

## Virtual Instrumentation – Significant Means of Effective Engineering Education

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**ABSTRACT:** *Electro technical or electronic field or area of inquiry frequently requires measurement of electric quantities, such as voltage, current, resistance etc. Clearly, such important activity implies that it should be attempted on a professional level. The question arises as to how that could be achieved effectively. One possible, and perhaps the easiest, way to meet this goal is to make the educational process more efficient and attractive. In this contribution we describe a process that is currently being tested in two laboratories at the Department of Electrical Measurements of the VSB – Technical University of Ostrava and which is based on virtual instrumentation principle. Some relevant details including the user interface of the virtual instrument created by the author are also highlighted in this paper.*

### 1 INTRODUCTION

There can be no doubt as to rising importance and specific position of the human activity connected with measurement of electrical quantities; this is particularly relevant when one is surrounded by plethora of electrical and electronic devices and gadgets or even by the electromagnetic field they produce. We could even talk about the dominant position among other kinds of measurements due to some advantages. For example – electrical signal can be easily arranged, then measured with high accuracy or easily recorded and transferred. Using electrical signals we can also measure a large number of non-electrical quantities. This could be one of the reasons why people ought to be better and more educated in the branch of electrical engineering or electronics and especially in the sphere of electrical measurements. The educational process should begin at all technical schools including technical universities in the first place. The problem is that to make somebody able to measure effectively (and therefore also quickly and correctly) at least basic electrical quantities such as voltage, current or resistance is not easy; furthermore it requires a lot of training and time. To acquire good skills in that sphere requires not only repeated measurements and hence large amount of values and data, but also using many types of instruments working on different physical principles; the more the better.

This last requirement has been met in two laboratories at the Department of Electrical Measurements of the VSB – Technical University of Ostrava. The students have been given the task to measure electrical quantities with many different instruments, the greater part of which have been digital multimeters. However, difficulties have arisen soon: the students have not been able to compute the accuracy of attempted measurements, mainly due to a somewhat difficult theory of the measurement errors. Another reason has been a bit long searching of all essential computation parameters in the corresponding manuals of the multimeters used. Unfortunately, similar difficulties have later been encountered by the lecturers as well as by their assistants who had to check and evaluate students' assignments. That activity (using a pocket calculator) has taken them a lot of time.

All of the above mentioned problems should be solved by the virtual instrument, or a set of virtual instruments, the model of which has been developed in the framework of financially supported scientific and research project. Since the virtual instruments are basically programs installed on computers, they have to be created in some programming environment. In this case, Lab VIEW, the graphically oriented and powerful programming language, distributed by the National Instruments Corporation has been selected. Using the virtual instrument, both the students and the academics can now check easily, quickly and also reliably their computation results; in addition, they can see on the screen not only the results but also graphical courses of different types of measuring errors. The latter helps students to better understand the rather complicated theory of electrical measurements. Besides, the instrument could (in the future)

also help distance learners in the same way. The model was already installed in one laboratory at the end of last year and soon afterwards in the other one and currently both the instruments are being tested.

## 2 ERRORS' THEORY IN BRIEF

As the electrical quantities are random, it is never possible to find out their true values by any means. Besides, there are some other factors that influence the result of a measurement, e.g. the measuring instrument's construction or large number of external conditions, the so called reference conditions such as temperature, humidity, electromagnetic field, frequency etc. Therefore, in addition to the value measured, we are always interested in which tolerance limits the actual value of the measured quantity lies. In other words, we should always find out what the accuracy or error of the performed measurement is, particularly when exact result had been sought. The error can arise in the following areas in particular:

- Method error
- Instrument error
- Operating error

The method error can be caused in most cases by the assumption of measuring instrument used and in the large majority of cases it can be determined as well as corrected because the error sign is always known.

The instrument error arises due to imperfect construction of measuring instruments. The main reason for occurrence of such error can be manufacturing inaccuracy and calibration, destructive forces, internal disturbing magnetic and electric field, aging of the material etc. In contrast to the previous type of error, correction cannot be realized in this case since we do not know the sign of the kind of errors. (Some of the above-cited errors can have partially random character.)

The operating error can be caused when an operator chooses the wrong measuring range, selects the wrong measuring method, does not read the measured value correctly or calculates the tolerance limits incorrectly etc. All such errors typically arise due to failing of the human factor.

To simplify the rather complicated theory of the measurement errors in this paper, we subsequently consider only the above mentioned instrument error and suppose that all reference conditions meet the given tolerances. In that case the indication error of the meter is equal to the instrument error.

## 3 MEASUREMENTS BY MEANS OF ANALOGUE INSTRUMENTS

Currently the two large groups of the measuring instruments are predominantly used (not only) in the schools' electrical laboratories:

- Analogue
- Digital

In case of analogue instrument, the maximum relative error (the so called accuracy class or just class) must be determined by the manufacturer providing that all reference conditions are met. The accuracy class is very important characteristic and it's the number from a normalized row that can for example look like this: 0,05 - 0,1 - 0,2 - 0,5 - 1 - 1,5 - 2,5 - 5. However, in some countries the rows can somewhat diverge from each other. But in spite of that, the accuracy class is always marked out on the meter's scale plate, which is one of the advantages of analogue meters.

If the accuracy class is known, it is then possible to determine the absolute error respectively accuracy (both terms are equivalent) of a single measurement (e.g. using only one meter) as follows

$$\text{absolute indication error} = \pm \frac{\text{full scale value}}{100} \cdot \text{class} \quad (1)$$

or the relative error of the same measurement using the formula

$$\text{relative indication error} = \pm \frac{\text{absolute indication error}}{\text{value measured}} \cdot 100 [\%] \quad (2)$$

respectively, when substituting the expression in the numerator, we get

$$\text{relative indication error} = \pm \text{class} \cdot \frac{\text{full scale value}}{\text{value measured}} \cdot 100 [\%] \quad (3)$$

In all formulae we must write the signs in front of the fractions, since both absolute and relative indication errors have random character.

From the first formula it is obvious that the absolute error is constant on any point of the range. On the other hand – it is not always quite clear (especially in case of some learners) that the relative indication error is the hyperbolic or even the equiangular hyperbolic function of the measured value and that the lesser value will be measured, the greater indication error we get. Therefore it is very important to carry out the measurements at least in the second third of the scale and constantly emphasize this practice during the training sessions.

#### 4 MEASUREMENTS BY MEANS OF DIGITAL INSTRUMENTS

In case of digital instruments, determination of measurement accuracy or error is slightly more complicated due to some of the following factors:

- Accuracy is not defined by a single number
- Accuracy is defined for various quantities and ranges by different specifications
- Non-uniform notation in specifications in different countries
- Usage of different math expressions in specifications
- Finding of digital mode or maximum number of digital units
- Accuracy specification and other necessary information must be found in vendor's documentation.

Accuracy of a digital meter is most often stated in the corresponding documentation as the sum of two expressions that represent two types of partial errors of the meter. The first partial error is proportional to the measured value and is usually called “reading error”. The second partial error is independent of the measured value and is called “span error”.

The accuracy specification can generally be defined in two substantially different ways as follows:

$$\text{Accuracy} = \pm(m\%R + nD), \quad (4)$$

where  $m\%R$  means  $m\%$  of the reading,  
 $nD$  means  $n$  digits ( $D$  is the least significant digit on display)

or:

$$\text{Accuracy} = \pm(m\% \text{ of } rdg + n\% \text{ of } FS), \quad (5)$$

where  $m\% \text{ of } rdg$  means  $m\%$  of the reading,  
 $n\% \text{ of } FS$  means  $n\%$  of the full scale

There are many other ways of writing the accuracy specifications one of which is shown in Figure 1. That large variability can be a cause of many faults while calculating the measurement result errors but unfortunately not only among learners. Let us take some example:

Assume that a result of DC voltage measurement in the 20 V range using a 4 ½ digit mode multimeter, 15.258 is displayed.

When the measurement error specification is  $\pm(0.05\% \text{ of } rdg + 3 \text{ dig})$  then, according to equation (4), we get

$$reading \text{ error} = \pm 0.05 \cdot \frac{15.258}{100} = \pm 0.007629 \text{ V} = \pm 7.629 \text{ mV},$$

$$span \text{ error} = \pm 3 \text{ dig} = \pm 0.003 \text{ V} = \pm 3 \text{ mV},$$

and, as we are always interested in the maximum value of the measurement error, we can write

$$indication \text{ error} = measurement \text{ accuracy} = \pm(7.629 + 3) = 10.629 \text{ mV}.$$

If using the equation (5), we must transform the number of digits to the value expressed in percentage of the maximum number of digital units at first. We used the multimeter with 4 ½ digit mode, which automatically means that the maximum number of digital units is 20 000, respectively the maximum number displayed is 19 999 (those information we could read out directly in the documentation as well). Subsequently we obtain

$$n = \frac{3}{20000} \cdot 100 = 0.015 \%,$$

$$span \text{ error} = \pm 0.015 \cdot \frac{20}{100} = \pm 0.003 \text{ V} = \pm 3 \text{ mV},$$

and, since the reading error must be the same as using the equation (4), the result of the indication error will also be the same and equal to 10.629 mV.

## ELECTRICAL SPECIFICATIONS

Accuracy is given as  $\pm$ ( % of reading + no. of least significant digits) at 23°C  $\pm$  5°C, with relative humidity Less than 80% R.H.

In the 4 3/4 digit mode, multiply the number of least significant digits(dgt) by 10.

### (A) True RMS model:

#### □ DC VOLTAGE

Range	Resolution	Accuracy	Overload Protection
40mV	10 μV/ 1μV	±(0.08%rdg+5dgt)	600V DC/ AC rms
400mV	0.1mV/10μV	±(0.06%rdg+3dgt)	
4V	1mV /0.1mV		
40V	10mV/1mV		
400V	0.1V/10mV		
1000V	1V/0.1V		
			1200V DC or 850V AC rms

- Input Impedance: 10M $\Omega$  (1000 M $\Omega$  for 40mV and 400mV)

#### □ AC VOLTAGE (TRUE RMS : From 5% to 100% of range. )

Range	Resolution	Accuracy			Overload Protection
		50/60Hz	45Hz ~5k Hz	5kHz~20kHz	
40mV	10μV/1μV	±(0.7%rdg+5dgt)	±(1.5%rdg+5dgt)	±(2%rdg+5dgt)	600V DC/ AC rms
400mV	0.1mV/10μV				
4V	1mV/0.1mV				1200V DC or 850V AC rms
40V	10mV/1mV				
400V	0.1V/10mV				
750V	1V/0.1V				
			±(3%rdg+5dgt)	NO SPEC.	

- Input Impedance: 10M $\Omega$  // less than 100pF(1000M $\Omega$  for 40mV and 400mV)  
Crest factor: >3:1

Figure 1 – Extract of the ESCORT 95/97 multimeter's operation manual

## 5 VIRTUAL INSTRUMENTATION

An application developed in Lab View programming environment is called virtual instrument (VI). In other words, all virtual instruments are programs in graphical programming language that uses icons instead of text lines. Lab View uses a so called data flow programming in contrast to text-based programming, where instructions determine program execution. While programming a virtual instrument, we build a user interface (front panel) at first by using a set of tools and objects as Figure 2 shows. The front panel can be built with many types of objects

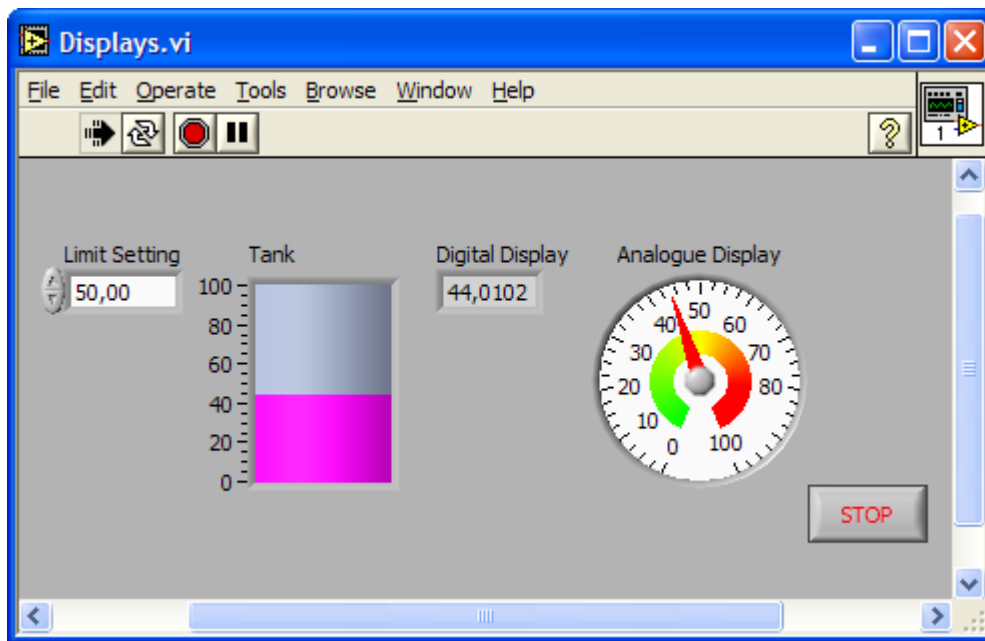


Figure 2 – Front panel example

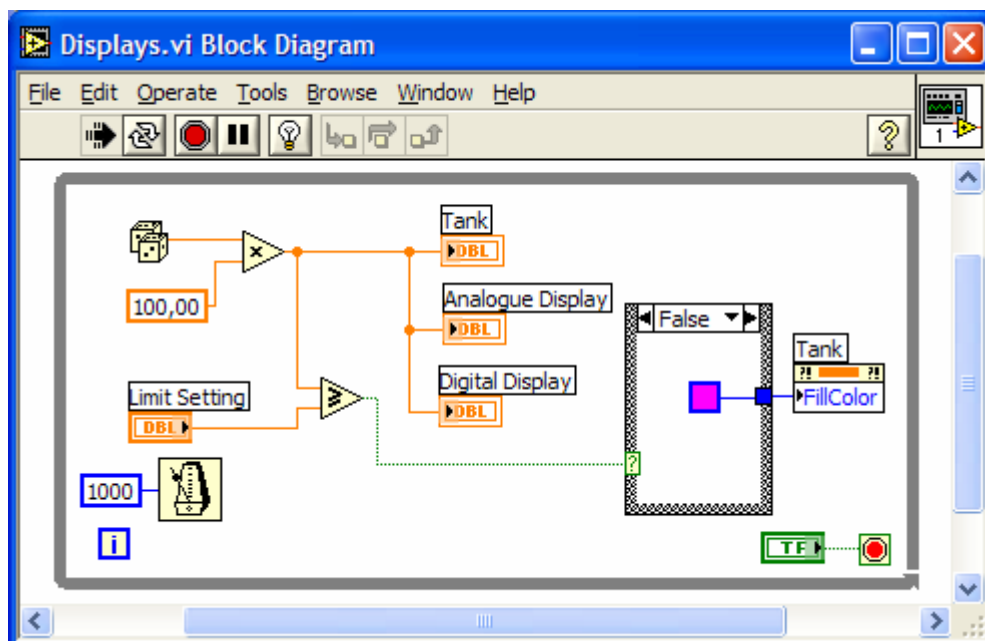


Figure 3 – Block diagram example

that are called controls (knobs, dials, push buttons, input boxes etc.) or indicators (graphs, tanks, slides, bars and so on). Once the front panel has been created, we add some code to the so-called block diagram (see Figure 3) using graphical representations of functions to control the front panel objects. Lab View uses three types of palettes that give the options needed for creating or editing the front panel and block diagram. By means of virtual instruments we can relatively easily simulate both the appearance and behavior of various physical instruments. In addition, Lab View also contains comprehensive libraries for data acquisition, analysis, presentation and storage.

## 6 USER INTERFACE OF VIRTUAL INSTRUMENT PRESENTED

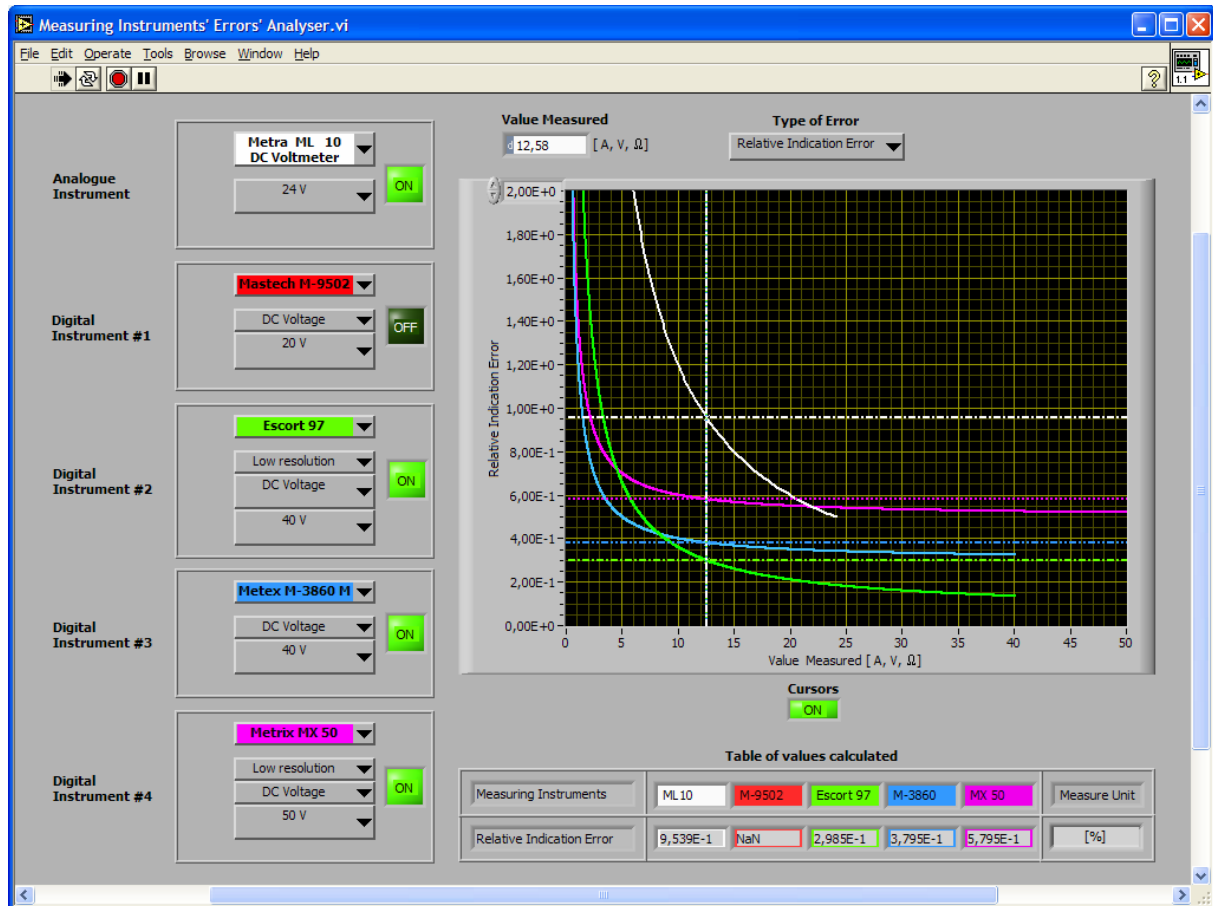


Figure 4 – User interface of the VI for measurement errors' evaluation and monitoring

To avoid some comprehension problems, it is convenient to build the user interface of a virtual instrument in such a way that everybody can handle it easily and effectively. This goal has been followed while developing the VI presented in this paper, particularly when it had been clear that the instrument would serve the users to master the relatively difficult subject matter. Now the students have a good opportunity to manipulate thirteen measuring instruments in all that can occur in their workplace, only by clicking the mouse on corresponding buttons. Having done that, they can quickly decide for example which meter will be the best for the task required or if the expected error will not be too large. They can easily check their computation results executed by hand as well as monitor the various error plots of different types of meters (see Figure 5) and so forth. Using the context help is also available.

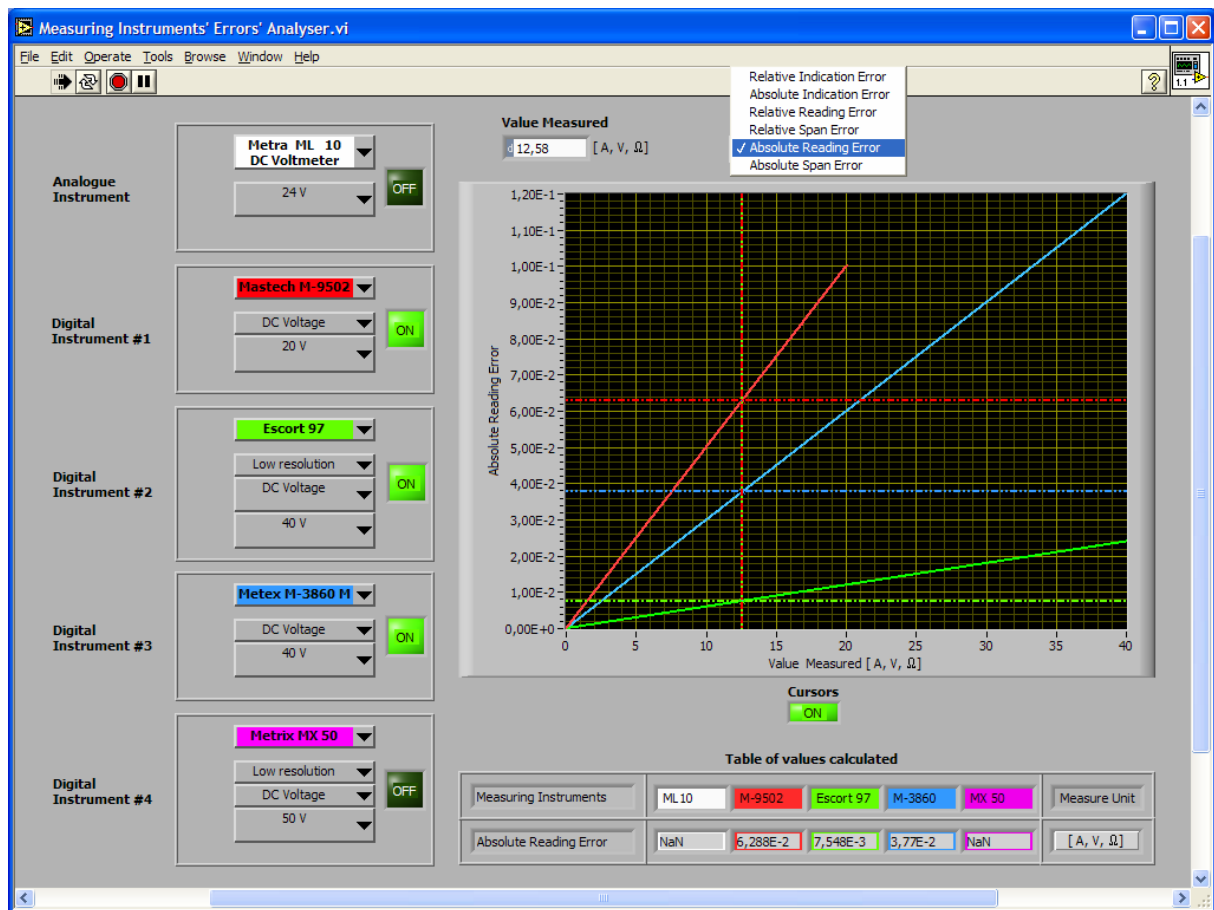


Figure 5 – Plots of absolute reading error with 3 different multimeters

## 7 CONCLUSIONS

The virtual instrument presented in this paper is currently being tested in two laboratories at Department of Electrical Measurements of the VSB – Technical University of Ostrava. It is plausible to predict that usage of this modern tool will improve the current methodology of training and that similar applications will emerge soon, and not only in the areas of electrical engineering or the present format of study. Results and indications obtained so far do seem to lend credible support to this prediction.

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