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Advanced technology of transformer winding condition control based on nanosecond probing impulse

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Abstract

One of the prospects of resource-effective technologies in power industry is control of electric equipment condition. Effectiveness of any electrical energy system strongly depends on stable work of power supply equipment. It, in turn, is defined by timely and reliable control of equipment condition. Power transformers are the key element of an electrical energy system. Winding defects caused by short circuit currents are the reason for an emergency situation. Reliable control of winding condition is an urgent task of modern power engineering technology. This paper deals with the experimental research of pulsed method of transformer winding control. A new approach to the winding condition control technology is described. The proposed method is based on short nanosecond range (compared to typical pulsed technology) probing impulse and front impulse durations. Experimental results of sensitivity growth at the nanosecond probing impulse duration are shown. Experimental equipment and measurements are described. Comparison of experimental results of the proposed pulsed method and FRA is given. It is shown that probing impulse of nanosecond duration allows upgrading sensitivity of diagnostics procedure. The main proposals are confirmed by measurement results obtained in the electric energy system transformer for different types of winding defects.

Keywords: Power transformers; failure diagnostics; FRA; pulsed method; winding defect; probing impulse; frequency range; axial and radial shift of turns

1. Introduction

Winding damage due to short circuit currents or other factors is developed rapidly. Revealing a defect at an initial stage is an urgent task of the state of the art control procedure. Therefore the development of technologies of controlling active parts condition is one of the main trends in modern electrical engineering. A pulsed method for controlling mechanical condition of transformer windings was proposed and described in 1966 [1]. The method lies in applying a probing impulse of microsecond with an amplitude of 100–500 V to one of the windings. Other windings are short-circuited and the shunt giving a response to a probing impulse is installed in them. The response represents the signal corresponding to the transient, arising in windings, as reaction to the probing impulse influence. First of all, it was necessary to measure the so-called normogram – a response from the winding of the transformer working properly. At the next tests the procedure of sounding is repeated. The comparison of normograms and current sounding (defectograms) allowed making a conclusion about the condition of the winding. The difference between the normogram and defectograms is the evidence of the problem in the winding. Further this method was recognized more than in 45 countries [2] and received the name of the Low-Voltage Impulses method (LVI).

Further in 1976–1978 in the companies Ontario Gydro, Canada, the LVI method was modified and transformed to the method of measuring amplitude-frequency characteristics. The method lies in measuring amplitude-frequency characteristics in one of the transformer windings while a sinusoidal signal with amplitude of about 10 V of various frequencies is applied to the other winding. The obtained amplitude–frequency characteristics are compared with the normograms, obtained in this serviceable transformer. Now this method is called the Frequency-Response Analysis method or FRA Technology and it is widely used around the world [3–5]. A physical FRA interpretation that is based on the analysis of physical electrical parameters is not feasible until now since one of the most

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important parameters, the winding series capacitance, cannot be determined in transformer bulk [5]. Special generators for diagnostic procedure by the FRA technology are produced. The range of frequencies for diagnostics of high-voltage transformers are in the range of 2. . .3 Hz to 1. . .3 MHz.

Both the LVI and the FRA methods do not always provide exact diagnostics and also sometimes have low sensitivity. We suppose that it is the result of rather narrow frequency range of probing signals. The standard storm impulse has the top frequency of about 500 kHz, the FRA method – 1 . . . 3 MHz. Further the increase of the sensitivity condition control procedure could be reached by short probing impulse application. A nanosecond probing impulse (duration range of 400–100 ns) is the advanced technology method of winding condition control. To figure out the effectiveness of the proposed technology compared with FRA, a number of experiments have been carried out.

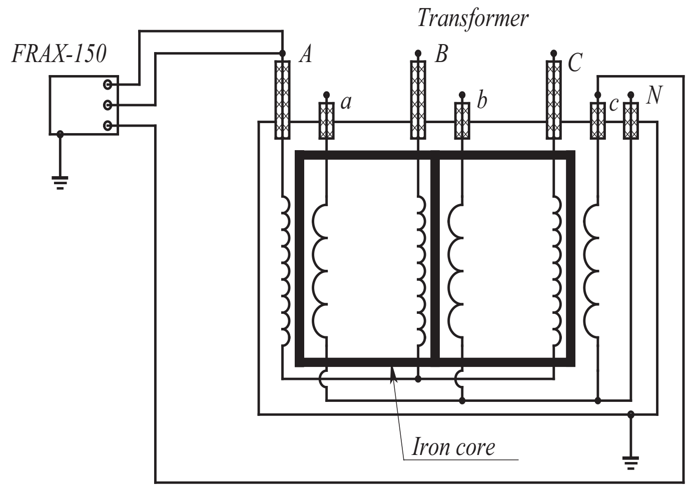

Fig. 2. Scheme of experiment at the condition control by FRA.

2. Experimental research of state control sensitivity

Our approach to sensitivity enhancement of the LVI method lies in using a probing impulse with frequency range up to 50 MHz. It can be implemented by applying a rectangular probing impulse with amplitude of 200 V and front duration of 5. . .10 ns and impulse duration of 500. . .100 ns to one of the transformer windings. The experimental research of using a short probing impulse has confirmed the prospects of this approach. Both electrical (turn to turn short circuit) and mechanical (axial and radial shifts) damages of the winding were successfully revealed in different defect situations. The shorter probing impulse duration, the more exact the procedure of condition control [6–8].

The main objective of the research of the serviceable transformer is receiving normograms from the transformer windings in operating condition (the transformer was repaired). The next stage of the research is creation of various defects in the transformer windings which often occur using this type of transformer and receiving defectograms for comparing them with the normograms and determining sensitivity of the developed method of nanosecond impulses for specific defects. To compare the sensitivity of the developed method with the existing method of amplitude–frequency characteristics, a study of transformer characteristics by means of the FRA technology has been carried out. The schemes of controlling the condition of windings including the generator of probing impulses of nanosecond range, oscillographs controlling parameters of probing impulse and response signals, the arrangement of phases of high voltage (HV) and low voltage (LV) windings are shown in Fig. 1. Electrical circuits of experiments for impulse and FRA methods are shown in Figs. 1 and 2.

The procedure of investigating the windings condition lies in applying a probing impulse to one of the windings, and registering the signal response – normogram – from the other winding. During the study the parameters of a probing impulse varied in order to determine the optimal duration of a probing impulse from the initial one with parameters of 200 V, 500 nanoseconds. The measuring procedure was completely identical to that used in experiments in the physical model of transformer and it is described in detail in Refs. [6–8].

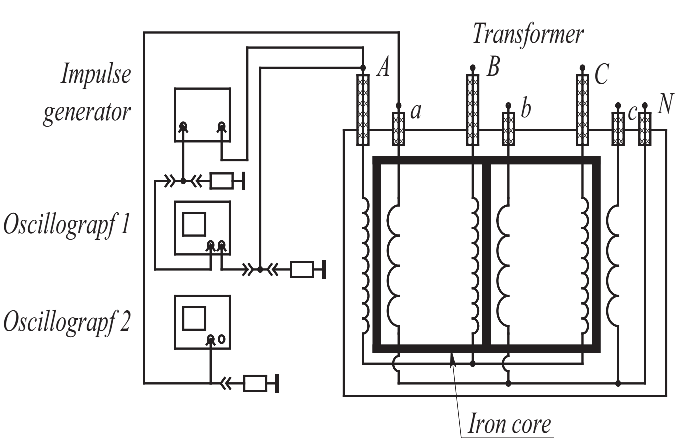

Fig. 1. Scheme of experiment at the condition control by the nanosecond pulsed method.

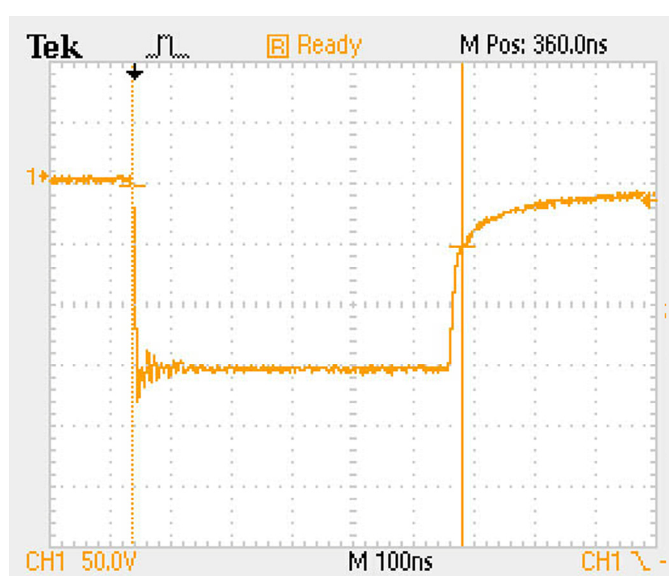

Fig. 3. View of the probing impulse applied to the transformer winding.