}.

$$\left(\sigma + j\omega\varepsilon^{\prime}\right)E_z = \frac{1}{r}\frac{\partial}{\partial r}(rH_\vartheta), \qquad (2)$$

where H_ϑ is the intensity of magnetic field, E_z is the intensity of electric field, μ, ε', and σ are permeability, permittivity, and conductivity of dielectric medium and ω is angular frequency.

The solution of equation (1) and (2) gives relations for permittivity calculation in universal shape [4], but in practice, when very small samples are used, only slightly influencing the field shape, it is possible at reducing quantities respecting this circumstance to write the relation for permittivity in the form

$$\frac{\varepsilon'}{\varepsilon_0} = 0.269\frac{V}{v}\frac{\Delta\nu}{\nu_0}, \qquad (3)$$

where V and v are volumes of the resonator and sample, Δν is a frequency difference of the resonator with the sample and without it and ν0 is a resonant frequency of the empty resonator. The relation for the loss tangent of sample has the form

$$\mathrm{tg}\delta = \frac{0.269a^2}{\frac{\varepsilon'}{\varepsilon}b^2}\cdot\left(\frac{1}{Q}-\frac{1}{Q'}\right), \qquad (4)$$

where a is diameter of the resonator, b is diameter of the sample, Q is the quality of the resonator with the sample and Q′ is the quality of the resonator without sample.

Our measurement was realized with the sample created from granules of dimension not falling outside the scope of 2 mm. For the sample creation a thin-wall Teflon pipe was used, which at insertion in the resonator without the sample did not disturb the field configuration of the used working mode of resonator. The inner diameter of the sample was 5mm and the demarcation of the sample length was realized by two cylindrical bottoms likewise not influencing the field configuration. The sample granules were inprinted in the room created this way with the high 10.8 mm.

The measurement was performed on the equipment according to Fig. 6.

According to the given theory the resonant frequency of the empty resonator (ν_0) was measured as well as the frequency with the inserted sample and the quantity Δν was obtained in the form (3). The quantities V and v were obtained from the appropriate dimensions, where the diameter of the cylindrical resonator was 50.3 mm and the length 35.4 mm. The resonant frequency of the empty resonator was 8900 MHz and the frequency of the resonator with the sample was 10800 MHz. from these data for relative permittivity of measured sample according to form (3) resulted

$$\frac{\varepsilon'}{\varepsilon_0} = 13{,}0$$

and for loss tangent of measured sample according to form (4) and measured value Q = 866,

and Q = 328 resulted $\mathrm{tg}\delta = 33{,}0 \cdot 10^{-4}$.

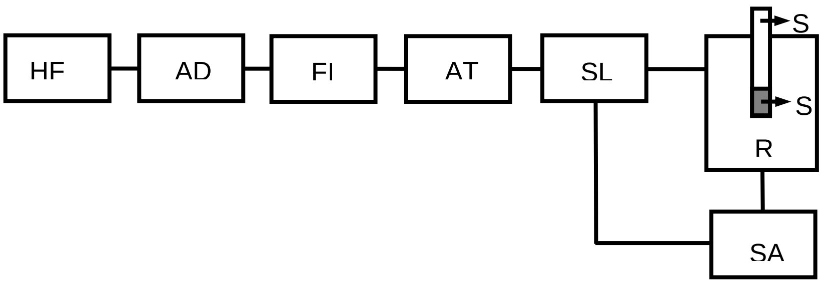

Fig. 6. Blok diagram of measuring system.
HFG – high frequency generator, AD – adapter, FI – ferrite insulator, AT – attenuator, R – resonator, ML – measuring line, SH – sample holder, S – sample, SA – selective amplifier.

5. Conclusion

The coils in these transformers types are made from aluminium on which a layer of isolating varnish is coated (Fig. 7 and Fig. 8). Isolating varnish is being old through natural way and frequent mechanical stress at short circuits, at atmospheric discharges and overload of the transformer cause its speed – up degradation. This causes micro cracks on the isolating varnish what causes an emergence of an interturn short circuit, because the windings are winded stock - a block. When under the influence of mechanical stress and temperature ageing there occurs a damage of the insulating varnish on the coil windings an interturn short circuit occurs in the contiguity. In that place an arc begin to burn and so chemical reactions begin in the transformer oil. Their results are a formation of methane, acetylene, ethane, furane and other gases. At the burning of arc in the place of interturn short circuit (Fig. 9) the temperature increases, melts the adjacent windings and thus form bigger amounts of gases dissolved in oil, and in the case if the transformer does not have Buchholzs´ relay, eventually the transformer protections are adjusted incorrectly its destruction occurs and subsequently ecological and economics losses. The following pictures illustrate dismantling works of the transformer resulting in revelation the hidden interturn short circuit of the phase C of the primary winding. The analysis and study of the sample from the burnt part of the winding by means of the microwave resonator technique determined the value of loss factor belonging to the mixture of the sintered aluminium, bitumen and transformer oil.

Adaption the measurement of distributive transformers 22/0.4 kV by means of SFRA method would influence to a large extent the high of coils connected with the inspection of transformers older more than 20 years. Before the repair of such transformer a measurement of frequency characterisations would be realised. If we show up the breakdown of more serious dimensions by means of them, finances connected with its planed inspection would be saved up. The transformer is automatically put out of operation and ecologically liquidated. In view of the fact that repair costs of detected breakdown are considerably higher, the investment in a new transformer is more advantageous.

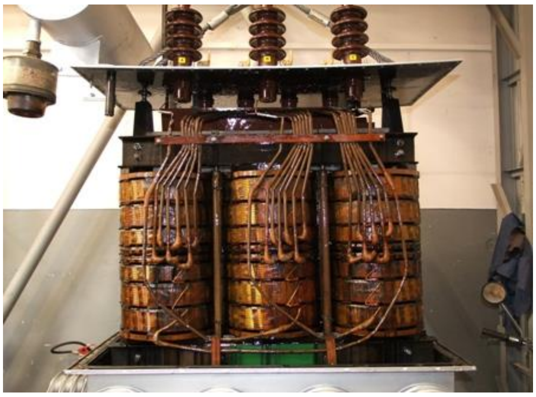

Fig. 7. Remove the transformer from the tank.
(full colour version available online)

Fig. 8. Demounting the transformer core and coils.
(full colour version available online)

Fig. 9. Photo of interturn short circuit.
(full colour version available online)

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