REFERENCE ELEMENTS BASED ON POLAR-COORDINATES IMPEDANCE SIMULATORS

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Abstract — The paper contains the analysis of two types of metrological polar - coordinate impedance simulators: with current control and with voltage control. The synthesis of impedance simulators circuits is considered, stability study is carried out and the conditions of their optimal application in resonance meters of impedance components are defined. The offered devices have a high exactitude and simplicity of practical realization and are suitable for application both in simple and cheap automatic impedance meters, and in meters of a high exactitude.

Index Terms — Impedance measurement, polar – coordinates impedance simulator, reference elements.

1. Introduction

Electrical impedance, or simply impedance, describes a measure of opposition to alternating current. Electrical impedance extends the concept of resistance to AC circuits, describing not only the relative amplitudes of the voltage and current, but also the relative phases.

Measurement of high precision components of admittance and impedance is performed by the balancing method implemented in the bridge measurement circuits, with compensation, or resonance. The accuracy of measurement by this method is determined primarily by the precision of reference element (ER), which, in measuring circuit, reproduce a standard size, consistent with measured size (measure).

ER determines the common characteristics of the measuring device, such as measuring algorithm, simplicity of use, cost price. Traditionally, as the ER in admittance and impedance measurement, is used resistors, capacitors, high-precision coils, which is characterized by its size and price cost considerable, discomfort in use. ER characteristics can be significant lift through the use of metrological simulators of electrical passive quantities, more widely known as "metrological impedance simulators"

2. Operating algorithm

The term "simulator of passive quantities" (SMP) will define the technical means to reproduce simulated quantities. It executes the function of the reference impedance (measure) and there are imposed to it a requirements bound with metrological support of measurements. Among them:
- Low error and high stability of reproduced impedances;
- Possibility of any character impedance reproduction
- Separate regulation of the impedance components;
- The known and warranted systematic error;
- Digital control of the character and values of impedance components.
- Exclusion of adjustable reactive elements.

By the quantities of entry the realization of two types of MSI is possible:
- The current controlled impedance simulator stable down to a no-load condition(I-MSI)(Fig. 1.a),
- The voltage controlled simulator stable down to a condition of short-circuit (U-MSI)(Fig. 1.b).

For MSI with current controlled of impedance, MPS is reproduce by forming a voltage U_i from input current I_i and its application in the input circuit .

For MSI with voltage controlled of impedance, MPS is form by current I_i interacting with the primary input voltage U_i.
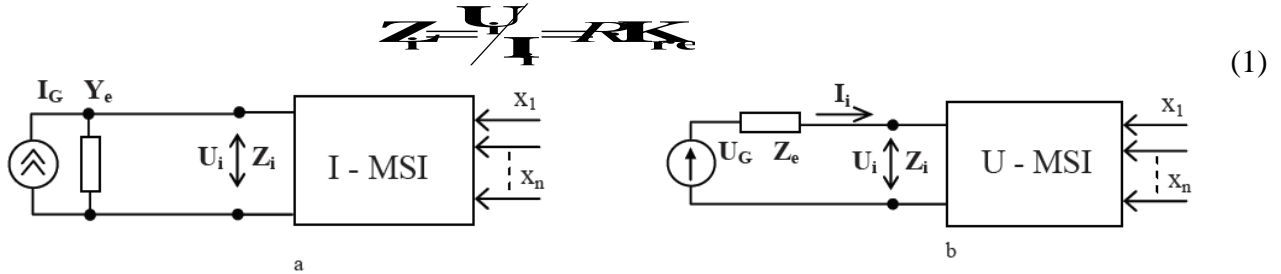
So we can determine for I-MSI

$$Z_i = U_i/I_i = R K_e$$

(1)

Fig. 1 The external connection of I-MSI (a) and U-MSI (b)

for U-MSI

$$Y_i = I_i/U_i = G K_e$$

(2)

U_i, I_i - Entry respective quantities; R, G - reference quantities; K_{regl} - coefficient which provides independent adjustment of components MPS .

2.1 The Current Controlled Impedance Simulator

The current - voltage converter with a null input resistance and with a conversion factor Z is applied for conversion of entering current I_i in voltage U_1.(Fig.2) Change of the module of voltage U_1 is executed by the programmable amplifier PA with a variable amplification factor K_m, and change of the phase of voltage U_2 - by programmable phase shifter PS. Voltage U_i, bee applied on input of the current - voltage converter results in simulation of an equivalent entering impedance Z_i .
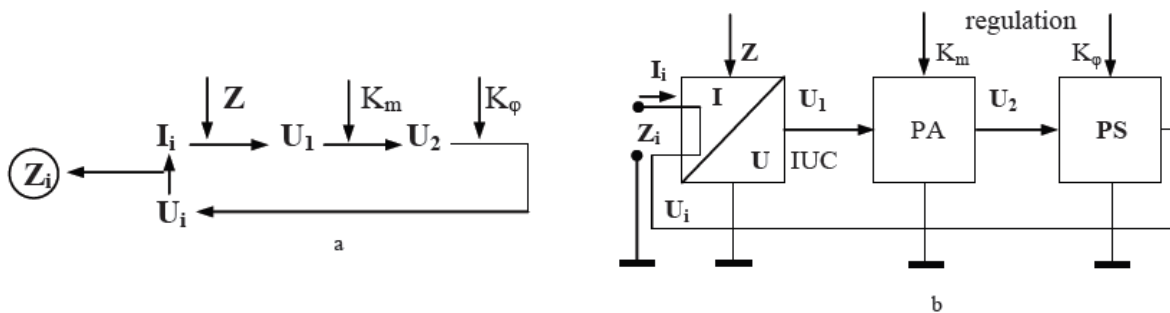

Fig. 2 The conversion algorithm(a) and the structure of I-MSI

On OA A1 an inverting current - voltage converter is realized, the voltage U_1 on which output is determined:

$$U_1 = U_i - R\, I_i$$

(3)

As the programmable amplifier PA ,an inverting amplifier, is applied, and as the programmable phaser PS. The voltages on their outputs are equal respectively:

$$U_2 = -U_1 R_2/R_1 = -(U_i - R\, I_i)\, R_2/R_1$$

(4)

$$U_i = U_2 \exp(j\varphi) = -(U_i - R\ I_i) \exp(j\varphi)\ R_2/R_1 \qquad (5)$$

where φ - the phase angle introduced by phaser .

Considering equality to zero of voltage between the inputs of OA in linear operation mode, the input impedance $\mathbf{Z_i}$ of the simulator can be determined:

$$Z_i = U_i / I_i = R\ K_m \exp(j\varphi) / [K_m \exp(j\varphi) - 1] = Z_i \exp(j\varphi_i) \qquad (6)$$

where: Z_i, φ_i – respectively, module and phase of impedance $\mathbf{Z_i}$,

$K_m = -R_2/R_1$.

2.2 The Voltage Controlled Impedance Simulator

Entering voltage U_i will be transformed to voltage U_1 under action of a regulated real transmission factor K_m, in the programmable amplifier (PA) on which output is :

$$U_1 = K_m\ U_i \qquad (7)$$

The programmable phaser PS will transform voltage $\mathbf{U_1}$ to voltage $\mathbf{U_2}$, entering the phase shift φ:

$$U_2 = U_1 \exp(j\varphi) \qquad (8)$$

The current - voltage converter with transfer conductance G will transform the voltage $\mathbf{U_2}$ to a current $\mathbf{I_i}$ flowing past through entering terminals of the simulator and exterior impedance attached to them:

$$I_i = GU_2 \qquad (9)$$

The simulated input impedance $\mathbf{Z_i}$ is determined:

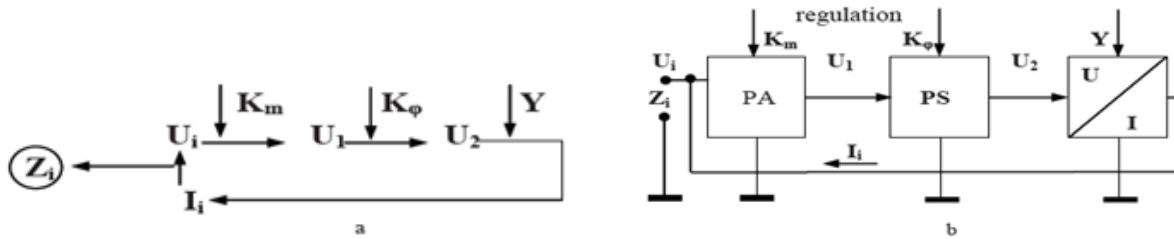$$Z_i = U_i / I_i = (K_m)^{-1}\ G^{-1} \exp(-j\varphi) \qquad (10)$$

Fig. 3 The conversion algorithm(a) and the structure of U-MSI

3. Stability of Impedance Simulators

The problem of MSI stability is rather important and requires a complex analysis. As in the MSI circuits there is a combined variable feedback, it is necessary to consider three types of stability: stability on a direct current, stability on high frequencies, functional stability.

For estimation of stability conditions, we shall take advantage of Nyquist criterion in application to the circuits containing operational amplifiers.

$$\mathrm{Re}\ (\beta A) > -1 \qquad (11)$$

where β – the feedback unit transmission factor, $\mathbf{A}$ – the basic unit transmission factor.

$$A = K_d K_m K_\varphi = K_m \exp(j\varphi) \tag{12}$$

where $K_d, K_m = 1$, $\beta = 1$.

The loop transfer function H_{24}:

$$H_{24} = U_o / U_i = A Z / Z_e = (Z / Z_e) K_m \exp(j\varphi) \tag{13}$$

Considering $\mathbf{Z} \equiv R$, $\Rightarrow$

$$Re (H_{24}) = (R K_m / |Z_e|) \cos(\varphi - \varphi_e) > -1 \tag{14}$$

For ensure the stability of the circuit in all range of simulated impedance phase variation $\varphi = 0 \div 360°$, we consider the most critical case when $\cos(\varphi - \varphi_e) = -1$, $\Rightarrow$ condition of stability:
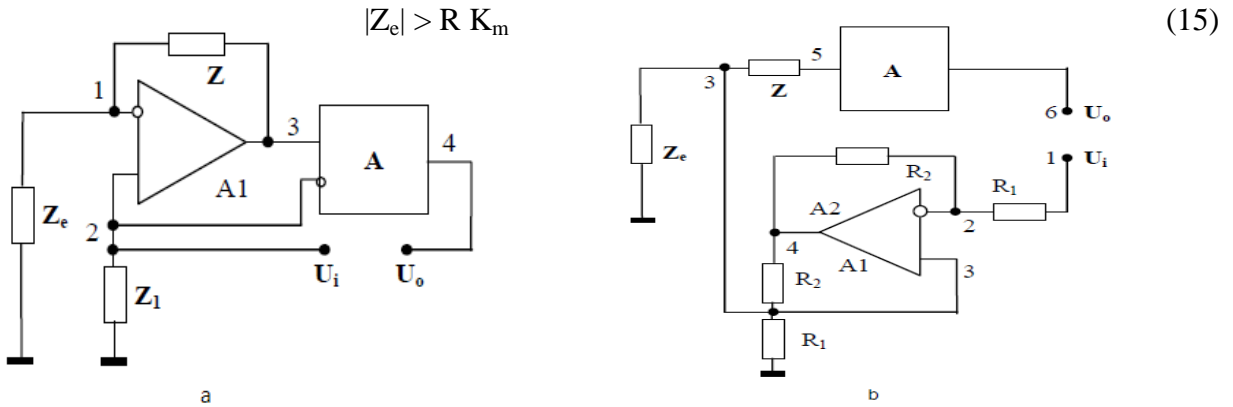
$$|Z_e| > R K_m \tag{15}$$

Fig.4 The model of I-MSI (a) and U-MSI (b) for stability analysis

As follows from above-stated, the offered circuit of I – MSI maintains stability at variations of regulating module parameter K_m and regulating phase parameter φ of simulated impedance in limits:

$K_m = 0 \div |Z_e| / R$
$\varphi = 0 - 360°$

For the voltage controlled impedance simulator (U - MSI) the condition of stability can be determined similarly.

$$Re (\beta A) = Re [- K_m \exp(j\varphi) Z_e / R_1)] = - (K_m |Z_e| / R_1) \cos(\varphi + \varphi_e) > -1 \tag{16}$$

$$\cos(\varphi + \varphi_e) = 1, \Rightarrow - K_m |Z_e| / R_1 > -1 \tag{17}$$

$$|Z_e| < R_1 / K_m \tag{18}$$

$K_m = 0 \div R_1 / |Z_e|$,

$\varphi = 0 \div 360°$

4. Conclusions

In polar - coordinate impedance meters with simulated resonance as reference element the polar - coordinate impedance simulators it is necessary to use.

The simulators have separate control of simulated impedance module and phase and ensure reproduction of any character impedance without use of variable reactive elements and without commutations in the circuit.

As follows from the stability analysis, current controlled impedance simulator save absolute stability in the series resonance circuit with signal supply from a current source, the voltage controlled - in the parallel circuit with signal supply from the voltage source.

MSI can be used in resonance meters of impedance components,like reference element in mesurements circuits of impedance,in radio devices.

5. References

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