Analysis of three-phase asymmetrical currents in the secondary voltage of signal change sensors in the power supply system using graph models

Azizjan Abubakirov[1], *Timur* Kurbaniyazov[1,2*], and *Muratbay* Bekimbetov[2]

[1]Nukus Mining Institute at Navoi State University of Mining and Technologies, Department of Electric power and automation of General Technology Faculty, Nukus city, Republic of Karakalpakstan, 230112, Uzbekistan
[2]Karakalpak State University named after Berdakh, Department of Electrical Engineering and Metrology of Physics Faculty, Nukus city, Republic of Karakalpakstan, 230112, Uzbekistan

Abstract. This article presents the principles of modeling three-phase asymmetrical currents in the form of secondary voltages of signal change sensors in the power supply system. The classical methods of signal transformation modeling do not provide the necessary accuracy due to the complexity in representing the interdependence between input and output quantities and parameters, as well as the difficulty in capturing the inter-chain dependencies and associated physical-technical effects. The analysis in this work focuses on the principles of signal transformation based on graph models, including the physical and technical effects of the three-phase primary current electromagnetic sensor that creates the interacting magnetic fields. The modifications to elements with nonlinear parameters and the values of the electric network currents in the power supply system during estimation have been considered as an object with concentrated parameters. In contrast to traditional single-phase current transformers, the complex transducing components, weight, and volume of the items are labor-intensive when used in combined power measurement and control systems. They also do not provide the universality of the output value when interfacing with microprocessors and electronic technologies in intelligent systems.

1 Introduction

In power supply systems (PSS), changes in information signals occur in measuring and control elements and devices of the three-phase power network. It is clear that the main function of energy conversion in primary transformers of electric current is the process of changing current or voltage information signals for the measurement and control system. Therefore, converting current signals to voltage representation is the most optimal, because

* Corresponding author: kurbaniazoff@gmail.com

the signal range is small due to the rapid saturation of current signals, which is relatively better in voltage representation signals.

The physical basis of electromagnetic transducer sensors is based on the force interaction of the measured current with auxiliary magnetic fields or ferromagnetic elements, they have a number of advantages such as simplicity of structure, high reliability, implementation of multiple limits, the ability to measure direct, alternating and impulse currents. For this reason, most of the industrial electro-magnetic current transformers operating at currents from 10 amperes to 5000 amperes are made on the basis of an electro-mechanical measuring mechanism [1, 2].

2 Materials and methods

In experimental works, this sensor was analyzed on the basis of graph models. It is one of the main tasks of the principle of construction of the signal sensors of the primary currents of the asymmetrical three-phase power supply system in the form of secondary voltages on the basis of a simple or flat measuring coil or reed switch, and to measure the three-phase currents in the power transmission networks, is to simplify the structure of the sensor and increase its functionality based on the change to a secondary element at the same time (Figure 1).

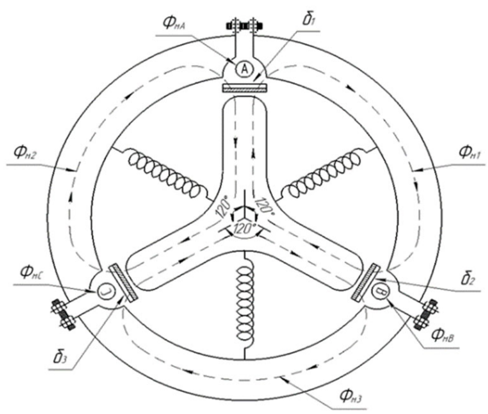

Fig. 1. View of the magnetic switching parts of the input current to output voltage conversion sensor in asymmetrical three-phase power supply system.

where: ΦμA, ΦμB, ΦμC – A, B, C main magnetic currents generated by the phase currents of the electrical network and crossing the corresponding sensitive element; Φμ1, Φμ2, Φμ3 - magnetic currents created by non-basic phase currents for a sensitive element; δ1, δ2, δ3 - magnetic resistance of air gaps and magnetic currents flowing through the magnetic core.

Input currents of reactive power sources in the PSS - when phase currents flow from the first IA, second IB, third IC, primary windings of the sensor, in the common-base magnetic core and parallel cores Φμ1, Φμ2 and Φμ3 magnetic currents are generated, which also flow through the air gap between the cores [4, 5].

In the measurement and control of reactive power currents of asymmetrical three-phase PSS, the value of primary load currents is based on the functional-structural approach of modeling, in the analysis of current transformer sensor devices, the value of primary load currents in the form of voltage output signals, the types of such converter sensors is one of the important factors in comparison. On the basis of the functional-structural approach, a graph model is created that reflects the interrelation of the physical and technical effects used in the structure of the elements and devices of the current transformer sensor under study and in the transformation processes. It is appropriate to adopt a research method in the form of a graph for the structural research and design of the current transformer sensor used in the measurement and control of reactive power currents of asymmetrical three-phase PSS. When constructing a research model in the form of a graph, it is necessary to study and analyze the existing types of current converter sensors from the point of view of feasibility, relevance and efficiency of developing new types [6, 7].

3 Results and discussion

There is a principle of signal conversion in the transformation of one, two, three-phase reactive power currents flowing in the reactive power of asymmetrical three-phase power supply systems into the form of a secondary voltage signal. In particular, when three flat coils are used in current transformer sensors, the primary current (currents), the transformer circuit or structure, its geometric shape and dimensions, and the applied principle of signal transformation are based on the physical-technical effect and it is studied based on the following algorithm:

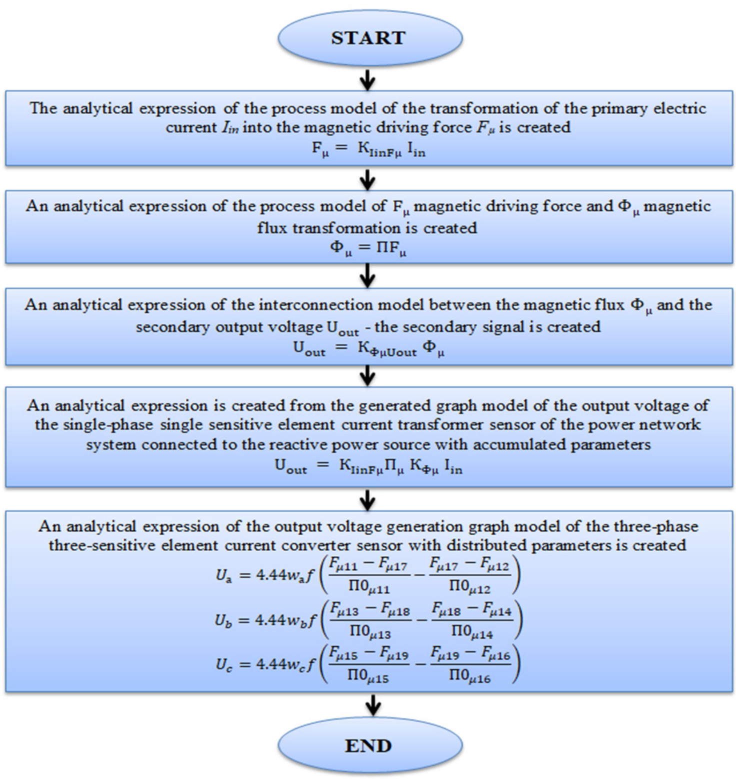

Fig. 2. Algorithm of conversion of primary current to secondary voltage.

The graph model of generating the output voltage of the distributed parameter three-phase three-sensitive element current transformer sensor of the electrical network connected to the reactive power source in the power supply system is presented in Figure 3:

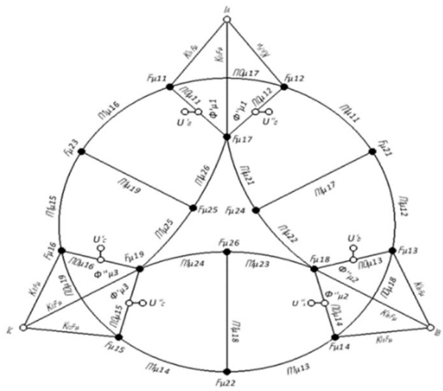

Fig. 3. The graph model of generating the output voltage of the current-to-voltage converters of the three-phase three-sensing element current converter sensor with distributed parameters.

Based on Kirchhoff's 1st and 2nd laws, a system of fifteen unknown equations is created from the generated distributed parameters graph model. The unknown magnetic driving forces (M.D.F) are determined according to the distribution in the magnetic field and the magnetic parameters, and the values of the M.D.Fs determine the quantities of the transfer functions (1) [8, 9].

$$\begin{cases}
\frac{F_{\mu11}-F_{\mu41}}{\Pi0_{\mu11}}+\frac{F_{\mu11}-F_{\mu12}}{\Pi0_{\mu21}}+\frac{F_{\mu11}-F_{\mu23}}{\Pi1_{\mu16}}=K_{I_AF_\mu}I_A \\
\frac{F_{\mu12}-F_{\mu41}}{\Pi0_{\mu12}}+\frac{F_{\mu12}-F_{\mu11}}{\Pi0_{\mu21}}+\frac{F_{\mu12}-F_{\mu21}}{\Pi1_{\mu11}}=K_{I_AF_\mu}I_A \\
\frac{F_{\mu41}-F_{\mu11}}{\Pi0_{\mu11}}+\frac{F_{\mu41}-F_{\mu12}}{\Pi0_{\mu12}}+\frac{F_{\mu41}-F_{\mu33}}{\Pi2_{\mu16}}+\frac{F_{\mu41}-F_{\mu31}}{\Pi2_{\mu11}}=K_{I_AF_\mu}I_A \\
\frac{F_{\mu13}-F_{\mu42}}{\Pi0_{\mu13}}+\frac{F_{\mu13}-F_{\mu14}}{\Pi0_{\mu22}}+\frac{F_{\mu13}-F_{\mu21}}{\Pi1_{\mu12}}=K_{I_BF_\mu}I_B \\
\frac{F_{\mu14}-F_{\mu42}}{\Pi0_{\mu14}}+\frac{F_{\mu14}-F_{\mu13}}{\Pi0_{\mu22}}+\frac{F_{\mu14}-F_{\mu22}}{\Pi1_{\mu13}}=K_{I_BF_\mu}I_B \\
\frac{F_{\mu42}-F_{\mu13}}{\Pi0_{\mu13}}+\frac{F_{\mu14}-F_{\mu14}}{\Pi0_{\mu14}}+\frac{F_{\mu42}-F_{\mu31}}{\Pi2_{\mu12}}+\frac{F_{\mu42}-F_{\mu32}}{\Pi2_{\mu13}}=K_{I_BF_\mu}I_B \\
\frac{F_{\mu15}-F_{\mu43}}{\Pi0_{\mu15}}+\frac{F_{\mu15}-F_{\mu16}}{\Pi0_{\mu23}}+\frac{F_{\mu15}-F_{\mu22}}{\Pi1_{\mu14}}=K_{I_CF_\mu}I_C \\
\frac{F_{\mu16}-F_{\mu15}}{\Pi0_{\mu23}}+\frac{F_{\mu16}-F_{\mu43}}{\Pi0_{\mu16}}+\frac{F_{\mu16}-F_{\mu23}}{\Pi1_{\mu15}}=K_{I_CF_\mu}I_C \\
\frac{F_{\mu43}-F_{\mu15}}{\Pi0_{\mu15}}+\frac{F_{\mu43}-F_{\mu16}}{\Pi0_{\mu16}}+\frac{F_{\mu43}-F_{\mu32}}{\Pi2_{\mu14}}+\frac{F_{\mu43}-F_{\mu33}}{\Pi2_{\mu15}}=K_{I_CF_\mu}I_C \\
\frac{F_{\mu21}-F_{\mu12}}{\Pi1_{\mu11}}+\frac{F_{\mu21}-F_{\mu13}}{\Pi1_{\mu12}}+\frac{F_{\mu21}-F_{\mu31}}{\Pi1_{\mu21}}=0 \\
\frac{F_{\mu22}-F_{\mu14}}{\Pi1_{\mu13}}+\frac{F_{\mu22}-F_{\mu15}}{\Pi1_{\mu14}}+\frac{F_{\mu22}-F_{\mu32}}{\Pi1_{\mu22}}=0 \\
\frac{F_{\mu23}-F_{\mu15}}{\Pi1_{\mu15}}+\frac{F_{\mu23}-F_{\mu11}}{\Pi1_{\mu16}}+\frac{F_{\mu23}-F_{\mu33}}{\Pi1_{\mu23}}=0 \\
\frac{F_{\mu31}-F_{\mu21}}{\Pi1_{\mu21}}+\frac{F_{\mu31}-F_{\mu41}}{\Pi2_{\mu11}}+\frac{F_{\mu31}-F_{\mu42}}{\Pi2_{\mu12}}=0 \\
\frac{F_{\mu32}-F_{\mu22}}{\Pi1_{\mu22}}+\frac{F_{\mu32}-F_{\mu42}}{\Pi2_{\mu13}}+\frac{F_{\mu32}-F_{\mu43}}{\Pi2_{\mu14}}=0 \\
\frac{F_{\mu33}-F_{\mu23}}{\Pi1_{\mu23}}+\frac{F_{\mu33}-F_{\mu41}}{\Pi2_{\mu16}}+\frac{F_{\mu33}-F_{\mu43}}{\Pi2_{\mu15}}=0
\end{cases} \tag{1}$$

where: $K_{I_AF_\mu}$, $K_{I_BF_\mu}$, $K_{I_CF_\mu}$ – number of sensitive element coils (respectively w_a, w_b, w_c); I_A, I_B, I_C - primary currents; $\Pi 1_{ij}$, $\Pi O_{\mu ij}$ – respectively resistances of magnetic core and air gap magnetic parameters; $F_{\mu i,j}$ - M.D.F's in the magnetic core of the sensor.

Using the above expression, it is possible to generate output voltages as follows (2) through magnetic currents generated by M.D.F.

$$
\begin{aligned}
U_a &= U'_a - U''_a = 4.44 w_a f\left(\frac{F_{\mu 11}-F_{\mu 17}}{\Pi 0_{\mu 11}} - \frac{F_{\mu 17}-F_{\mu 12}}{\Pi 0_{\mu 12}}\right)\\
U_b &= U'_b - U''_b = 4.44 w_b f\left(\frac{F_{\mu 13}-F_{\mu 18}}{\Pi 0_{\mu 13}} - \frac{F_{\mu 18}-F_{\mu 14}}{\Pi 0_{\mu 14}}\right)\\
U_c &= U'_c - U''_c = 4.44 w_c f\left(\frac{F_{\mu 15}-F_{\mu 19}}{\Pi 0_{\mu 15}} - \frac{F_{\mu 19}-F_{\mu 16}}{\Pi 0_{\mu 16}}\right)
\end{aligned}
\tag{2}
$$

So, as can be seen from the above formula, we can get the secondary output voltage in the sensing range of a sensitive element (a coil wrapped on a flat plate) inserted into the magnetic field created by the M.D.F. If there is not asymmetrical state, that is, there is symmetry between the phases, then the secondary output voltage will be zero.

We can conclude as follows on the basis of experimental tests carried out in measuring the change of three-phase current asymmetry in power supply devices of reactive power and introducing control, in these cases it has a simple construction, high sensitivity, speed and reliability and which does not have a complex measuring part that limits their application processes, and it is effective to convert the input current signal into a standard secondary voltage signal using asymmetrical current transformer sensors [10-13].

Nowadays, although there are alternating current converters, but in the direction of the change of three-phase currents of the reactive power supply sources, their advantages and rational selection of constant and alternating current converter sensors should be considered. It is required to analyze its shortcomings and use them in development, measurement and control systems. A relative comparison of current transformer sensors is presented in Table 1.

Table 1. A relative comparison of current transformer sensors.

№	Types	Measuring range	Error	Advantages	Disadvantages
1	Rogowsky belt	10-100 Amp	0.2 – 0.5%	The simplicity of the structure	Large size and weight
2	Resistive	0-10 kAmp	0.2 – 0.5%	Constructive simplicity	Need to break the chain
3	Current transformer	0-150 kAmp	0.2 – 0.5%	Reliable, easy to service	Large size and weight
4	Electro mechanic	0-1000 Amp	5 %	The simplicity of the structure	The presence of a moving part
5	Magnetic galvanic	0-0.2 MAmp	0.1 – 0.5%	Great accuracy and sensitivity	Structure and schematic difficulty
6	Asymmetrical three-phase current change sensor	0-0.5 kAmp	0.2 – 0.45%	Simplicity of the constructive structure, reliability, accuracy and application in symmetrical currents, linearity of the output description	Sensitivity to external magnetic currents and temperature dependence

Analyzing the above, an initial comparison of the structures of electromagnetic current transformers is shown in Table 1, and a relative comparison in the given data shows that the reactive power in the power supply consumption of power supply systems is asymmetrical. Due to the simplicity of the structure and the processes of its preparation, as well as high reliability, the input current-to-voltage signal converter sensors are the most optimal for carrying out and monitoring current measurements. In the future, it is necessary to develop and redevelop similar generations of sensors from a structural and physical-technical point of view, to connect current-changing sensors to next-generation devices, as well as to information communication tools, to form the fields of remote information acquisition and processing.

4 Conclusion

The following conclusions can be drawn by summarizing the graph models based on the current transformer sensor mentioned above and the analytical expressions derived from them, along with the results obtained through their application.

The research algorithm and graph models of the process and components of the transformation of symmetrical three-phase reactive power currents into the secondary signal Uout voltage have been developed.

Graph models provided an opportunity to study the signal transformation process and structure of three-phase current sensors on the basis of clarity and high formalization.

The created cumulative and distributed parameter graph models are used to determine the values of the output voltages of the electromagnetic current to voltage converters UA, UB, UC, based on the criterion of right angle and uniform distribution of the crossing of the surface of the sensitive elements of the magnetic current converter, and a method of accurate calculation of the values of the magnetic driving force and magnetic current of the switching parts of the control transformers has been developed.

References

1. I.K. Siddikov, A.B. Abubakirov, A.U. Djalilov, T.U. Kurbaniyazov, A.A. Abdumalikov, AIP Conference Proceedings **2789** 060002 (2023)
2. I.K. Siddikov, A.B. Abubakirov, Q.M. Najimatdinov, M.N. Bekimbetov, Y.A. Lezhnina, AIP Conference Proceedings **2526(1)** 020026 (2023)
3. T. Taithongchai, E. Leelarasmee, 6th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology. – IEEE **1**, 278-281 (2009)
4. F. Du et al., Journal of Physics: Conference Series **2378** 012002 (2022)
5. S. Amirov, K. Jurayeva, Z. Nazirova, E3S Web of Conferences **461** 01058 (2023)
6. J. Blake, W. Williams, C. Glasov, R. Bergh, K. Fetting, E. Hadley, G. Sanders, *Optical Current Transducers for High Voltage Applications* (2nd EPRI Optical Sensors Systems, Atlanta, 2000)
7. S.F. Amirov et al., *Electromagnetic converters of high currents for traction power supply systems* (Tashkent, 2019)
8. Shameem Ahmad, Saad Mekhilef, Hazlie Mokhlis, International Transactions on Electrical Energy Systems **31(7)** e12922 (2021)
9. E.M. Lightner, S.E. Widergren, IEEE Transactions on Smart Grid **1(1)**, 3-10 (2010)

10. B. Crowhurst et al, *Single-phase grid-tie inverter control using DQ transform for active and reactive load power compensation,* in 2010 IEEE International Conference on Power and Energy (2010)
11. D. Mukhitdinov, S. Boybutayev, O. Goziev, J. Qudratov, E3S Web of Conferences **414** 05009 (2023)
12. Y. Kadirov, O. Boeva, R. Eshqobilov, S. Toshmurodova, D. Abdullaeva, E3S Web of Conferences **414** 05003 (2023)
13. O. Sattarov, E3S Web of Conferences **390** 03012 (2023)