NEW TECHNOLOGIES OF PRECISE ELECTROMETRY

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Rezumat. Nouă abordare a problemei de creştere a preciziei de măsurare a cantităţilor electrice este descrisa. Această abordare se bazează pe variaţiile de influenţa a surselor de incertitudine la rezultatul măsurării. De obicei modelul matematic descrie rezultatul măsurării şi circuitul de măsurare în funcţie de valoarea măsurată şi diferite surse de incertitudine. Influenţa tuturor acestor surse incertitudine la rezultatul măsurării este bine descris, dar valoarea surselor de incertitudine în sine rămâne necunoscută. Investigarea diferitor circuite de măsurăra a arătat că de fiecare dată poate fi găsita calea de a schimba influenţa oricarei surse de anumite ori sau de anumită valoare. Aceasta ne permite să furnizam variaţie a sursei de influenţă incertitudine şi, de fiecare dată după o astfel de variaţie, a măsura rezultatul nou de măsurare. Toate aceste rezultate ale măsurătorilor sunt descrise prin un sistem de ecuaţii. Ca urmare, soluţia acestui sistem elimina influenţa surselor de incertitudine cu privire la rezultatul măsurării şi noi putem gasi adevărata dimensiune a valorii măsurate. Din cauza ca avem nevoie de un număr de măsurări pentru a obţine valoarea reală, metoda variaţionala duce la cresterea timpului de măsurare şi la acumularea a componentei incertitudine aleatoare. Pentru a exclude aceste efecte, gruparea surselor de incertitudine a fost propusa. Au fost propuse si dezvoltate două tipuri de grupare. Primul tip de grupare foloseşte diferite deviere in timp a surselor de incertitudine diferite (grupare de timp). În acest caz, vom împărţi tezaur de surse de incertitudine pe clustere, având similare derivă in timp. Presupunând că astfel de grupuri sunt independente şi că sursele de incertitudine cu un timp mai lung derivă nu-şi schimbă valorile lor de incertitudine în timpul deplasarea clustere, cu un timp mai scurt, putem oferi calibrare variaţionala separat pentru grupe diferite cu frecvenţe brusc diferite. În aşa fel timpul de calibrare variaţional ar putea fi drastic redus. Al doilea tip de grupare foloseşte posibilitatea de a se îmbina surse diferite de incertitudine, situate în o parte a circuitului de măsurare (de grupare spaţiu). În acest caz, vom împărţi întreg circuitul de măsurare in quadripole separate sau cicluri cu semnale de ieşire corespunzătoare. Fiecare din aceste quadripole sau cicluri uneşte mai multe surse de incertitudine. Pentru calibrarea variaţionala se efectuarea variaţia coeficienţilor de transfer al acestor quadripole sau cicluri. După măsurărea semnalelor corespunzătoare se compune sistem adecvat de ecuaţie. Rezolva acestui sistem de ecuatii ne da adevarata valoare a rezultat măsurat. În acest caz, timpul de calibrare şi componenta acumulata a incertitudinei aleatoare ambele scăd bruscă. Rezultatele elaborarii pe baza metodei de variaţie a aparatelor exacte în diferite domenii de măsurare electrice sunt date.

Cuvinte cheie: măsurare, impedanţă, capacitate, inductanţă, rezistenţă, de incertitudine, coeficient de transfer, modificarea, corectarea.

Abstract

The new approach to the impoving of the accuracy of the electrical quantities measurements is described. This approach is based on the variations of the influence of uncertainty sources on the result of measurement. Using this well known variations the number of measurements, equal to the number of the uncertainty sources is provided. The system of equations, describing these measurements, is solved. In such way the influence of the appropriate uncertainty sources on the result of measurement is eliminated. Results of accurate variational devise developments in different areas of electrical measurement are given.

Key words: measurement, impedance, capacitance, inductance, resistance, uncertainty, transfer coefficient, variation, correction.

Introduction

Electricity is the basis of today civilization. Of course, it can't exist without appropriate measurements of different electrical quantities. During last two centuries the main guidelines of measurement accuracy improving are based on the next:

-improving of the methods and algorithms of measurements,

-improving of the devises structure,

- improving of the components parameters.

A lot of well known scientists and corporations worked and work today in all these areas. It is simply impossible to name all of them in this short report.

Usually to increase measurement accuracy all these ways are used. But every time increasing of the measurement accuracy leads to increasing of the devises weight and cost. So, creation of the new methods of measurement, which permits to increase measurement accuracy without sufficient increasing of the devises weight and price, is very important. This report describes one of possible decisions of arising problem.

Decision of the problem

To increase measurement accuracy usually or the better components and standards are used, or the appeared errors are corrected using appropriate methods. There is the lot of methods of the error correction. Either of them has different restrictions (same of them too complicate measuring system, other cut off the frequency range and so on).

Here we will describe the new method of error correction. This method is illustrated by the Fig.1 and Fig.2. On Fig.1 the simple measuring system is shown. Here the X is the value to be measured. It is applied to the input of measuring system. Y is the result of measurement, given by measuring system. Fig.1 shows that the result Y of measurement depends not only on the X, but on the disturbing factors. These unknown factors $\delta_1 \ldots \delta_n$ cause the errors of the measurement. Their influence on the result of measurement has to be eliminated.

Dependence (1) of the result Y of measurement on the value X to be measured and disturbing factors (the mathematical model of measuring circuit) usually is well known. Only values of these disturbing factors remains unknown.

$$Y = \varphi(X; \delta_1; \delta_2; \ldots; \delta_i; \ldots; \delta_n) \tag{1}$$

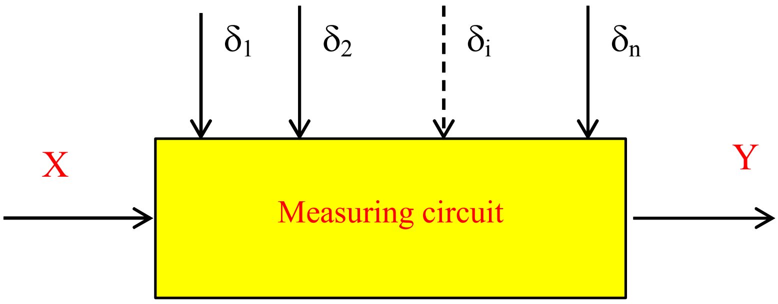

Fig.1.

Let we'll suppose, for simplicity, that there are no correlation between uncertainty sources and all of them are distributed by normal low. Common measurement uncertainty, caused by these sources, taking into account uncertainty δ_s, caused by the measuring system sensitivity, in this case could be described by formula:

$$\delta_c = \sqrt{\delta_s^2 + \sum_i (\delta_I)^2} \tag{2}$$

Let we'll suppose, that the disturbing factors values during the measurement doesn't change and remains constant. To improve the accuracy measurement in this case we can use variational method.

The variational method is illustrated by Fig.2., and, in principle, consists in the next. To eliminate the dependence of the result of measurements on the disturbing factors $\delta_1 \ldots \delta_n$ we vary everyone of these factors influence on the result of measurement (multiply the influence of appropriate factor on $\alpha_1 \ldots \alpha_n$ or add the similar variation). Measuring system provides main measurement of the input value X without variation and measures this value after everyone variation. In such way we get n+1 results of measurement $Y_0, Y_1 \ldots Y_n$. It get us possibility to create equation system (see the system (3)), describing whole measuring process. Solving this system we find the true result of measurement Y.

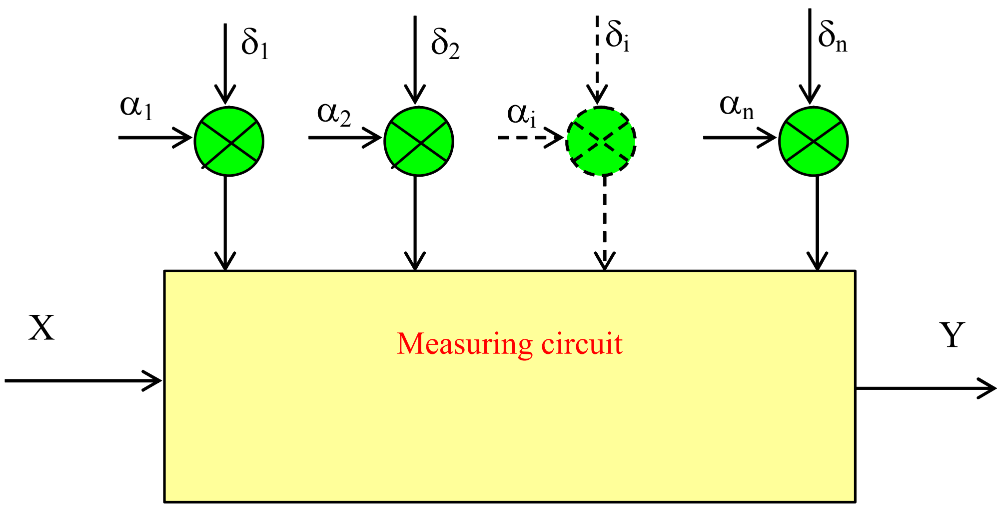

Fig.2.

$$\begin{cases} Y_0 = \varphi_1(X;\delta_1;\delta_2;\ldots;\delta_i;\ldots;\delta_n) \\ Y_1 = \varphi_2(X;\alpha_1;\delta_1;\delta_2;\ldots;\delta_i;\ldots;\delta_n) \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ Y_n = \varphi_n(X;\delta_1;\delta_2;\ldots,\delta_i;\ldots;\alpha_n;\delta_n) \end{cases} \quad (3)$$

It is easy to show that if sensitivity and appropriate uncertainty δ_s in all provided measurement remains the same and accuracy of every variation will be $\Delta\alpha_i$, the resulting uncertainty of measurement will be described by formula:

$$\delta_c = \sqrt{\delta_s^2 + \sum_i \delta_i(\delta_{ai} + \delta_s)} \quad (4)$$

Formula (4) evidently show that measurement uncertainty sharply decrease in ratio, determined by uncertainty of variation δ_{ai}. Let uncertainty source δ_i create uncertainty 10^{-3} and we need to decrease it to the value 10^{-6}. It means that we have to provide appropriate variation with uncertainty better that 10^{-3} only.

At the same time formula (4) show that using of the variational method leads to increasing of the contribution of measurement sensitivity in common measurement uncertainty.

Variational method needs **n** measurements instead **one** only. It means that in common case common time t_c of measurement increase to value:

$$t_c = \sum_n t_i \quad (5)$$

These two disadvantages of variational method can be overcome in different ways. Here we will shortly describe ***time and space clustering of the uncertainty source thesaurus***.

a) ***Time clustering.*** Let we'll analyze thesaurus of the uncertainty sources. We will see that different uncertainty sources have different typical speeds of drifting. It permits us to provide time clustering of the thesaurus of uncertainty sources. To provide such clustering we divide thesaurus of uncertainty sources on clusters, having congruous time of drift. In this case we could provide variational calibration for every cluster separately with different frequency. This approach is illustrated by Fig.3.

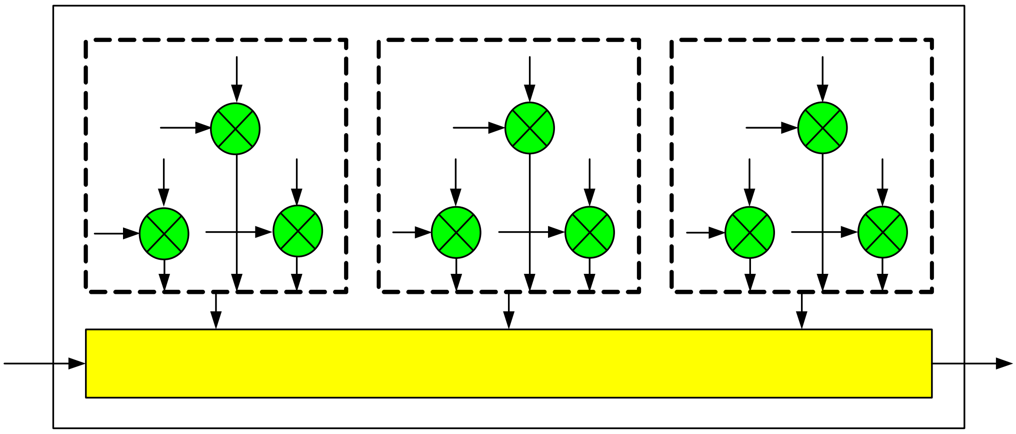

Fig.3.

$$\begin{cases} Y_{10} = \varphi(X;\delta_{11}\ldots\delta_{1n}) \\ Y_{11} = \varphi(X;\delta_{11};v_{11};\ldots\ldots\delta_{2n}) \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ Y_{1n} = \varphi(X;\delta_{11}\ldots v_{1n};\delta_{1n}) \end{cases} \quad (6a)$$

$$\begin{cases} Y_{20} = \varphi(X;\delta_{21}\ldots\delta_{2m}) \\ Y_{21} = \varphi(X;\delta_{21};v_{21};\ldots;\delta_{2m}) \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ Y_{2m} = \varphi(X;\delta_{11};\ldots.;v_{2m};\delta_{2m}) \end{cases} \quad (6b)$$

$$\begin{cases} Y_{30} = \varphi(X;\delta_{31};\ldots;\delta_{3l}) \\ Y_{31} = \varphi(X;\delta_{31};v_{31};\ldots;\delta_{3l}) \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ Y_{3l} = \varphi(X;\delta_{31};\ldots.;v_{3l};\delta_{3l}) \end{cases} \quad (6c)$$

Here thesaurus of uncertainty sources is divided, as example, onto three clusters T1, T2, and T3.

First cluster could combine into one uncertainty sources having typical drift time in units of month (drift of the inner standard parameters, etc.). Variational calibration for this cluster of uncertainty sources we provide with frequency, for example, one time per month. This calibration procedure is described by system of equation (6a).

Second cluster could combine into one uncertainty sources having typical drift time in units of hours (for example, drift of the parameters, caused by change of the inner temperature, etc.). Variational calibration for this cluster of uncertainty sources we provide with frequency, for example, one time per hour. This calibration procedure is described by system of equation (6b).

Third cluster could combine into one uncertainty sources, which change their value depend on X value, i.e. during every measurement. Variational calibration for this cluster of uncertainty sources we provide during every measurement. This calibration procedure is described by system of equation (6c).

Described approach permits to decrease all the time of calibration nearly in the ratio of clusters number or more. But the increasing influence of measurement sensitivity on the measurement uncertainty remains the same and common uncertainty of measurement, as early, is described by equation (4).

b) S***pace clustering.*** There are described two examples of space clustering.

First of them (*four-pole clustering*) is illustrated by Fig.4 and consists in the next.

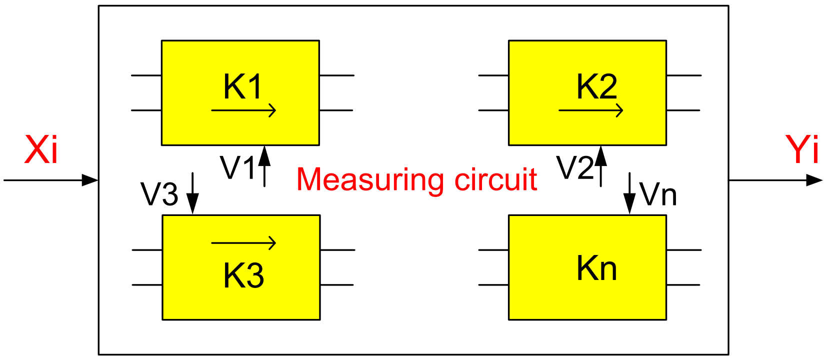

Fig.4.

Analysis of measuring circuit permits us to represent it as complex of four-poles. Everyone four-pole could be described by transfer coefficient K_i. In this case the dependence between X and Y can be described by function:

$$Y = f(K_1, K_2, ...K_n, X) \quad (7)$$

Appropriate dividing of the measuring circuit permits to get the number of the four-poles much lower than uncertainty sources. As it, now we can provide subsequently the variation of every four-pole transfer coefficient on V_i and measure appropriate results. All this procedure will be described by equation system (8).

$$\begin{aligned} &Y = f\ (K_1,\ K_2,\ K_3,\ K_n,\ X); \\ &Y_1 = f\ (K_1,\ V_1,\ K_2,\ K_3,\ K_n,\ X); \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ &Y_n = f(K_1,\ K_2,\ K_3,\ K_n,\ V_n,\ X) \end{aligned} \quad (8)$$

Deciding this system we get the true value of measured parameter.

In case of *four-pole clustering* we provide the number of measurements, equal to the number of four-poles. It means that the time of measurement will be much lower and uncertainty accumulation, caused by measurement circuit sensitivity, will be much lower as well. Common measurement uncertainty of measurement in this case can be calculated by formula (4), where summing have to be provided by the number of four-poles

Second of them (*contour clustering*) consists in the next.

Measuring circuit could be analyzed as complex of separate contours, all of them including part of measuring circuit, responsible for the appropriate part of uncertainty sources and having its own output. Such approach is illustrated by Fig.5.

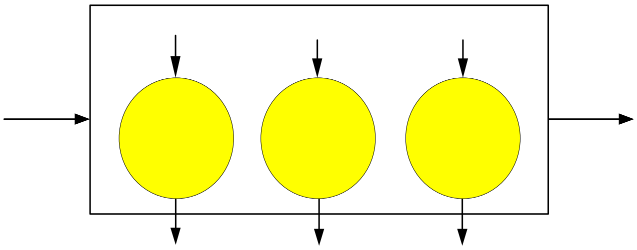

Fig.5.

In this case data of measuring circuit output as well as data of contours output are analyzed without variation at the same time. After it variation is provided separately in every contour. Appropriate output signals are measured after variation. All this complex of measurement is described by equation system (9).

$$
\begin{aligned}
&Y = f(L_1,\ L_2,\ L_3,\ X);\\
&Y_1 = \varphi(L_1,\ V_1, X);\\
&Y_2 = \psi(L_2,\ V_2, X);\\
&Yi = Q(Li,\ V_i, X).
\end{aligned}
\qquad (9)
$$

In case if between contours exist interference, it could complicate system of equation. But today it isn't problem.

Simultaneous measurements here sharply increase speed of measurement and decrease uncertainty accumulation cased by sensitivity of measuring system. Of course, it needs some complication of the measuring system.

On the base of described above approach during last 15 years the new generation of measuring devises for measurement of impedance parameters (capacitance, inductance, resistance, etc.), for conductivity measurements, for temperature measurements, for measurement of different parameters in power systems, etc. has been developed and now are serially manufactured. It was the long way of engineering development from described above ideas to optimal decisions. This complex cover today the devises for different application: from working devises to primary standards, from uncertainty 0.1% to uncertainty 0.000001%

Some of them are shown below.

50 Hz Automatic bridge
CA 7100, δ ≤ 0,02%

50 Hz Voltage and current
transfer coefficient meter, δ ≤ 0,01%

RLC-meter DC-1 MHZ
MHC - 1100, δ ≤ 0, 01/0.001 %

50 Hz Complex for
isolation test δ ≤ 0,1%

Universal measuring system
CA320-2MT , δ≤ 0.003/0.0003 %

Sugar purity meter
WM2000, δ≤ 0.3/0.01%

Universal measuring system
CA320, δ ≤ 0,002/0.0002%

Thermoconductivity meter
TK4100, δ ≤ 0,02/0.003%

Fig.6 . **Serial working divises.**

Capacitance meter
"Sibiryachka" δ ≤ 0,0001/0.00001 %

Precise impedance comparator
"Gladiator", δ ≤ 0,00002/0.000001%

Comparator CA507,
δ ≤ 0,001%

Multychannel capacitance comparator
Sultan", δ ≤ 0,0001/0.00001 %

High voltage bridge CA7100M,
δ ≤ 0,001/0.00005%

Standard thermometer CA 300,
δ ≤ 0,0002/0.00002%

Fig.7. **Serial standard devises.**

Primary inductance and dissipation factor standard

Primary high current transfer coefficient standard

Primary capacitance and dissipation factor Standard

Primary PH standard

Primary conductivity standard

Fig. 8. **Primary standards**