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ADVANCED CONTROL STATE TECHNOLOGY OF TRANSFORMER WINDINGS

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Abstract- Power transformers are key components of any electrical power systems. Timely state control of transformer winding is necessary step to provide a stability of electric energy system. Otherwise, incident with serious damages, like fire, is very probable. Some technologies to control winding state are developed, but no one can provide exact and reliable winding diagnostics. Method of low voltage pulses used in Russian electrical power systems. It has high enough inaccuracy percentage and cumbersome diagnostic procedure. FRA method is popular enough in American, European and Asian electrical power systems, but important diagnostic frequency range of it is restricted by 2 MHz. As result, diagnostic procedure by FRA has not too high sensitivity, despite progress in this technology. As for electric motor windings, here is no one real control state technology except simple resistance measurement. New approach to winding state control technology is described. Proposed method is based on short (compare with typical pulsed technology) probe pulse length (nanosecond range). Experimental results of sensitivity growth are shown. Experimental equipment, measurements are described. It is shown that smaller probe pulse duration allows to reach more sensitivity of diagnostic procedure. Method was experimentally used on real power transformer 63 MVA.

Keywords: Winding of Power Transformer, Short Probe Pulse, Response Signal Form, Sensitivity of Diagnostic Procedure.

I. INTRODUCTION

A big amount of the power transformer population all over the world being in service at the moment, have been reached an age of 30-40 years and more. Those transformers might be close to their end of life. Commutations, inrush currents, short-circuit currents take place in any electrical power system. Any next short circuit regime could cause emergency situation. Thus, active part diagnostics of power transformers is an important part of a modern power equipment maintenance strategy. Traditional diagnostic methods such as, winding checking by resistance measurement and vibration control are not effective in most of cases.

Low voltage pulsed method based on probe pulse duration 1 microsecond requires exact reproducibility of all steps of measurement procedure, existence normograms for the transformer, which was were measured in the same exact conditions as current measurements, detailed analysis of response signals. These factors make a diagnostics procedure too cumbersome and difficult. Probability of failed diagnose is high enough. FRA technology is used in European, American and Asian electric energy systems, but accuracy and reliability are not enough sometimes. Mistakes in winding diagnosis took place at the using FRA technique. In this connection, new winding control technology development is really actual scientific and engineering task. Method was experimentally used to make state control of windings at real power transformer 63 MVA and AC electric motors [1]. It is necessary to note that all experimental measurements, oscillograms and results below are original, received by authors and published never before.

II. BASIC PRINCIPLES OF WINDING STATE CONTROL BY SHORT PROBE PULSES

Method of low voltage pulses (LVPM) is most progressive winding control technology among using in electric energy systems. This technology was developed by electrical engineers V. Lekh and L. Tyminskiy in Poland in 1966 [2]. The method is recognized in transformer diagnostics world as reliable and sensitive technology to control mechanical deformations more than 45 years [3].

In many countries, including Russia, LVPM is included in national standards of power transformer test methods to electrodynamic firmness of winding control and successfully use in Russian electric power system [4]. The crux of matter is in rectangular pulse of low-voltage supply to one of winding of transformer; at the same time transient signal is registered on the other one. Transient signal (response) is reaction of the winding to rectangular probe pulse [5]. Comparative analysis of differences in pulsed transient current curves before and after electrodynamic impact is basic fundamentals [2-5]. Analysis is comparison of normogram (signal from "healthy" winding) and defectogram (signal from damaged winding).

It is important fact that, many types of power transformers have no normograms at all. This fact makes diagnostics procedure very difficult and practically impossible in some cases. In such cases analogical phase normograms of similar transformer types or classes are used, but diagnostics accuracy are not reliable at such approach [6].

Our approach is based on probe pulse using with smaller duration and more rapid pulse front. Duration of rectangular pulse in standard method is around 1 microsecond. We propose to use probe pulse duration no more than 350-375 nanosecond and less. Pulse front is several units of nanosecond. Decrease of pulse and front duration up to nanosecond range leads to much more exact fixing of transient process in comparison with standard LVPM. Basic idea of our approach is following - diminished probe pulse duration improves a sensitivity method due to response signal forms in capacitive elements only. As result oscillations are excited with bigger intrinsic frequency than in LVPM. Any changes of winding geometry changes, even most negligible are caused by radial or axial deformations, inpressing, lodging conductors, turn to turn and turn to ground short circuits and other factors lead to considerable changes of longitudinal and cross winding capacities. Reaction of windings is changed seriously at the same time and provides more exact measurement result.

To realize our approach, special test generator "Nanotest-1" was designed and engineered. Test generator parameters are following: pulse amplitude is 100-300 V, pulse duration is around 350 ns, front of pulse on the matched load is no more than 10 ns. Test generator is engineered on base of Vvedenskiy [7] scheme with main elements: cable line, capacities, discharger. To research basic fundamentals of nanosecond pulse state control technology, physical model of transformer was engineered. Results of experiments on physical model of transformer are described below.

III. EXPERIMENTS ON PHYSICAL MODEL OF POWER TRANSFORMER

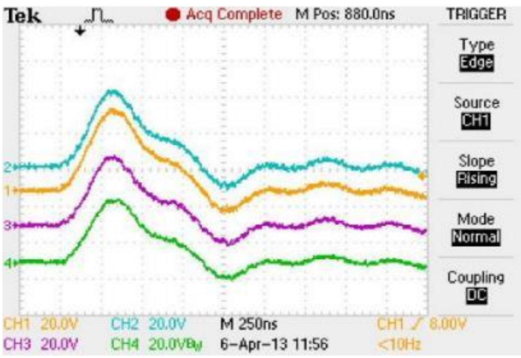
General view of transformer model with probe pulse generator "Nanotest-1" and measurement devices (two oscilloscops "Tektronix") is shown on Figure 1.

Figure 1. General view of physical model of three-phase power transformer with generator of nanosecond probe pulse and oscilloscopes

One of the main questions about quality of diagnostics procedure is probe pulse form. In early papers devoted to LVPM the question about form of probe pulse is discussed [2, 3, 8, 9]. In classical work which first source about the subject and was written by authors of LVPM, probe pulse form was the same as at transformer test - 1.2/50 microseconds [2]. In [3] is said that form of probe pulse is not important. At the same time in [2, 3, 8, 9] is mentioned that rectangular form of pulse with rapid front is desirable.

It is necessary to note that no one paper contains figures or oscillograms of view of probe pulse. The form of probe pulse and stability of its parameters are key question here, so it is a base of whole diagnostics procedure and next results. Probe pulse is supply on the high voltage (HV) winding, response signal which is transient process result is fixed on low voltage (LV) winding of physical model. Typical oscillograms of different forms of probe pulse and correspondence response signals on different sweeps are shown on Figures 2-4. Probe pulse is moved on entrance of HV winding, response signals were fixed on LV.

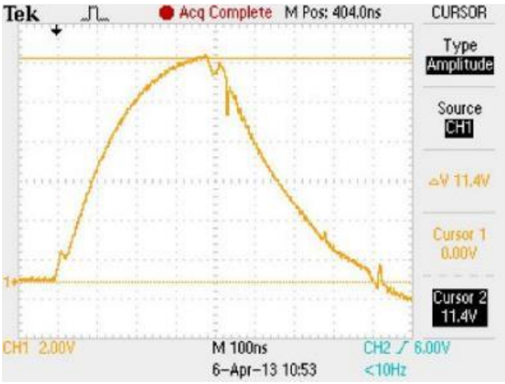
(a)



(b)

(c)

Figure 2. (a) Oscillograms of probe pulse of "hand bell" form and slow front growth, response oscillograms on sweeps (b) 250 ns, (c) 500 ns



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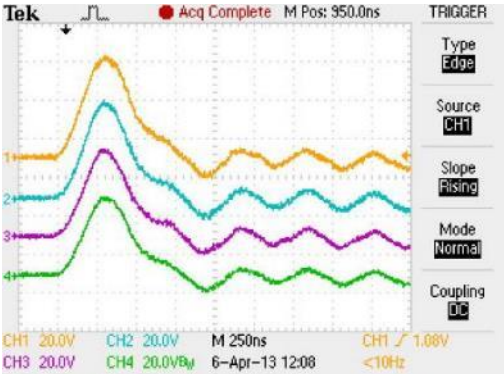

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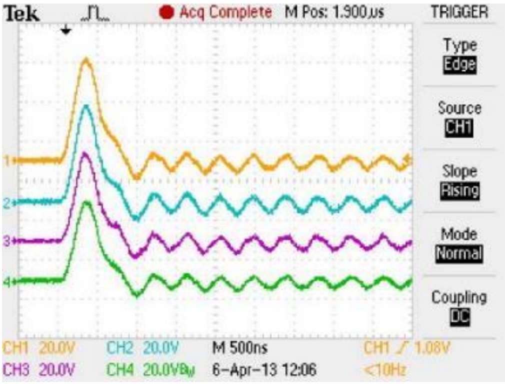
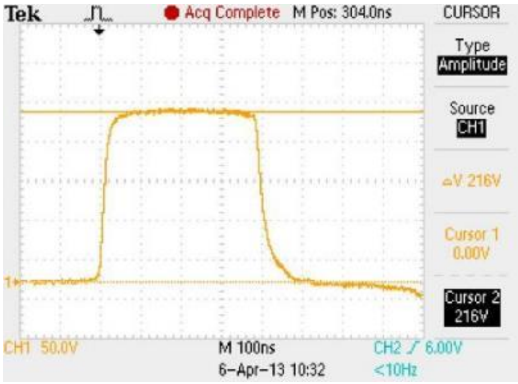


(c)

Figure 3. (a) Oscillograms of probe pulse of "hand bell" form and faster front growth, response oscillograms on sweeps (b) 250 ns, (c) 500 ns

Four responses on oscillograms correspond to measurement points on low voltage winding: beam 1 (5 turns) ground; beam 2 (10 turns) ground; beam 3 (15 turns) to ground; beam 4 (20 turns) ground or whole winding. General view of low voltage winding is shown on Figure 5. Measurements of probe pulse form and corresponded responses carried out at the same conditions shown that form and front steepness of probe pulse strongly influences to response content. At the probe pulse of "hand bell" form and slow front growth response signals have one peak of amplitude at the beginning of curves. Further even on 500 ns sweep, responses are smooth enough without the obviously expressed hesitations (Figure 2). Situation is practically the same at the probe pulse of "hand bell" form and faster front growth (Figure 3).



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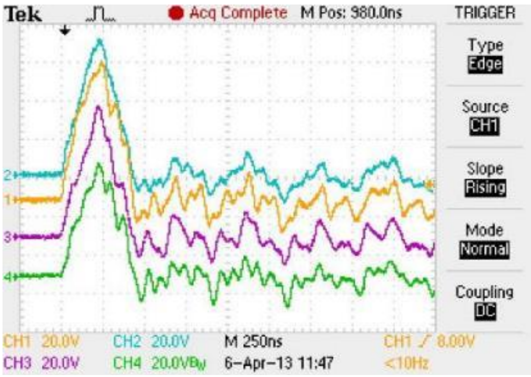

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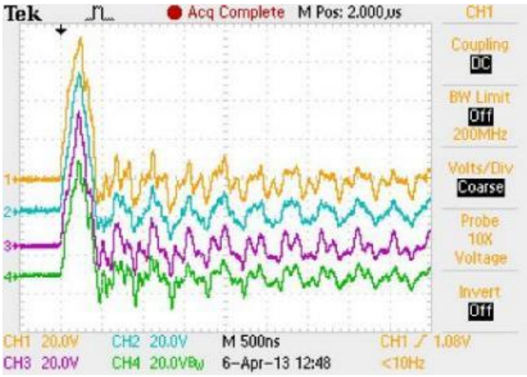


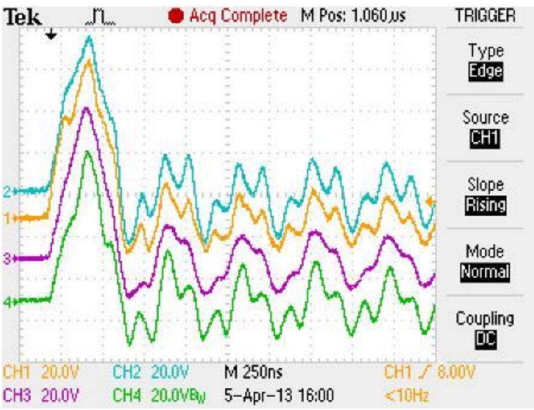
(c)

Figure 4. (a) Oscillograms of probe pulse of rectangular form, response oscillograms on sweeps (b) 250 ns (c) 500 ns

Common picture changes in case probe pulse of rectangular form with front duration around 10 ns. In this case response signals contain first enough sharp peak of amplitude with sharpness on the recession. Whole range of response signal length contains obviously expressed fluctuations with specific sharpness and slow attenuations (Figure 4). Namely these fluctuations, their amplitude value, period of attenuations, common form are a base for analysis of winding state. Any defective condition leads to inductance and most of all capacities changes. As result oscillatory contour parameters of winding are changed also. To find these changes detailed analysis of response signal curve is necessary. It is possible when response signal is informative enough, like in case illustrated on Fig. 4. This, in turn, is possible in case of short rectangular probe pulse with rapid front.

So, one of way to increase of sensitivity of diagnostics procedure is using of rectangular form of probe pulse with rapid front and small (nanosecond range) duration. At such form and parameters probe pulse has reach large enough filling by high frequencies. Reaction degree of capacitive elements is as stronger as the frequency range of probe signal higher. That's why diminishing duration and front steepness of probe pulse is necessary condition of exact and reliable winding state control. High sensitivity of the method is illustrated by measurement results with and without additional capacity.

Figure 5. General view of low voltage winding with soldered tap, which brings additional capacity at whole winding



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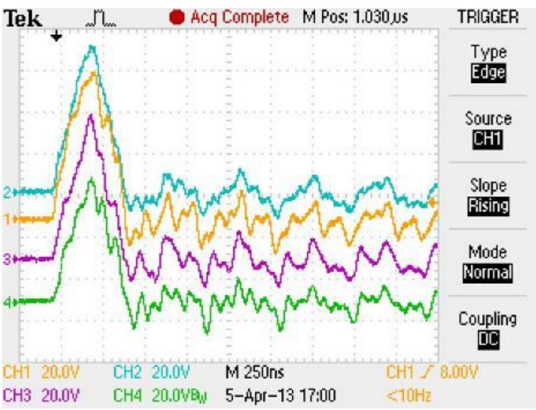
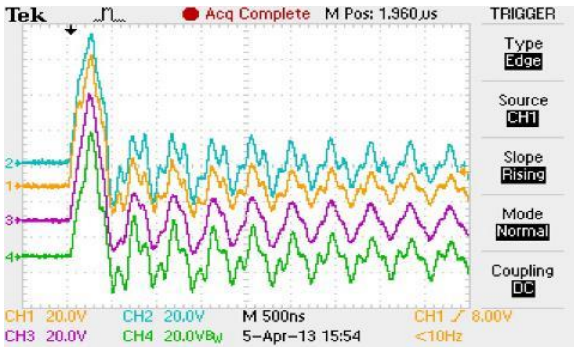


(b)

Figure 6. Oscillograms of response signal for two different cases, sweep duration 250 ns: (a) low voltage winding has no any additional capacities, (b) low voltage winding contains additional capacity

Additional capacity was formed by metal wire 5 cm long soldering to middle of one of turn of low voltage winding as shown on Figure 5. Probe pulse has the same form and parameters as above description and shown on Figure 4(a). Measurement result-response signals are shown on Figures 6 and 7. Figures 6(a) and 7(a) are for case when was no additional capacity (no wire) at winding area. Figures 6(b) and 7(b) correspond to situation when additional capacity was put in the middle of low voltage area.

The difference of response signal is essential enough. Period of fluctuation, form of amplitude peak and common view of curve are obviously changed. This picture takes place on both 250 and 500 ns sweep. Existence of really small capacity leads to shortage of fluctuation period, changes of form and value of first amplitude. So, presence of additional capacitance in low voltage winding area leads to serious change of response signal. These results confirm high sensitivity of short pulse method. Such typical defects of winding like turn to turn short circuit, axial or radial displacement and others lead to essential changes of capacities. Taking into account the results illustrated on Figures 6 and 7, it is possible to reveal winding defects which are in only just arising condition. It is necessary to note that using probe pulse different from rectangular couldn't allow to find a difference in responses with and without specific additional capacity.



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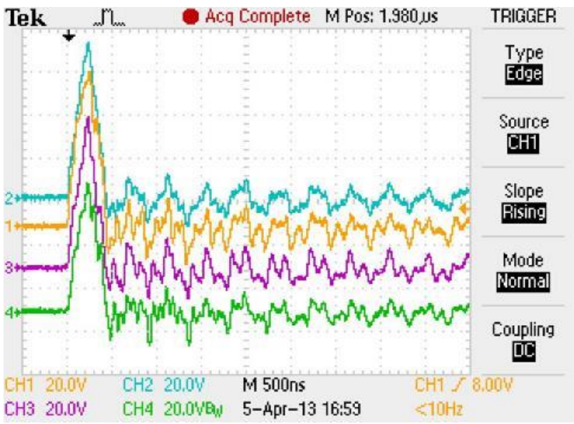

(b)

Figure 7. Oscillograms of response signal for two different cases, sweep duration 500 ns: (a) low voltage winding has no any additional capacities, (b) low voltage winding contains additional capacity

Such effective sensitivity is result of application for diagnostics procedure rectangular pulse with rapid front (no less than10 ns) and short duration (350 ns). More intensive enrichment of probe pulse by high frequencies allows forming more detailed and informative response. Advanced state control technology, based on LVPM with probe pulse parameters duration 1 microseconds and front steepness 50 ns [10], offers a using probe pulse with shorter duration.

IV. CONCLUSIONS

To improve famous low-voltage pulse method to control winding state a nanosecond probe pulse duration was used. This approach was called "nanosecond pulsed measurement technology" and successfully applied to transformer and electrical motor winding diagnostics [1]. Form of probe pulse has primary meaning and essentially influences to whole diagnostics procedure. Rectangular pulse form is necessary condition of high quality diagnostics procedure. Application of shorter pulse duration with rapid front is really good way to increase of sensitivity of diagnostics procedure.

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BIOGRAPHIES

Valeriy A. Lavrinovich was born on 7 November 1948. He received the Ph.D. degree from High Current Electronics Institute of Russian Academy of Sciences (Tomsk, Russia) in 1985 and Doctor of Science degree from the Tomsk Polytechnic University (Tomsk, Russia) in 2005. Both dissertations are dedicated to investigation and elaboration of high-voltage vacuum spark gaps and commutators. He was director of Russian Research Institute of Electrotechnical Industry from 1989 to 1998. Now he is Professor of Department of Electrical Power Engineering Systems and High Voltage Engineering. He is laureate of Russia Government Prize in area of Science and Technology. He published more than 90 scientific articles. His areas of interest include pulsed power and electrical power engineering.

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