Spectral approach to the estimation of the time series of the power change in the substation metering units and its application in the control modes of substation electricity metering systems

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Abstract. The wide possibilities of modern interval metering devices installed at substations of distribution grid companies are not fully used today. In the process of measuring the electrical parameters of the network meters, there may be abnormal modes of electricity metering substations, resulting from intentional or negligent actions of staff, failure of existing equipment or parts thereof. The considered circumstances lead to large economic losses of electric power enterprises, expressed in the underestimation of electricity. One of the effective ways to solve this problem is the use of intelligent techniques to identify incorrectly operating metering stations of the substation network, as well as the development of an optimal model of an automated multifunctional information and measuring system for industrial use and software implementation. The purpose of the study – the development of methods of control and diagnosis of normal operation of the substation electricity metering system, determined by compliance with the reliability of electricity metering substation information and measurement systems. On the basis of the offered method the algorithm of control and diagnostics of modes of operation of the information-measuring equipment of the system of accounting the electric power of substations is offered. The software for a two-level multifunctional measurement system combining the functionality of an automated electricity metering system, a system for monitoring and diagnosing the modes of operation of the information and measuring complex of substations, and a system for monitoring the quality of electricity has been developed. The results of the research were used in the development of recommendations for the construction of automated information and measurement systems based on existing power metering systems of substations for distribution grid companies. The developed technique and the corresponding algorithm of control and diagnostics of abnormal operating modes of information-measuring complex of substations allow to quickly determine the technical condition of the metering system of substations, to plan corrective measures to eliminate violations.

1. Introduction
The balance method, reviewed Zhelezko Y.S. [1], in control of maintenance of normal modes of work of substation systems of the account of the electric power is used by power engineers quite often. At the same time, at the moment there is no clear idea of the possibility of its use in automated control systems
of the above modes, which is confirmed by the lack of control modules and diagnostics of information-measuring systems of electricity metering as part of automated control systems of power facilities, reviewed Kochneva E.S. [2]. For automatic measurement of the unbalance power in the substation and report on the work of substation metering system, reviewed Pazderin A.V. [3], requires that the reference values of the quantity under consideration imbalance of power was obtained at a single time and date that can be implemented with function "latch" the instantaneous States of the energy consumption that characterize the current volt-ampere the status of metering of electricity, reviewed Mironovskiy L.A. [4].

2. Materials and methods

The statistical processing of experimental data of full-scale field tests and mathematical description of the random law of change in the magnitude of the substation unbalance of instantaneous power, as well as its computer simulation.

3. Development of methods to identify faulty information measuring complex by calculating the power in the substation metering stations

Simultaneous calculation of power on all metering devices of the substation and calculation of unbalance of instantaneous power is made by the formula:

$$\text{HB}_W = \frac{W_{vv} - W_{ot}}{W_{vv}} \times 100\%$$

where $\text{HB}_W$ – the relative value of the actual unbalance of power at the substation, $W_{vv}$ – the sum of the capacities in the metering stations of the substation inputs and in the communication lines of substations, when electricity is supplied through them, $W_{ot}$ – the sum of the capacities in the metering stations of the outgoing connections, in practice, usually does not exceed ±2,2 % of the substation.

In fact, the calculation of the value $1$ in time resembles a non-harmonic periodic oscillatory process, reviewed Soldatov A.A. [5], which can be represented as a result of the addition of a certain number of harmonic oscillations of changes in the power differences recorded by the information-measuring units of electricity metering of the input and output connections of the substation.

For a three-phase network, the sum of the products of the values of phase currents, voltages and the cosine of the angle between them, taking into account the transformation coefficients, determines the amount of electric power. A change in any of the parameters under consideration leads to a change in the value of the total power fixed by the electricity metering device. At the same time, a sharp change in the state of the value 1 should be understood as an abnormal measurement or a miss, and the repetition of an abnormal character on several consecutive measurements indicates a deliberate interference in the work of electricity metering devices or a technical malfunction in which the values of the current, voltage or cosine of the angle are underestimated, due to which the substation accounting of electricity becomes unreliable.

It is required to describe the random process of changing the value of the substation unbalance of instantaneous power for the possible determination of the boundaries of the confidence interval of the measured unbalance of instantaneous power, within which the normal modes of operation of substation electricity metering systems are supported.

To carry out the appropriate control, it is required to have software and hardware computing facilities reviewed Pichugin V. N. [6], capable of implementing instantaneous power data acquisition from all substation information and measuring power metering units, with further processing of the received information.

For the period from Dec 2018. to February 2019. at different times of day produced $n=2202$ measurements substation imbalance of power. At daily intervals $t=24$, the average values of the unbalance of the power $y_i$ for the entire period under consideration were determined by the values given in table 1.
Table 1. Average power unbalance $y_i$

| $\tau_i$ | The number of the measurements for the time interval $y_i$ | Average $\overline{y_i}$ |
|----------|----------------------------------------------------------|--------------------------|
| 1        | 94.00                                                    | -0.18                    |
| 2        | 82.00                                                    | -0.19                    |
| 3        | 81.00                                                    | -0.21                    |
| 4        | 70.00                                                    | -0.19                    |
| 5        | 72.00                                                    | -0.19                    |
| 6        | 84.00                                                    | -0.085                   |
| 7        | 113.00                                                   | -0.057                   |
| 8        | 106.00                                                   | -0.058                   |
| 9        | 95.00                                                    | -0.13                    |
| 10       | 105.00                                                   | -0.028                   |
| 11       | 100.00                                                   | -0.077                   |
| 12       | 112.00                                                   | -0.067                   |
| 13       | 104.00                                                   | -0.097                   |
| 14       | 96.00                                                    | -0.097                   |
| 15       | 95.00                                                    | -0.068                   |
| 16       | 76.00                                                    | -0.067                   |
| 17       | 66.00                                                    | -0.073                   |
| 18       | 71.00                                                    | -0.020                   |
| 19       | 62.00                                                    | -0.077                   |
| 20       | 62.00                                                    | -0.12                    |
| 21       | 102.00                                                   | -0.13                    |
| 22       | 146.00                                                   | -0.14                    |
| 23       | 108.00                                                   | -0.15                    |
| 24       | 100.00                                                   | -0.20                    |
| **Subtotal** | **2202.00**                                      | **-0.11**                |

When calculating the average values for each hour interval specified in the table, the power unbalance data were used, which were characterized by small average deviations from each other. This means that there is no shift that distinguishes one day of measurement from the other, and there are only cyclic fluctuations associated with the magnitude of the unbalance of power. In turn, the value of the unbalance of power depends on the error of information-measuring metering units, which in turn depends on the current load of the current transformers of a separate information-measuring metering unit. The average value imbalance for all time intervals $\tau_i$ performed to reduce the level of the random component $\varepsilon(\tau)$ time series. Consider the value $\overline{y_i}$ as a time sample of a series, investigating the structure of the hourly cyclic oscillations of the daily change in the unbalance of power at the substation. Make a matrix of values $\{\tau_i, \overline{y_i}\}, i=1,2,\ldots,24$ and build a graph of the values of the time series $\overline{y_i}$. By figure 1 you can see the broken oscillatory character of the value change $\overline{y_i}$, in this connection, to determine the structure of this time series, you can use the methods of harmonic analysis.

Find the coefficients of the Fourier series by formulas (2)–(4):

$$a_0^* = \frac{1}{n} \sum_{i=1}^{n} y_i$$

$$a_k^* = \frac{2}{n} \sum_{i=1}^{n} y_i \cos \left( \frac{2\pi k T}{T} \tau_i \right)$$

$$b_k^* = \frac{2}{n} \sum_{i=1}^{n} y_i \sin \left( \frac{2\pi k T}{T} \tau_i \right)$$
For $T = 24$, $\Delta \tau = 1$, $n = 24$ it is advisable to calculate $a_0$, $a_1^*$, $a_2^*$, $b_1^*$, $b_2^*$, $a_{n/2}^*$=$a_{12}^*$, $b_{n/2}^*$=$b_{12}^*$. The symbol "*" means that the coefficients are calculated by discrete values of the time series.

Value

$$S_k = a_k^2 + b_k^2$$  \hspace{1cm} (5)

characterizes the energy contribution of the $k$-th harmonic to the function $y(\tau)$. We determine the spectral composition of the function $y(\tau)$ as a function of the value $S_k$ of the harmonic number $k$, for which we consider table 2.

| $k$ | $a_k$ | $b_k$ | $S_k$ |
|-----|-------|-------|-------|
| 1   | -0.056| -0.026| 0.0038|
| 2   | 0.012 | 0.0039| 0.00099|
| 3   | 0.011 | 0.0033| 0.00015|
| 4   | -0.012| 0.0057| 0.00019|
| 5   | -0.0027| -0.014| 0.00015|
| 6   | 0.0027| 0.0061| 0.00015|
| 7   | -0.00091| 0.0088| 0.00032|
| 8   | -0.0025| -0.0099| 0.000044|
| 9   | -0.0066| 0.0088| 0.000079|
| 10  | -0.0097| 0.0099| 0.00011|
| 11  | 0.015 | 0.0000011| 0.000072|
| 12  | 0.0015| 0.000011| 0.000016|

Since, $a_0$=-0.11, we get $S_0=0.013$.

By conducting further studies for individual substations, it is possible to obtain the values of the functions $y(\tau)$. Having established the maximum possible threshold of change $y(\tau)$, it is possible to offer as a criterion of observance of reliability of the substation account of the electric power a condition of not exceeding of the considered size.

4. Conclusion

In the course of research, an appropriate algorithm for simulation of changes in the operating modes of the substation electricity metering system based on the experimental statistical base was developed. On the basis of provisions and conclusions the software of the automated multipurpose information and measuring system is developed and realized. The results of the study can be used as a basis for the development of tools for detecting the unreliability of electricity metering on intersystem power lines. Based on the recommendations developed in this paper, methods can be developed to improve the efficiency of measurement and control systems of electricity metering.
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