Method for Body Impedance Measurement

R. Copîndean, R. Holonec, F. Dragan, and C. Muresan

Abstract

The paper proposes a method for body or bioelectrical impedance (BI) measurement based on voltage measurement and analysis at different frequencies with a four-electrodes configuration and the principles of virtual instrumentation. The measured values are used to calculate: the effective (root mean square) values of voltages and currents, the apparent power, the active power, the phase shift, the resistance and the electrical capacity of the body. For the experiment, an NI PCI-6110 data acquisition board and the LabVIEW programming environment from National Instruments were used.

Keywords

Biolectrical impedance • Series/parallel resistance • Series/parallel capacity • Data acquisition • Virtual instrumentation • LabVIEW

1 Introduction

When the human body is coupled to a voltage supply, its electrical resistance is an important factor in determining the amount of the current flowing through it.

The magnitude of the bioelectrical resistance is essentially determined by the structure of the tissues on where the electric current flows. Other factors that influence the value of human body resistance are [1–3]:

- the value of applied voltage;
- duration of the current going through the tissues;
- temperature;
- the place of touch;
- surface and contact pressure;
- humidity;
- mental condition etc.

The resistance of the human body has a nonlinear behavior and it decreases considerably as the electric current flows, which determines the increase of damage caused by the electrocution. Because there are diverse human body tissue structures, there are different resistances and consequently different values for measured current. Considering these aspects, it's very difficult to reproduce an equivalent electrical circuit of the human body. Thus, by simplification, the resistance of the human body is believed to have two components: skin resistance and the resistance of the internal tissues. The resistance of the skin has the largest weight in the total of the human body resistance. The electrical resistance of the skin can be expressed by R_{skin} as:

$$R_{skin} = \frac{\rho \cdot d}{S}. \tag{1}$$

In relation (1) "ρ" is the electrical resistance of the skin that corresponds to the contact surface; "d" is the thickness of the skin and "S" is the contact surface area.

The electrical resistance of the skin R_{skin} also depends on body part that is touching the voltage supply. All these elements are to be considered to determine the dielectric strength of the protective electro-insulating equipment. The values ρ and d can be extremely different, not only for different people but also for the same person and they may vary widely in relation with the contact point.

The impedance of the human body, which is considered a non-homogeneous electric conductor, is called the bioelectrical impedance (Z) and it represents a combination of the electrical resistance R and capacitive reactance $1/\omega C$, in the form of [4]:

$$Z = \sqrt{R^2 + \frac{1}{\omega^2 \cdot C^2}}. \tag{2}$$

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In relation (2), C represents the total electrical capacity of the human body. It consists of an electrostatic capacity that occurs due to the voltage applied on the outer skin surface and a polarization capacity due to the phenomenon of polarization when the electrical current passes through the human body. In practical applications the influence of the electrical capacity is neglected, so that, finally, the biological impedance is considered as an equivalent electrical resistance.

In connection to the greater or lesser predisposition to electrocution, it has been tried the characterization of the electrical properties of the human body by the so-called "impedance angle". Thus, considering the impedance of the human body as being formed by its resistance and capacitive reactance, the value of the impedance angle, denoted by δ, can be determined as in Fig. 1.

In the specialized literature, results are given related to the complementary angle and the tangent of this angle:

$$\tan \varphi = \frac{1}{R\omega C}. \tag{3}$$

The impedance as a complex size [5, 6] can be determined under:

- Cartesian form, as:

$$Z = R + jX. \tag{4}$$

where R, the resistance, is the real part and X, the reactance, the imaginary part.

- Polar form, as:

$$Z = |Z|e^{j\varphi} = |Z|(\cos\varphi + j\sin\varphi). \tag{5}$$

In (5), the impedance module and phase shift are expressed through the next relations:

$$|Z| = \sqrt{R^2 + X^2} \tag{6}$$

$$\varphi = \arctan\frac{X}{R}. \tag{7}$$

The nature of the impedance of the human body is given by the sign of the imaginary component:

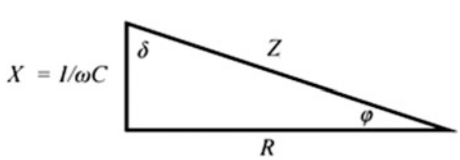

Fig. 1 The triangle of the human body impedance [4]

- X > 0 inductive nature,
- X < 0 capacitive nature,
- X = 0 resistive nature.

In this paper, the capacitive nature of the skin, and the capacitive reactance X_C are discussed:

$$X_C = \frac{1}{\omega C}. \tag{8}$$

Circuit parameters for the impedance are defined by models of associated electric circuits. Equivalent series circuits or parallel circuits are used as simplified models to represent the impedance in most of the situations. These simplifications, where the parasite circuit elements are neglected, can be made by respecting some severe measurement conditions.

Classical series and parallel circuit models for the human body impedance comprise resistance and capacity connected as in Fig. 2.

In case of the series circuit, Z is preferred to be represented as:

$$Z = R_s + jX_s. \tag{9}$$

In case of the parallel circuit, Y being the admittance, is preferred to be represented as:

$$Y = \frac{1}{z} = G + jB. \tag{10}$$

In (10), the conductance and susceptibility are determined as:

$$G = \frac{1}{R_P} \tag{11}$$

$$B = \frac{1}{X_P}. \tag{12}$$

Both models (series and parallel) describe the susceptibility B and the impedance Z as

$$B = \frac{1}{R_P} + j\frac{1}{X_P} = \frac{1}{R_S + jX_S} = \frac{1}{Z}. \tag{13}$$

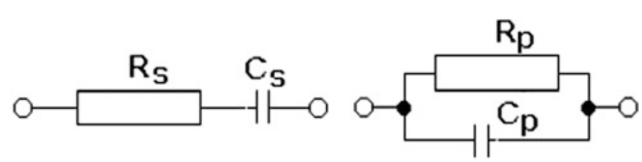

Fig. 2 Series and parallel circuit models for the equivalent impedance of the human body

Thus, the equivalence relations are obtained:

$$R_P = \frac{R_S^2 + X_S^2}{R_s} \quad (14)$$

$$X_P = \frac{R_S^2 + X_S^2}{X_s}. \quad (15)$$

In conclusion, by knowing the elements of a series/parallel model of the human body, the elements of the other parallel/series model can be determined.

2 The Principle of the Method

In Fig. 3, the four-electrode bioelectrical impedance measurement configuration is represented. Here the voltage measuring circuit is separated from the current injection circuit.

The effective value of the voltage with a high impedance $Z_{voltmeter} > 10\ M\Omega$ can be measured. Because the current delivered through voltage measuring circuit is considerably smaller than the one delivered by the sinusoidal signal generator I = 1 ÷ 100 μA, the measured voltage will be not affected by the resistance of the electrodes which is smaller than the voltmeter impedance.

The value, in module, of the impedance is:

$$|Z| = \frac{V_{RMS}}{I_{RMS}}. \quad (16)$$

If the measurements are realized by a data acquisition system then the samples of the voltage v_k and the current i_k, taken over several periods of the signal provided by the generator, can be calculated [7, 8] as:

$$V_{RMS} = \sqrt{\frac{1}{n}\sum\nolimits_{k=1}^{n} (v_k)^2} \quad (17)$$

$$I_{RMS} = \sqrt{\frac{1}{n}\sum\nolimits_{k=1}^{n} (i_k)^2}. \quad (18)$$

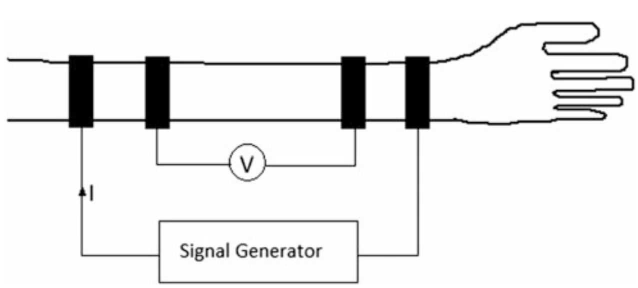

Fig. 3 The principle of impedance measurement and electrodes placing

It is possible to obtain the active power P, the apparent power S and the cosφ power factor according to the relations:

$$P = \sqrt{\frac{1}{n}\sum\nolimits_{k=1}^{n} u_k * i_k} \quad (19)$$

$$S = V_{RMS} * I_{RMs} \quad (20)$$

$$cos\varphi = \frac{P}{S}. \quad (21)$$

For the series circuit model of the impedance, from the Eqs. (5), (9), (16), (21), the series resistance is obtained:

$$R_S = |Z|\cos\varphi = \frac{V_{RMS}}{I_{RMS}} \cdot \frac{P}{S} = \frac{P}{I_{RMS}^2} = \frac{\sqrt{\frac{1}{n}\sum_{k=1}^{n} u_k * i_k}}{\frac{1}{n}\sum_{k=1}^{n} (i_k)^2}. \quad (22)$$

The series reactance X_S will be:

$$X_S = |Z|\sin\varphi = \frac{V_{RMS}}{I_{RMS}}\sqrt{1 - \left(\frac{P}{S}\right)^2} = \frac{1}{2\pi f C_S}. \quad (23)$$

In relation (23) f represents the signal generators frequency.

The series capacitance will be:

$$C_S = \frac{1}{2\pi f \frac{V_{RMS}}{I_{RMS}} \sqrt{1 - \left(\frac{P}{S}\right)^2}}. \quad (24)$$

3 Experimental Implementation

3.1 Hardware

The measurement method is implemented by using the hardware configuration illustrated in Fig. 4 where the bioelectric impedance *Z* is connected to the data acquisition (DAQ) unit using a four electrodes configuration.

The practical application was realized with the help of the following components:

- NI PCI-6110 data acquisition board (National Instruments) [9], where an analog output AO0 was used to generate the signal and two analog differential inputs AI1, AI2, for the reading of the voltage and the current;
- 1 kΩ resistance for the conversion of voltage to current;
- Body impedance (represented by the analyzed subject);
- Conductive textile tape electrodes.

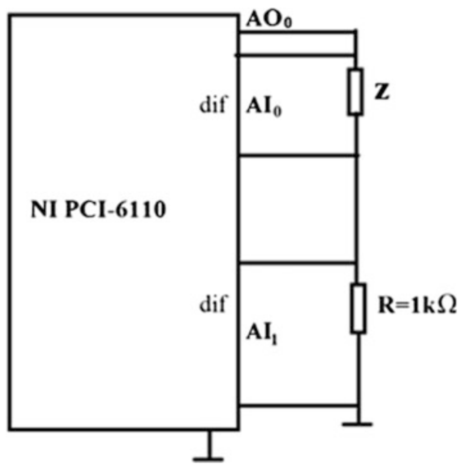

Fig. 4 Scheme for the impedance connections to the DAQ board

3.2 Software

For the application control and also for data processing, LabVIEW graphical programming software from National Instruments [10] was used. The algorithm (Fig. 5) uses the function called Signal-Sine for the signals generation and sends the signals to the analog output AO0.

Two differential analog inputs, AI0 and AI1, where used to read the voltage and electrical current. The voltage on the body impedance is read directly. The voltage dropping on the resistance will be divided by 1000 in order to obtain the value of the electrical current. Therefore, the current will have low values (μA) reaching maximum 1 mA.

The effective value of the voltage and electrical current will be calculated. There is also calculated the value of the instantaneous power which, mediated, will give the value of the active power P. The apparent power S is computed by multiplying the effective voltage with the effective current.

The voltage-to-current phase shift is calculated by dividing the active power to apparent power, and finally the values of cosφ and sinφ are obtained. Having both values, cosφ and sinφ, and multiplying them with the Z impedance module, the real and the imaginary parts are obtained.

3.3 Experimental Data

In order to validate the proposed method, measurements were made on a set of resistors and capacitors connected in series and then in parallel.

Measurements were made on the same subject, with four and two electrodes. Results can be observed in Table 1.

In the case of the four-wire measurements, the voltage measuring electrodes were placed at 9 cm one to another. The current electrodes were placed as in Fig. 3, the with a distance of 15 cm between them.

For the case of the two-wire measurements, only the voltage electrodes were used, he current electrodes where attached to them.

It can be observed that in the case of two-wires measurements, at the same frequency, the resistance values are higher than in the case of four-wires measurements.

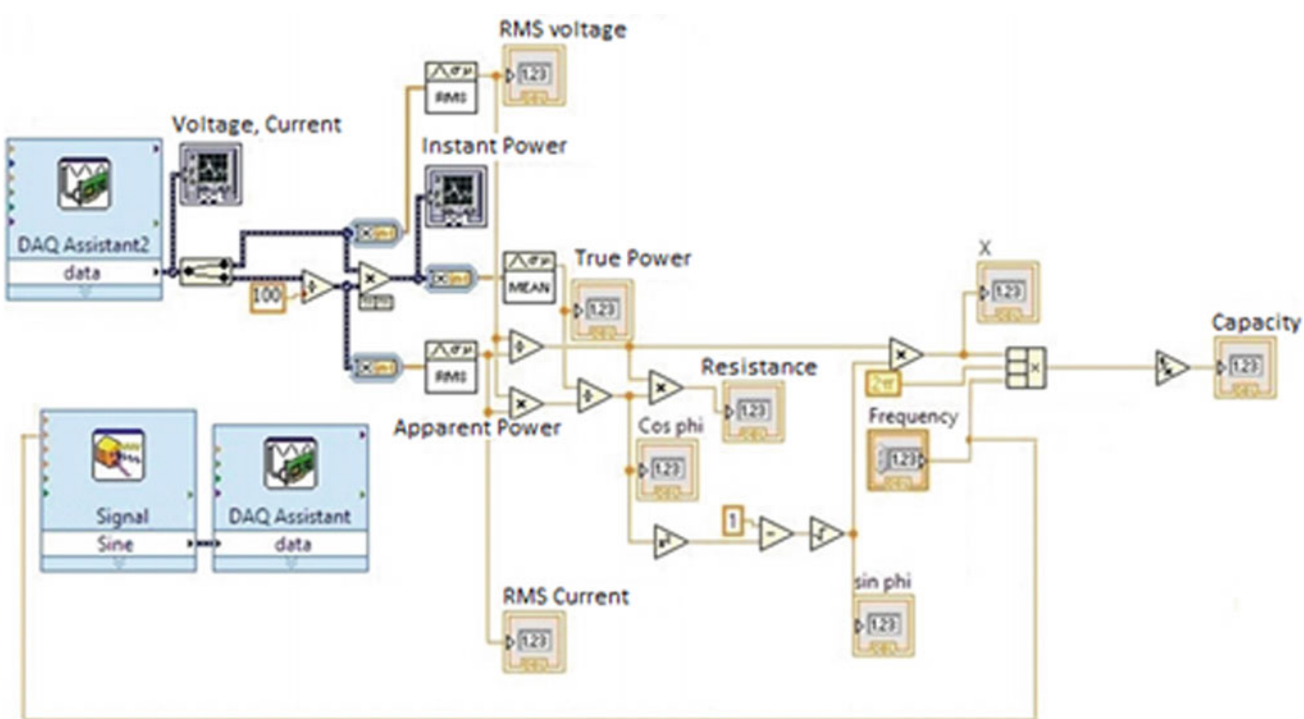

Fig. 5 Block diagram of the application

Table 1 Measurements performed on a subject with four and two electrodes

Electrode numbers	Frequency (Hz)	R_S (KΩ)	C_S (nF)	R_P (kΩ)	C_P (nF)
4 wire	100	46	24	130	16
	1000	6	9	47	9
2 wire	100	58	24	135	12
	1000	7	10	50	8

4 Conclusions

In Fig. 3, a four-wires impedance measurement method was proposed in order to eliminate the influence of the contact electrode resistance.

Impedance measurement gives information about the resistance and capacity of a human body. Using clinical tests, one can determine what information are significant regarding the measured capacity.

The LabVIEW programming environment offers many features that greatly facilitate numerical processing. The equations presented in the paper can be implemented on a microcontroller, and in consequence portable and low cost devices can be developed.

Conflict of Interest The authors declare that they have no conflict of interest.

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