IMPEDANCEMETER WITH SIMULATED RESONANCE

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Abstract – *An impedancemeter based on the method of simulated resonance for impedance components measuring is presented. The impedancemeter is based the on serial resonant measuring circuit and containing an impedance simulator as reference element. The method of measurement based on the resonance effect, the impedance simulator and the impedancemeter structure and algorithm of measurement are described.*

Keywords – *impedancemeter, simulated resonance, impedance simulator, impedance components.*

1. INTRODUCTION

For precision measuring of the impedance components with various characters the method of simulated resonance (MRS) may be applied [1]. The essence of MRS consists in obtaining of the resonance effect between the measured impedance and a simulated impedance, the components of which may be separately regulated. In the state of the full resonance of the reproduction of the reference impedance in the measurement process and it directly determines the measurement accuracy. The questions of developments and applications of these devices are very complex and require the separate examination, but some of them are examined in [9]. For our purposes was applied the current – commanded MSI, wich ensure reproducing of the simulated impedances expressed in Cartesian coordinates. Its structure is synthesized by the formal – structural method and ensures the separate regulation of the both components of impedance.

As it will be shown in further, the presented below automatical impedancemeter possesses a high accuracy of the impedance components measurement, has a simple measurement algorithm [6] and it can be practically realized both in the simple variant of tester and in the form of a precise laboratory device.

2. THE MEASUREMENT METHOD

Differently from the classical resonance method of measurement of the both impedance components, the method of simulated resonance is based on the full resonance in the measuring circuit [7]. The effect of resonance is reached at the both components of measured impedance, active and reactive, independently on its characters. For this purpose, the impedance which ensures the resonance effect is reproduced by means of impedance simulator, which makes it possible the control of the character and of the values of its components. The diagram of conversion information process for the method is represented on fig. 1. measuring circuit, the unknown components of measured impedance are determined from the known equations of equilibrium.

Practical implementation of the MRS is possible in serial or parallel resonance measuring circuits (RMS). Each type of them has specific features, which determines its domain of application. Particularly, the serial RMS is recommended for measuring of impedances with great values of the parameters, while the parallel RMS – for measuring the components of admittance in the opposite case . The above presented impedancemeter contain the serial RMS and the result of measurement is presented in the form of active and reactive components values. On the necessity, the result may be recalculated in any other necessary form.

An integral component of the impedancemeter is the metrological impedance simulator (MSI) [2]. It executes the function of

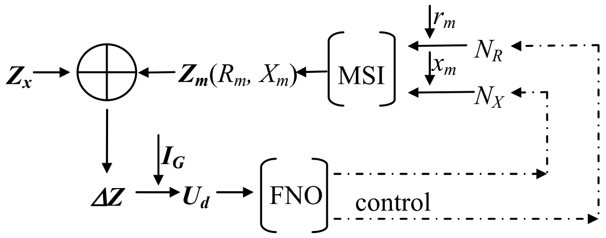

Fig.1 - The diagram of information conversion process

The measured impedance Z_x is summarized by the reference Z_m impedance reproduced by MSI and forms the resulting impedance ΔZ:

$$\Delta Z = Z_x + Z_m \tag{1}$$

Under the influence of the curent I_G, the resulting impedance ΔZ is converted into the voltage U_d, containing information about the state of the measuring circuit:

$$U_d = I_G \cdot \Delta Z = I_G (Z_x + Z_m) \tag{2}$$

The functional organum of null FNO in dependens the voltage U_d regulates the digital values D_r and D_x, which, under the influence of elementary measures of rezistence r_m and of the reactive component x_m , forms the active R_m and the reactive X_m components of the reproduced by MSI reference impedance Z_m. The type of FNO may be extremal or phase – commanded, in dependence on the equilibration algorithms. The process of measurement consists in the consecutive regulation of active and reactive components of simulated impedance $\boldsymbol{Z_m}$ before obtaining the state of equilibrium in the measuring circuit. The simplest condition of equilibrium:

$$\boldsymbol{U}_d = \boldsymbol{I}_G(\boldsymbol{Z}_x + \boldsymbol{Z}_m) = 0 \qquad (3)$$

from where it follows:

$$\mathbf{Z_x} + \mathbf{Z_m} = R_x + jX_X + R_m + jX_m = 0 \qquad (4)$$

where R_x , X_x – respectively, the active and the reactive components of measured impedance $\boldsymbol{Z_x}$. Solutions of (4) are:

$$R_x = -R_\mathrm{m}, X_X = -X_m \qquad (5)$$

As follows from (5), after equilibration of the measuring circuit at the active and reactive components, the unknown components R_x, X_x of the measured impedance Z_x are determined from the known components R_m, X_m of the reproduced by MSI reference impedance Z_m,. From (5) it also follows the condition of practical realizability of the equilibration algorithm: the components R_m, X_m should have the opposite character to the respective components R_x, X_x of the measured impedance Z_x.

3. THE MEASURING CIRCUIT

The practical implementation of the measuring process is possible in the series RMC (Fig. 2.a). RMC contains the measured impedance Z_x connected in serial with the virtual impedance Z_m reproduced on the poles of MSI and commanded by digital values D_r, D_x.

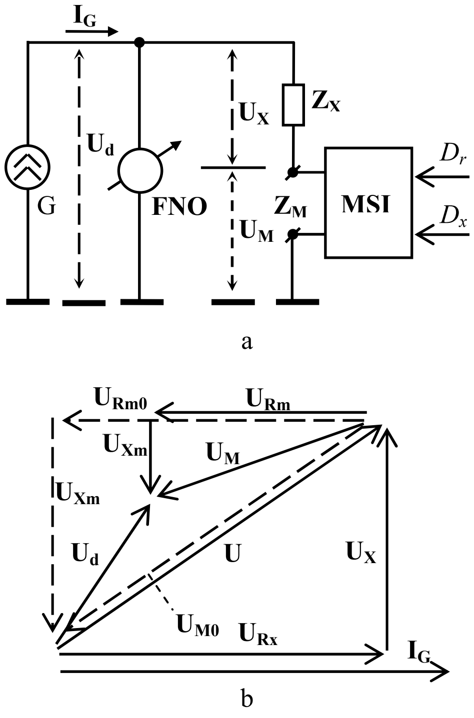

Fig.2 - The series measuring circuit (a) and its vector diagram (b)

The measuring circuit is supplied with current $\mathbf{I_G}$ from the signal generator G. The voltage $\mathbf{U_d}$ (2) is used by FNO for command the equilibration process.

In fig. 2.b is presented the vector diagramm of the measuring circuit for the case of series equivallent circuit of impedance $\boldsymbol{Z_X}$ and inductive character of it. For convergence of the equilibration process, as following from the diagram, MSI will reproduce the reference impedance $\boldsymbol{Z_M}$ with an opposite character of components $\mathrm{R_M}$, $\mathrm{X_M}$ in comparison with the character of measured components R_x, X_x respectively. In the equillibrum state, the components $\mathrm{R_M}$, $\mathrm{X_M}$ take values $\mathrm{R_{M0}}$, $\mathrm{X_{M0}}$ which satisfies the equillibrum condition (4).

The RMC may bee used for measuring only of one component of impedance $\boldsymbol{Z_X}$: acive R_x, or reactive X_x. For this purpose the equilibration process (Fig. 2,b) will be made by regulation the respective component of the impedance $\boldsymbol{Z_M}$. In this case in the circuit takes place the partially resonance, after the active components:

$$R_x + R_m = 0 \qquad (6)$$

or, after the reactive components:

$$\mathbf{j}(X_X + X_m) = 0 \qquad (7)$$

4. THE IMPEDANCE SIMULATOR

The most important unit of the resonant measuring circuit is the impedance simulator (MSI), executing the function of reference element. The term “metrological” applied to it, denotes some specific requirements to this unit, determined by metrological assistence of measurements. Amont them:

- Low error and high stability of reproduced impedances;
- The known and warranted value of systematic error of the reproduced impedance;
- Possibility of the impedance components separate regulation ;
- Digital control.

The mentioned requirements are satisfied by I-MSI synthesized by the formal – structural method (Fig. 3) .

The current $\boldsymbol{I_i}$ is converted into the voltage $\boldsymbol{U_I}$, used for creation of the voltage drops on the active ($\boldsymbol{U_R}$) and on the reactive ($\boldsymbol{U_X}$) components of the reproduced impedance $\boldsymbol{Z_i}$. The turn of the voltage $\boldsymbol{U_I}$ phase on the angle of 90º with consequent regulation of its magnitude at the factor $\mathrm{N_X}$ for creation the voltage $\boldsymbol{U_X}$ are used. Only the regulation of magnitude $\boldsymbol{U_I}$ on factor $\mathrm{N_R}$ for creation $\boldsymbol{U_R}$ is applied. The voltages $\boldsymbol{U_R}$ and $\boldsymbol{U_X}$ are summarized, forming the voltage $\boldsymbol{U_i}$, which, in conjunction with the current $\boldsymbol{I_i}$, form the reproduced impedance $\boldsymbol{Z_i}$.

Presented above algorithm of information conversion is realized in the block – diagram of the impedance simulator represented in the fig. 3.b [8].

The current - voltage converter IUC is applied for conversion of the current $\boldsymbol{I_i}$ into the voltage $\boldsymbol{U_I}$:

$$\boldsymbol{U}_I = \boldsymbol{I}_i \cdot R - \boldsymbol{U}_i \qquad (8)$$

where R – the conversion factor of the converter I/U. To obtain algorithmically correct dependence between the current $\boldsymbol{I_i}$ and the voltage $\boldsymbol{U_I}$ by elimination of effect of a stray feedback [8], the differential amplifier DA is applied. The voltage on its output:

$$\boldsymbol{U_I^1} = \boldsymbol{I_i} \cdot R_C - \boldsymbol{U_i} + \boldsymbol{U_i} = \boldsymbol{I_i} \cdot R_C \tag{9}$$

For creation of the phase shift 90º and for regulation of voltages – the phasor F and the programmable amplifiers PA1, PA2 are used. Formed with these elements the voltages $\boldsymbol{U_R}$, $\boldsymbol{U_X}$ are equal respectively to:

$$\boldsymbol{U_R} = N_R \cdot \boldsymbol{U_I^1} = N_R \cdot R_C \cdot \boldsymbol{I_i} \tag{10}$$

$$\boldsymbol{U_X} = N_X \cdot \boldsymbol{U_I^1} \cdot j\sin 90^0 = j \cdot N_X \cdot R_C \cdot \boldsymbol{I_i} \tag{11}$$

The summering amplifier SA sums the voltages $\boldsymbol{U_R}$, $\boldsymbol{U_X}$ and forms the voltage $\boldsymbol{U_i}$ applied to the input of the simulator:

$$\begin{aligned} \boldsymbol{U_i} &= U_R + U_X = N_R \cdot R_C \cdot \boldsymbol{I_i} + \\ &+ j \cdot N_X \cdot R_C \cdot \boldsymbol{I_i} = R_C(N_R + jN_X)\boldsymbol{I_i} \end{aligned} \tag{12}$$

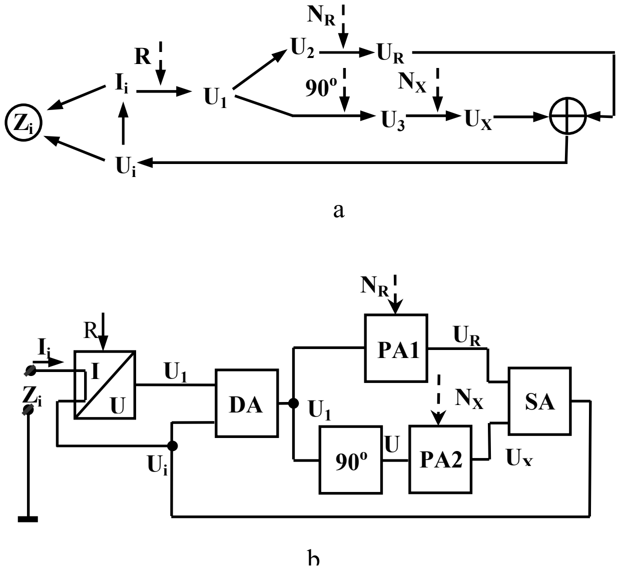

Fig.3 - The conversion algorithm for synthesis (a) and the structure (b) of I -MSI

The impedance $\boldsymbol{Z_i}$ reproduced by the simulator on its entering poles is determined by:

$$\boldsymbol{Z_i} = \frac{\boldsymbol{U_i}}{\boldsymbol{I_i}} = R_C(N_R + jN_X) \tag{13}$$

As follows from (13), the reproduced impedance $\boldsymbol{Z_i}$ is represented in Cartesian coordinates and allows realizing the separate control of its active and reactive components by change the gain factors N_R, N_X of the programmable amplifiers PA1, PA2. From (13) also follows that the character of the reproduced impedance (Fig. 4) depend only on the band of variation of N_R and N_X.

If the band of N_R is located in the field of positive values and the band of N_X – in the domain ($-N_0 \div +N_0$), the reproduced impedance can have the character of a resistance in a combination with inductive or capacitive component. The case when the both N_R and N_X have a range of change ($-N_0 \div +N_0$) is more interesting. As following from (13), the area of regulation of $\boldsymbol{Z_i}$ character in this case covers all the complex plane; i.e. $\boldsymbol{Z_i}$ can have the character of a different combination of the positive or negative resistance with the capacitive or inductive impedance components.

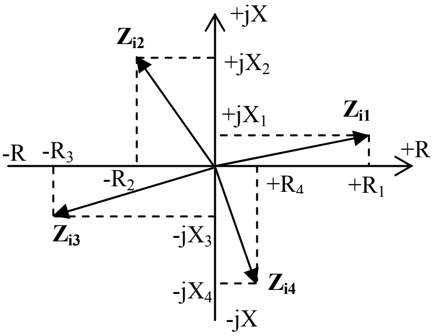

Fig.4 - The various character of the simulated impedance

All units of I-SIM are implemented on the base of operational amplifiers (OA) and precisious resistors. In the phasor, only one precious capacitance is used, for digital command of the programable amplifiers the DAC are used.

In the fig. 5 is represented the practical implementation of the designed I-SIM.

It contains the next units: a current-voltage convertor (OA A_1), a differential amplifier (OA A_2), the first and the second programmable amplifiers (respectively, OA A_3, A_4), a phase shifter with a 90^0 dephasage (AO A_5) and a summator on the OA A_6 basis [8].

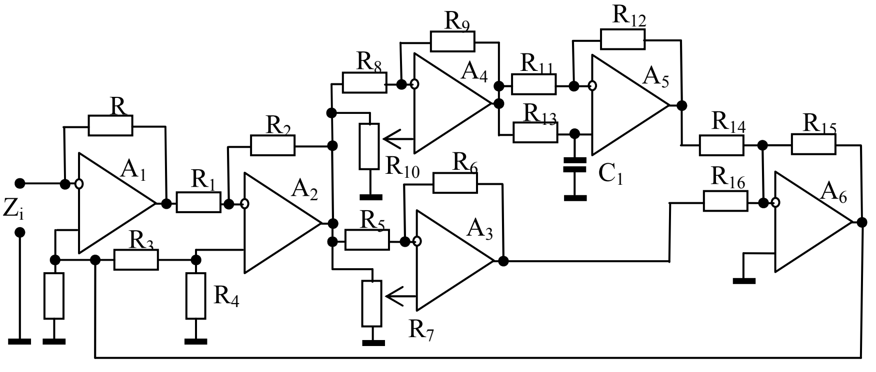

Fig.5 - Practical implementation of I-SIM

The adjustment of the active component of reproduced impedance is carried out by means of the resistor R_7, and that of the reactive component – by the resistor R_{10} .

5. THE IMPEDANCEMETER

The impedancemeter is based on the series resonant measuring circuit [1], containing a current commanded impedance simulator as reference element [2].

The structure of impedancemeter is represented on the fig. 6. It also contains an amplifier A, two comparators C_1 and C_2 and the command unit (CU). The A amplifier amplifies the imbalance signal of the resonant circuit, while the comparator C_2 converts it into rectangular pulses, which serve as imbalance signal $\mathbf{U_{de}}$ for the command unit. The voltage in the reference point of the SIM has the same phase as the voltage on the reactive component of the reference impedance. This voltage is also transformed into rectangular pulses by the comparator C_1 and constitutes the reference signal $\mathbf{U_{ref}}$ for the command unit. CU performs the resonant circuit balancing by adjusting the active component R_R and the reactive component X_R of the reproduced by SIM impedance $\mathbf{Z_R}$.

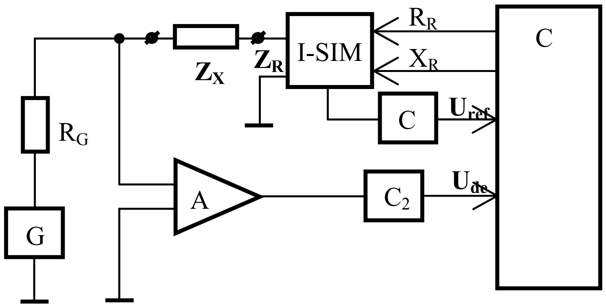

Fig.6 - The structure of impedancemeter

The measurement process takes place in two steps (Fig. 7). In the initial state of the measuring circuit (Fig. 7, a) SIM reproduces an arbitrary vector of impedance $\mathbf{Z_m}$. At the first step (Fig. 7, b) the command unit installs the minimal value of the active and reactive components of the impedance reproduced by the SIM and adjusts slowly the active component N_R till the appearance of a phase shift equal to 0° or 180° between the $\mathbf{U_{de}}$ and the $\mathbf{U_{ref}}$ signals. At the second step (Fig. 7, c) the CU adjusts slowly the reactive component X_R till the transition of the above mentioned phase shift from 0° to 180° or from 180° to 0° values.

At the completion of the measurement process the command unit has the information about the active R_R and reactive X_R components of the reproduced by the SIM impedance, which determines the values of the active component $R_X = - R_R$ and the reactive component $X_X = - X_R$ of the measured impedance.

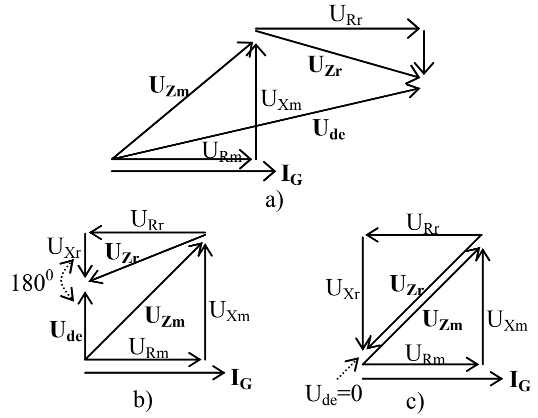

Fig.7 - The measurement process: initial stage (a), balanced by active component (b), total balance (c)

6. CONCLUSIONS

The impedance measurement by method of simulated resonance ensures a high precision, simplicity of the measurement process and its automation. The high precision is determined by the precision of the simulator reproduced impedance.

The use of impedance simulator with independent control of components ensures a simple measurement algorithm for impedances of any character. The balancing of the measurement circuit is completely automatic, which is due to the use of digital-analog converters as regulation elements and exclusion of adjustable reactive elements.

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