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Modeling the processes of conversion of asymmetrical three-phase currents into output voltage

T.U. Kurbaniyazov[1][a], A.B. Bazarbaev[1][b]

[1]Nukus Mining Institute at Navoi State University of Mining and Technologies, Nukus, Republic of Karakalpakstan, Uzbekistan

Abstract: In the monitoring and management of electric power supply systems around the world, great attention is paid to determining and standardizing the values of measured and controlled quantities and parameters based on signal transformation processes, to the accuracy and reliability of measurement indicators, and to the algorithms and practical software products that provide them. In this direction, in countries with advanced technology and technics, including the USA, Germany, France, Sweden, Italy, Japan, China, Korea, and Russia, measuring and control devices, tools, and measuring and control signals that determine the multi-parameter, functionality, and speed of reactive power indicators, the development of new structures, work algorithms and software of transducers and sensors supplying primary signals is considered urgent, and the application of research results to practice is of great importance.

Modern calculations and design require the use of complexes in the study of electromagnetic converters of primary current into secondary voltage of complex and variable quantities. This articale presents mathematical expressions for determining the values and parameters used in electrical and magnetic transformer parts and sensor designs of assymmetrical three-phase current converter sensors (ATPCCS) used in control and reactive power control systems of power plants. supply systems are presented.

Keywords: assymmetrical three-phase current, sensors, primary currents, secondary voltage, graph model

1. Introduction

In modern power supply systems (PSS), the accurate measurement and control of reactive power are critical for ensuring energy efficiency, maintaining power quality, and optimizing system reliability. These tasks are particularly challenging in environments where asymmetrical and non-sinusoidal currents occur due to unbalanced loads, harmonic distortions, or the integration of distributed energy resources. Addressing these challenges requires advanced measurement and sensing technologies capable of reliably converting complex electrical quantities into manageable signals for analysis and control.

Assymmetrical three-phase current converter sensors (ATPCCS) require the use of modern calculation and design complexes in research issues involving three-phase primary current to secondary voltage electromagnetic converters. This article presents research models and mathematical expressions of the processes, quantities, and parameters of the three-phase electromagnetic current transformers used in the measurement and control systems of the reactive power of the power supply systems (PSS), as well as the elements and structures of the three-phase electromagnetic current transformers [1,2].

Asymmetrical Three-Phase Current Converter Sensors (ATPCCS) represent an innovative solution to these challenges. These sensors are specialized electromagnetic devices designed to transform three-phase primary currents into secondary output voltages. ATPCCS play a crucial role in modern PSS by enabling the monitoring and management of reactive power under both ideal and non-ideal operating conditions. Their applications extend to industrial automation, renewable energy systems, and smart grid technologies, where precise and efficient reactive power control is essential.

This article presents a comprehensive study of the operational principles, mathematical models, and design elements of ATPCCS. It focuses on the conversion processes of three-phase primary currents into secondary voltages and investigates the parameters and structures that influence their functionality [3,4].

2. Research Methodology

The process of changing the reactive power of power supply systems from symmetric three-phase primary currents to the output signal in the form of secondary rated voltage and the modeling and research of the devices and sensors involved in this process are carried out on the basis of the following algorithms:

ATPCCS devices with different physical and technical characteristics that provide the conversion of electrical energy into a secondary signal, the process of energy and signal conversion in energy sources, and the process of monitoring and modeling the structure of the control sensor:

1. A model of the process of converting the primary electric current I_{in} into the magnetic driving force F_μ is created (Fig. 1):

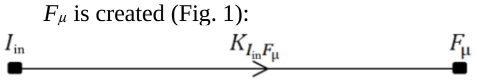


Fig. 1. Model of the process of transformation of the primary electric current I_k into the magnetic driving force F_μ

where - $K_{I_{in}F_\mu}$ is the interchain coupling coefficient of the conversion of electric quantity to magnetic quantity.

[a] https://orcid.org/0000-0001-5296-4600
[b] https://orcid.org/0009-0002-2617-9320

- an analytical view (1) of the relationship between the magnetic driving force F_μ of the magnetic switching part and the primary electric circuit current I_k is created:

$$F_\mu = K_{I_{in}F_\mu} I_{in}, \quad (1)$$

where $K_{I_{in}F_\mu}$ is the inter-chain coupling coefficient of the process of transformation of the magnetic driving force F_μ into the primary current of the electric circuit I_k.

2. A model of the process of changing the magnetic driving force F_μ and the magnetic flux Φ_μ is created (Fig. 2):

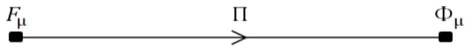


Fig. 2. Model of the process of transformation of F_μ - magnetic driving force into Φ_μ - magnetic flux

where Π is the coupling coefficient of the conversion of the magnetic driving force to the magnetic flux.

- an analytical view (2) of the relationship between the magnetic flux Φ_μ magnetic driving force F_μ and the primary electric circuit current is created:

$$\Phi_\mu = \Pi F_\mu, \quad (2)$$

where Π is the coupling coefficient of the magnetic driving force F_μ and the process of changing to electromagnetic current Φ_μ.

3. A model of the interconnection between the magnetic flux Φ_μ and the secondary output voltage U_{out} - the secondary signal is created (Fig. 3):

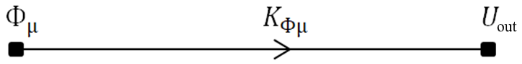


Fig. 3. Model of the process of converting the magnetic flux Φ_μ into the secondary output voltage U_{out} - the secondary signal.

The analytical expression (3) of the process of converting the magnetic flux Φ_μ into the three secondary output voltages U_{out} of the magnetic transformer part is made:

$$U_{out} = K_{\Phi\mu Uout}\, \Phi_\mu, \quad (3)$$

where $K_{\Phi\mu Uout}$ is the inter-chain coupling coefficient of the transformation of the magnetic flux Φ_μ into the secondary output voltage U_{out}.

a) A graph model for generating the output voltage of a single-phase single-sensing element ATPCCS with aggregate parameters of the power supply system (PSS) connected to the reactive power source is formed (Fig. 4).

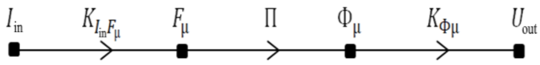


Fig. 4. A graph model for generating the output voltage of single-phase single-sensing element electromagnetic current-to-voltage converters with increased functionality

An analytical expression (4) formed on the basis of the graph model of generating the output voltage of a single-phase single-sensing element ATPCCS with aggregated parameters of the PSS reactive power source of the power network is in the form of an analytical expression (4) [9]:

$$U_{out} = K_{IinF\mu} \Pi_\mu K_{\Phi\mu} I_{in} \quad (4)$$

where: $K_{IinF\mu}$ is the inter-circuit coupling coefficient of the process of transformation of the magnetic driving force into the primary current of the electric circuit.

Π_μ - the inter-chain coupling coefficient of the conversion of the magnetic flux to the magnetic current.

$K_{\Phi\mu}$ - the inter-circuit coupling coefficient of the conversion of the magnetic current to the secondary output voltage.

I_{in} - electric circuit primary current.

A graph model of the output voltage of the two-phase single-sensing element ATPCCS with distributed parameters of the power network connected to the PSS reactive power source is formed (Fig. 4).

b) The graph model of generating the output voltage of three-phase three-sensing element ATPCCS with distributed parameters of the power network connected to the PSS reactive power source is presented in Figure 5:

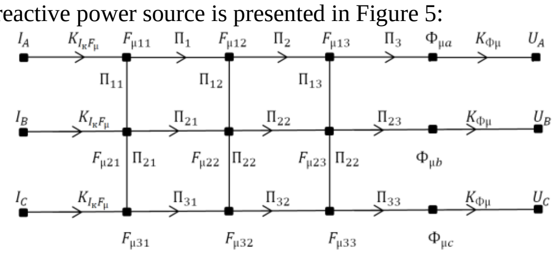


Fig. 5. Graph model of output voltage generation of electromagnetic current-to-voltage converters with extended functionality with distributed parameter three-phase three sensitive elements

The analytical expression formed on the basis of the graph model for the formation of the output voltage of the three-phase ATPCCS with three sensitive elements with distributed parameters is in the form of (5), (6) and (7):

$$U_A = W_{IU}(I_A, U_A)I_A + W_{IU}(I_B, U_A)I_B + W_{IU}(I_C, U_A)I_C, \quad (5)$$

$$U_B = W_{IU}(I_A, U_B)I_A + W_{IU}(I_B, U_B)I_B + W_{IU}(I_C, U_B)I_C, \quad (6)$$

$$U_C = W_{IU}(I_A, U_C)I_A + W_{IU}(I_B, U_C)I_B + W_{IU}(I_C, U_C)I_C, \quad (7)$$

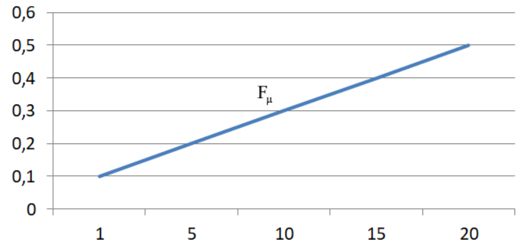
where: $W_{IU}(I_A,U_A)$, $W_{IU}(I_B,U_A)$, $W_{IU}(I_C,U_A)$, $W_{IU}(I_A,U_B)$, $W_{IU}(I_B,U_B)$, $W_{IU}(I_C,U_B)$, $W_{IU}(I_A,U_c)$, $W_{IU}(I_B,U_c)$, $W_{IU}(I_C,U_c)$ - primary currents I_A, I_B, I_C transfer functions secondary to U_A, U_B, U_C through the switching band. Analysis of analytical expressions generated based on graph models and algorithms presented in Figures 4 and 5. [5,6,7,8].

Three-phase electromagnetic current-to-voltage converters are reliable devices for determining reactive power asymmetry in the power supply system, allowing to ensure the control of the power source with the specified accuracy and speed based on the reception of normative signals for information measuring devices [10,11].

High accuracy, speed, extended functionality of the ATPCCS information-measurement system used in the control and management of reactive power of power supply systems, i.e. changing one, two, three and more values and parameters at the same time and ensuring the fulfillment of the requirements for sensitivity are the main indicators of signal converters.

Table-1

$K_{I_{in}F_\mu}$	0.1	0.2	0.3	0.4	0.5
I_{in}	1	5	10	15	20

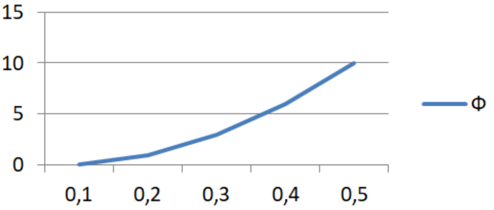


Graph-1. This graph given by (1)

Graphic representation of the relationship between the magnetic driving force F_μ of the magnetic switching part and the primary electric circuit current $I_к$.

Table-2

П	0,1	0,2	0,3	0,4	0,5
F_μ	0,1	1	3	6	10

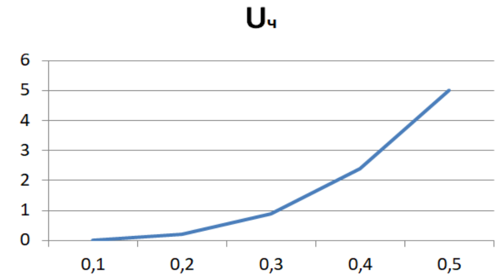


Graph-2. This graph given by (2)

Graphical representation of the relationship between the magnetic flux Φ_μ magnetic driving force F_μ and the primary circuit current.

Table-3

Φ_μ	0,01	0,2	0,9	2,4	5
$K_{\Phi_\mu U_ч}$	0,1	0,2	0,3	0,4	0,5



A graphical representation of the process by which the magnetic transformer converts the magnetic flux Φ_μ into a three-secondary output voltage U_{out}.

3. Conclusion

To sum up, the need to take into account the interaction of three-phase currents flowing from the primary phases of electric networks with the help of electromagnetic converters, to analyze the magnitudes and changes of magnetic currents and to generate signals in the form of voltage in the secondary circuit made it possible to create a new category of three-phase current-to-voltage converters. Therefore, the research algorithm and models of the process and parts of the transformation of the multiphase primary currents of the reactive power sources into the secondary signal $U_ч$ - the output voltage were created. The created graph models provided an opportunity to study the signal transformation process and structure of three-phase current sensors based on clarity and high formalization.

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Information about the author

Kurbaniyazov Timur Urunbayevich	Nukus Mining Institute at the Navoi State Mining and Technological University, PhD., Acting Associate Professor of the Department of

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