

# DETERMINATION OF INSTANTANEOUS VALUES OF POWER COMPONENTS IN AN ELECTRONIC VOLTAGE AND CURRENT TRANSFORMER

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**Abstract:** The method of determining instantaneous power components is based on the application of the p-q-r theory. The implementation of this method allows analyzing the components of instantaneous power and using the data for the purposes of various secondary systems.

**Key words:** electronic transformer, power, instantaneous power theory, control system.

## 1. Introduction

At the present time the development of the electric power industry in many countries is focused on the intellectualization of measurements and is usually associated with the concept of Smart Grid. A key element in this concept is a digital substation. The substation control is performed by a hardware-software complex which combines the use of new measurement technologies, data transfer, processing, storage, control, protection, analysis etc. The main elements of the digital substation are digital current and voltage transformers [1]. Using digital transformers allows eliminating losses during the data transfer, performing unlimited data replication, ensuring measurement synchronization, performing single analog-to-digital conversion. As opposed to this one at the traditional substation there are various losses in secondary circuits of instrument transformers, multiple analog-to-digital conversions and unnecessary measuring the same parameters in each device. Therefore, there is no synchronization between measurements and the impact of electromagnetic fields.

## 2. Theoretical background

The instantaneous values of current and voltage, if considered as improving factors for better grid performance, are the most complete and all-purpose data for all secondary microprocessor systems that use different informative parameters of measured signals (instantaneous or integral values of the full signal, its individual components and their derivatives etc.) [2]. Using digital processing means of instantaneous signal values makes possible choosing some new control criteria for the modes of electrical energy objects (EEO) operation and finding new ways to analyze them for different control functions. The number of informative parameters that may be used for solving various control problems increases with time. It is better to calculate them once in the electronic unit of the instrument transformer for the needs of all secondary systems.

As a result of research the adaptive current and voltage instrument transducer (ACVIT) was developed by the Institute of Electrodynamics of NAS of Ukraine. It is characterized by complete informational, electrical and functional compatibility with digital automated control systems (ACSs) of EEO and electrical power systems (EPSs) [3]. In this integrated measurement tool not only measurements and a scale transformation of currents and voltages of EEO, but also their normalization, analog-to-digital conversion, measurement data processing is performed using the built-in electronic unit in primary transducer. In addition, a number of intellectual functions (the change of an operation algorithm, based on situation assessments, the software correction of an output signal, the change of the characteristics of the output signal according to the needs of secondary systems, metrological analysis, a self-diagnostic check, and high-performance communication with other electronic devices of ACS) are carried out.

Digital signal processor (DSP) in the ACVIT construction provides wide opportunities for processing of measured signals in real time and for the calculation of their informative parameters. It should be noted that modern signal processors are constantly evolving, their functionality and overall performance improves. For the use in ACVITs the DSPs have enough speed to perform all the necessary tasks of signal processing. Excess computing power of the DSP can be used to extend the functionality of the ACVIT and to build integrated measuring tools, processing and transferring much more complete information about the state of the EEO in real time.

Thus, the purpose of the article is to highlight the mathematical model of determining instantaneous power components that can be used for the needs of secondary systems (ACSs) of the EEO. The advantage of this method is its quite easy implementation in the electronic voltage and current transformer.

## 3. Mathematical implementation

The method of the determining instantaneous power components is based on the application of the instantaneous power theory [1]. This theory is used in the construction of the components compensating the reactive power that improve electromagnetic compatibility of EEO. But the

theory has more advantages. Its extended version, called  $p$ - $q$ - $r$  theory [1], can be the basis of the measurement of the instantaneous power components for monitoring the mode parameters and diagnostics of electrical equipment, accounting energy and controlling power quality and energy balance. Defining instantaneous power components according to the  $p$ - $q$ - $r$  theory is based on the use of instantaneous values of current and voltage. The calculation of instantaneous power components is done by the use of matrix transformations of instantaneous values to other coordinates. Mathematical transformation of instantaneous voltage and current values to  $\alpha\beta 0$  coordinates is performed by using the Clarke operator that represents an orthogonal matrix:

$$\begin{bmatrix} u_\alpha \\ u_\beta \\ u_0 \end{bmatrix} = \mathbf{K} \cdot \begin{bmatrix} u_A \\ u_B \\ u_C \end{bmatrix}, \quad \begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \mathbf{K} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix},$$

where

$$\mathbf{K} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix},$$

$u_A, u_B, u_C$  are the instantaneous values of voltage;  $i_a, i_b, i_c$  are the instantaneous values of current;  $u_\alpha, u_\beta$  and  $i_\alpha, i_\beta$  are the instantaneous values of voltage and current in  $\alpha$ - $\beta$  coordinates;  $u_0$  is the residual voltage;  $i_0$  is the residual current.

The transformation current values to  $p$ - $q$ - $r$  coordinates is obtained by multiplying the vector current by the coefficient matrix with normalized by the absolute space vector voltage values given in  $\alpha$ - $\beta$ - $0$  coordinates. In this way the separate magnitudes of currents are obtained for different power components. In  $\alpha$ - $\beta$ - $0$  coordinates the scalar value of the voltage vector is the spatial diagonal of the system ( $u_\alpha - u_\beta - u_0$ ):

$$u_{\alpha\beta 0} = \sqrt{u_\alpha^2 + u_\beta^2 + u_0^2} = u_p,$$

where  $u_{\alpha\beta} = \sqrt{u_\alpha^2 + u_\beta^2}$  is the diagonal of the rectangle ( $u_\alpha - u_\beta$ ) on the plane.

In  $p$ - $q$ - $r$  coordinates the components of the current are defined as follows:

$$\begin{bmatrix} i_p \\ i_q \\ i_r \end{bmatrix} = \begin{bmatrix} \frac{u_\alpha}{u_{\alpha\beta 0}} & \frac{u_\beta}{u_{\alpha\beta 0}} & \frac{u_0}{u_{\alpha\beta 0}} \\ -\frac{u_\beta}{u_{\alpha\beta 0}} & \frac{u_\alpha}{u_{\alpha\beta 0}} & 0 \\ -\frac{u_0 \cdot u_\alpha}{u_{\alpha\beta} \cdot u_{\alpha\beta 0}} & -\frac{u_0 \cdot u_\beta}{u_{\alpha\beta} \cdot u_{\alpha\beta 0}} & \frac{u_{\alpha\beta}}{u_{\alpha\beta 0}} \end{bmatrix} \cdot \begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix}$$

The power components are the products of the scalar value of voltage vector and components of the current in  $p$ - $q$ - $r$  coordinates and are obtained as follows:

$$\begin{bmatrix} p \\ q_q \\ q_r \end{bmatrix} = u_p \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \cdot \begin{bmatrix} i_p \\ i_q \\ i_r \end{bmatrix} = \begin{bmatrix} \bar{p} \\ \bar{q} \\ \bar{r} \end{bmatrix} + \begin{bmatrix} \tilde{p} \\ \tilde{q} \\ \tilde{r} \end{bmatrix},$$

where  $u_p = \sqrt{u_A^2 + u_B^2 + u_C^2}$  is the scalar value of voltage space vector of power supply;  $p$  is the instantaneous active power,  $q_q$  is the instantaneous reactive power;  $q_r$  is the instantaneous reactive power, closed through the neutral wire. Also derived components can be divided into permanent and variable ones for the evaluation of rippling power components.

So, appearing components of instantaneous power can be defined as follows:

$\bar{p}$  – averaged active power in the interval period of the unit, consumed by the load in the absence of a purely reactive load;

$\bar{q}$  – averaged reactive power in the interval period at the mains, reflecting the additional energy transfer between the source and the load;

$\bar{r}$  – averaged power closed through the neutral wire. In practice it is not detected and can be artificially reproduced by a rectification load current.

$\tilde{p}$  – variable component part of active power consumed by the load, represented as a ripple of active power consumption.

$\tilde{q}$  – variable part of reactive power, represented as a pulse consumption of reactive power. In the general case it appears when asymmetry voltage power supply or load current exists;

$\tilde{r}$  – variable part of power closed through the neutral wire (exists during asymmetrical loading).

Components  $\bar{p}$  and  $\bar{q}$  of the power reproduce the physical meaning of conventional units of power capacity and satisfy the following equation:

$$\bar{p} = P = \frac{3}{2} U_m \cdot I_m \cdot \cos \varphi,$$

$$\bar{q} = Q = \frac{3}{2} U_m \cdot I_m \cdot \sin \varphi, \quad S = \sqrt{P^2 + Q^2},$$

where  $U_m$  and  $I_m$  are the amplitude values of voltage and current. Components  $\tilde{p}$  and  $\tilde{q}$  reflect power distortion.  $\bar{r}$  and  $\tilde{r}$  are parts of the above power; they are closed due to the neutral line.

#### 4. Conclusion

The software implementation of the method for determining instantaneous power components, that characterize the energy processes in the system, is based on the  $p-q-r$  theory. It allows analyzing the components of instantaneous power in the network-load, network-network systems and using the information for the purposes of various secondary systems, solving problems of mode parameter estimation and monitoring of the current state of EEO power equipment, building predicted loads and modes of EEO and electric power system operation.

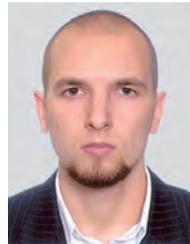
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### ВИЗНАЧЕННЯ МИТТЄВИХ ЗНАЧЕНЬ СКЛАДОВИХ ПОТУЖНОСТІ В ЕЛЕКТРОННОМУ ТРАНСФОРМАТОРІ СТРУМУ ТА НАПРУГИ

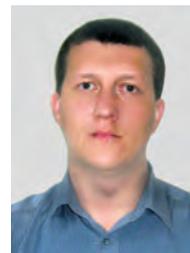
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Подано метод визначення складових миттєвої потужності, що ґрунтується на застосуванні  $p-q-r$  теорії. Реалізація цього методу в цифровому трансформаторі струму та напруги дозволяє проаналізувати складові миттєвої потужності і використовувати отриману інформацію для потреб різного роду вторинних систем.



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