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DEVELOPMENT OF ADVANCED TECHNOLOGY FOR HIGH VOLTAGE TRANSFORMER WINDING CONDITION CONTROL BASED ON PROBING IMPULSE OF NANOSECOND DURATION

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Abstract

The paper deals with the experimental research of the pulsed method of transformer winding control in comparison with FRA technology. A new approach to winding condition control technology is described. The proposed method is based on short (compared with a typical pulsed technology) probe pulse and front pulse durations. The experimental results of sensitivity growth at decreasing front pulse duration are shown. The experimental equipment and measurements are described. A comparison of the experimental results of the proposed technology and FRA is given. It is shown that shorter front of probe pulse duration allows upgrading sensitivity of the diagnostic procedure.

INTRODUCTION

Smart power grid includes big amount of high voltage transformers of different types and power range. To provide a stable operation of any smart grid is necessary to control high voltage equipment condition, first of all, power transformers. At the same time, park of power transformers are old enough and have been working already 30-40 years and more. That is why the development of technologies of high voltage transformer condition control is an important task for any smart grids. The pulsed method to control a condition of transformer windings was proposed and described in 1966 [1]. The principle of the method consists in applying probing standard lighting impulse of 1.2/50 microsecond with the amplitude around 300 V to one of the windings. Other windings were short-circuited and the shunt which gave a response to a probing impulse was installed in them. The response represents the signal corresponding to transient, arising in windings, as a reaction to a probing impulse. First of all, it was necessary to measure the so-called normogram – a response from the winding of the working transformer. The procedure of sounding was repeated at the next test. Comparison of normograms and current sounding (defectograms) allows making a conclusion about winding state. The difference in the normogram and defectograms represents the problem in the winding. Further, this method was recognized more than in 45 countries [2] and was called the Low-Voltage Impulses method (LVI). In the end of last century, the LVI method was modified and transformed into a method of measurement of amplitude-frequency characteristics. It has been practicing as main in North American and European smart grids. The principle of this method consists in measuring the amplitude-frequency characteristics from one of the transformer windings when applying to the other winding a sinusoidal signal with the amplitude around 10 V of various frequencies. Then the amplitude-frequency characteristics are compared with the normograms, received on the serviceable transformer. Nowadays this method is called a Frequency-Response Analysis method or a FRA Technology and it is widely used around the world [3-5]. The FRA interpretation that is based on the analysis of physical electrical parameters is not feasible since one of the most important parameters, the winding series capacitance, cannot be determined in transformer bulk [6]. Despite many advantages there is problem to reveal the winding faults in most initial stage. This drawback is for both technologies – FRA and LVI.

Main goal of this work is to upgrade sensitivity of the LVI method to find winding faults on the most initial stage. It could be achieved by means of a probing pulse using the frequency range up to 50 MHz. It can be implemented by applying to one of the transformer windings a rectangular probe pulse with the amplitude of 200 V and a front duration of 10 ns and pulse duration of 400 ns. A short probe impulse is a way to increase sensitivity of the diagnostic procedure.

EXPERIMENTAL RESEARCH

To prove the viability of the approach, a special generator of nanosecond impulses was developed. It allows forming unipolar pulses with the above mentioned parameters. The model of three-phase two-winding transformers has been developed. The model includes three low voltage coils inserted in high voltage ones. The total number of turns at the low voltage coil is 20, at the high voltage coil – 120 respectively. A nanosecond rectangular impulse with different front duration was supplied on entrance of the high voltage coil. The response signal was measured on exit of the low voltage coil. Ocilloscopes Tektronix TDS 2024 were used to control the form of a probe impulse and response signals.

The electric circuit of the experiment to define the influence of the front duration of a probing impulse on sensitivity of the LVI method is given in Figure 1.

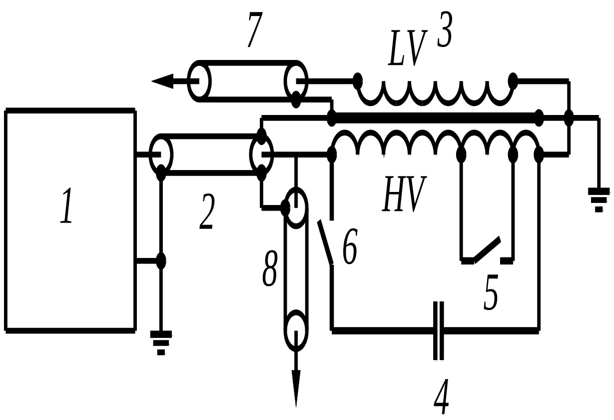
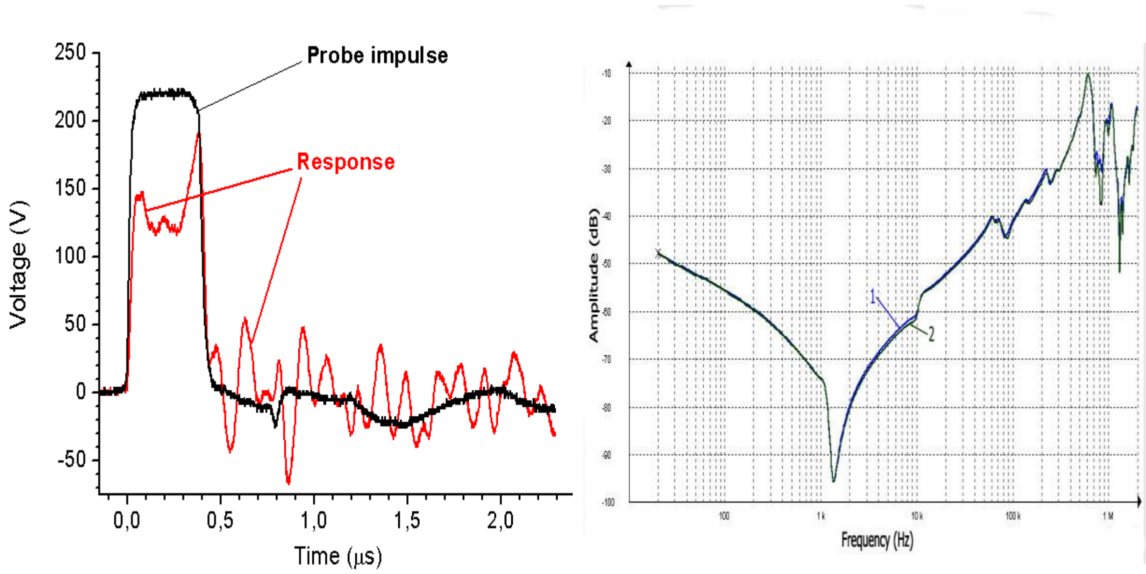


Fig. 1. Electric circuit of the experiment: 1 – the generator, 2 – the connecting coaxial cable with a wave resistance (impedance) of 75 Ohms and 2 meters length, 3 – the diagnosed transformer (HV—high voltage, LV – low voltage), 4 – the condenser for change of the front of a probing impulse, 5 – short-circuit of rounds (turns) 96…98 (common turn number is 120), 6 – the commutator (switch) for connection of the condenser 4;7, 8 – probes for connection to a multichannel oscilloscope TDS 2024.

The rectangular impulse created by the generator was applied to a high-voltage winding of the transformer, the impulse-response was measured on a low-voltage winding of the transformer. Windings had no loads (a case of completely switched-off transformer). On the high-voltage winding taps which can be connected among themselves for imitation of short circuits between certain turns have been made. Defect turn to turn short circuit between 96 and 98 turn number was organized at the high voltage area of phase A. A comparative experiment on the transformer model has been carried out to compare the sensitivity of FRA and our “nanosecond pulsed method”. Waveforms for the nanosecond pulsed condition control are given in Figure 2, a. Waveforms which are given in Figure 2, b are at the same situation, but for FRA technology. A comparative experiment on the transformer model has been carried out to compare the sensitivity of FRA and our “nanosecond pulsed method”. The experiment consisted in comparison of the normograms and responses at the same defect type – turn to turn short circuit of 96 – 98 turns of the high voltage winding for both technologies.



a b

Fig. 2. a) Waveforms at short circuit between turns 96…98 of the high-voltage windings of the transformer at the front of a probing impulse of 25 nanoseconds: black curve – a form of a probing impulse on the entrance of the high-voltage winding, a red curve – a response pulse on the low-voltage winding.
b) Amplitude-frequency characteristics received by means of the FRAX-150 device on the transformer model: curve 1 is the normogram; curve 2 is the defectogram obtained at short circuit between turns of 96-98 of the high voltage winding. A signal is supplied to phase C, amplitude-frequency characteristics is fixed on exit of phase A.

As it is followed from figures, sensitivity of nanosecond pulsed technology is higher than FRA one.

CONCLUSIONS

Despite many positive characteristics, in some cases sensitivity of FRA is not too appropriate and the percent of mistakes during the transformer diagnostics is high enough. One of the reasons for that is restriction of the upper boundary of the frequency range. It is around 2 – 3 MHz. A noise level in a common signal is too high and this restricts the top of working frequency range at FRA.

To overcome this problem a solution for using probe pulse with short duration and rapid front was proposed. Application of a probing pulse with pulse duration of 400 ns and a rise time of 25 ns allows an increase in the diagnostic sensitivity in comparison to the FRA testing under the same test conditions.

Proposed technology of winding condition control is high enough and looks prospective for smart grids.

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ПРИНЦИПЫ РЕАЛИЗАЦИИ РЕЛЕЙНОЙ ЗАЩИТЫ, ОСНОВАННОЙ НА РАСПОЗНАВАНИИ ВОЛНОВЫХ ПОРТРЕТОВ

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Современные распределительные сети и системы электроснабжения характеризуются внедрением возобновляемых источников энергии (ВЭИ), виртуальных электростанций. Вероятностный режим работ ВЭИ, обусловленный нестабильностью энергоносителей, создает проблемы для устойчивой работы сети, для систем управления и автоматики и для релейной защиты (РЗ). Режим работы систем электроснабжения с ВЭИ постоянно меняется: изменяется конфигурация сети, изменяются потоки мощности по отдельно взятым ЛЭП, меняются токи КЗ и т.д. Все это приводит к усложнению схем защиты и автоматики, необходимости разработки и внедрения новых алгоритмов работы устройств защиты.

Можно выделить два подхода к решению данной проблемы.

Первым подходом является разработка гибких, адаптивных защит, подстраивающихся под изменяющийся режим работы сети. В данном направлении проводятся различные исследования, как за рубежом, так и в нашей стране и уже предложены различные методы. Например, предлагается использовать набор уставок для разных режимов работы и на основе работы алгоритма распознавания режимов выбирать тот или иной набор уставок. Еще можно использовать алгоритмы, в которых уставки будут непрерывно меняться в соответствии с определенными вероятностными закономерностями в зависимости от характера изменения параметров режима. [1]