




To Increase the Sensitivity of the Electromagnetic Current Transducers

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Abstract: The article discusses a way to increase the sensitivity of an electromagnetic current converter used in the electric power industry, in particular relay protection. The distribution of the magnetic flux in the magnetic system of an electromagnetic converter with an output signal convenient for reception and processing is investigated. An electronic circuit is used to increase the output signal.

1 INTRODUCTION


Ensuring uninterrupted power supply requires paying special attention to primary information and measuring tools related to the values and parameters of stability, stability, reliability of control and management. The problem of developing and implementing signal converters (current) – sensors of the process of controlling sources of power supply systems based on digital technology – is considered one of the important tasks that requires the development of new designs based on it. The use of special sensing elements provides unified values for both output current (100 mA) and voltage (20 V), and creates conditions for the use of digital devices for monitoring, protecting, and controlling reactive power sources (Amirov, Safarov, Rustamov, Ataulaev, 2018; Amirov, Safarov, 2010; Safarov, Sattarov, 2019).


The conversion of primary electric current is the main value of the power supply, mainly based on electromagnetic phenomena, therefore, electromagnetic converters of the primary current signal into an output signal in the form of a secondary voltage for monitoring and control are currently very


optimal. The widespread use of primary electromagnetic current converters with high accuracy, linearity of output characteristics, unified output values, and extended ranges of converted quantities is limited due to insufficient formation of the principles of construction, calculation methods, and design of distributed magnetic current converter systems (Amirov, Safarov, 2009; Safarov, Jumaboyev, Sattarov, 2020). The results of the study showed that electromagnetic current converters with distributed magnetic parameters in the current monitoring and control system of power supply sources fully meet the requirements in terms of efficiency, reliability and accuracy. However, increasing sensitivity during current conversion, despite the use of various methods, remains an unresolved issue.

2 MATERIALS AND METHODS

The purpose of this article is to increase the sensitivity of an electromagnetic current converter based on an electronic circuit.

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A general view of the design of the proposed device for converting current to voltage is shown in Fig.1, the layout of the modulating and output windings is shown in Fig. 2.

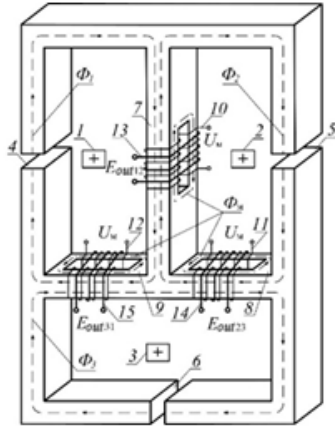


Figure 1: Electromagnetic field design current converter.

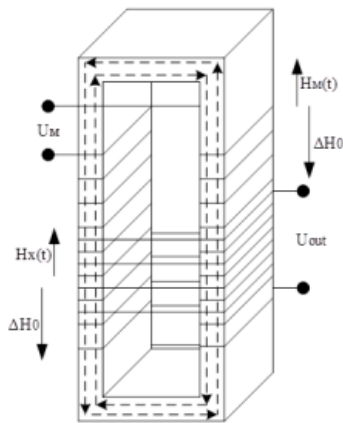


Figure 2: Arrangement of the modulating and output windings.

The electromagnetic current converter contains three current-carrying busbars 1, 2, 3 passing through the corresponding windows of a three-circuit magnetic circuit consisting of non-adjacent rods 4, 5, 6 with corresponding air gaps and adjacent rods 7, 8, 9 made with rectangular cutouts, on the parallel branches of which are located modulating windings 10, 11, 12 and output windings 13, 14, 15, covering each rod together with a cutout and interconnected according to the open triangle pattern.

The converter works as follows: when determining the unevenness of the current load of parallel branches, direct currents $I_1, I_2,$ and I_3 pass through buses 1, 2, 3 in the same direction. These currents in non-adjacent rods 4, 5, 6 of a three-circuit

magnetic circuit create permanent magnetic fluxes Φ_1, Φ_2 and Φ_3 and in adjacent rods 7, 8, 9 there is a difference in magnetic fluxes $\Delta\Phi_{12} = \Phi_1 - \Phi_2,$ $\Delta\Phi_{23} = \Phi_2 - \Phi_3,$ and $\Delta\Phi_{31} = \Phi_3 - \Phi_1.$ When the modulating windings 10, 11, 12 are connected to an alternating voltage source $U_M,$ a modulating alternating magnetic flux Φ_M is closed along the branches of each rectangular cutout. There is no EMF from the magnetic flux Φ_M in the corresponding output windings 13, 14, 15. This is due to the fact that the magnetic flux lines Φ_M do not cover the turns of the output windings. When the currents $I_1, I_2,$ and I_3 are equal, then their magnetic fluxes Φ_1, Φ_2 and Φ_3 are equal, and the difference magnetic fluxes are zero, i.e. $\Delta\Phi_{12} = 0, \Delta\Phi_{23} = 0,$ and $\Delta\Phi_{31} = 0.$ Therefore, the EMF values $E_{out12}, E_{out23}, E_{out31}$ at the ends of the output windings 13, 14, 15 are also zero.

If the currents in the current-carrying busbars 1, 2, 3 differ in magnitude, then the corresponding difference magnetic fluxes are not zero and, according to the law of electromagnetic induction, an EMF appears at the ends of the corresponding output windings, proportional to the magnitude of the corresponding difference magnetic flux and, consequently, the difference current in adjacent buses.

When installing the proposed device in three-phase AC circuits, the modulating windings are disconnected from the source. In this case, the voltage at the output terminals of the open triangle will be proportional to the asymmetry of the currents in the three-phase circuits. In the symmetrical mode of the three-phase circuit, the output voltage will be zero.

Since the sensing element of an electromagnetic current converter uses the effect of magnetic modulation, consider the condition for the appearance of an EMF at the output of the output winding. Considering that the principle of operation of the sensing element is based on the interaction of two fields created by a modulating current flowing through the modulating winding of an alternating magnetic field with a voltage and created by the flow of direct current through the busbars and a constant field with a voltage ΔH_0 (their directions are shown in Fig.2) defined as the voltage difference $H_{0л}$ and $H_{0п}$ created by the corresponding busbar currents in the rod. Therefore, in the case of equality of tensions $H_{0л}$ and $H_{0п}$ tensions $\Delta H_0 = H_{0л} - H_{0п}.$ In this case, there is no signal at the output of the output winding. However, as soon as a voltage ΔH_0 other than zero appears in the rod, the voltages of direct ΔH_0 and alternating modulating currents overlap $H_m(t)$ (Shevchenko, Ba'oiycluiuk, Boltentkov, 2019).

In the general case, the superposition of the strengths of these fields in the rod is given by the expression (Bessonov, 2016):

$$H_{\Sigma}(t) = \Delta H_0 + H_m(t). \quad (1)$$

The vector of magnetic induction B acting inside magnetizable cores can be found based on the dependence

$$B = \varphi([H_{\Sigma}]). \quad (2)$$

Here is the φ – vector of the function describing the anisotropic and nonlinear properties of the cores; square brackets indicate the ambiguity of the function due to hysteresis phenomena.

The EMF induced in the output winding can be found based on the law of electromagnetic induction:

$$e(t) = -w_2 \frac{d\Phi}{dt} = w_2 S \frac{dB}{dt} \quad (3)$$

where w_2 – is the number of turns of the output winding; $\Phi = Bs$ - magnetic flux in the cores; S - total cross-sectional area of the converter cores.

If we ignore the phenomena of anisotropy and hysteresis in cores, instead of the complex dependence (2), we can obtain a simple one that takes into account only the nonlinearity of the main magnetization curve $B = f(H_{\Sigma})$.

The modulus of the instantaneous value of the total field strength is found from expression (1):

$$H_{\Sigma} = \sqrt{\Delta H_0^2 + 2\Delta H_0 H_m \cos\alpha + H_m^2}, \quad (4)$$

where α - is the angle between the vectors ΔH_0 and H_m .

Let us consider the operation of a sensitive element with mutually parallel fields, i.e.:

$$\alpha = 0^\circ, H_{\Sigma} = \Delta H_0 \pm H_m. \quad (5)$$

For this purpose, we will use the most common in practice magnetic modulator with two rod cores. In this case, we will assume that the vector ΔH_0 is directed along the longitudinal axes of the cores, as well as the cores and the coils surrounding them are identical.

3 RESULTS AND DISCUSSION

The magnetic induction in each parallel core of the middle rod (3) will be equal to

$$B' = f(\Delta H_0 + H_m), B'' = f(\Delta H_0 - H_m). \quad (6)$$

The EMF induced in the output winding of the converter, according to (3) and taking into account (6):

$$e(t) = w_2 s \frac{d}{dt} (B' + B''), \quad (7)$$

where s – is the cross-sectional area of one core.

We show that with a $\Delta H_0 = \text{const} \neq 0$ (constant transformable field), the appearance of EMF $e(t)$ is fundamentally possible only in the presence of a nonlinear dependence $B(H)$.

Let's propose the opposite, i.e. we will consider this dependence to be linear: $B = aH$, where a - is constant coefficient. Then

$$B' + B'' = 2a\Delta H_0, e(t) = -2asw \frac{d\Delta H_0}{dt} \Big|_{\Delta H_0 = \text{const}} = 0.$$

Now we approximate the dependence $B(H)$ by a shortened polynomial of the third degree:

$$B = aH - bH^3, \quad (8)$$

where a and b are positive approximation coefficients. Then, taking into account expression (7), we obtain:

$$\begin{aligned} B' &= a\Delta H_0 + aH_m - b\Delta H_0^3 - 3b\Delta H_0^2 H_m - 3b\Delta H_0 H_m^2 - bH_m^3; \\ B'' &= a\Delta H_0 - aH_m - b\Delta H_0^3 + 3b\Delta H_0^2 H_m - 3b\Delta H_0 H_m^2 + bH_m^3; \end{aligned} \quad (9)$$

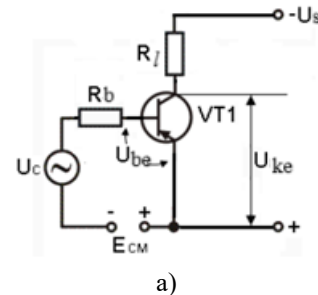
$$B' + B'' = 2a\Delta H_0 - 2b\Delta H_0^3 - 6b\Delta H_0 H_m^2. \quad (10)$$

The term emphasized in (10) is characterized by the fact that it contains the product of the voltages of the converted difference constant and auxiliary alternating magnetic fields, and it is precisely responsible for the appearance of EMF in the output winding of the converter:

$$e(t)|_{\Delta H_0 = \text{const} \neq 0} = 6bsw\Delta H_0 \frac{d}{dt} H_m^2(t) \neq 0 \quad (11)$$

From this it can be seen that the non-linearity of the dependence $B(H)$ is indeed the fundamental factor responsible for the appearance of the EMF carrying information about the converted direct current.

It follows from formula (11) that improving the sensitivity of a current converter with a change in design parameters is limited due to its overall dimensions, and the value of the difference in permanent magnetic voltages is determined by the configuration feature of the converter in question, which does not allow for increased sensitivity. To increase sensitivity, a well-known AC amplifier circuit can be used.



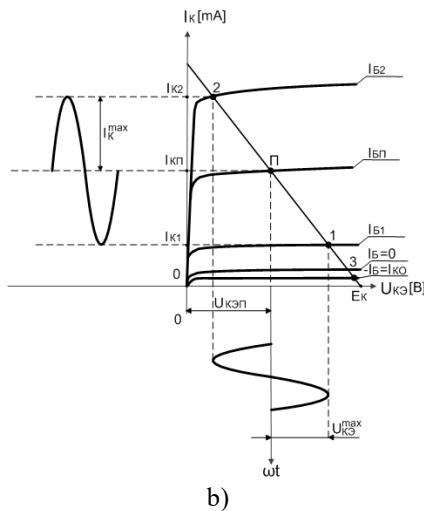


Figure 3: Circuit of an amplifier on a bipolar transistor with a common emitter (a) and the output dynamic characteristic of the transistor (b).

Figure 3, a shows the circuit of an amplifier on a bipolar transistor with a common emitter, and Figure 3, b shows the output dynamic characteristic of the transistor with the highest power gain (both current and voltage). In practical circuits, the E_{cm} bias source is rarely used, and the value of the quiescent current I_B is set by the E_k source. At the same time, additional bias resistors are introduced into the circuit and an n -fold increase in the output signal (voltage) and its regulation is achieved, which expands the dynamic range that allows the converter to be used in digital monitoring and control systems.

4 CONCLUSION

Electromagnetic current converters (ECC) based on various physical effects are widely used in many monitoring and control systems due to their high reliability against external mechanical influences, wide conversion range, small dimensions and other technical indicators. However, the value of the output signal, therefore, the sensitivity of ECC is low, which limits their scope of application in modern digital devices.

Analytical expressions of the output signal are obtained depending on the design and magnetic characteristics of the converter, the analysis of which showed that the sensitivity value is limited by the dimensions and principle of operation of the converter. To increase the sensitivity of the converter, it is proposed to use an amplifier circuit on a bipolar

transistor with a common emitter, which allows to increase the output signal n -fold.

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