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Comparative Tests of Electric Voltage and Resistance with the Use of Virtual Measurement Systems

Michał Macek[1], Paweł Kuźma[1], Wojciech Żyłka[2], Marta Żyłka[3*], Marcin Biskup[1]

[1] Graduated from the University of Rzeszow, Aleja Tadeusza Rejtana 16C, 35-310 Rzeszów, Poland
[2] College of Natural Sciences, University of Rzeszow, Pigonia 1, 35-310 Rzeszów, Poland
[3] The Faculty of Mechanical Engineering and Aeronautics, Department of Aerospace Engineering, Rzeszów University of Technology, Aleja Powstańców Warszawy 12, 35-959 Rzeszów, Poland
* Corresponding author's e-mail: mzylka@ur.edu.pl

ABSTRACT
The article discusses issues related to virtual measurement systems and presents the results of comparative measurements of resistance and electric voltage measured with various measuring devices, including virtual NI Elvis systems. The accuracy and measurement errors were compared, as well as the advantages and disadvantages of the devices and methods used for the measurements. Moreover, a computer simulation of the measurements in the Multisim software was performed, and its results were compared with the actual indications of the meters.

Keywords: virtual measurement systems, NI Elvis system, digital measurement methods, LabVIEW

INTRODUCTION

The constant development of technology in various industries (medical, electronic, chemical, etc.) [1, 2]. forces the complete replacement of "old" technologies with new solutions, often by improving known technical solutions. Improving the applied solutions instead of replacing them completely allows for a significant increase in efficiency and quality improvement while keeping the costs of introduced changes low [3]. Classic measurements in electrical metrology are performed with the use of multimeters and analog or digital devices (in newer solutions). There is a trend in the world to switch to digital measurement methods [4]. For over a dozen years dedicated measurement cards and PCs have been used to perform metrological measurements [5, 6], Many activities and production processes are automated to eliminate monotonous human activities or to save time and money [7, 3].

By automating a given process (or activity), the user gains more control over it, speeds up the measurements, allows for saving current data to a file and for further processing and analysis of the results. Thanks to the appropriate interpretation of variables – by a dedicated algorithm included in the program, the user can be informed (e.g. by means of visual controls) about the failure states of the device and any errors that may occur in it. The purpose of this study was to establish the permissible ranges, accuracy and errors of measurements, and to present the advantages and disadvantages of measuring devices and methods used in modern electronics.

MEASUREMENT METHODS

Direct method

The direct method is one in which the value of the measured quantity is obtained directly, i.e. without the need to perform additional calculations. It is a method most frequently used in measurements, because it is fastest and simplest, and its accuracy is completely sufficient in everyday use. Currently, such measuring devices are used, in which the measurement consists only in reading the obtained results directly from the display screen on the measuring instrument [8-10].

Indirect method

Indirect measurement is the direct measurement of quantities other than the one you want to obtain, but are obtained as a result of calculations or transformations. This method is often referred to as the technical method. For example, for measuring resistance, two instruments should be used: an ammeter and a voltmeter. In an ideal voltmeter, the resistance value should be infinitely large, and in an ideal ammeter, it should equal 0. Due to the fact that measuring devices have a finite internal resistance that falsifies the measurement result, the ammeter can be connected in two ways, either behind or in front of the voltmeter, the so-called measurement with the method of correctly measured current and correctly measured voltage [8, 9, 11].

An example of an indirect method

A conventional system for measuring the internal resistance of a voltage source (indirect method) is based on the use of two multimeters measuring the current and voltage and a manual mechanical switch (Fig. 1). The test consists in connecting the actual system, measuring electrical quantities (measuring the voltage with the switch open, and then measuring the current intensity with the closed switch) and calculating the value of the internal resistance of the voltage source.

The presented measurement method is time-consuming with a large number of measurements for different voltage sources. The same measurement can be performed using the presented automated measuring stand. Automation of the stand was achieved by connecting the NI ELVIS II* module to a PC into an appropriately modified conventional measurement system (Fig. 2).

In the described measurement system, the hardware part of measurement data acquisition is performed on the National Instruments NI ELVIS II* laboratory module [12, 13].

NI ELVIS II. It is characterized by a compact housing integrated with 12 of the most commonly used laboratory instruments; including oscilloscope, digital multimeter, function generator, regulated DC power supply. The whole is connected to a PC via a USB cable. On the module one can efficiently connect and run various prototype electronic circuits, and the presence of a contact plate eliminates the need to solder discrete and integrated elements [3]. In place of "removed multimeters" (for the purposes of connection to the ELVIS set) specially prepared adapters/signal connectors have been added. These are appropriately marked small plastic enclosures with banana plugs installed in them. The modules have been marked accordingly, as: "*V*" (Volt voltage measurement), "*A*" (*A* current measurement), BAT (battery connection) [14].

The role of the mechanical switch was taken over by the relay electronic circuit built on the board included in the NI ELVIS II* set. The actual test stand is presented in Figure 3.

The measurement control program was prepared in the LabVIEW environment of the National Instruments company (G language) [15, 16] (Fig. 4). The prepared program measures the *U*1, *U*2 voltage and the current intensity I. After this operation, the obtained results are immediately displayed on virtual meters: voltmeters and a single ammeter. After taking the measurements, the program automatically calculates the resistance value of the voltage source and the load resistance. The program displays the results of the calculations with the value of the voltages *U*1, *U*2

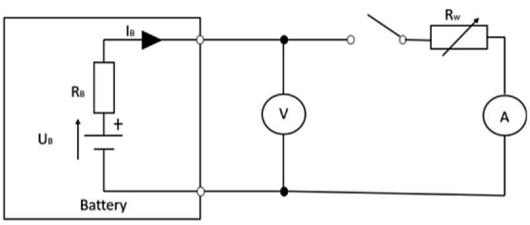

Fig. 1. Diagram of a conventional system for measuring the internal resistance of a voltage source [3]

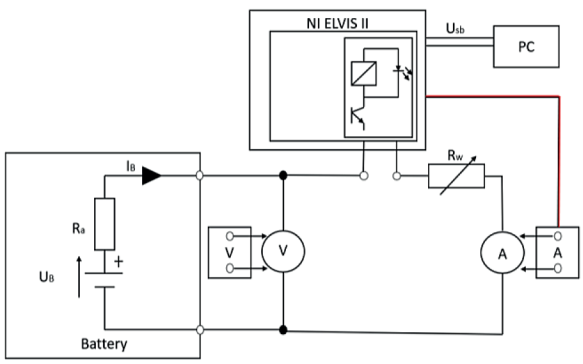

Fig. 2. Diagram of an automated system for measuring the internal resistance of a voltage source [3]

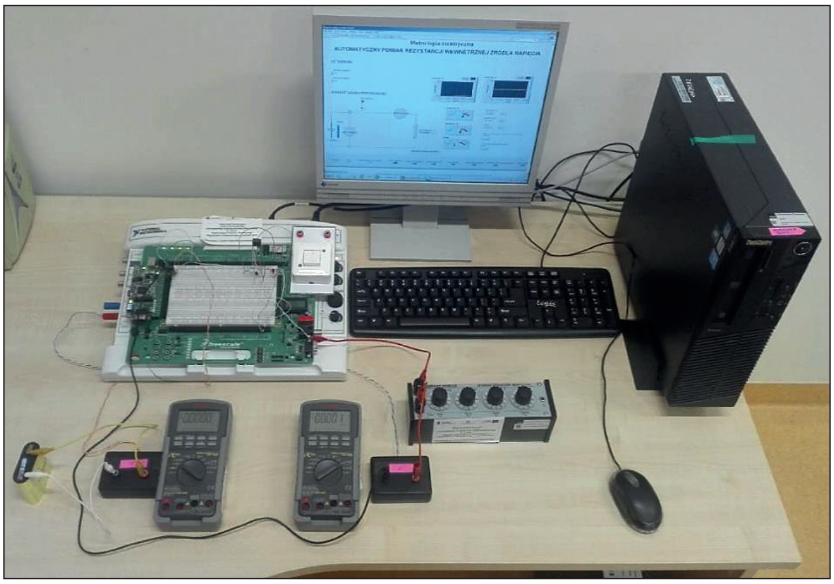

Fig. 3. Automated stand for measuring the internal resistance of the current source [3]

and the current *I* in appropriately labeled visual indicators (Fig. 5). Additionally, the program interface is equipped with the "Waveform Chart" windows displaying the *U*1 and *U*2 voltage values

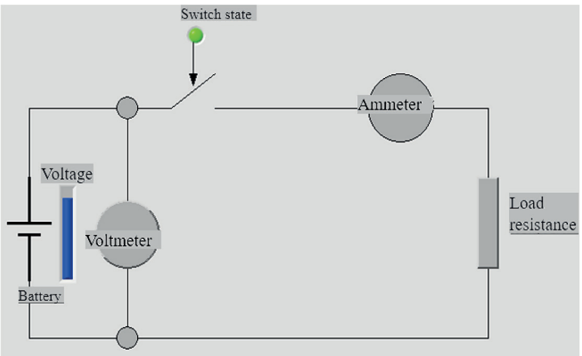

Fig. 4. Diagram of the resistance measurement system after activating the switch [3]

during the course the measurement (in the form of a *U*[V]/*t*[s] graph) [3].

By replacing the traditional measurement with a virtual measuring instrument, it is possible to quickly compare and demonstrate changes in measurement results for various measured elements of the same type (voltage source resistance for several batteries or resistance for several values, etc.) [3].

COMPARATIVE STUDIES OF RESISTANCE

The results of resistance measurements measured with selected measuring devices were compared, i.e. digital multimeters, analog meters, NI Elvis system, milliohmmeter, whereas simulations of resistance measurements were carried out

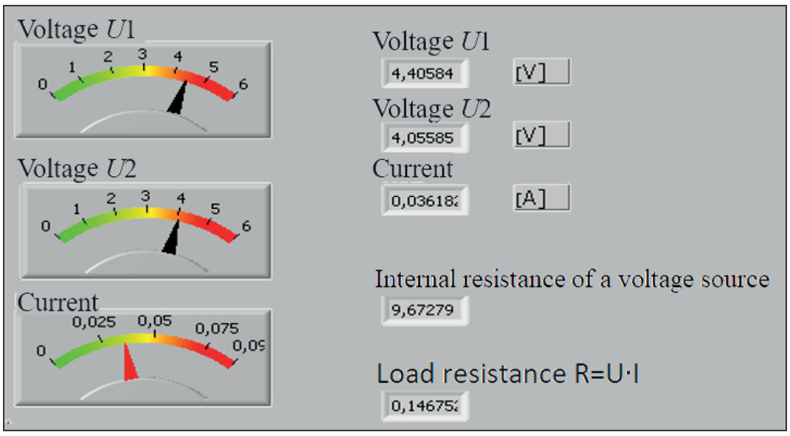

Fig. 5. Measurement results [3]

using the Multisim application. Analogous tests were performed for the measurements of the electric voltage source. Measurement errors were calculated according to the formulas for each device and measurement method. The absolute measurement error was calculated for each of the measuring devices using the following formula (1):

$$\Delta = |X - Xp| \quad (1)$$

where: X – actual quantity,
Xp – measured value.

Then, using the formula (2), the relative measurement error was calculated:

$$\delta = \frac{\Delta}{X} \cdot 100\% \quad (2)$$

The absolute errors of the meters were calculated using the formulas (3–4). For a digital meter and a milliohmmeter acc. to formula (3):

$$X = a\%x_{reading} + n\,dgt \quad (3)$$

For analog meters acc. to formula (4):

$$\Delta X = \frac{class \cdot range}{100} \quad (4)$$

For NI Elvis acc. to formula (5):

$$\Delta X = ppm\ of\ reading + ppm\ of\ range \quad (5)$$

where: *ppm* stands for 'parts per milion'.

The research began with the direct method of measuring the resistance. Resistance standards were measured with the values: 0.01 Ω, 0.1 Ω, 1 Ω, 1,000 Ω, 10,000 Ω. Table 1 shows the obtained relative errors in the measurements of the resistance using the above-mentioned instruments.

Analyzing data from Figure 6, it can be noticed that in the direct method the largest measurement error, up to 900%, occurred at very low resistances of 0.01 Ω and 0.1 Ω for analog meters. However, with higher values, above 100 Ω, the error was practically imperceptible. Computer

Table 1. List of reference resistance measurements using the direct method

Standard resistor, Ω	Description	Resistance, Ω	Mistake			Result, Ω
			Absolute, Ω	Relative, %	Gauge, Ω	
0.01	Digital meter	0.089	0.079	790	0.06	0.089 ± 0.06
	Analog meter	0.1	0.09	900	0.25	0.1 ± 0.3
	Multisim simulation	0.01	0	0	0	0.01 ± 0
	NI Elvis platform	0.082	0.072	720	0.031	0.082 ± 0.031
	Milliohm meter	0.01	0	0	0.004	0.010 ± 0.004
0.1	Digital meter	0.175	0.075	75.00	0.060	0.175 ± 0.06
	Analog meter	0.19	0.094	94.00	0.25	0.19 ± 0.25
	Multisim simulation	0.1	0	0	0	0.1 ± 0
	NI Elvis platform	0.137	0.037	37.00	0.031	0.137 ± 0.031
	Milliohm meter	0.1	0	0	0.004	0.10 ± 0.04
1	Digital meter	1.124	0.124	12.40	0.062	1.124 ± 0.062
	Analog meter	1.2	0.2	20.00	0.25	1.2 ± 0.3
	Multisim simulation	1	0	0	0	1 ± 0
	NI Elvis platform	1.052	0.052	5.20	0.031	1.052 ± 0.031
	Milliohm meter	1	0	0	0.006	1.158 ± 0.006
100	Digital meter	100.03	0.029	0.03	0.260	100.03 ± 0.26
	Analog meter	102	2	2.00	2.50	102.0 ± 2.5
	Multisim simulation	100	0	0	0	100 ± 0
	NI Elvis platform	100.044	0.044	0.04	0.076	100.044 ± 0.076
	Milliohm meter	100	0	0	0.600	100.00 ± 0.6
1,000	Digital meter	999.714	0.286	0.03	2.599	999.7 ± 2.6
	Analog meter	1000	0	0.00	25.00	1000 ± 25
	Multisim simulation	1000	0	0	0	1000 ± 0
	NI Elvis platform	999.758	0.242	0.02	0.550	999.76 ± 0.55
	Milliohm meter	1000	0	0	2.004	1000.0 ± 2.1
10,000	Digital meter	9999.094	0.906	0.01	25.998	9999 ± 26
	Analog meter	10010	10	0.10	250.00	10000 ± 250
	Multisim simulation	10000	0	0	0	10000 ± 0
	NI Elvis platform	10000.674	0.674	0.01	5.500	1000.7 ± 5.5
	Milliohm meter	10010	10	0.1	20.060	10010 ± 21

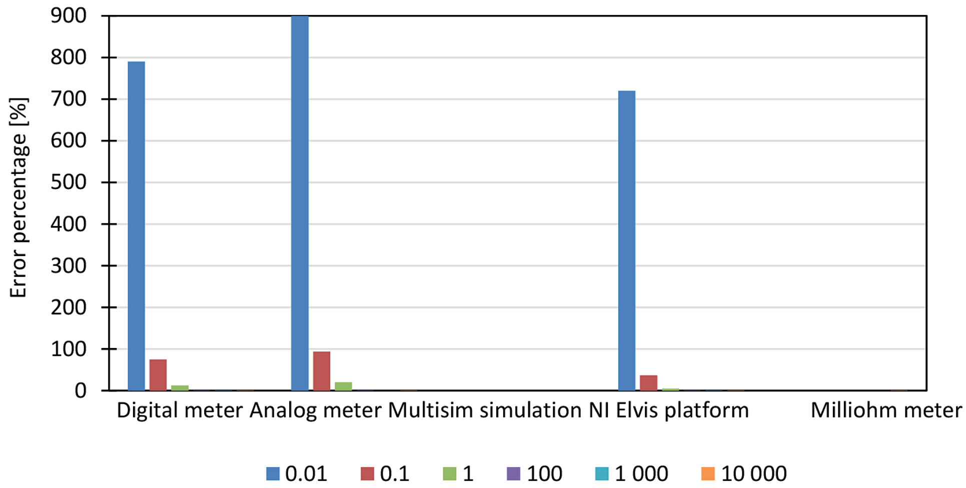

Fig. 6. Relative errors of resistance measurement for the direct method

simulation in the Multisim software, based on a mathematical algorithm, is a virtual measurement pattern without errors. Hence, for each of the tested resistances, an error equal to 0 was obtained.

An extremely accurate device turned out to be a milliohmmeter based on the Kelvin bridge. For the measured resistances, the relative error did not exceed 0.1%. The NI Elvis circuit appeared to be more precise than the analog meters. The measurement with the NI Elvis system required writing a program in the LabVIEW application (Fig. 7).

Automatic resistance measurement only required connecting a resistor and clicking the "run" button in the application; the finished results were obtained in a spreadsheet. The measurement itself took place in a very short time compared to other instruments. The choice of the used ohmmeter has a great influence on the final result of the resistance measurement. Figure 8 shows the instrument errors depending on the measuring range.

Subsequently, an indirect method was used to measure the resistance. The measuring system was prepared for measurement with the method of correctly measured current and voltage. Measurements were carried out with the use of the following devices: digital multimeters, analog meters, NI Elvis system, and simulations of measurements were performed in the Multisim software. Figure 9 shows the relative errors of measurements for individual meters.

The greatest measurement errors occur at low resistances. This is due to the inaccuracy of the meters used and the resistance of the wires and terminals, which have a significant effect at low resistance values. A distinctive error in both methods occurred using NI Elvis system. The reason for this is a single measuring range of the ammeter. At low current flows (while measuring the resistance of 10,000 Ω), the NI Elvis system is seriously flawed. In addition, the system was unable to measure two values simultaneously:

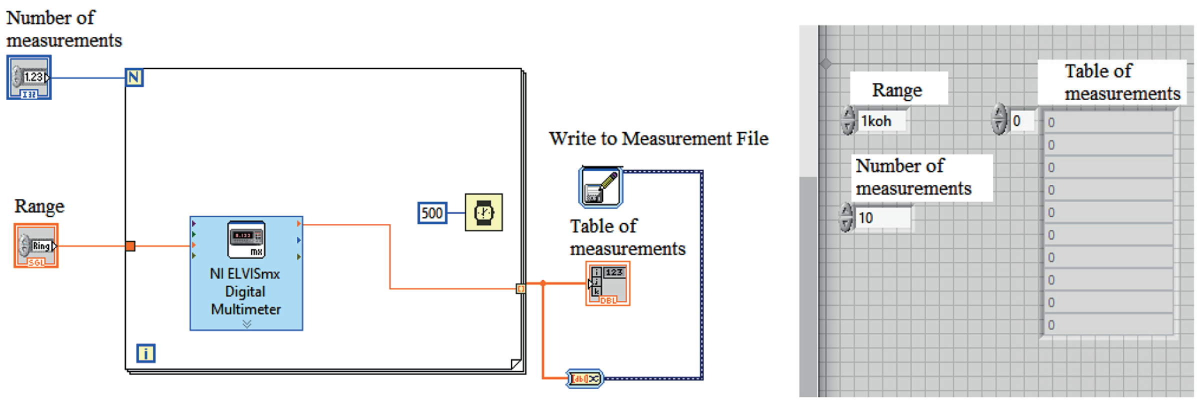

Fig. 7. Scheme of the program for measuring resistance using the direct method in LabVIEW

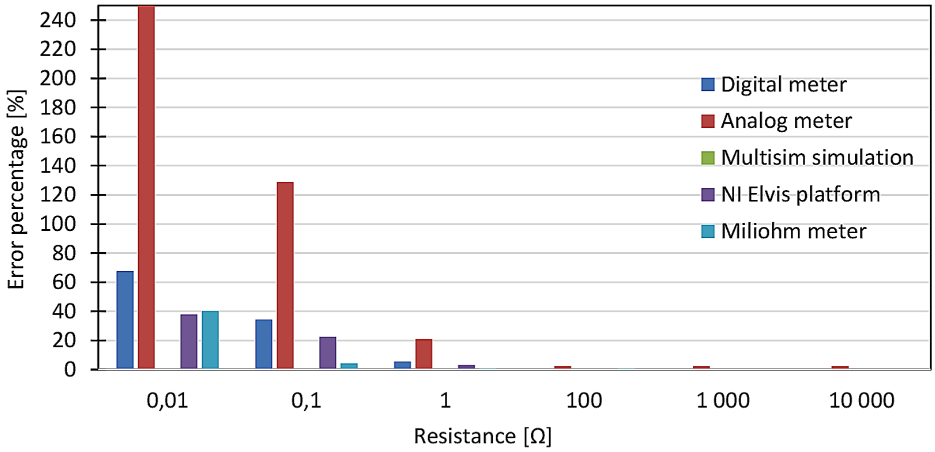

Fig. 8. Errors of ohmmeters in direct resistance measurements

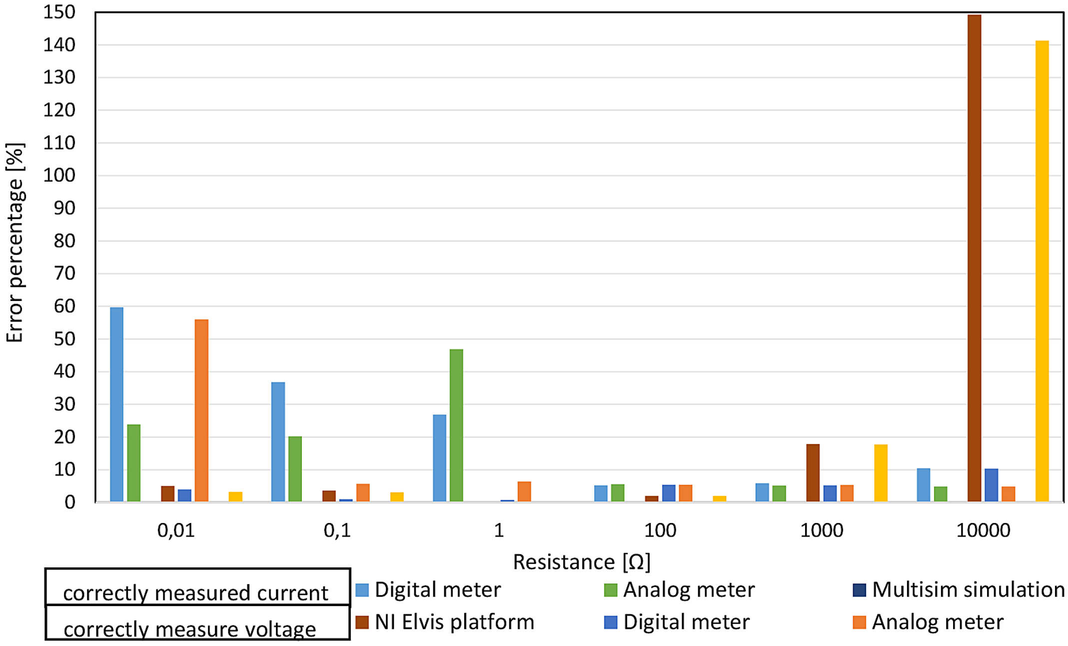

Fig. 9. Relative errors of resistance measurements using the technical method for selected meters

voltage and current. This necessitated the use of two platforms and increased the time taken to perform the measurements as the automatic measurement program could not be used. Nevertheless, an additional function of the NI Elvis system to measure the NI Elvis Two-Wire Current-Voltage Analyzer current-voltage characteristic was tested. In the case of resistance, where this dependence is proportional, the function did not work well because the results were very different from the actual value.

COMPARATIVE TESTS OF ELECTRIC VOLTAGE

A laboratory power supply, model APS3005S, was used to test the DC voltage. Then, the read voltage values were compared with various meters: analog, digital, NI Elvis system and simulation in Multisim software. The tests were performed for four nominal voltage values of: 1.5 V, 2.5 V, 5 V and 7 V. The measured DC voltage measurement values and the calculated errors were recorded in the measurement table.

From the obtained results presented in Table 2, it can be seen that in the case of the NI Multisim simulation program, the obtained results of the direct current value are equal to the value of the generated voltage. NI Multisim is only a measurement simulation, an equivalent of a virtual reference method based on a mathematical algorithm based on physical formulas.

Table 2. Measurement of direct current voltage for selected measuring instruments

DC meter	Meter Analog class of accuracy 2.0	Meter Analog class of accuracy 0.5	Digital Multimeter	Simulation Ni Multisim	LabView – Ni Elvis
Measurement of DC voltage with a 1.5 [V] generator power source					
Averae:e value *U*	1.546	1.550	1.583	1.500	1.5682
Relative error of measurement δ*U*	0.03	0.033	0.06	0	0.05
Absolute error of measurement	0.046	0.05	0.083	0	0.07
Measurement error of the device	0.07	0.03	0.011	0	0.0008
Measurement of DC voltage with a 2.5 [V] generator power source					
Average value *U*	2.531	2.499	2.563	2.500	2.563
Relative error of measurement δ*U*	0.01	0.0004	0.03	0	0.03
Absolute error of measurement	0.031	0.001	0.063	0	0.063
Measurement error of the device	0.07	0.03	0.016	0	0.001
Measurement of DC voltage with a 5 [V] generator power source					
Average value *U*	5.000	4.999	5.101	5.000	5.101
Relative error of measurement δ*U*	0	0.0002	0.02	0	0.02
Absolute error of measurement	0	0.001	0.101	0	0.101
Measurement error of the device	0.15	0.11	0.03	0	0.0015
Measurement of DC voltage with a 7 [V] generator power source					
Average value *U*	7.031	7.000	7.121	7.000	7.124
Relative error of measurement δ*U*	0.004	0	0.017	0	0.02
Absolute error of measurement	0.031	0	0.121	0	0.124
Measurement error of the device	0.15	0.11	0.04	0	0.002

For very low voltages of 1.5 V, 2.5 V DC, the digital multimeter shows greater measurement accuracy, so its measurement error is smallest, not exceeding 5%. For higher DC voltage values, the DMM achieves measurement results comparable to the results obtained with the NI Elvis device. Then, comparative voltage measurements were made with selected measuring tools. Having considered the errors of the measuring devices, comparative results were obtained for each of the devices (Fig. 10).

Analog meters used for direct current measurements, are marked by a small measurement error in comparison with digital multimeters, and even with virtual devices. The RIGOL model DG1022 digital generator was used to carry out the testing of alternating current, which has the function of generating alternating voltage in the

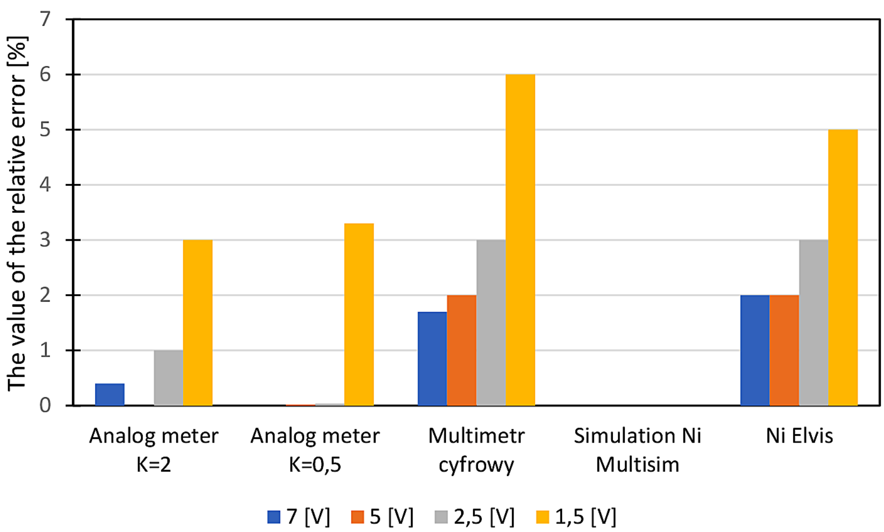

Fig. 10. Measurement errors of selected devices for the direct current voltage measurement using the direct method

Table 3. Measurement of sinusoidal alternating current voltage for selected measuring instruments

AC meter	Meter Analog class of accuracy 2.0	Meter Analog class of accuracy 0.5	Digital Multimeter	Simulation Ni Multisim	LabView – Ni Elvis
Measurement of sinusoidal current voltage for a generator power source with avoltage of 1.5 [V]					
Average value *U*	1.406	1.450	1.517	1.500	1.5042
Relative error of measurement δ*U*	0.063	0.033	0.012	0	0.003
Absolute error of measurement	0.094	0.050	0.017	0	0.0042
Measurement error of the device	0.07	0.03	0.017	0	0.005
Measurement of sinusoidal current voltage for a generator power source with avoltage of 2.5 [V]					
Average value *U*	2.440	2.550	2.499	2.500	2.476
Relative error of measurement δ*U*	0.024	0.020	0.0004	0	0.001
Absolute error of measurement	0.060	0.050	0.001	0	0.024
Measurement error of the device	0.07	0.03	0.027	0	0.017
Measurement of sinusoidal current voltage for a generator power source with a voltage of 5 [V]					
Average value *U*	5.312	5.000	5.069	5.000	5.021
Relative error of measurement δ*U*	0.064	0	0.014	0	0.001
Absolute error of measurement	0.312	0	0.069	0	0.021
Measurement error of the device	0.15	0.11	0.052	0	0.025

form of any signals. After that, a series of voltage measurements were made with the use of analog and digital meters and techniques using computer-aided measurement. The test (Table 3) was performed for an alternating voltage signal of 1.5, 2.5 and 5 V.

For analog meters, the measurement error increases with the voltage value, reaching the level of 6% for the voltage of 5 V. Measurement with a digital multimeter is more accurate for low voltage values, and in the case of voltage increase above 5 V, the measurement results are marked by an increasing measurement error. The NI Elvis platform and the LabVIEW environments for low sinusoidal voltage are characterized by the best measurement accuracy, with the relative measurement error of up to 0.3%.

The authors have conducted an extensive series of analogical tests of alternating current for signals with a triangular and rectangular shape. For these signals also, the values obtained from the compared measuring devices were compared. Interestingly, the NI Elvis layout appeared to be the most accurate. A detailed summary analysis of

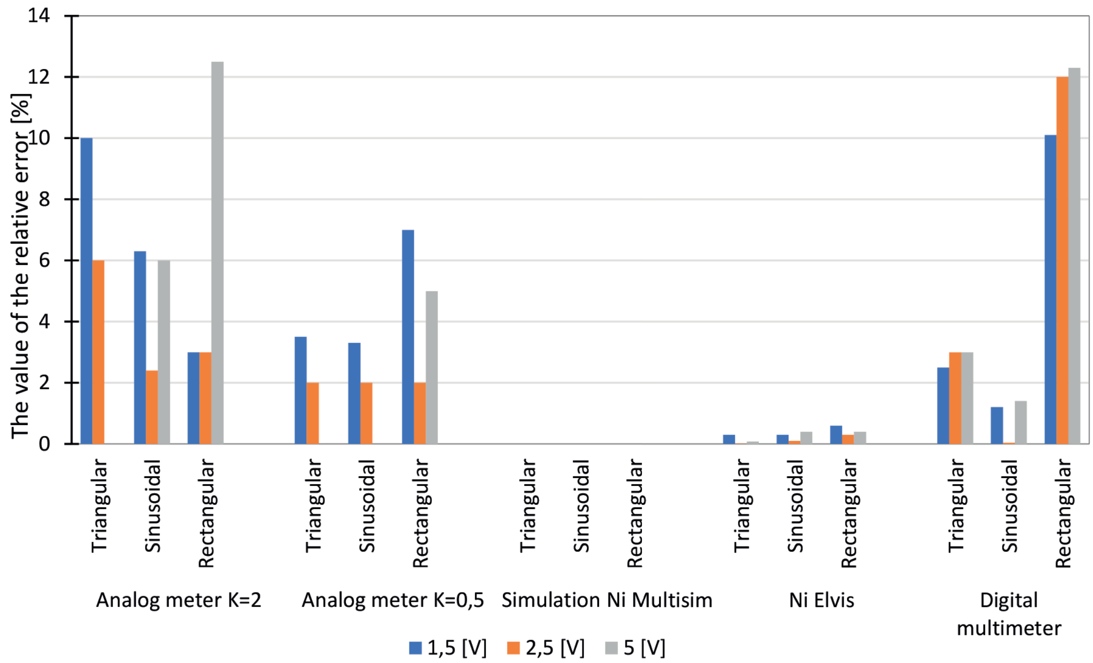

Fig. 11. Relative errors of AC voltage measurements with the direct method for selected meters

the practical selection of a measuring device for alternating current is displayed in Figure 11.

Measurements with the NI Elvis platform for alternating current in the form of sinusoidal, square and triangular signals were characterized by the lowest relative errors, none exceeding 0.6%. In turn, for a digital multimeter, it can be seen (Fig. 11) that for a sinusoidal signal, the relative errors reached a maximum of 1.4%. The evidently least precise measurement results originate from analog meters.

CONCLUSIONS

The advantage of virtual measuring systems is not only the operation speed and efficiency, but also the versatility, e.g. one stand equipped with the NI ELVIS II* module can be used in several different configurations and replace several different classic measuring devices. The obtained results of the comparative electric voltage tests indicate that, in the case of measuring the value of the DC electric voltage, the NI Elvis measuring device produces a large measurement error. Compared to analog meters of 2 and 0.5 classes and a digital multimeter, significantly better results were achieved by the NI Elvis platform when measuring AC voltage for three tested signals: sinusoidal, triangular and rectangular. The advantage of the NI Elvis platform is the ability to create measurement programs using the LabVIEW environment. As a result, it is a possibility of saving and post-hoc processing of the measurement results obtained.

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