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Increasing the Accuracy of Electrical Power Measurement

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***Abstract*— Correlation of direct measurement errors of voltage and current is ignored and assumed to be zero in the measurement of electrical power signals. Therefore, the accuracy of power measurement is obtained less than the accuracy of direct measurements. In this regard, increasing the power measurement accuracy is an urgent task by taking into account correlation of direct measurement errors. A certain methodology is proposed in the paper taking into account the correlation of direct measurement errors, which increases the accuracy of the power signal measurement.**
***Index Terms*— power measurement, correlation, error, polarity, direct measurements..**

I. Introduction

A number of parameters should be measured for monitoring and diagnostics equipment and technological processes in the automation of production processes. Some of them concern only indirect measurements. The measurement is meant by indirect measuring in which the desired value of the quantity is based on the known relationship between the value p and the values u *and* i subjected to direct measurements [1,2]:

$$p = u * i \qquad (1)$$

These parameters are subject to the effects of internal and external destabilizing factors that create correlated measurement errors of these parameters. For these reasons, an indirect estimate of the parameter p occurs with an error. In most cases the correlation of direct measurement errors is ignored and assumed to be zero. Therefore, the accuracy of indirect measurements is less than the accuracy of direct ones. In this regard, increasing the accuracy of indirect measurements is an urgent task by taking the correlation of direct measurement errors into account [3].

II. THE STRUCTURE OF PROBLEM

Analysis of the data transformation processes in devices of indirect measurement of physical parameters has shown that this kind of structure is the same as the differential device model with spatial distribution of input signals i *and* u, where the error of measurement i *and* u appear under the influence of independent uncorrelated destabilizing factors. Therefore, the existing mathematical model of indirect measurement process of physical parameters p appears in the following implicit form [4]:

$$Z = F\left(f_x(x; a_1, a_2, \dots, a_m); f_y(y; b_1, b_2, \dots, b_k)\right) \qquad (2)$$

The analysis of this model showed that it does not stimulate the development of new methods and means of increasing the accuracy of indirect measurements, since there is no clear functional and statistical dependence between the values of the components of direct measurements and destabilizing factors, which is very important in the development of effective methods and means to minimize them.

III. THEORY

With the aim to find the ways to increase the accuracy of indirect measurements, the formula (2) has been distributed into the Taylor series [4,5]. After a certain transformation the formula was obtained to estimate indirect measurement error:

$$dp = \frac{\partial F}{\partial f_x} \times \frac{\partial f_x}{\partial x} \times dx + \frac{\partial F}{\partial f_y} \times \frac{\partial f_y}{\partial y} \times dy + \\ + \frac{1}{2} \times \left[\frac{\partial^2 F}{\partial^2 f_x} \times \frac{\partial^2 f_x}{\partial x^2} \times dx^2 + \frac{\partial^2 F}{\partial f_y^2} \times \frac{\partial^2 f_y}{\partial y^2} \times dy^2 + \right. \\ \left. + \frac{\partial F}{\partial f_x} \times \frac{\partial f_x}{\partial x} \times \frac{\partial F}{\partial f_y} \times \frac{\partial f_y}{\partial y} \times dy \times dx \right] \qquad (3)$$

For carrying out this equation

$$dz = dz_{lin.} + \mathrm{dz}_{\mathrm{unlin.}} \qquad (4)$$

where

$$\mathrm{dz}_{\text{лин.}} = \frac{\partial \mathrm{F}}{\partial \mathrm{f}_{\mathrm{x}}} \times \sum_{i=1}^{m} \frac{\partial f_x}{\partial a_i} \times da_i + \frac{\partial F}{\partial f_y} \times \sum_{i=1}^{k} \frac{\partial f_y}{\partial b_j} \times db_j; \qquad (5)$$

Choosing a generalized formula to minimize the error of indirect measurements based on numerical estimation of linear and nonlinear terms of Taylor's formula are as follows.

As it is seen from the model, the values of the nonlinear terms is much less than the values of linear terms, so the function of non-linear members may be discarded. Thus, a generalized condition of minimizing the indirect measurement errors can be taken:

$$\frac{\partial F}{\partial f_x} \times \sum_{i=1}^{m} \frac{\partial f}{\partial a_i} \times da_i + \frac{\partial F}{\partial f_y} \times \sum_{j=1}^{k} \frac{\partial f}{\partial b_j} \times db_j = 0 \quad (6)$$

The terms for minimizing indirect measurement errors are as follows:

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$$\frac{\partial F}{\partial f_x} \times \frac{\partial f}{\partial a_i} \times da_i = 0 \text{ and } \frac{\partial F}{\partial f_y} \times \frac{\partial f}{\partial b_j} \times db_j = 0 \quad (7)$$

$$\frac{\partial F}{\partial f_x} \times \sum_{i=1}^{m} \frac{\partial f}{\partial a_i} \times da_i = 0, \frac{\partial F}{\partial f_x} \times \sum_{j=1}^{k} \frac{\partial f}{\partial b_j} \times db_j = 0 \quad (8)$$

$$\frac{\partial F}{\partial f_x} \times \frac{\partial f_x}{\partial a_i} \times da_i + \frac{\partial F}{\partial f_y} \times \frac{\partial f_y}{\partial b_j} \times db_j = 0 \quad (9)$$

$$\frac{\partial F}{\partial f_x} \times \sum_{i=1}^{m} \frac{\partial f_x}{\partial a_i} \times da_i + \frac{\partial F}{\partial f_x} \times \sum_{j=1}^{k} \frac{\partial f_y}{\partial b_j} \times db_j = 0 \quad (10)$$

Terms (7) - (10) show that the methods for increasing the accuracy of indirect measurements can be divided into 4 groups to minimize errors in indirect measurement: the methods for reducing the individual components of the measurement values of direct measurement errors; methods for reducing the total value of direct measurement errors; methods of correction or mutual compensation of the individual components of indirect measurement errors; methods of correction and mutual compensation of the total error of indirect measurements.

As it is seen in these terms, existing methods for increasing the reliability of RO implement these conditions (7) - (9) and significant results haven't been obtained.

However, condition (10) hasn't been investigated and hasn't been used to solve this problem. Therefore, analyzing the condition, further research has been stated.

IV. OPERATION PRINCIPLE

Suppose parameter Z is found by measuring parameters *x and y*. When measured at the actual values these parameters overlap the errors $\Delta x \cdot sign(\Delta x)$ и $\Delta y \cdot sign(\Delta y)$, where Δx and Δy are respectively the absolute values of the error measuring parameters x and y, a, $\Delta x \cdot sign(\Delta x)$ и $\Delta y \cdot sign(\Delta y)$, are their polarities. Then:

$$\begin{aligned} Z = x \cdot y = &(x_\partial + \Delta x \cdot sign(\Delta x))* \\ &*((y_\partial + \Delta y \cdot sign(\Delta y)) = \\ &= (x_\partial \cdot y_\partial + x_\partial \cdot \Delta y \cdot sign(\Delta y)) + \\ &+ y_\partial \cdot \Delta x \cdot sign(\Delta x) + \\ &+ \Delta x \cdot sign(\Delta x) \cdot \Delta y \cdot sign(\Delta y), \end{aligned} \quad (12)$$

where *x and y* are respectively actual values of parameters *x and y*.

$$Z = Z_\partial = x_\partial \cdot y_\partial$$

should be in the ideal case to minimize the errors of indirect measurement. This is possible in the carrying out the following equality:

$$\begin{aligned} &x_\partial \cdot \Delta y \cdot sign(\Delta y) + y_\partial \cdot \Delta x \cdot sign(\Delta x) + \\ &+ \Delta x \cdot sign(\Delta x) \cdot \Delta y \cdot sign(\Delta y) = 0 \end{aligned} \quad (13)$$

After rising to the second power the formula takes the following form:

$$\begin{aligned} &x_\partial^2 \cdot \Delta y^2 \cdot sign^2(\Delta y) + y_\partial^2 \cdot \Delta x^2 \cdot sign^2(\Delta x) + \\ &+ 2 \cdot x_\partial \cdot \Delta y \cdot sign(\Delta y) \cdot y_d \Delta x \cdot sign(\Delta x) = \\ &= -\Delta x^2 \cdot sign^2(\Delta x) \cdot \Delta y^2 \cdot sign^2(\Delta y). \end{aligned} \quad (14)$$

Taking this into consideration $sign^2(\Delta y) = sign^2(\Delta x) = +1.$

$$\begin{aligned} &x_\partial^2 \cdot \Delta y^2 + y_\partial^2 + 2 \cdot \Delta y = -2 \cdot x_\partial \cdot \\ &\cdot \Delta y \cdot sign(\Delta y) \cdot y_\partial \cdot \Delta x \cdot sign(\Delta x). \end{aligned} \quad (15)$$

This equality is presented in the following form:

$$\begin{aligned} &x_\partial^2 \cdot \Delta y^2 + y_\partial^2 \cdot \Delta x^2 - \Delta x = -2 \cdot x_\partial \cdot \Delta y \cdot \\ &\cdot sign(\Delta y) \cdot y_\partial \cdot \Delta x \cdot sign(\Delta x). \end{aligned} \quad (16)$$

Taking this into consideration the following condition should be carried out for the validity of equation:

$$sign(\Delta y) = -sign(\Delta x). \quad (17)$$

Applying this rule to the power measurement by ammeter and voltmeter it is necessary to achieve any of the conditions:

$$sign(\Delta U) = -sign(\Delta I). \quad (18)$$

During the indirect method power measurement is carried out as P=UI. In this case, certain condition should be carried out in order to minimize the error of indirect measurement:

$$sign(\Delta U) = sign(\Delta I). \quad (19)$$

For the form of indirect measurement, the condition should be performed:

$$sign(\Delta X) = sign(\Delta Y), \quad (20)$$

and the condition should be carried out in that form:

$$sign(\Delta X) = -sign(\Delta Y). \quad (21)$$

Terms and conditions can be obtained by apparatus and algorithms. The apparatus should comply with the conditions in the hardware method of minimizing errors in indirect measurement. For example, this type should be selected in the analog method of measuring the power of the voltmeter, in which the error is of positive polarity. And for an ammeter such type should be selected that the error is of negative polarity.

The channels of voltage and current measurements must have opposite polarity errors in digital power measurement method of electrical signals.

V.ALGORITHM

Algorithmic method of this condition is more simple and is implemented as follows. The arrays of their digital values are formed by repeatedly measuring the voltage and current: The power is defined by:

$$P = U_{i,\max} \cdot I_{i,\min} \qquad (22)$$

where $U_{i,\max}$ and $I_{i,\min}$ are respectively the maximum and minimum values in the arrays of the data.

Computer simulations were carried out to check the efficiency of the algorithm. The arrays are formed by repeatedly measuring: $\{U_i | i = \overline{1,n}\}$ and $\{I_i | i = \overline{1,n}\}$. The first array was ranked in increasing order, and the second one in decreasing order. New array values of the power $\{P_i | i = \overline{1,n}\}$ were formed by the newly created arrays of the ranked values of voltage and current. The clarified power value is equal to the arithmetical mean value of the data array. Simulation results are shown as follows.

X_i = 90, 100, 88, 93, 93, 80, 100, 95, 100, 92, 101, 93, 88, 93, 88, 100, 98, 99.
Yi = 81, 100, 98, 100, 91, 100, 88, 93, 94, 87, 99, 98, 98, 92, 101, 92, 87, 92.

ranked arrays

80, 88, 88, 88, 90, 92, 93, 93, 93, 93, 95, 98, 99, 100, 100, 100, 100, 101.
81, 87, 87, 88, 91, 92, 92, 92, 93, 94, 98, 98, 98, 99, 100. 100, 100, 101.

The values of arrays are presented in order and according to the formulas:

$$Z_{1,I} = X_{i,\max} - Y_{i,\min} \qquad (23)$$

$$Z_{1,I} = Y_{i,\max} - X_{i,\min} \qquad (24)$$

$$Z_{1,I} = X_{i,\max} - Y_{i,\max} \qquad (25)$$

$$Z_{1,I} = X_{i,\min} - Y_{i,\min} \qquad (26)$$

$$Z_{1,I} = X_i - Y_i \qquad (27)$$

The following values were obtained after processing the data:

In the first formula: $mz = mx \cdot my = 8825{,}559$; z_1 , Average = 8798.333; standard deviation - 282, 72.

In the second formula: $mz = mx \cdot my = 8825{,}559$; z_2 , Average = 8798.333; standard deviation - 282, 72.

In the third formula: $mz = mx \cdot my = 8825{,}559$; z_3 , Average = 8856.111; standard deviation - 1024.735.

In the fourth formula: $mz = mx \cdot my = 8825{,}559$; z_3 , Average = 8856.111; standard deviation - 1024.735.

In the normal flow of information: $mz = mx \cdot my = 8825{,}559$; z_3 , Average = 8818.389; standard deviation - 654.38.

As it is seen from the results, the use of the proposed method significantly reduces the error of indirect measurement of the electrical signals power.

VI. CONCLUSION

1. Correlation between the errors of direct measurements of the individual components must be taken into account in order to assess the indirect measurement errors accurately;
2. The device should be constructed by obtaining the necessary correlation between the errors in the measurement of individual components in order to minimize the errors of indirect measurement.

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