Meters of Impedance with Simulated Resonance

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Abstract — **A meter of impedance based on the method of simulated resonance for impedance components measuring is presented. The meter of impedance is based on series resonant measuring circuit containing an impedance simulator as reference element. Excepting the very high power levels, the four-quadrant chopper has certain advantages such as: high operational frequency, smooth and linear control, high efficiency and fast response.**

Key words — **meter of impedance, simulated resonance, impedance simulator, impedance components.**

I. INTRODUCTION

For precision measuring of the impedance components with various characters, the method of simulated resonance (MRS) may be applied [1]. Essence of MRS consists into 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 measuring circuit, the unknown components of measured impedance are determined from the known equations of equilibrium [1].

Practical implementation of the MRS is possible in series or parallel resonance measuring circuits (RMS). Each type of them are the specifically features, which determines its domain of application. Particularly, the series RMS is recommended for measuring of impedance with the great values of the parameters, the parallel RMS – for measuring the components of admittance in the opposite case [1]. The presented above meter of impedance contain the series RMS and the result of measurement is presented in the form of values of active and reactive components. On the necessity, the result may be recalculated in any other necessary form.

An integral component of the meter of impedance is the metrological impedance simulator (MSI). It executes the function of reproduction of the reference impedance in the process of measurement 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 [1], [1]. For our purposes was applied the current – commanded MSI capable to reproduce the simulated impedances expressed in Cartesian coordinates. Its structure is synthesized by formal – structural method [1] and ensures the separate regulation of the both components of impedance.

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

II. METHOD OF MEASUREMENT

In difference from the classical resonance method of measurement of impedance components, the method of simulated resonance is based on the full resonance in the measuring circuit. The effect of resonance is reached at the both components of measured impedance, active and reactive, independent on its characters. For this purpose the impedance ensuring the effect of resonance is reproduced by means of impedance simulator, wich makes it possible to control the character and the values of it components. The diagram of conversion information process for the method is represented on fig. 1.
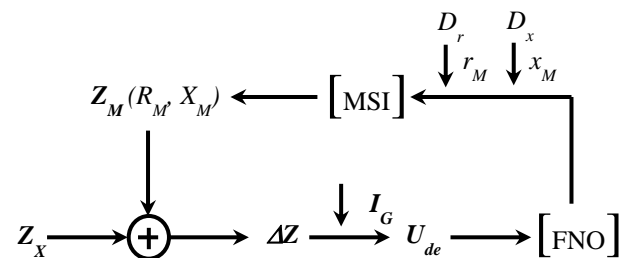

Fig. 1. Diagram of the conversion information process.

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

$$\Delta Z = Z_x + Z_m. \qquad (1)$$

Under the influence of the current I_G, ΔZ is converted into voltage U_{de}, containing information about the state of the measuring circuit:

$$U_{de} = I_G \cdot \Delta Z = I_G \, (Z_x + Z_m). \qquad (2)$$

The functional organum of null FNO, in dependents of voltage U_d, regulate the digital values D_r and D_x, wich, under the influence of elementary measures of resistance r_m and 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 [2], in dependence of the equilibration algorithms [3]. The process of measurement consists in the sequential regulation of active and reactive components of simulated impedance Z_m before obtaining the state of equilibrium in the measuring circuit. The simplest condition of equilibrium [4]:

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

from where it follows:

$$\boldsymbol{Z}_x + \boldsymbol{Z}_m = R_x + j\,X_x + R_m + j\,X_m = 0, \qquad (4)$$

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

$$R_x = - R_m , \quad X_x = - X_m. \qquad (5)$$

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 $\boldsymbol{Z}_x$ are determined from the known components R_m, X_m of the reproduced by MSI reference impedance $\boldsymbol{Z}_m$. From (5) 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 $\boldsymbol{Z}_x$.

III. THE MEASURING CIRCUIT

Practical implementation of the measuring process is possible in the series RMC (fig. 2.). It is constituted by the measured impedance $\boldsymbol{Z}_x$ connected in series with the virtual impedance $\boldsymbol{Z}_m$ reproduced on the poles of MSI and commanded by digital values D_r, D_x . The measuring circuit is supplied by current $\mathbf{I}_G$ from the signal generator G. The voltage U_d (2) is used by FNO for command the equilibration process.
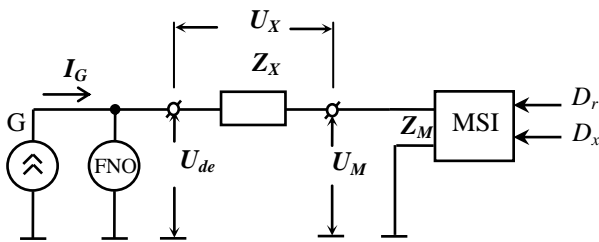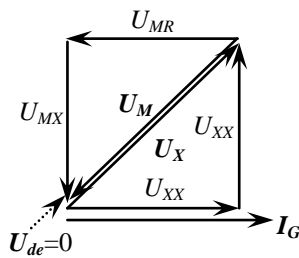

Fig. 2. Series measuring circuit

Fig. 3. Vector diagram of the measuring circuit.

On fig. 3 is presented the vector diagram of the measuring circuit for the case of series equivalent circuit of impedance $\boldsymbol{Z}_X$ and inductive character of it. For convergence of the measurement, as follows from the diagram, MSI will reproduce an reference impedance $\boldsymbol{Z}_M$ with opposite character of components R_M, X_M to the character of measured components R_x, X_x respectively. In the state of equilibrum the components R_M, X_M take values R_{M0}, X_{M0} wich satisfies the equilibrum condition (3).

IV. 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 denote some specific requirements to this unit determined by metrological assistance of measurements. Amount them [5]:

- 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.

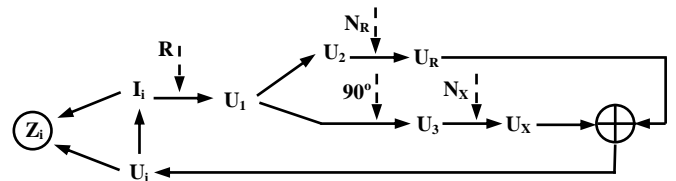The mentioned requirements are satisfied by I-MSI synthesied by the formal – structural method (fig. 4).

Fig. 4. The conversion algorithm for synthesis of I –MSI.

The current $\mathbf{I}_i$ is converted into the voltage $\mathbf{U}_1$, used for creation the voltage drops on the active ($\mathbf{U}_R$) and on the reactive ($\mathbf{U}_X$) components of the reproduced impedance $\mathbf{Z}_i$. The turn of the voltage $\mathbf{U}_1$ phase on the angle 90º with consequent regulation of its magnitude at the factor N_X for creation the voltage $\mathbf{U}_X$ are used. Only the regulation of magnitude $\mathbf{U}_1$ on factor N_R for creation U_R is applied. The voltages $\mathbf{U}_R$ and $\mathbf{U}_X$ are summarized, forming the voltage $\mathbf{U}_i$, which, in conjunction with the current $\mathbf{I}_i$, form the reproduced impedance $\mathbf{Z}_i$.

Presented above algorithm of information conversion is realized in the block – diagram of the impedance simulator represented in the fig. 5.
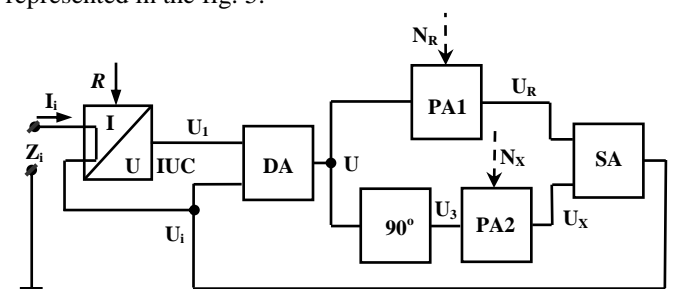

Fig. 5. The structure of I –MSI.

The current - voltage converter IUC is applied for conversion of the current $\mathbf{I}_i$ into voltage $\mathbf{U}_1$:

$$\mathbf{U}_1 = \mathbf{I}_i \cdot R - \mathbf{U}_i \, , \qquad (6)$$

where R – the conversion factor of the converter I/U. To obtain algorithmically correct dependence between the current $\mathbf{I}_i$ and the voltage $\mathbf{U}_1$ by elimination of effect of a stray feedback [5], the differential amplifier DA is applied. The voltage on it output:

$$\boldsymbol{U}_1 = \boldsymbol{I}_i \cdot R_C - \boldsymbol{U}_i + \boldsymbol{U}_i = \boldsymbol{I}_i \cdot R_C \qquad (7)$$

For creation of the phase shift 90° and for regulation of voltages – the phase shifter and the programmable amplifiers PA1, PA2 are used. Formed with these elements the voltages U_R, U_X are equal respectively:

$$U_R = N_R \cdot U_1 = N_R \cdot R_C \cdot I_i \qquad (8)$$
$$U_X = N_X \cdot U_1 \; j \sin 90° = j \, N_X \cdot R_C \cdot I_i \qquad (9)$$

The summering amplifier SA sum the voltages U_R, U_X and forming the voltage U_i applied to the input of the simulator:

$$U_i = U_R + U_X = R_C \, (\, N_R + j \, N_X \,) \, I_i \qquad (10)$$

The impedance Z_i reproduced by the simulator on its entering poles is determined:

$$Z_i = U_i \, / \, I_i = R_C \, (\, N_R + j \, N_X \,) \qquad (11)$$

As follows from (11), the reproduced impedance 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 (11) also follows (fig. 6) that the character of the reproduced impedance 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 follows from (11), the area of regulation of Z_i character in this case covers

all complex plane; i. e. Z_i can have the character of a different combination of the positive or negative resistance with the capacitive or inductive impedance components.
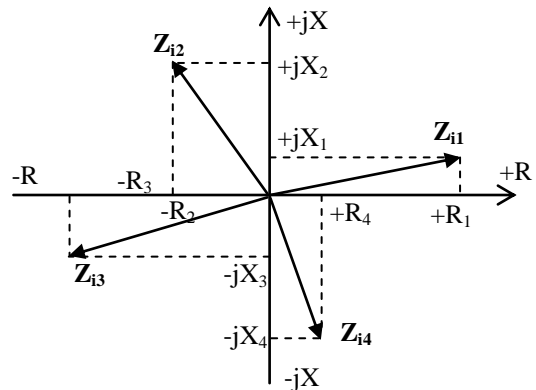

Fig. 6. The various character of the simulated impedance.

All units of I-MSI are implemented on the base of operational amplifiers and precision resistors [6]. In the phase shifter only one precisions capacitance are used, for digital command of the programmable amplifiers are used the DAC.

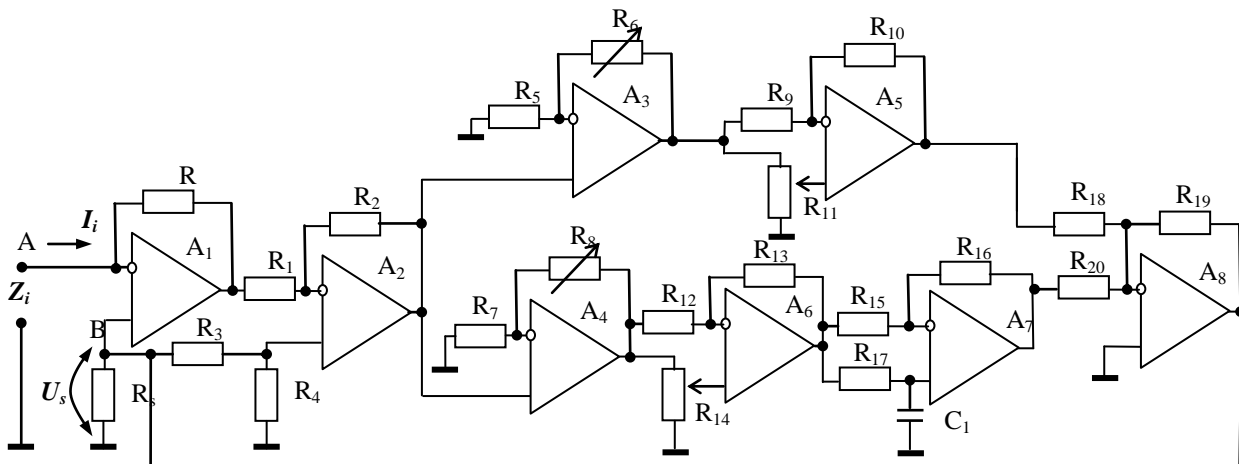On the fig. 7 is represented the practical implementation of the designed I-SIM.

Fig. 7. Practical implementation of I-MSI.

V. I-MSI MODELING IN THE MULTISIM PROGRAM

In the process of modelling the series resonant circuit in the Multisim program (fig. 8) it was used as a current generator a V1 tension generator with a high internal resistance $R_1 = 10$ MΩ. The measured impedance is modelled with the $R_2 = 1$ kΩ resistance and the $C_1 = 5$nF condenser and is connected in series with the V1 generator and the MIS-I [14].

The process of balancing consists of the two stages and it is represented in fig. 9. At B entrance of the oscilloscope it is applied the reference signal from the convertor exit (marked „o"), and at A entrance it is applied the imbalance signal (marked „x").

Initially it is modified the active component by adjusting R_{10} and R_{15} potentiometers until it is obtained a 180^0 dephasing between these signals (fig. 9, a), then at B entrance
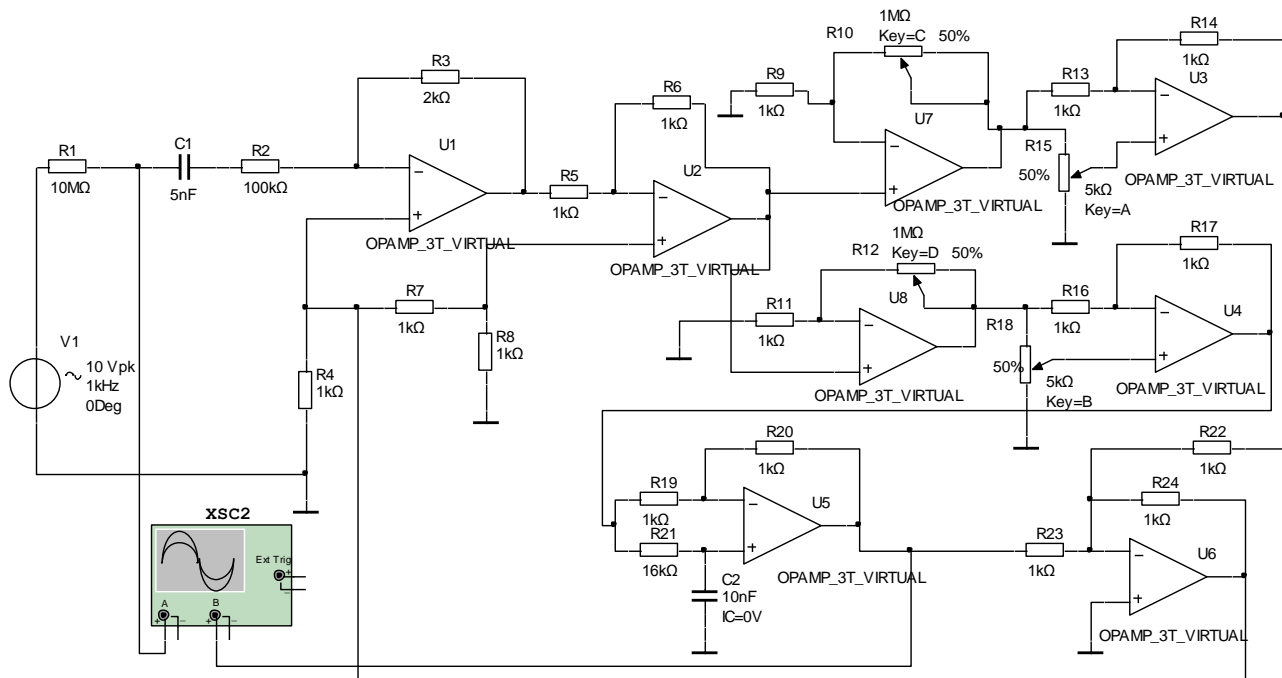
Fig. 8 Series resonant circuit modelled in Multisim.

it is applied the signal from V1 tension generator and it is modified the reactive component by means of R_{12} and R_{18} potentiometers till the imbalance signal reaches 0 value (fig. 9, b).

The active component of the reproduced impedance can be determined with the next relation [15]:

$$R_i = R_3 (R_{10} \cdot c / 100 + 1) [2 \cdot (100 - a) / 100 - 1], \quad (12)$$

where a and c – represent the variation percentage of R_{10} and R_{15} potentiometers. These measurement will have the values $a= 76\%$ and $c=10\%$ at the circuit balance after the active component. According to relation (12) it is obtained $R_i=-105,04$ kΩ.

The reactive component of the reproduced impedance is determined with the next relation:

$$X_i = R_3 (R_{12} \cdot d / 100 + 1) [2 \cdot (100 - b) / 100 - 1], \quad (13)$$

where b and d represent the variation percentage of R_{12} and R_{18} potentiometers.

These values will have the values $b=58\%$ and $d=10\%$ at the circuit complete balance.
According to relation (13) it is obtained $X_i= -32,32$ kΩ. The impedance reproduced by the simulator will have the next value:

$$\mathbf{Z}_i = R_i + jX_i = (-105,04 - j32,32) \text{ k}\Omega. \quad (14)$$

The impedance measured in accordance with C_1 and R_2 values represents:

$$\mathbf{Z}_M = R_2 + j / 2\pi f C_1 = (100 + j31,84) \text{ k}\Omega. \quad (15)$$

where f is the G generator signal frequency. Relations (14) and (15) entirely confirm the theoretical analysis [16].
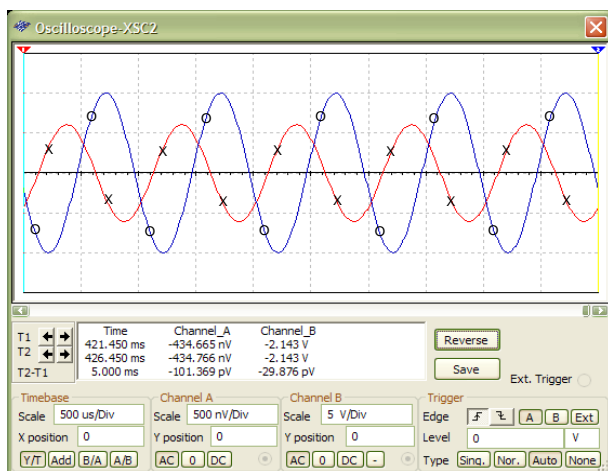
VI. METER OF IMPEDANCE

The meter of impedance is based on serial resonant measuring circuit [10], [11], containing an impedance simulator commanded in current as reference element [12].

The structure of meter of impedance is represented on the fig. 10. The meter of impedance 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 C_2 comparator 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 MSI 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 C_1 comparator 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 $\mathbf{Z_R}$ impedance reproduced by the MSI.

The measurement process takes place in two steps [13]. At the first step, 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, 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.
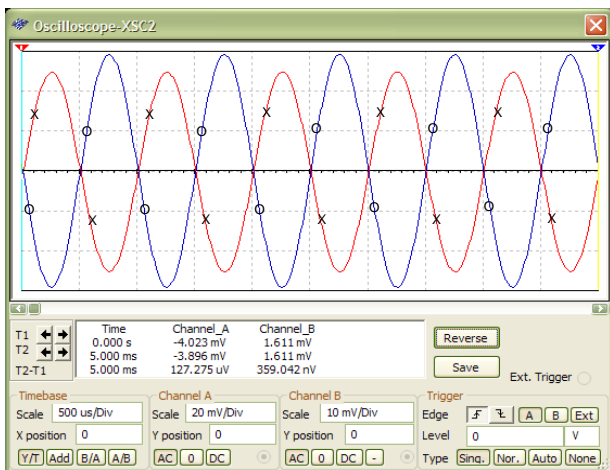
a

b

Fig. 9. Series resonant circuit balance modelled in Multisim a. Balance after the active component, b. Balance after the reactive component.
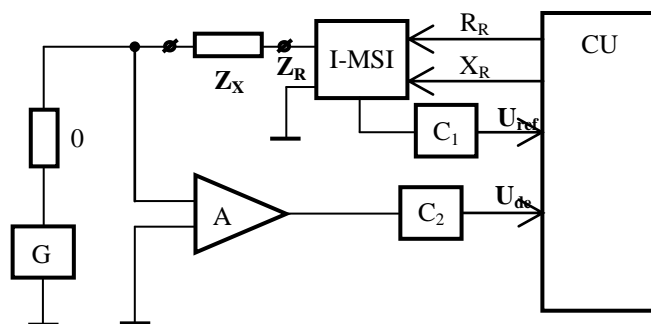

Fig. 10. The structure of meter of impedance.

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

VII. CONCLUSIONS

The impedance measurement using the simultaneous resonance method 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 components adjustment ensures a simple measurement algorithm for impedances of any nature. The balancing of the measurement circuit is completely automatic, which is due to the use of digital-analog converters and exclusion of adjustable reactive elements.

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