HIGH-FREQUENCY ANALYSIS OF THREE-WINDING AUTOTRANSFORMERS 400/121/34 kV

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Summary This article deals with a description of methods of an experimental analysis concerning the actual condition of windings and magnetic circuit of the autotransformer, which is required in power transmission companies all over the world.

1. INTRODUCTION

Considering a significance of power three-winding autotransformers (see Fig.1) in the electric system, their price and possible damages arising in accidents, it is necessary to pay attention to higher prevention of these devices. Windings of the auto-transformers should be designed to avoid various mechanical or thermal deteriorations caused by short-circuit currents occurring in operation.

Besides the permanent deformation effects of short-circuit current, there is also gradual aging process of the electrical device, which can worsen its mechanical properties. Heat shocks can cause decrease of mechanical strength of transformer and consequent unexpected damage of transformer during the operation.

To prevent a damage state of transformers, we perform different types of the measurements that should illustrate an actual condition of the measured equipment. It is therefore important to choose a suitable diagnostics for the right prediction of such conditions.

Fig.1 The autotransformer 400/121/34 kV

This article deals with a description of methods of an experimental analysis concerning the actual condition of windings and magnetic circuit of the transformer, which is required in power transmission and power distribution companies all over the world.

2. THEORY OF SFRA METHOD AND ITS IMPORTANCE IN TRANSFORMER DIAGNOSTICS

SFRA method belongs to current most effective analyses and allows to detect the influences of short-circuit currents, overcurrents and other effects damaging either winding or magnetic circuit of the transformer. This all can be performed without a necessity of decomposition of device and subsequent winding damage determination, which is very time consuming.

The method of the high-frequency analysis (Sweep Frequency Response Analyzer – SFRA [3]) is also one of the methods of undisassembling diagnostics of transformers. No intervention to the construction of tested device is demanded, the whole measurement is performed on detached device (not under the voltage). This method is applicable mainly for determination and measuring immediately after the manufacturing of device, i.e. for measuring of reference values. These parameters are consequently compared to the other measurements performed on the transformer, which is decommissioned, after the damages or revisions of transformer etc.

There is possible to detect by SFRA:

- a deformation of winding and its movements,
- a short-circuited turn or opened winding,
- a loose switching system,
- a damaged switching system,
- a core connection problem
- a partial breakdown of winding,
- a core movement or its wrong grounding.

Results measured on the new transformer can be used as the reference parameters for further comparison with values measured later after certain operation time of the transformer. They can be also compared with the test results performed after the transformer breakdown (or after the n-short-circuits) or repair or it can be used as a diagnostic test, when vibration sensors indicate some potential problem in transformer.

SFRA as a one of the most predictable methods is based on functional high-frequency generator and spectral recording analyzer principle, which are set up and controlled by computer. This method is used also by M5100 measuring system (see Fig.2) constructed by American DOBLE company [3].

Fig.2 DOBLE M5100 measuring system

According to [2] SFRA method determines the transformer responses in a time or frequency area. The time response measurement provides curve determination of the time response to the specific voltage impulse applied to winding input connection. The frequency response measurement consists in determination of amplitude eventually phase response to the harmonic voltage of variable frequency applied to winding input. While the time response is the record of time behaviour of voltage, frequency response is the amplitude response dependence on frequency.

A relation between the response and the winding condition is definite, otherwise it is complicated. It is impossible to expect the assessment of concrete damage of winding from differences in response behaviours. The measurement results lead us only to a statement of the fact that some change of winding condition really occurred. Such test results are very helpful to decide, whether it is unavoidable to open and revise the transformer or not.

3. MEASURING PRINCIPLES

The behaviour of transformer winding response reflects e.g. electromagnetic couplings between the winding and transformer tank, also between the primary and secondary (eventually tertiary) winding, between the windings of particular phases or between turns themselves of particular windings.

The power transformer measurement requires a setting up of the frequency range from 10 Hz to 2 MHz, whereas there is necessary to follow the right measuring technique to prevent various inaccuracies and faults. According to [2] and [3], measuring technique of three-winding autotransformer 400/121/34 kV (Fig.3) is as follows (see Tab.1).

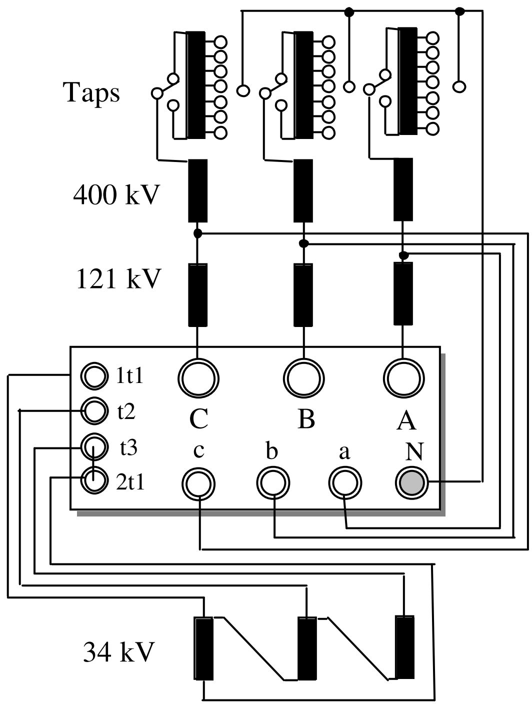

Fig.3 The three-winding autotransformer 400/121/34 kV tested by SFRA before its activation

Tab. 1

1. OPEN CIRCUIT TESTS								
400 kV			121 kV			34 kV tertiary winding		
Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
A – a	B – b	C – c	a – n	b – n	c – n	t3 – t1	t1 – t2	t2 – t3
2. SHORT CIRCUIT TESTS								
a-b-c short-circuited			t1-t2-t3 short-circuited			t1-t2-t3 short-circuited		
Test 10	Test 11	Test 12	Test 13	Test 14	Test 15	Test 16	Test 17	Test 18
A – n	B – n	C – n	A – n	B – n	C – n	a – n	b – n	c – n

During the **open circuit tests** a mechanical condition of tested winding and ferromagnetic core is detected. The following curves typical for this measurement provide us important information about changes in the core, which are visible in low frequencies, while higher frequencies refer to problems such as winding movements or turn-to-turn fault.

Fig.4 illustrates a simulation of gradual increase of turn-to-turn faults via open circuit test on autotransformer 400/121/34 kV (see Fig.3) at transformer taps of 1, 9, 13 and 17.

The application of analysis of phase attenuation depending on frequency is suitable for more complete evaluation of winding condition. This analysis enables to assess the processes of winding movements during the particular short-circuits influences.

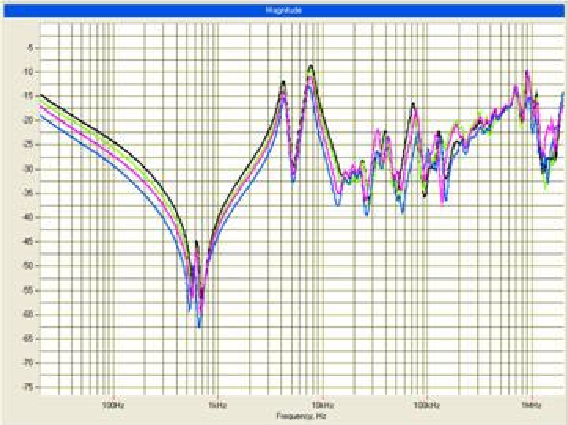

Fig.4 Simulation of turn-to-turn fault increase by open circuit test on autotransformer at transformer taps of 1, 9, 13 and 17

Problems with core grounding or shorted laminates in the core will typically change the shape of the lowest section of the curve (to 10 kHz). Mid frequencies (from 10 kHz to 200 kHz) represent axial or radial movements in the windings and high frequencies indicate problems such as e. g. winding knocking or problems with contacts.

During the **short circuit tests** only the winding condition in primary or secondary part of transformer is detected. This measurement notifies reliably of deformation of inner winding and its movement as a result effects of short-circuit currents.

4. CONCLUSION

Problem of the frequency analysis of transformers by SFRA method is very comprehensive and its application becomes interesting for many transformer manufacturers and operators. From the long-term point of view the SFRA method is supposed to be very useful and it provides enough information on tested transformers. These transformers have their reference data obtained by the manufacturers, suitable for the comparison with further data of particular transformer.

SFRA testing method represents one of the most effective alternative diagnostic methods compared to visual check. This method allows to detect the effects of the short-circuit currents, whereas we are able to evaluate the mechanical strength action on the transformer winding during previous operation It is also possible to identify the specific winding phase, which has been mostly influenced by the short-circuit currents, without a necessity of transformer dividing, which would be very time consuming.

There is also possible to identify the size of parameters of transformer **parallel circuit** as well as the position of its resonance frequency from particular curves (see Fig.5).

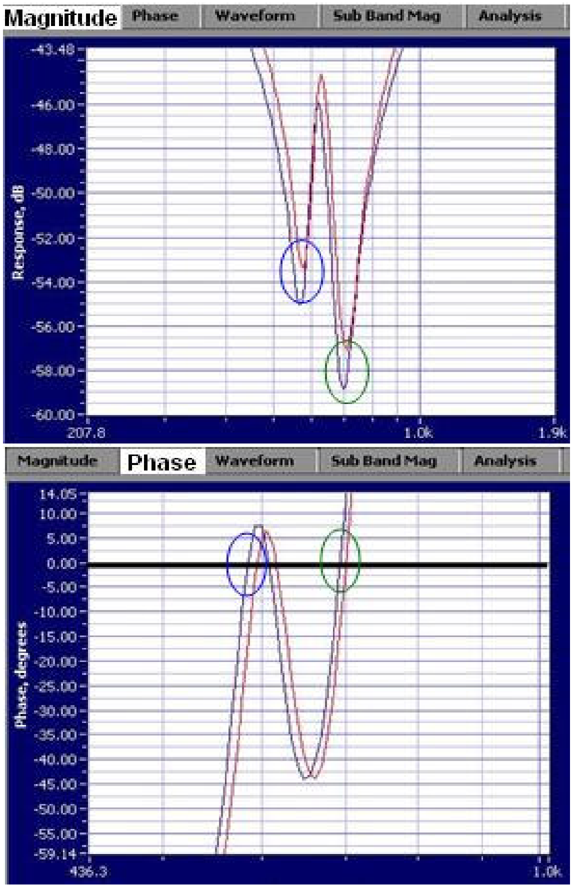

Fig.5 Comparison of amplitude attenuation [dB] and phase curve [°] in frequency dependence (measurement of the same transformer winding)

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