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Revolutionizing engineering education: Leveraging LabVIEW virtual instrumentation in electrical machines real-time control for distance learning

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Abstract

The rapid developments of science and technology of the last decade have given a fundamental change to the way of conceiving and solving problems in every field of science and in particular in engineering disciplines. Nowadays, Virtual Instruments are becoming an important part of solving engineering problems in particular in the area of Automatic Control of Industrial Processes and Education. Due to the continuously increasing performance and flexibility of PC combined with their cost reduction, virtual instruments are successfully concurring the traditional instruments. In this work, we have created a closed-loop control system for testing the PID controller for a DC motor using the HIL technique and Ziegler-Nichols tuning rule for education purposes.

1. Introduction

The rapid developments of science and technology of the last decade have given a fundamental change to the way of conceiving and solving problems in every field of science and in particular in engineering disciplines.

The revolution of personal computers (PC) has placed them in the position of an indispensable tool in solving many problems encountered by engineers in practice.

Until the 1990s, the focus was on computer architecture, which would be used in industry for a specific task, but today attention is increasingly directed towards the so-called: software architecture [1].

From several years of work, with students during teaching practices in several industrial enterprises, we have established that the process of control and monitoring of production lines is carried out by special software of leading companies in the respective fields.

From the teaching point of view, to build the applications in the laboratory, all engineering problems deal with some physical quantities such as potential difference, electric current, temperature, pressure, speed, position, mechanical torque, moisture level, etc. We can see these quantities by using a computer coupled with conditioning circuits, data acquisition, transducers, and software. Moreover, these data can be processed, and stored, and even we can publish them on the Internet. Figure 1 illustrates an experimental test bed supported by the computer in real-time.

At the Automation Department of the Electrical Engineering Faculty in Tirana, we are working on implementing LabVIEW software, a well-known software for measurement, data acquisition and visualization, in creating new prototypes of controlling desired parameters of electrical machines, since it is also a programming language (Figure 2).

In this work have built a virtual instrument for speed control of 220V, 1500 rev/min Separately Excited DC Motor in our Electrical Measurement Laboratory "Figure 3" and tested for finding the PID controller coefficients using the so-called Hardware in the Loop (HIL) technique [2] and Ziegler-Nichols empiric tuning rule [3].

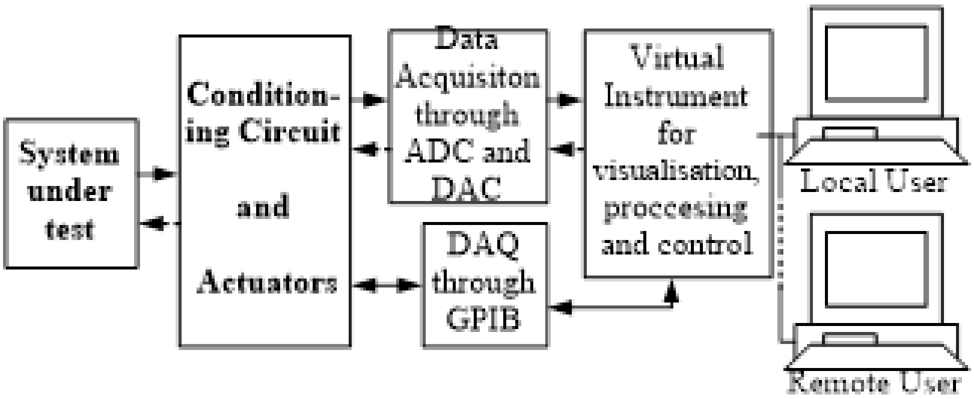

Figure 1. Block diagram of a laboratory test bench based on PC.

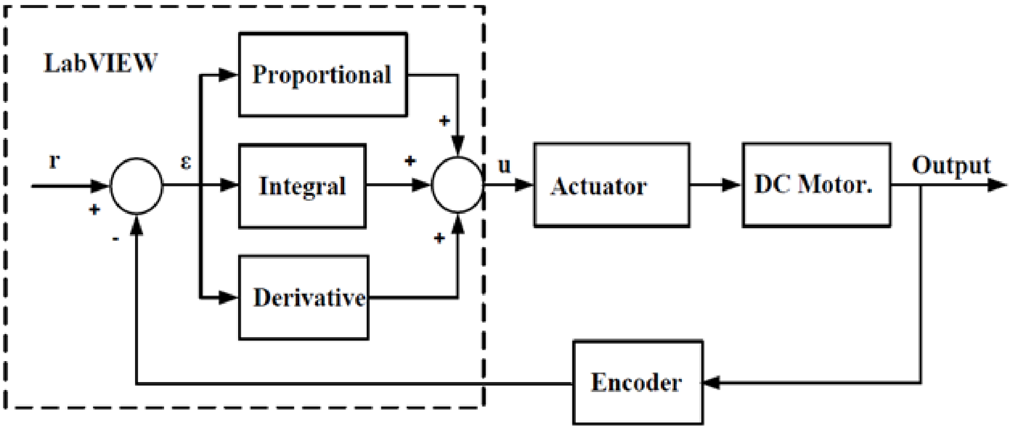

Figure 2. Block diagram of using LabVIEW as PID controller for DC motor speed control.

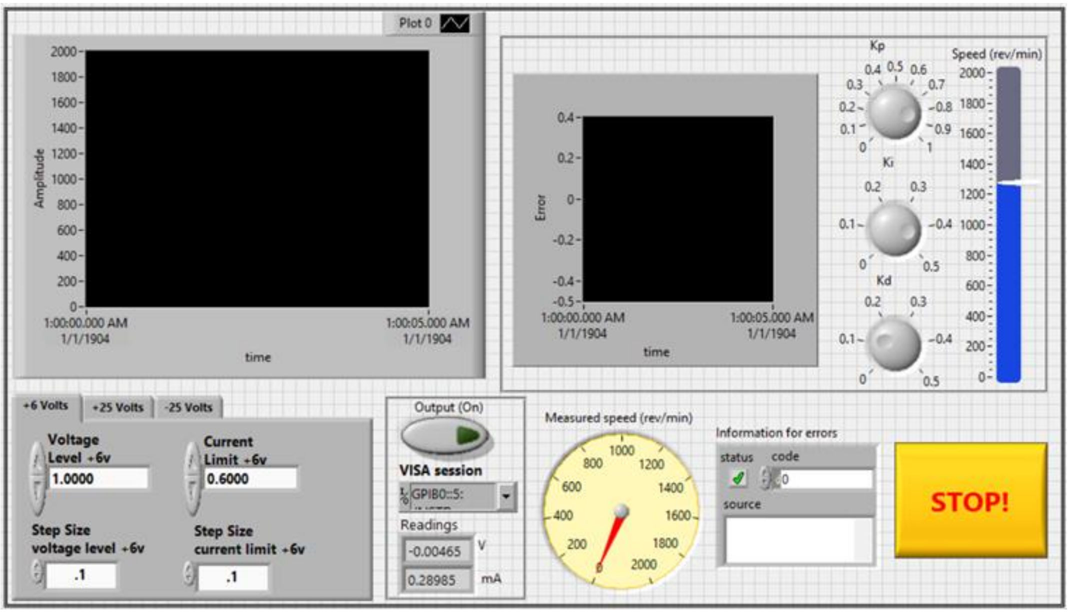

Figure 3. Virtual instrument for DC motor speed control and monitoring.

2. Material and Method

2.1. Overall System for DC Motor Speed Control

To build the DC Motor speed control Virtual Instrument we relied on [4-5] for instrument programming.

For the DC Motor formulas and theory, plenty of literature can be found on the internet. However, we are referring to literature in Albanian [6] for the equation of the DC Motor angular speed –ω, that is (Equation 1):

$$\omega = \frac{U_i}{k \cdot \varphi} - \frac{R_i}{(k \cdot \varphi)^2} \cdot M \tag{1}$$

Where U_i- is the armature voltage, R_i – armature resistance, M- motor torque, k- a coefficient and φ-field flux.

To measure the motor angular speed we have used an incremental encoder from Baumer model ITD 40A with 1024 pulse/rev, NI 6008 USB DAQ and LabVIEW to build a virtual instrument used as a subVI in the top application (Main VI).

The control of the motor speed is done by changing the armature voltage under the rated value by using a custom-built AC-DC converter [5]. The set point of the driver is set programmatically by the programmable power supply Agilent E3631A through the GPIB interface.

The Separately Excited DC motor coil is fed by a constant 220V DC voltage obtained by the LabVolt power supply used in the laboratory.

We built in LabVIEW also a soft starter to start the DC motor from the standstill to its rated value of 1500 rev/min by generating a ramp signal from the programmable power supply. The Overall system for DC Motor speed control is shown in Figure 4.

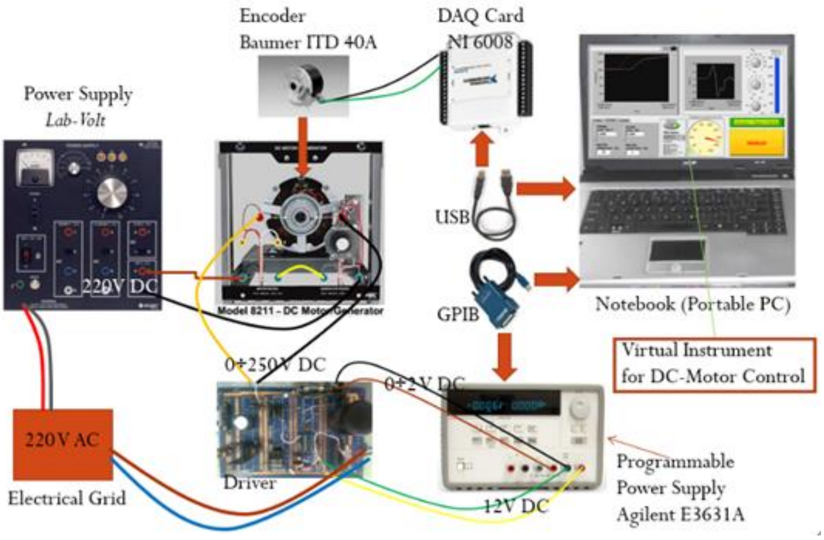

Figure 4. Overall system for DC motor speed control.

2.2. System components integration and programming in LabVIEW

Based on the system illustration of Figure 4 and the NI 6008 DAQ documentation [7] first, we built in the LabVIEW environment the angular speed measurement virtual instrument. This parameter will be controlled to remain inside predetermined limits. So, we must pay attention to the angular speed meter accuracy when building the instrument.

In Figure 5 it is shown the incremental encoder used for angular speed measurement. In Figure 6 is shown the virtual instrument front panel and in Figure 7 its block diagram.

Figure 5. Incremental Encoder 1024 rev/min.

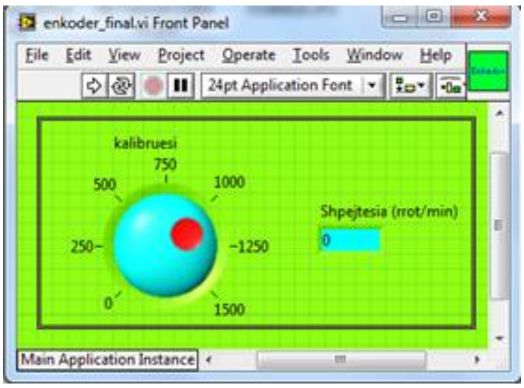

Figure 6. Angular speed instrument front panel.

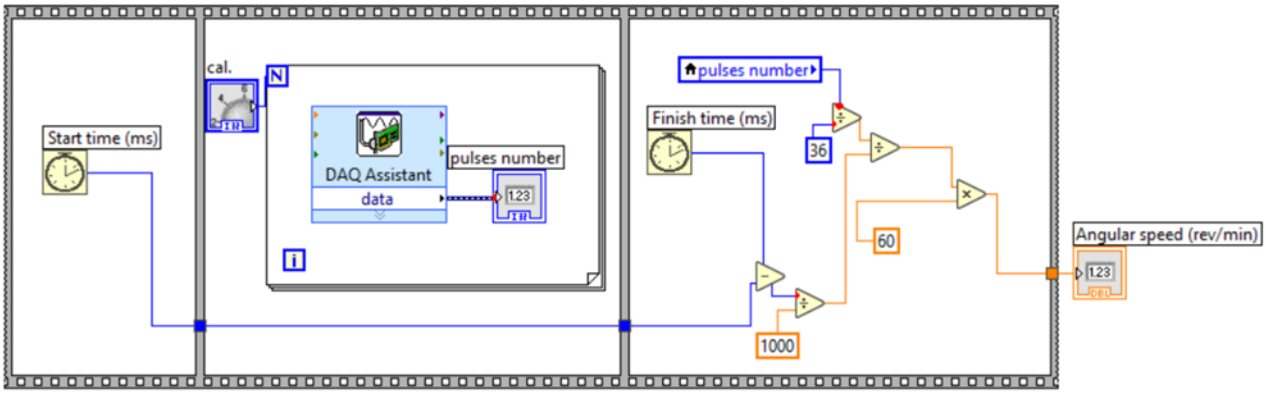

Figure 7. Angular speed virtual instrument graphic code.

Initially, we configure the DAQmx driver for NI 6008 DAQ USB to acquire 5 volt pulses through pin 29 (PFI 0) of this card. The incremental encoder Baumer ITD 40A is connected to produce 5 V $_{pk-pk}$ rectangular pulses when rotates. Since the reated motor speed Model 8211 from LabVolt is 1500 rev/min it is equal to 25,6kHz pulse train.

We have used a signal generator to find the instrument accuracy experimentally. We have to compare the frequency of quadratic signal (for calculated speed values) generated from the high accuracy digital signal generator with the angular speed measured from the virtual instrument.

In Table 1 it is shown the calculation of errors and class of accuracy. It can be seen that the maximum error value during speed measurement is -0.295%. It depends mostly from the time period tolerances of pulses counted in Windows, because it is known that encoders are used primary for angle measurement in electric machines, but in this work we are using it for angular speed measurement. For smaller speed measurement error one should use a Real-Time Operating System (RTOS) [5].

Table 1. Virtual instrument speed meter accuracy determination.

nx (rev/min)	n0 (rev/min)	Ga (rev/min)	Correction	Grel (%)	Gref (%)
0.00	0.00	0.00	0.00	0.00	0.000
152.23	152.70	-0.47	0.47	-0.31	-0.032
292.86	294.30	-1.44	1.44	-0.49	-0.096
446.17	448.50	-2.33	2.33	-0.51	-0.155
598.62	600.00	-1.38	1.38	-0.23	-0.092
740.51	743.70	-3.19	3.19	-0.43	-0.213
918.30	922.20	-3,90	3,90	-0.42	-0.260
1057.35	1061.10	-3.59	3.59	-0.34	-0.240
1205.78	1210,20	-4,42	4,42	-0,36	-0,295
1348.69	1351.80	-3.11	3.11	-0.23	-0.207
1498.23	1502.40	-4.17	4.17	-0.28	-0.278

The angular speed virtual instrument is then configured as a subVI using patterns in LabVIEW. In this way, using LabVIEW software modularity, we will insert it in the Main VI.

Second, based on DC machine parameters [8] we designed a custom-built AC-DC converter. It was designed to generate a triangle signal with a frequency of 20 kHz and the PWM (pulse width modulation) signal is produced by comparing a reference DC voltage in the range of 0 V to 2 V with the triangle signal. The reference voltage is produced by a voltage drop in a potentiometer or by an analog voltage coming from an external source. Source selection is done by a simple 3-way (3-pole) switch.

In Figure 8 is shown the electronic schematic of the custom-built AC-DC converter in the Multisim software environment. Here we have shown only the DC Chopper of the custom-built AC-DC Converter. It converts a 250 V DC in a variable 0 V to 250V DC voltage. The reverence voltage is obtained from the 47kΩ potentiometer (R_3). This voltage determines the pulse width of the PWM circuit. As the final stage, we used IRF 840 Mosfet N-channel transistor with a current of up to 8A and a voltage of 500 V. The AC-DC converter is built up with a reactor, 8 A, 600V Graetz bridge and a big filter composed of four 450V 220μF electrolytic capacitors.

In Figure 9 is shown the simulation in Multisim of this circuit and Figure 10 shows the custom-built AC-DC converter. With this circuit, we will feed the armature coil of the DC Motor. The field coil of the DC Motor will be fed from a 220V constant DC voltage from the LabVolt power supply (see Figure 4).

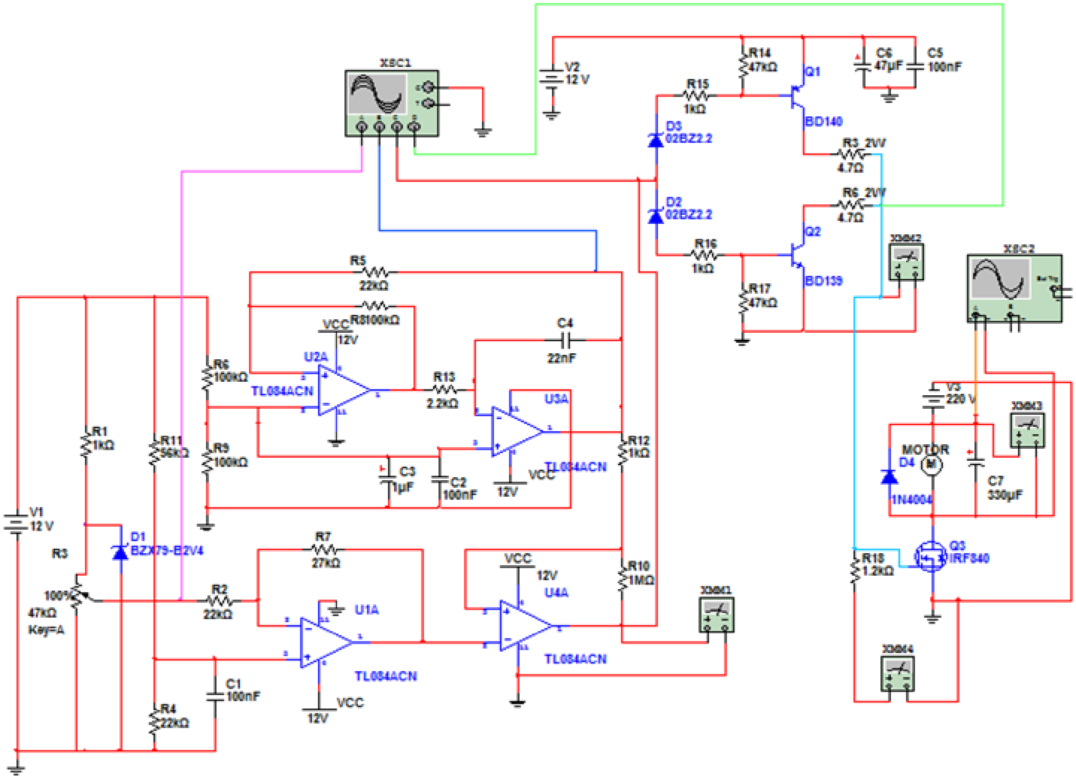

Figure 8. Costum-built DC chopper in multisim environment.

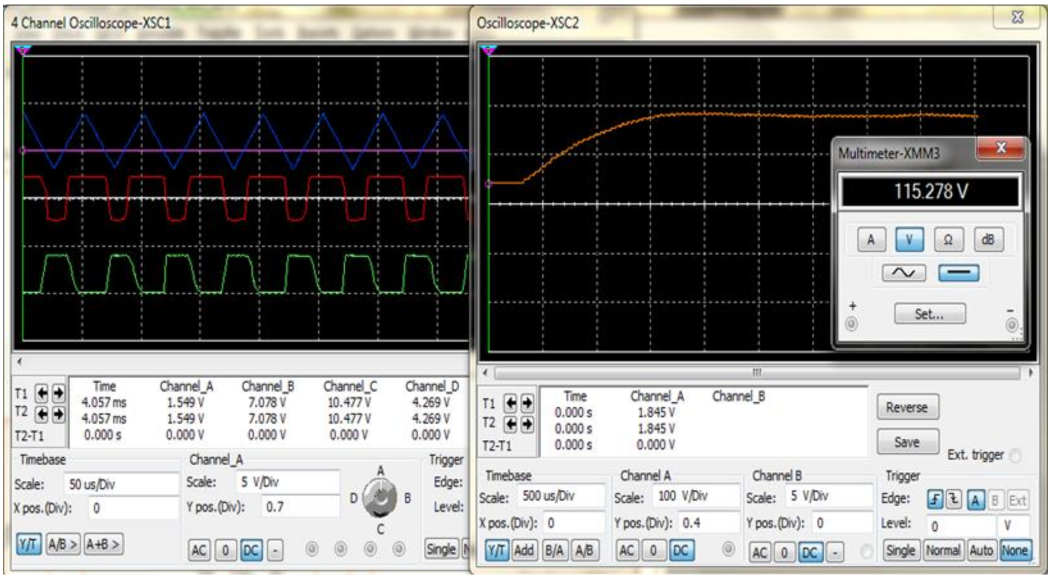

Figure 9. DC chopper simulation in multisim.

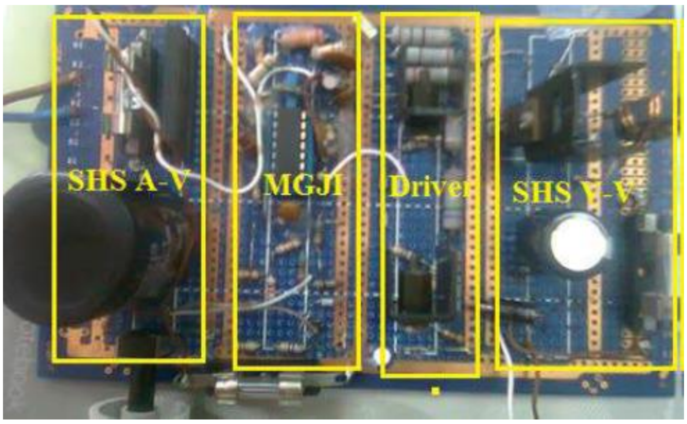

Figure 10. Custom-built 0-250 V, 0-8 A, AC-DC converter.

Third, the reference voltage in the range of 0 V to 2 V is obtained from Agilent E3631A programmable power supply. The control voltage to this device is sent from LabVIEW software virtual instrument (Main VI) through E3631A instrument driver and GPIB interface.

In Figure 11 is shown the E3631A instrument front panel. This program can be downloaded for free from National Instruments website or the LabVIEW software interface. This program lets the user to control the power supply through Personal Computer. But since it imitates the instrument's front side there must be a user in front of the PC to use the mouse and the keyboard to control the instrument. We modified this program in order to take voltage values automatically from the DC motor control virtual instrument and so to control the motor speed through the voltage change in its armature coil.

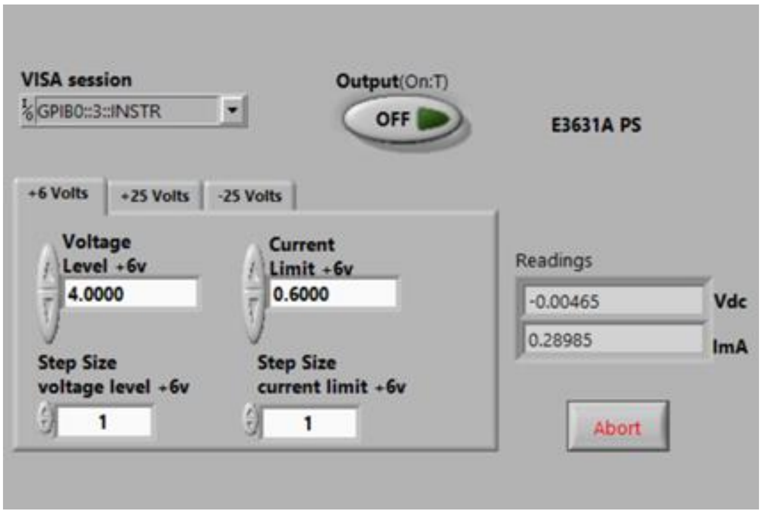

Figure 11. Agilent E3631A programmable power supply driver in LabVIEW.

2.3. DC Motor Main VI (GUI)

In this paragraph, we will show the Main VI of the DC motor control and monitoring in its final version.

Based on the considerations of paragraph 2.2., in Figure 12 is shown the virtual instrument front panel used to monitor and control the Separately Excited DC Motor. The motor angular speed is displayed on the virtual instrument front panel in a "Meter gauge". Also, the speed measured (white graph line) and the speed desired (red graph line) are both shown in a "Waveform chart" graph indicator. The desired value can be changed during the program running and the LabVIEW virtual instrument will try to equal the measured speed with the desired one based on the PID coefficients we determine during execution, using the Ziegler-Nichols tunning rule, in real-time by rotating the three knobs on the virtual instrument front panel.

Although the PID controller coefficients can be changed several times, we recommend students find them only one time and then to change only the setpoint value of the angular speed, since the DC Motor is connected in a closed loop with the virtual instrument and can lead to unexpectable behaviour till DC motor armature coil damage or custom-built driver fuses burning.

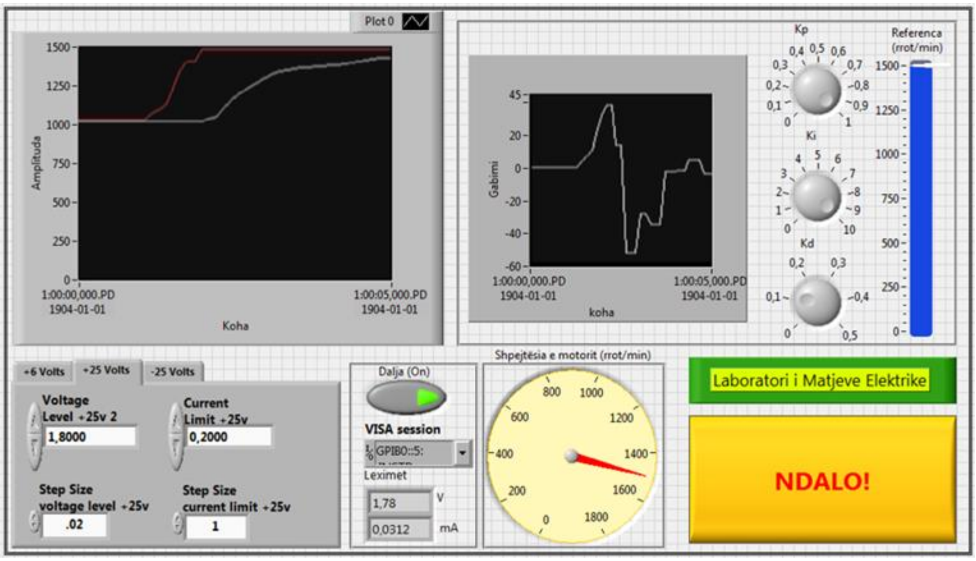

Figure 12. Virtual instrument for DC motor speed control and monitoring front panel.

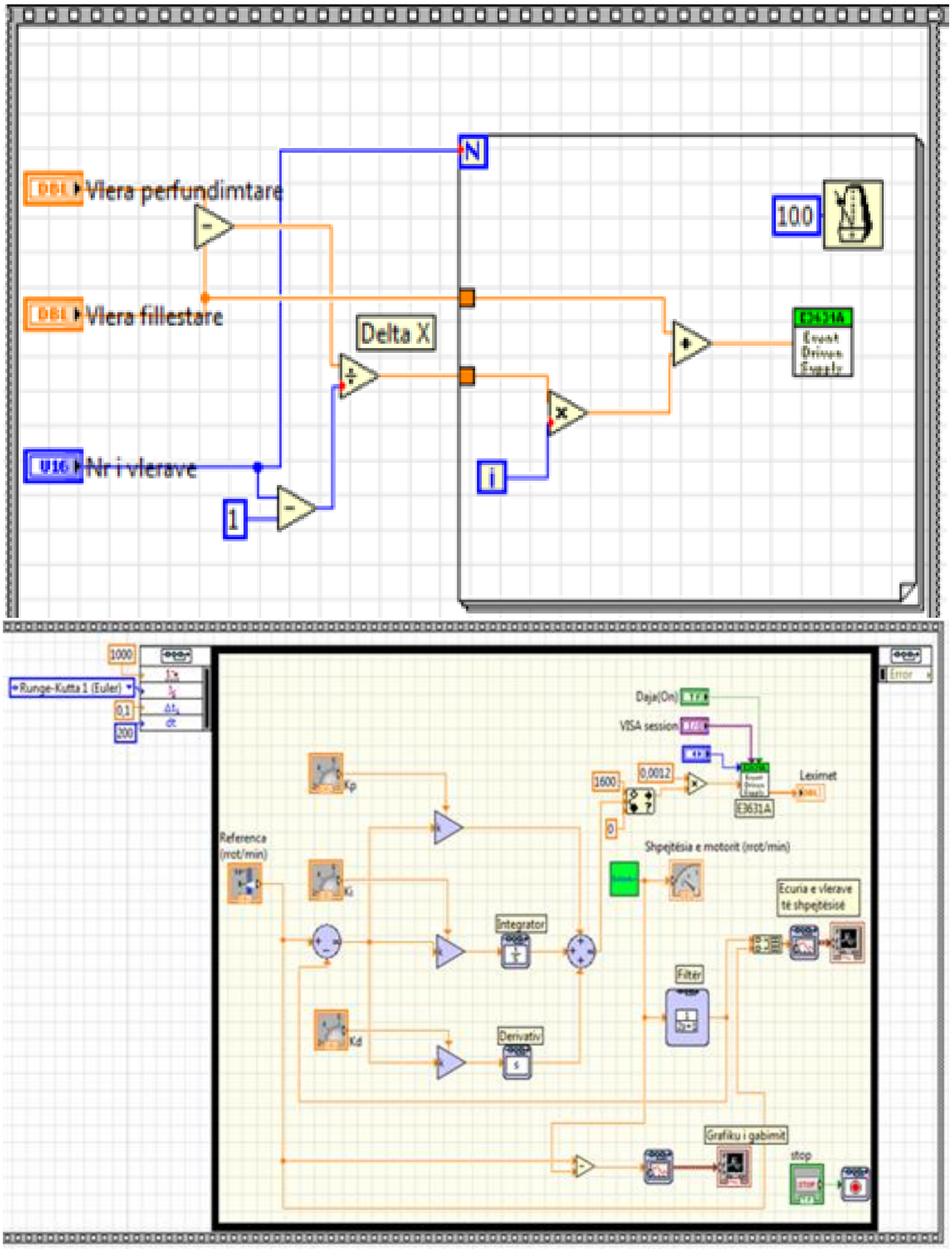

Figure 13. Virtual instrument block diagram.

The Virtual Instrument graphical code is shown in Figure 13. It consists of 2 frames. The first frame (left) picture in Figure 13 soft-start the DC motor and the second frame (right picture) is used to monitor the motor angular speed and to find the desired PID controller coefficient by interacting with the DC motor using the HIL technique and Ziegler-Nichols empiric tuning rule. It is known that DC motors when started require 6 to 8 times the rated current value, so to limit the current resistor or soft-starter devices are used. Since the Agilent E3631A programmable power supply is driven by the LabVIEW program we have used it initially as a soft-starter by generating a ramp signal from 0 V to 2V DC using the left frame which executes first. We take a value every 100ms and let's say if we want to start the motor from standstill at its rated speed in 5 seconds we run the for loop 50 times. Every 100ms the driver will update the programmable power supply output till the value 2 V after 50 iterations. The custom-built AC-DC converter will increase gradually the PWM duty cycle and so we will have an increased DC voltage in the motor armature coil till 230 V, which corresponds to the rated speed.

After processing the left frame, LabVIEW execute the right frame when a control design loop is placed. The loop parameters like start time, finish time, ode solver etc., can be set in the left-upper side of the loop.

The green subVI inside the loop is the angular speed measure virtual instrument of the Figure 7.

The other subVI (white-green) is the modified driver of E3631A programmable power supply. We have shown in the front panel also its voltage and current generated during execution time.

In Figure 14 is illustrated the test of the virtual system using HIL technique.

Figure 14. Photo during a test of the virtual system.

Last, we can publish the virtual instrument online using LabVIEW G Web Server so the students can interact and perform remote laboratory work. The procedure for configuring the virtual instrument to be published on a web page is shown in [9].

3. Results

From a teaching point of view, the speed control of a DC Motor with the LabVIEW software can be used to carry out laboratory work on the subject of Electric Drives, allowing the students to become familiar with computer-based control systems, despite the limitation in infrastructure, which our laboratories have in our faculty.

4. Discussion

This approach lacks the problem that there must be always qualified personnel in the laboratory during tests to survey for any problem students may face during experimentation because the controller coefficient can be changed in real-time and can lead to unexpected behavior of the machine if not found correctly.

We think it will be a good start to use virtual instrumentation for all the classic instruments used to perform laboratory works in Engineering Faculties so as to be ready in every case to use techniques based on PC for remote laboratory works and other targets.

5. Conclusion

Using remote virtual instrumentation is very helpful when the number of students is larger than the respective laboratory can accommodate or when it is not physically possible for the student to be present in the lab.

From an educational point of view, using this approach it is possible to help some of the laboratories in the Electrical Engineering Faculties which lack the infrastructure to perform specific laboratory work so the students narrow the gap between theory and practice.

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Author contributions

Gentian Dume: Conceptualization, Methodology, Instrument programming, Writing-Original draft preparation.
Jurgen Metalla: Validation, Remote testing, Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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