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MODELING OF STATE CONTROL PROCEDURE OF POWER TRANSFORMER WINDING BY SHORT PROBE PULSES

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Abstract- Power transformers are important part of electrical power systems. Timely state control of transformer winding is necessary procedure. Present day state control technologies can't meet constant increasing present day requirements. Development of new technologies of state control is key direction of modern high voltage engineering. One of these technologies is transformer winding state control by short probe pulses. This method is based on short (compare with typical pulsed technology) probe pulse length (nanosecond range). It is shown that smaller probe pulse duration allows reaching more sensitivity of diagnostic procedure. But to develop and improve the quality of state control results, it is necessary to make modeling of whole diagnostic procedure. Probe pulse parameters and its frequency range determine the specific of diagnostics procedure. So, drawing up equivalent circuit and calculation of frequency range parameters of probe pulse is a content of the paper.

Keywords: Modeling of Diagnostic Procedure, Winding of Power Transformer, Equivalent Circuit of Winding, High Frequency Filling of Short Pulse.

I. INTRODUCTION

Power transformer is one of the most important units of electric power systems. Particularly relevant in this context is the timely detection of developing windings defects which help repair the power transformer before failure occurs. In order to make transformer windings diagnosis by low-voltage nanosecond pulses one uses a pulse generator that generates pulse with duration of a few hundred nanoseconds and a pulse front of a few nanoseconds. Technology based on low voltage pulse method (LVPM) showed promising results [1]. LVPM is described in [2, 3]. Main idea of this approach is using for winding diagnostics procedure of rectangular short (no more than 350 ns) pulse with rapid front (no more than 10 ns). The goal of this paper is to calculate the inductance and resistance frequency dependence of coil turns with circular and rectangular cross-sections. It is necessary to note that all calculations and results below are original, received by authors and published never before.

II. THE CALCULATION OF EQUIVALENT CIRCUIT ELEMENTS

High frequency currents occur in transformer windings due to the spectrum of applied nanosecond pulse contains plenty of high frequency components. When high-frequency current flows through the conductor, the current density cross-section distribution is placed on the periphery of the conductor. It is a well-known phenomenon called the skin effect.

Power transformer winding can be replaced by equivalent electrical circuit. View of the equivalent circuit of one turn is shown on Figure 1.

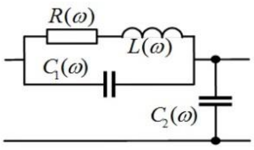


Figure 1. Equivalent circuit of one turn of power transformer winding

The $R(\omega)$, $L(\omega)$ and $C_1(\omega)$ are resistance, inductance and capacity between turns correspondently, $C_2(\omega)$ is capacity on turn to ground. During the forming of the equivalent circuit three important circumstances need to be taken into account:

Since the applied nanosecond pulse has short duration, the equivalent circuit need to be distributed. To form equivalent circuit of one turn-component of coil one can form distributed circuit of coil using components in series. Since, the applied pulse contains high frequency components hence one should take into account the frequency dependence of equivalent electrical circuit elements. Resistance and inductance depend on frequency when skin effect takes place.

Frequency superposition principle needs to be used for simulating transient processes of equivalent electrical circuit. Hence frequency range of applied impulse needs to be determined by decomposing into Fourier series. Then transient process for each Fourier component of applied pulse is calculated by using equivalent circuit with the corresponding frequency. To obtain these values cross section current density distribution has been calculated.

Using Maxwell equations one can obtain equation for vector magnetic potential A_ϕ to calculate cross-section current distribution density:

$$\left(j\omega\sigma-\omega^2\varepsilon\right)A_\phi+\nabla\times\left(\mu^{-1}\nabla\times A_\phi\right)=\frac{\sigma V}{2\pi r} \tag{1}$$

where, A_ϕ is vector magnetic potential, V is conductor voltage, ε is permittivity, ω is frequency, μ is permeability, σ is Conductivity, and j is Imaginary unit.

To obtain current and current density we used follow relations:

$$J_\phi=\nabla\times\left(\mu^{-1}\nabla\times A_\phi\right),\quad I=\pi\int_0^R J_\phi r^2 dr \tag{2}$$

Magnetic energy can be calculated by:

$$W=2\pi\iint A_\phi r dr \tag{3}$$

The definition of energy through inductance gives us the value of inductance by relation:

$$L=\frac{2W}{|I|^2} \tag{4}$$

The resistance of conductor can be obtained by:

$$R=\mathrm{Re}\left(\frac{V}{I}\right) \tag{5}$$

For definition of pulse frequency range the experimental data have been used.

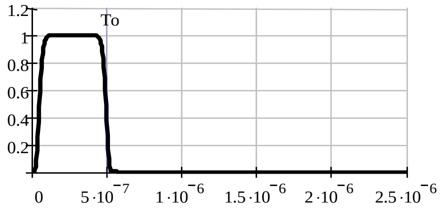


Figure 2. Graphical view of probe pulse

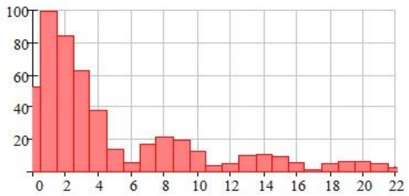


Figure 3. Frequency range of probe pulse

The frequency of the first harmonic in decomposition equals f_1=4×10^5 Hz or ω_1=2.51×10^6 Rad/sec. Taking into account 22 of first harmonics the investigation was conducted in the frequency range of $\omega \in [0, 5.5\times10^7]$ Rad/sec. The external winding is wound with copper cable of diameter d=2 mm with the pace h=4 mm, the number of turns is n=120, internal diameter is d_{in} = 140 mm, external diameter is D_{out}=160 mm, the length of copper cable is l=370 mm, the basis–polymeric cylinder. The internal winding is wound by copper bus with size of a = 4 mm, b = 7 mm, the number of turns n=20, internal diameter d_{in}=86 mm, external diameter D_{out}=102 mm, the length of copper cable l=370 mm, the basis is polymeric cylinder (Figure 2).

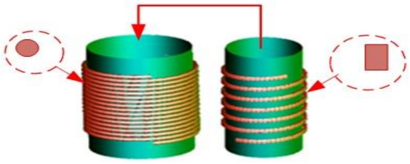
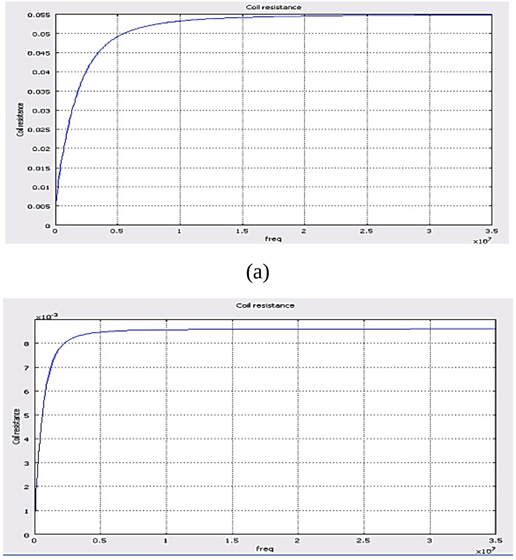


Figure 4. View of coils for simulation procedure

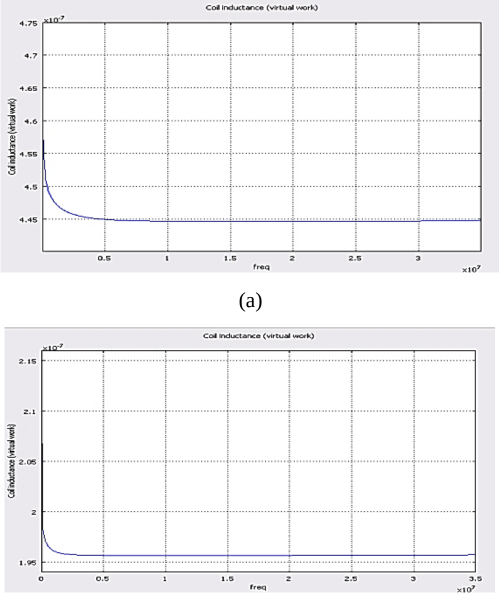
To solve differential Equation (1) and (2) to (5) finite elements method with COMSOL Multi physics has been used. The obtained dependences of resistance R and inductance L from frequency ω for two cross sections of power transformer windings are shown in Figures 5 & 6.



(a)

(b)

Figure 5. Frequency dependence of resistance
(a) Cross section in the form of a ring with diameter
(b) Cross section in the rectangular form



(a)

(b)

Figure 6. Frequency dependence of inductance
(a) Cross-section in the form of a ring
(b) Cross-section in the rectangular form

III. 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. This process was modeled and calculations confirm experimental results.

Due to diminish of probe pulse duration and growth of front pulse high frequency filling is essentially increased. Growth of high frequencies in probe pulse leads to prevalence of capacitive element meaning of controlling windings. Thus, in turn, provides more detailed picture in winding receiving and as result-increasing of sensitivity.

Application of shorter pulse duration with rapid front is promising way increasing of sensitivity of winding 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 Electro Technical 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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