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FILTERING OF THE MAGNETIZING CURRENT AND REPRODUCTION OF THE PRIMARY VOLTAGE OF THE MEASURING TWO-WRINDED VOLTAGE TRANSFORMERS

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Abstract: *The paper studies a qualitatively new way to reduce the measurement error of phase voltages in solving the problem of filtering the magnetization current and the reproduction of the primary voltage signals of two-winding measuring transformers. Errors of voltage measuring transformers in these transient and stationary processes are primarily due to the nonlinearity of the magnetization characteristics of the electrical steel cores and, in addition, the active resistance of the windings, the load and their inductances, and in some cases, and capacity. In fact, errors are methodical and in many practical applications limit the use of various transformers because of the inability to provide the required accuracy class.*

The results obtained can be used for other types of these transformers in high voltage three-phase systems. Traditionally, such transformers are described using linear, electrical equivalent circuits, which leads to large, unacceptable errors in the analysis and control of various non-stationary processes in the transformer equipment and the power system circuit, where it is installed, which in turn can cause significant damage equipment, loss of stability of power supply systems, large economic losses and violation of the safety of their service.

Key words: *voltage transformer, magnetization current, loss current, error reduction, eddy currents, primary voltage recovery.*

INTRODUCTION The technical result consists in reducing the filtering error of the magnetizing current, taking into account the hysteresis, in expanding the functionality for practical use and research purposes in various applications. The method of filtering the

magnetizing current and reproducing the primary voltages of measuring voltage transformers includes drawing up a system of nonlinear equations reflecting real electromagnetic physical processes in the transformer, choosing measuring converters for connecting to the power system and for organizing a closed-loop computing system operating in real time, at the output of which voltages are generated, proportional to the components of the magnetizing current and the reproduced primary voltage, in analog or digital form, visualize the output information and additionally control the computational process, while controlling the reproduction errors.

Errors of measurement of voltage in said non-stationary x , as well as in stationary processes are due primarily nonlinearity characteristics magnetization electrical steel cores and, moreover, winding resistances, inductive loads and their axes, and in some cases, and capacity. In fact, the errors are methodical and in many practical applications limit the use of various transformers due to the impossibility of ensuring the required accuracy class. Therefore, to further improve the accuracy of measuring the primary voltage is, first of all, solving the problem of its reproduction by eliminating methodological and instrumental errors in non-stationary modes of electrical equipment, as well as increasing the linear range of voltage measurement. This is achieved by investigating a method for reproducing the primary voltage based on solving a system of nonlinear equations that reflect real physical electromagnetic processes in a transformer with features of hysteresis magnetization characteristics. Increasing the accuracy of measuring the primary values of voltage and current transformers in power systems and power supply systems is always an urgent task, since allows scientifically design, create means emergency control, to improve the quality of measurement processes, efficiency and safety of the production and distribution of the electric energy [1-3], expand precision calculating load schedules to ensure quality and reliability of supply of electric power to different consumers according the rules for the construction of electrical installations (PUE) . In this regard, the article discusses methodological issues of improving the accuracy of reproduction of the primary voltage of two-winding electromagnetic measuring voltage transformers in power systems of different voltage classes. The results obtained can be used for other types of these transformers in high voltage three-phase systems. Traditionally, such transformers are described using linear, electrical equivalent circuits [4-6], which leads to large, unacceptable errors in the analysis and control of various non-stationary processes in the transformer equipment and the power system circuit, where it is installed, which in turn can cause significant damage equipment, loss of stability of power supply systems, large economic losses and violation of the safety of their service. In this manner measuring the tolerates of voltage current in stationary as well as in a governmental hospital processes are due to the nonlinear characteristic magnetization steel cores, as well as active claimed windings, load and inductance, and capacity. In fact, the errors are methodical and in many practical applications limit the use of various transformers due to the impossibility of ensuring the required accuracy class. Therefore, the practical problem of further increasing the accuracy of measuring the primary voltage is to solve the problem of its reproduction by eliminating (or significantly reducing) methodological and instrumental errors in transient and steady-state conditions of the power system equipment, as well as increasing the linear voltage measurement range. Expanding the functionality of instrument transformers in terms of their use for various practical applications is also of great importance.

For example, for various means of relay protection, emergency automation, as well as measurements. The solutions to the questions posed can be achieved by further clarifying the description of physical processes in transformer equipment, taking into account the nonlinearity of its parameters, the features of the transformation itself, coordination with the load, which is what the content of the article is devoted to. Thus, the following system of nonlinear equations is proposed to describe the problems involved:

$$u_1 = i_1 R_1 + L_{s1} \frac{di_1}{dt} + \frac{d\psi_{\text{HAM}}}{di'_{\text{HAM}}} \cdot \frac{di'_{\text{HAM}}}{dt} + i'_{\text{HAM}} R_{1n}, \quad (1)$$

which is sequentially for clarity and is transformed to the following forms - expressions (2) - (5):

$$u_1 = i_{\text{HAM}} R_1 + L_{s1} \frac{di_{\text{HAM}}}{dt} + M_{\text{диф}} \frac{di'_{\text{HAM}}}{dt} + i'_{\text{HAM}} R_{1n} \quad (2)$$

$$u_1 = i_{\text{HAM}} R_1 + L_{s1} p i_{\text{HAM}} + u'_1, \quad (3)$$

$$u_1 = M_{\text{диф}} p i'_{\text{HAM}} + i'_{\text{HAM}} R_{1n} + (i'_{\text{HAM}} + i_n) R_1 + L_{s1} p (i'_{\text{HAM}} + i_n) \quad (4)$$

$$u'_1 = u_2 \cdot n + u_2 \cdot \frac{w_1}{w_2} \quad (5)$$

$$p \Psi_{\text{HAM}} + i'_{\text{HAM}} R_n = i_{\text{HAM}} R_n \quad (6)$$

$$i_{\text{HAM}} = i'_{\text{HAM}} + i_n \quad (7)$$

$$i_1 w_1 = Hl \quad \text{или} \quad i_{\text{HAM}} = \frac{Hl}{w_1} \quad (8)$$

$$\frac{p \Psi_{\text{HAM}}}{R_n} = i_n \quad (9)$$

$$i'_{\text{HAM}} = f(\Psi_{\text{HAM}}) \quad (10)$$

Where

u'_1 - is the primary voltage of the transformer due to the flux linkage of the winding, V;

u - primary voltage of the transformer,

u_2 - secondary voltage of the transformer,

Ψ_{HAM} - flux linkage of the secondary winding, due to the mutual induction of the primary and secondary windings $\Psi_{\text{HAM}} = w_2 \Phi_{\text{HAM}}$;

$i_1 = i_{\text{HAM}}$ - current of the primary winding of the transformer (it is also the magnetizing current), A ;

i'_{HAM} - the magnetizing current, determined from the magnetization curve of the steel of the core and creating a magnetic flux;

R_{Π} - resistance to losses due to the hysteresis of the magnetization curve and eddy currents,

i_{Π} - the second component of the magnetizing current, which creates losses in the core for hysteresis and eddy currents,

$$M_{\text{диф}} = \frac{d\Psi_{\text{HAM}}}{di'_{\text{HAM}}} = \frac{dw_2 \Phi_{\text{HAM}}}{di'_{\text{HAM}}}$$

$M_{\text{диф}}$ - differential mutual inductance magnetization, H;

i'_{HAM} - the magnetizing current, determined from the magnetization curve of the steel of the core and creating a magnetic flux;

L_{s1} - the leakage inductance of the primary winding of the transformer,

H - the magnetic field strength in the core, A / m;

l - the length of the middle magnetic line of the core;

w_1 и w_2 - the number of turns, respectively, of the primary and secondary windings of the transformer;

$\frac{w_2}{w_1} = n$ - transformation ratio;

p - the symbol of time differentiation d / dt .

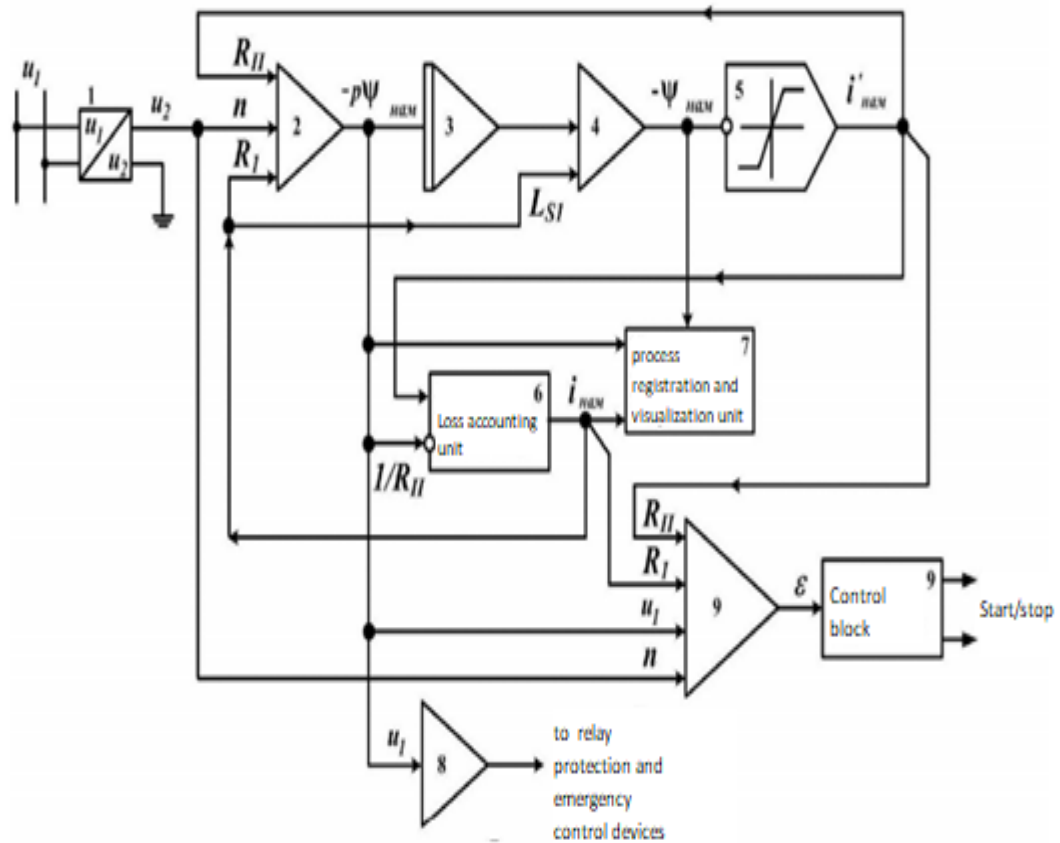


Fig.1-Scheme of filtering the magnetizing current and reproducing the primary voltage of measuring two-winding transformers

Figure 1 shows a circuit for filtering the magnetizing current and reproducing the primary voltage of measuring two-winding transformers, developed on the basis of the above nonlinear equations

The sequence of performing measuring and computational operations according to the given system of equations and the purpose of the elements is shown in Figure 2. Figures 3 - 4 show the most typical oscillograms record of the recovery processes of the primary voltage of the measuring voltage transformer (TV). In particular, Figures 3 , a and 3 , b show oscillograms record of the magnetizing current i'_{HAM} (Figure 3 , a), which creates a flow in a non-stationary mode and a loss current (Figure 3 , b) in the same mode.

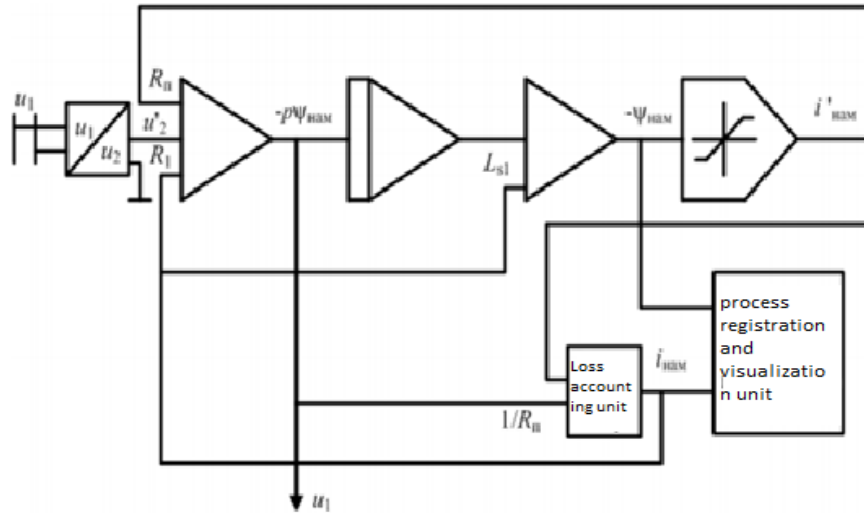
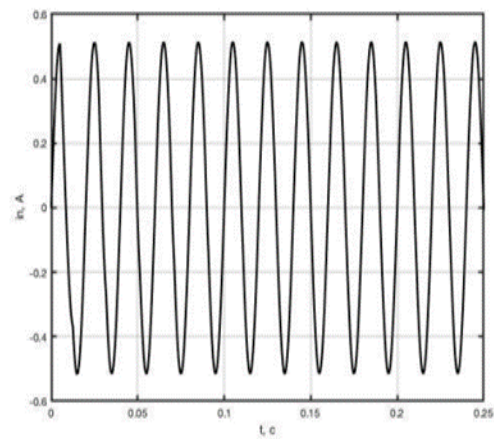
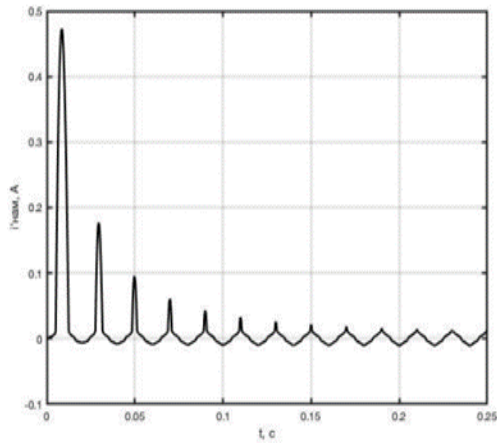


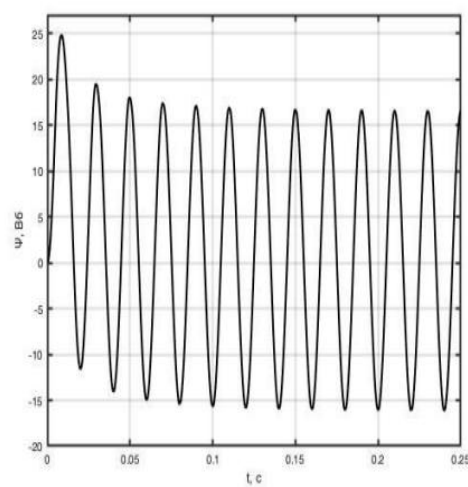
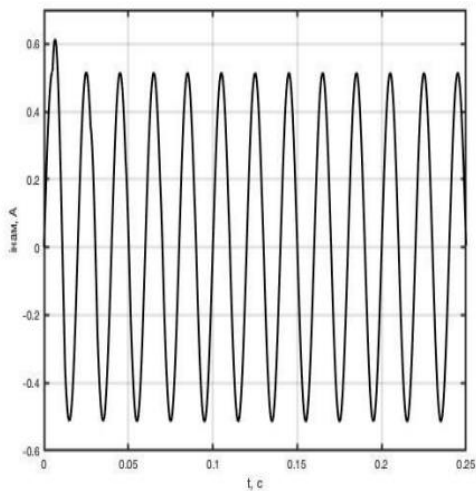
Fig.2- Block diagram of the primary voltage reproduction



a) magnetizing current

b) loss current

Fig.3- Oscillographs record of the magnetizing current i'_{HAM} (a) creating a flux and loss current (b) in a non-stationary mode i_{II}



a) net magnetizing current i_{HAM}

b) flux linkage Ψ

Fig.4- Oscillographs record of the resulting magnetizing current i_{HAM} (a), creating a flux and flux linkage Ψ (b) in a non-stationary mode

The oscillography *record* of the resulting magnetizing current i_{HAM} in the non-stationary mode is shown in Figure 4 , a. In turn, Figure 4 , b shows the oscillogram of the flux linkage of the primary winding of the voltage transformer for the process of connecting it to the network in the absence of load, i.e. in the absence of a secondary current, which is a feature of solving the problem of reproducing the primary voltage u_1 . The characteristic of magnetization in the process of turning on the transformer is shown in Figure 5 .

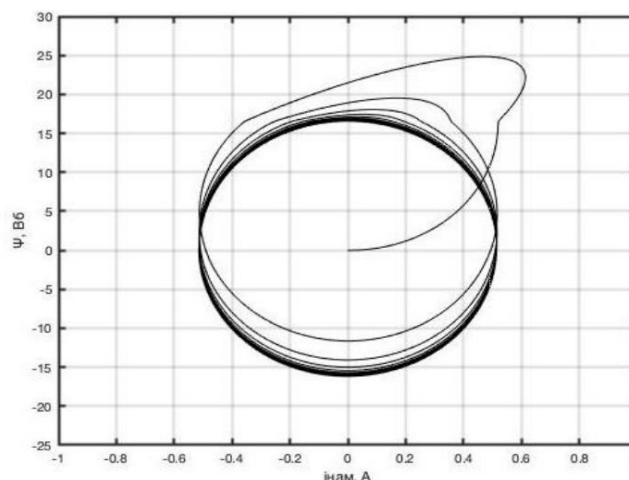


Fig.5 - Characteristics of magnetization in the non-stationary mode of switching on the voltage transformer

The oscillograms record of the input u_1 and output voltages $d\Psi / dt$ from the start of the process to the steady state (~ 0.075 s) is shown in Figure 6 . The verification of the proposed solution to the problem was carried out using mathematical modeling in the «Simulink» software environment .The main structural elements of the considered model of a two - winding measuring voltage transformer and its parameters are a magnetic circuit based on electrical steel 1512, 3414, primary and secondary windings based on PEL (PEL) wire, primary rated voltage $6.3 / \sqrt{3}$ kV , secondary rated voltage $100 / \sqrt{3}$ V, the number of turns of the primary winding $w_1 = 6300$, the number of turns of the secondary winding $w_2 = 100$, the transformation ratio $n = 63$, the maximum induction $B_m = 1.0$ Tl. In the computational experiment, the initial magnetization curve of steel 1512 with a sheet thickness of 0.3 mm and a winding wire with a cross section of ~ 0.0177 m² were used:

In this case, the studies were carried out to assess the effect on the error in reproducing the primary voltage of the u_1 error in reproducing the differential mutual inductance $M_{\text{диф}}$, the

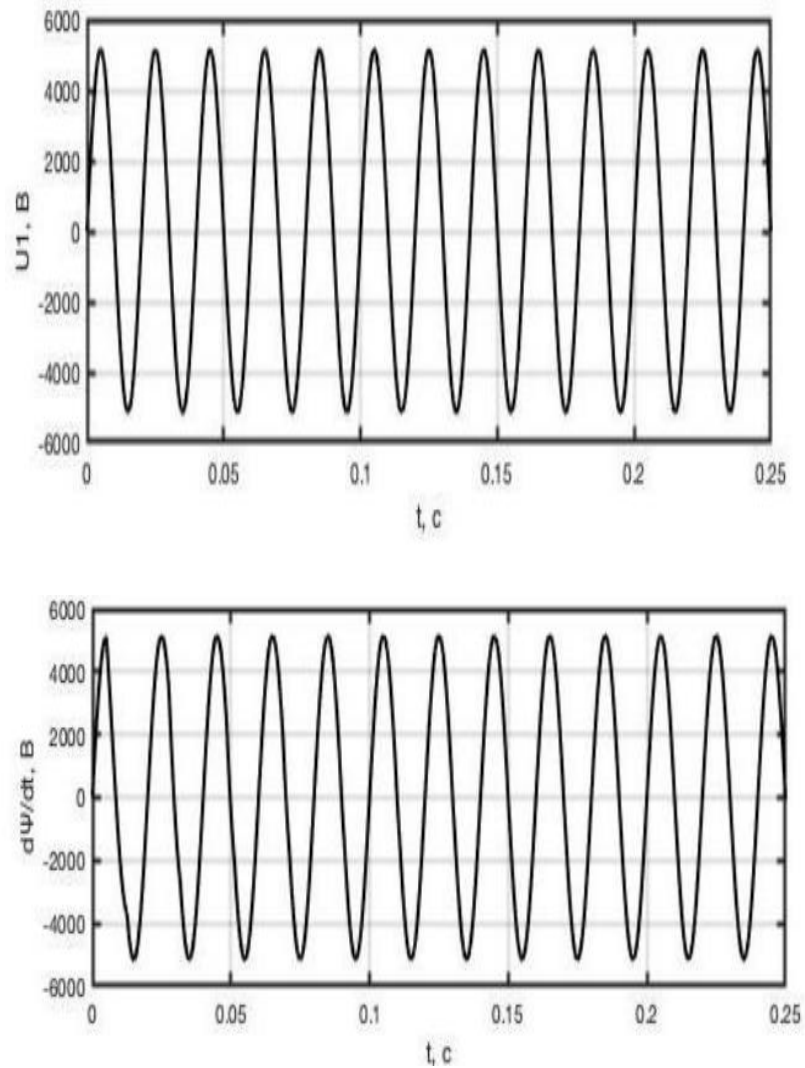


Fig.6- Oscillograms of the input (u_1) and output ($d\Psi / dt$) voltages from the beginning of the switch-on process to the steady state (~ 0.075 s)

magnetizing current i_{HAM} and its components, the loss current i_p , the magnetizing current i'_{HAM} that creates the magnetic flux Φ_{HAM} and the corresponding flux linkage Ψ_{HAM} , and the parameters of the primary winding R_1 and L_{S1} causing the additive components of the resulting error in the reproduction of the primary stress u_1 according to equation (4). Given the complexity of the analytical description of the resulting error, the article presents the corresponding oscillograms of changes in the individual components of the primary voltage reproduction process and the final result of its reproduction in Figures 2-5, which demonstrate the features of non-stationary and stationary reproduction processes and the positive result of solving the problem (oscillograms, Fig. 6).

CONCLUSIONS. The required instrumental error and functionality of the method are provided by the correct choice of technical characteristics of analog and digital means that implement various mathematical operations used to solve the problem.

First of all, these include, in digital implementation, the bit width and conversion rate, taking into account the permissible sampling in time and the error of the initial information provided by the manufacturer of the transformer equipment. Thus, methodical errors were eliminated.

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