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METROLOGICAL SUPPORT FOR THE INFORMATION-MEASUREMENT SYSTEM OF ELECTRIC ENERGY ACCOUNTING

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ABSTRACT

The primary features of the government tools used to measure electric energy include the errors that arise during electricity accounting, which is essential for the development of the national economy within an information-sharing system. Issues related to reducing these errors and the associated losses are also addressed. The study analyzes the main characteristics of the measurement devices employed for electric energy accounting. It explores the causes and origins of errors in the measurement channel when developing an information-measurement system. Based on the analysis results, the sources of errors in measurement channels are identified according to the structural schemes of information-measurement systems utilizing various measuring devices (such as voltmeters, ammeters, electric energy meters, and voltage and current transformers). It has been demonstrated that errors in the measurement channel arise not only from the design and operating principles of the measuring instruments and signal processing devices but also due to distortions caused by harmonics in the voltage and current within the electrical network, as well as specific interferences. The primary sources of measurement errors in determining electric energy are mainly related to inaccuracies in measuring voltage, current, and phase shift, along with errors induced by temperature effects on the elements and devices used for these measurements. Although temperature errors may not be immediately apparent, they can contribute to various types of inaccuracies. In this context, the importance of implementing temperature compensation or correction schemes has been emphasized once again.

1. Introduction

In our country, the production of electricity is constantly being increased in order to accelerate the development and reconstruction processes in the liberated territories. In this case, improving the accuracy of energy measurement and the integrity of its accounting during the production and consumption of electricity is one of the main issues [1]. The measurement of the consumed electric energy taking into account a large number of parameters is carried out using multi-functional automated accounting systems. In recent years, information-measuring systems (IMS) for electric energy accounting, as well as telemetering systems that allow accurate measurement of active, reactive and total power, phase voltages and currents in three- and four-wire three-phase networks, have become widespread.

Functional possibilities of existing electricity meters are wide. These include: multi-tariffing, accounting of direct and reverse electric energy flows, integration of active and reactive counters into one device, data transfer for information-metering and centralized energy accounting systems, ease of data collection and storage in a given time interval, as well as the current of the monitored network, includes capabilities such as measuring voltage, power, power factor, frequency characteristics, and constructing load graphs and tables. If the electricity measuring devices are multifunctional for sufficiently remote points, if the measuring points (points) are compactly located on the territory, it is more appropriate to transfer some complex functions of the electric energy meters to the information-measuring system of electric energy accounting.

2. Electricity modeling based on AC power and its cost

During the development of market relations in electric energy, more and more attention is paid to the reduction of commercial losses, which often exceed technical losses in many energy systems. Currently, up to 30-50% of commercial losses are determined by electricity metering errors and imperfect automated systems for electricity control and accounting [5].

Errors of measuring devices lead to inaccurate accounting of electricity produced by power plants and supplied to consumers. Therefore, this part of electrical energy loss can be called measurement losses (errors). Measurement losses are determined by the final error in each measurement channel, which in turn is characterized by total errors with random and systematic components [2].

Electricity is measured indirectly. The most common procedure for obtaining indirect measurement results is implemented in multichannel information measurement systems. In general, the required result is calculated as a function of the results of direct measurement of many variables - the parameters of a complex object, obtained by means of various measurement channels of the IMS.

The IMS for monitoring and accounting of electric energy should have unique features: installation of electric meters and measuring transformers produced by various manufacturers at the place of operation, distribution on the site and on the territory, and as a result, the presence of long communication lines between its multi-channel components, the possibility of installation during operation, constructive to the measuring objects connection, complete provision of computing equipment, etc. In addition, for monitoring and accounting of electric energy, most of the IMS should be included in more complex structures [4, 8].

In this case, the energy measurement is the result of an indirect measurement and is a function of a directly measured quantity (voltage, current, phase shift, and time). This situation arises not only in IMS, but also when using a digital device (digital electricity meter) with a processor or controller (microprocessor) or when manually processing the results of direct measurements of a quantity.

As you know, alternating current electric power and its price, electric energy is determined as follows:

$P = UI\cos\varphi$ və $W = PT = UIT\cos\varphi$, (1)

where P is electric power; U – applied voltage; I – intensity of the current flowing from the load (operator); φ – phase shift between voltage and current; W – electric power; T is the period of connection of the load to the network (food source). Here, the main quantity, electric energy *W*, is determined based on the results of direct measurements of other quantities u, i, φ.

The metrological structural scheme of indirect measurements for cases where the results of direct measurements, which are input data for computer programs, are calculated by means of a computer, is shown in Figure 1.

The metrological structure-scheme presented in Figure 1 uses fixed quantities as initial data and direct measurement results of variable quantities. Here, the measurement error of the time period T is not taken into account. At this time, the value of the indirectly measured electric energy W is related to the functional dependence of the voltage - u, current i and the phase shift between voltage and current - φ, which must be measured directly, and $W = U \cdot I \cdot T \cdot cos\varphi$. Real calculations are indirect measurement results

$$W^* = U^* I^* T \cos\varphi^* \quad (2)$$

this price will give

$$\Delta W = W^* - W = (u^* i^* \cos\varphi^* - ui\cos\varphi) \cdot T \quad (3)$$

contains absolute error.

Were

$$u^* = u + \Delta u;\ i^* = i + \Delta i;\ \varphi^* = \varphi + \Delta\varphi \quad (4)$$

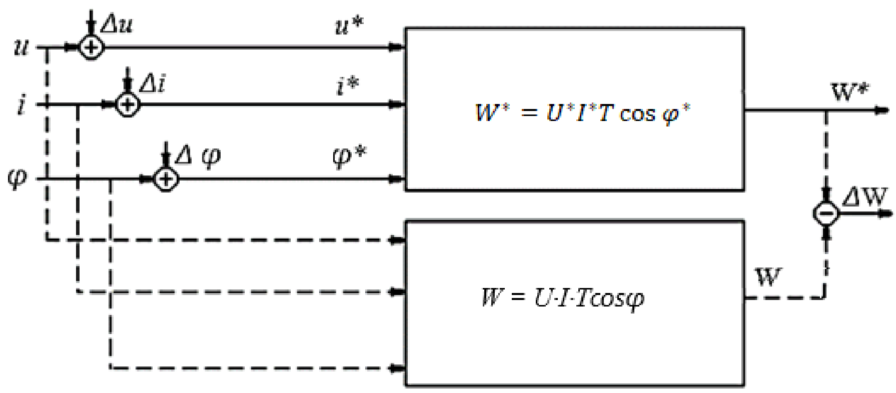

Fig. 1 Metrological structure of indirect measurements performed in the IMS

are the results of direct measurement of their quantities.

Errors in the results of indirect measurements are caused by the following reasons:

- approximate implementation of continuous functions and operations such as integration and differentiation in digital computers;
- Δu of direct measurement results, which creates hereditary errors in the results of indirect measurements; Δi and $\Delta\varphi$ errors;
- errors during calculations due to rounding, stopping iteration processes and other reasons.

In accordance with the theory of errors [6], to evaluate the accuracy of indirect measurements, the separation of the signal into the Taylor series is used without taking into account the second and higher order limits. In this case, the absolute value of the total error is determined as follows:

$$\Delta = \sum_{i=1}^{m} \left| \frac{df}{dx_i} \right| \Delta_i, \quad (5)$$

where m is the number of arguments; f – measurement function; x_i – the specified value of the i-th argument; Δi are the limits of the absolute error of the i-th argument.

At this time, the cumulative relative errors δ_{OK} of the measurement channels are deter-mined as follows:

for a four-wire connection scheme

$$\delta_{OK} = \frac{1,96}{\sqrt{3}} \sqrt{\delta_S^2 + \sum_{i=1}^{3}\left(\frac{1}{3}\delta_{xi}\right)^2 + \sum_{j=1}^{l}\delta_j^2 + \sum_{i=1}^{3}\left(\frac{1}{3}\delta_{CTi}\right)^2 + \sum_{i=1}^{3}\left(\frac{1}{3}\delta_{GTi}\right)^2 + } $$
$$+ \sum_{i=1}^{3}\left(\frac{1}{3}100 \cdot \theta_{CTi} tg\varphi\right)^2 + \sum_{i=1}^{3}\left(\frac{1}{3}100 \cdot \theta_{GTi} tg\varphi\right)^2 \quad (6)$$

- for a three-wire connection scheme

$$\delta_{OK} = \frac{1,96}{\sqrt{3}} \sqrt{\delta_S^2 + \sum_{i=1}^{2}\left(\frac{1}{2}\delta_{xi}\right)^2 + \sum_{j=1}^{l}\delta_j^2 + (\delta_{CT} + \delta_{GT})^2\left(\frac{1}{6}tg^2\varphi + \frac{1}{2}\right) + \left(100 \cdot (\theta_{CT} + \theta_{GT})\right)^2 \cdot}$$
$$\cdot \left(\left(\frac{1}{2}tg^2\varphi + \frac{1}{6}\right)\right). \quad (7)$$

where δ_S is the limit of the main relative error of the electricity meter (S), %; δ_{CT} – current error of current transformer (CT), %; δ_{GT} – voltage error of voltage transformer (GT), %; θ_{CT} and θ_{GT} – angular errors of current and voltage transformers, in radians; δ_{xi} and δ_{sez} – permissible voltage losses in the lines and additional errors of the meter; %; i – phase number; j – number of additional error of the meter; l is the number of additional errors of the counter.

3. Development of the structure of errors in IMS with transformer input circuit

In a four-wire circuit, the total error is less when measuring electricity with the same measuring devices. The schemes corresponding to the noted errors and measurement method for one measurement channel will be as follows (Figure 2 and Figure 3).

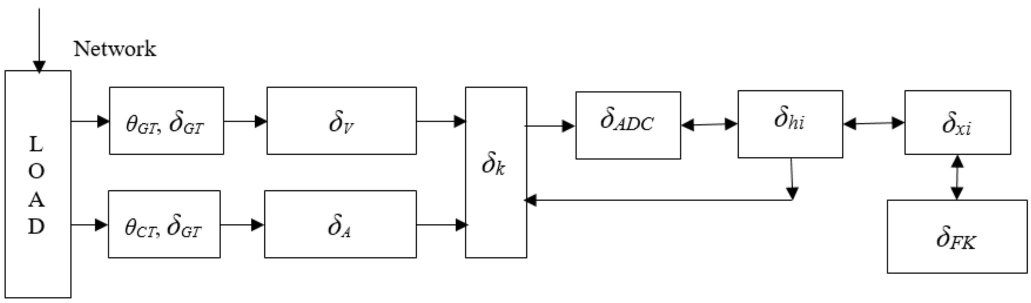

Fig. 2 Structure of errors in IMS with transformer input circuit: δ_V – voltmeter error; δ_A – ammeter error; δ_k – the error introduced by the switch; δ_{ADC} – analog-digital converter error; δ_{hi} – the error of the calculation-control device; δ_{KS} is the computer (server) error. The origin of the last error is an algorithmic error, related to rounding and iteration operations

The temperature errors on the blocks, modules, elements and devices shown in the structural schemes are inconspicuously included in the errors related to those components and manifest themselves when the temperature changes sufficiently. It is determined by the error caused by the effect of temperature on the devices - due to the heat generated by the environment and during the operation of the device. The temperature error is not obvious, it can be included in various types of errors. In this regard, it is appropriate to use a temperature compensation or temperature correction scheme or schemes.

In Figure 3, δ_{GS} is the voltage sensor error; δ_{CS} is the current sensor error. When measuring time-varying quantities u, i by means of multi-channel IMS, the aperture error, which is a component of the error in the results of direct measurements, can increase significantly. This is due to the fact that the measurement channels of the IMS are sequentially polled by the control controller, and the polling time is the sum of the measurement time in each channel, the time of the execution of the exchange protocol and the time due to the speed of the reconciliation interface devices.

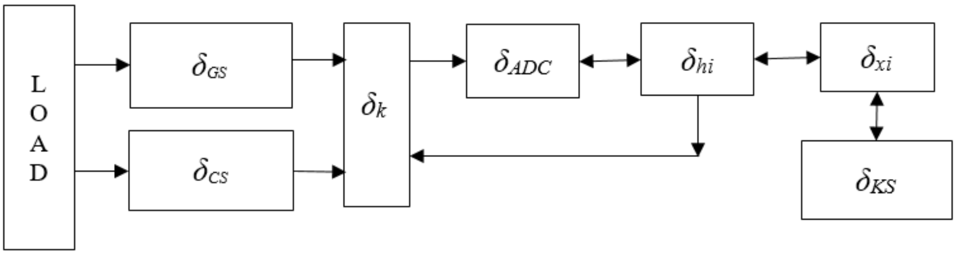

Fig. 3 The structure of errors in the IMS with a sensor input circuit

Therefore, the actual measurement moments performed by such channels differ. At the same time, each result of indirect measurement is attributed to a certain moment of time, as a rule, the moment of application to the first channel [7]. In multi-channel measurements, the difference in the actual measurement moments of the quantities included in the calculation formulas is large and can cause significant aperture errors in the indirect measurement results.

Thus, the expression for the error of the result of indirect measurements when measuring the time-varying quantities u, i and φ by means of a multi-channel IMS will be as follows:

$$\Delta W(t_i) = u^*(t_i + \Delta t_1) \cdot i^*(t_i + \Delta t_2) \cdot \cos\varphi^*(t_i + \Delta t_3) \cdot T - u(t_i + \Delta t_1) \cdot i(t_i + \Delta t_2) \cdot \cdot \cos\varphi(t_i + \Delta t_3) \cdot T, \quad (8)$$

where, Δt_1, Δt_2, Δt_3 are the time delay (shift) errors due to time recording of measurements on measurement channels.

These errors increase as the number of IMS channels increases (since transmitters are polled sequentially). A radical tool to reduce reading dating errors in multichannel measurement systems is a multichannel sampling and storage device (SSD). The SSD is connected before the switch. In normal operation, the output signal repeats the input signal and works in tracking mode. At the start of the channel request, a signal from the computer enters through the interface and switches the SSD to the mode of simultaneous storage of all signals at the output of the system channels. The switcher polls the channels and in turn sends the instantaneous values of the output signals at the same instant of time alternately to the input of the ADC and then to the computer's memory for recording or processing. The transition time of SSD from tracking mode to storage mode is tens of nanoseconds, and the dispersion of this time is even smaller. Therefore, the error of the switch (multiplexer) will be negligible. Thus, the effect of time-shifting errors is almost completely eliminated.

The structure of errors for the IMS using a modern type digital electricity meter will include the modern electricity meter, communication lines and computer-introduced errors and will be presented as shown in Figure 4. In Figure 4, δ_{MESn} is the error of a modern electricity meter (n = 1,N).

The common error in such a structured IMS is the error introduced by the switch; error of the calculation-management device (controller); it is possible to download by reducing the algorithmic error of the computer (server).

Additional errors in the proposed schemes will be determined both by the presence of harmonics in the network and by the errors caused by the influence of temperature on the measuring devices. In addition, the transmission of information through power lines will cause a certain change in the structure of the named errors, which is also related to the generation of harmonics in the power network [9].

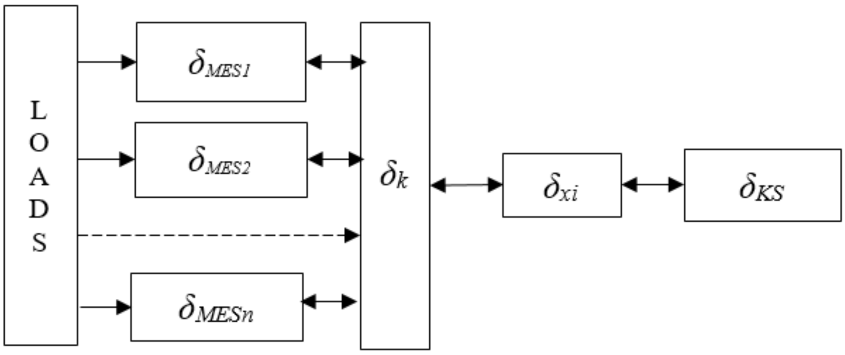

Fig. 4 The structure of errors in the modern electricity meter IMS

4. Conclusion

As a result of the analysis of the sources of errors in the measurement channel, it was shown that the occurrence of those errors is caused by the working principle and construction of the measuring devices, the conversion of information from analog to digital form and vice versa, and additional errors in the measurement of electric energy are determined by the presence of harmonics in the network and the errors caused by the influence of temperature on the measuring devices. is being

The temperature error caused by the effect of temperature on the devices - due to the heat generated by the environment and during the operation of the device is not obvious, it can be included in the composition of various types of errors. To reduce this error, it is advisable to use a temperature compensation or temperature correction scheme or schemes.

Due to the fact that it is not possible to perform measurements in multi-channel IOS in parallel, in direct measurements, the moments of the measurement are shifted, which eventually leads to the appearance of additional errors.

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