Personal computer/programmable logic controller based variable frequency drive training platform using WxPython and PyModbus

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ABSTRACT

Variable frequency drive (VFD) is one of the key elements in industrial field. It is used to match the three-phase induction motor's speed and torque to the industrial field process requirements in addition to energy saving and efficiency improvement. This important role of the VFD asks for the development of an efficient training and cost effective platform for the electrical engineering students, technicians, and maintenance personals. This paper introduces a user-friendly platform through which the users can understand and practice the configuration of the various parameters of the VFD unit. This platform uses two computing devices to deal with the VFD; these are the personal computer (PC) and the programmable logic controller (PLC) which is also a computer but designed to operate in wide range of temperature and humidity and can accept digital and analog signals. The PC uses WxPython (cross-platform graphical user interfaces (GUI) toolkit of Python programming language) and PyModbus communication utility to play the role of the human machine interfacing (which allows the user to execute the communication requirements and at the same time provide an oscilloscope like facility to display the platform response in real time mode or history recorded mode). With this platform, the VFD's parameters configuration is done via the RS-485 communication port using Modbus recommandation temporaire d'utilisation (RTU) communication protocol.

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1. INTRODUCTION

Variable frequency drives (VFDs) are microprocessor controlled inverters used for controlling the rotational speed of alternating current (AC) induction motors by controlling the frequency of the electric power supplied to the induction motors which take about two third of the electrical energy in the word [1]–[4]. Industrially, these may be called adjustable frequency drives, variable speed drives, AC drive, micro drive, or inverter drive [5], [6]. From the point of view of supported functions, to some extent, one can say they have a lot to share. The parameters codes and method of modification are brand dependent. So too well understand these key products and be ready to deal with any one of them, one must focus on understanding the physical meaning of the control terminals supported functions, the linear and nonlinear relationships between the VFD's output voltage and frequency, the protection functions, the speed control functions, the torque control functions, and the communication functions.

From the point of view of hardware, the VFD is microprocessor controlled three-phase inverter for which the direct current (DC) link voltage is supplied either using single or three-phase rectifiers followed by filter stage consisting of dc link choke or reactor and capacitor filter. This means it is a combination of passive power circuit components and active power electronic switching devices that are driven or controlled by microprocessor based control system. From the point of view of functions, they are used to control the speed and torque of drive machinery and to meet particular starting and stopping requirements [7].

The programmable logic controller (PLC) always shares the VFD the industrial activities control [8]–[10]. It is a microprocessor-based, solid-state, single processor device [11]. It has the ability to accept digital input signals coming from the industrial field input devices like proximity switches and shaft encoders [12]–[14]. It also can accept analog signal like that coming from the analog output of the VFD. It also has the ability to generate and send digital and analog driving signals for the industrial field output devices like the VFDs. PLC comes with built-in communication ports usually 9-pin RS232, RS-422, RS-485, and Ethernet [15]. From the point of view of operation modes, the PLC widely used modes of operation are the repetitive operation mode and the interrupt mode. The repetitive or scan mode of operation is the main operation mode that each PLC should have at least one of it. In this mode, the user application program is repetitively executed from its start statement to its end statement as long as the PLC is in the run mode. Here the program execution does not depend upon any condition. The interrupt operation mode is event driven one. In this mode of operation, the user application program includes more than one program. Mainly, it consists of a main scan program and one or more interrupt service or event driven programs. The interrupt service program execution does not occur automatically. Its execution is always stipulated to the occurrence of a certain interrupt signal. When an interrupt signal takes place, the currently executed program is suspended and the interrupt program is executed. From the point of view of programming languages, all the PLCs support ladder language and some of them in addition to the ladder language support function block and/or structured text-programming languages. In this work, the structured text programming language has been used. This language is very close to the well-known Pascal language.

WxPython is a cross platform for Python programming language. Its library allows programmers to develop highly graphical user interfaces (GUI) for their programs using menu bars, menus, panels, static text, text ctrl, radio item, check item, button, toggle button, and combo box. In WxPython all the elements of a GUI are contained within top level windows such as wx.Frame or wx.Dialog [16].

Modbus protocol is widely used in industrial field. It supports client/server communication between field devices such as PLCs, VFDs, and smart input/output units. Modbus devices are provided with well-defined Modbus memory map. PyModbus is a full Modbus protocol implementation. It uses asynchronous communication over TCP/IP connection [17]. It allows reading of data from PLCs and writing data to PLCs over Ethernet connection [18]. The PLCs data can be accessed as bit(s) and word(s).

Because of its key role in industry, the VFD gained the interest of researchers; Liang *et al.* [19] investigated the operation and starting of three phase induction motors driven by variable frequency drives. They stated, operation of induction motors with VFDs provides flexible speed control and to produce the same starting voltage as the cross-line starting for high inertia loads, the required starting voltage at the motor terminal shows large variation at the starting frequency of VFDs between 2-10 Hz and this explain why VFDs are provided with voltage boost function. Jiang and Zhang [20], used VFD and PLC to build speed regulation system for elevator. With this combination they found, the elevator reliability and passenger comfort had been improved in addition to reduced maintenance and power consumption. Mahmood *et al.* [21] developed a PLC-HMI driven platform to control the speed of VFD fed three-phase induction motor using a fuzzy logic controller and the traditional proportional integral derivative (PID) controller. Jasim *et al.* [22] introduced an Arduino based speed controller for three-phase induction motor through the adoption of the constant voltage to frequency ratio (V/f) operation mode of the AC drive. Ramesh *et al.* [23] show that conservation of energy for hydraulic clamping system in CNC machine can be achieved when using a VFD driven pump. Puja and Syed [24] stated that VFD allows to control the induction motor with the reduction in power consumption. Gómez *et al.* [25] studied the feasibility of energy saving by implementing flow regulation at constant load in feed water pumps in a sugar industry. Jasim *et al.* [26] used four VFD units to control the speed of four submersible water pump and the light intensity of four lamps (each VFD controls one pump and one lamp) according to the voltage control signals derived from the IIR filter.

The VFD is provided with simple keypad to configure its parameters. This keypad is not robust, but it is suitable and efficient for industrial applications in which the VFD is configured during the design phase and may be modified in the commissioning and running phase. It cannot be used for training applications which exposes the keypad’s keys for large number of finger pressing in addition to the time period required for each parameter modification or setting. To overcome this situation and create a practical VFD training platform, the proposed platform should have the following features: i) having a user-friendly educational software utility to practice the VFD’s parameter configuration, ii) provide real time monitoring for the behavior of the VFD under parameters changes, iii) provide history recording utility for the VFD’s voltages

(DC link voltage and output voltage), output frequency, Output current, and torque in addition to the shaft speed, and iv) allow the experimental understanding of the VFD built-in PID utility.

2. THE PROPOSED PLATFORM HARDWARE AND THE WXPYTHON BASED GRAPHICAL USER INTERFACE

To fulfill the requirements of the work's aim, the platform's overall construction has been divided into two parts. These are the hardware part and the software one. The details of the platform hardware setup and the graphical user interface based WxPython are will explain in the next subsections.

2.1. The platform's hardware setup

The hardware part consists of a personal computer, PLC panel, VFD unit, two induction motor, shaft encoder, and capacitor bank as shown in Figure 1. The specification of the various components is listed in Table 1. The hardware wiring is illustrated in Figure 2.

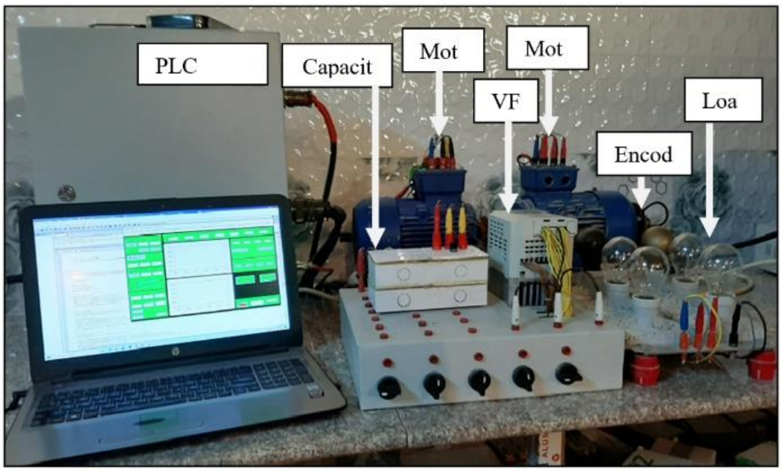

Figure 1. Hardware setup

Table 1. Hardware components

Component	Description
PC	HP, Processor: Intel® Core ™ i5
PLC	XEC-DR28UA/DC
VFD: LSLV00-155100-4EONNS	Input: 380-480 V, 3 phases, 50/60 Hz, HD=4.2A, ND=5.5 A. Output: 0-Input voltage, 3 phases, 0.1-400HzHz, HD=4 A, ND=5.1 A.
3-Phase Induction Motor (M1)	220/380 V, Delta/Star, 0.75 KW, 3.2/1.6 A, 2845 r.p.m
3-Phase Induction Motor (M2)	220/380 V, Delta/Star, 0.75 KW, 3.55/2.05 A, 1390 r.p.m
Capacitor Bank	3×20 µF ;star connected
ABL8RDS24030	A 24 VDC, 3 A, power supply
Resistive Load	6×100 W lamps
Magnetic Contactors: LC1D09	Two magnetic contactors.

2.2. The WxPython based graphical user interface

The operation screen of the proposed training platform is shown Figure 3. From the figure, it can be noticed how user configures the LSLV-S100 VFD's parameters, run the VFD for driving the three-phase induction motors, and monitor or record the current, voltage, and frequency supplied to the motor. In addition to that, also the shaft speed, torque, and DC link voltage may be configured.

2.3. Method

The proposed work anchored on two internal PLC's communication networks. These are the computer network (Cnet) and the fast Ethernet network (FEnet). The former, the Cnet, has been used to communicate the PLC with the VFD (LSLV-S100). For this network, the peer-to-peer (P2P) has been selected as operation mode whereas the Modbus RTU Client has been selected as P2P driver. The read and write areas for this network are listed in Table 2. The later, the FEnet has been used to establish the communication between the PLC and the PC. For this one, the Modbus server has been adopted as server mode with %IX0.0.0 as bit read area start address, %QX0.0.0 as bit write area start address, %MW0 as word read area start address, and %MW100 as word write area start address for the Modbus settings.

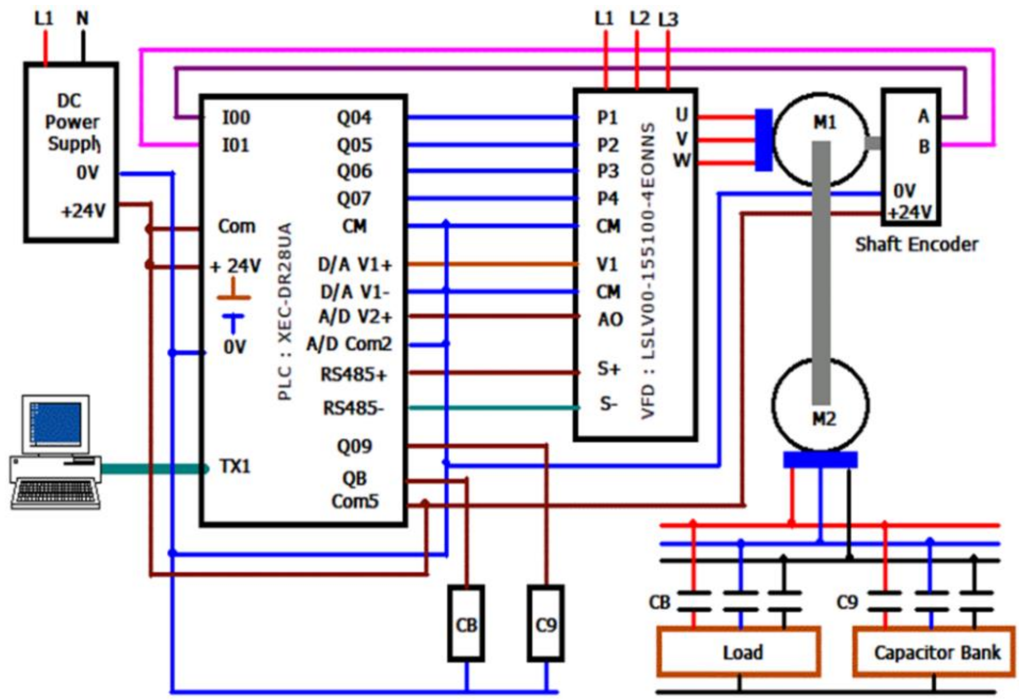

Figure 2. Hardware wiring

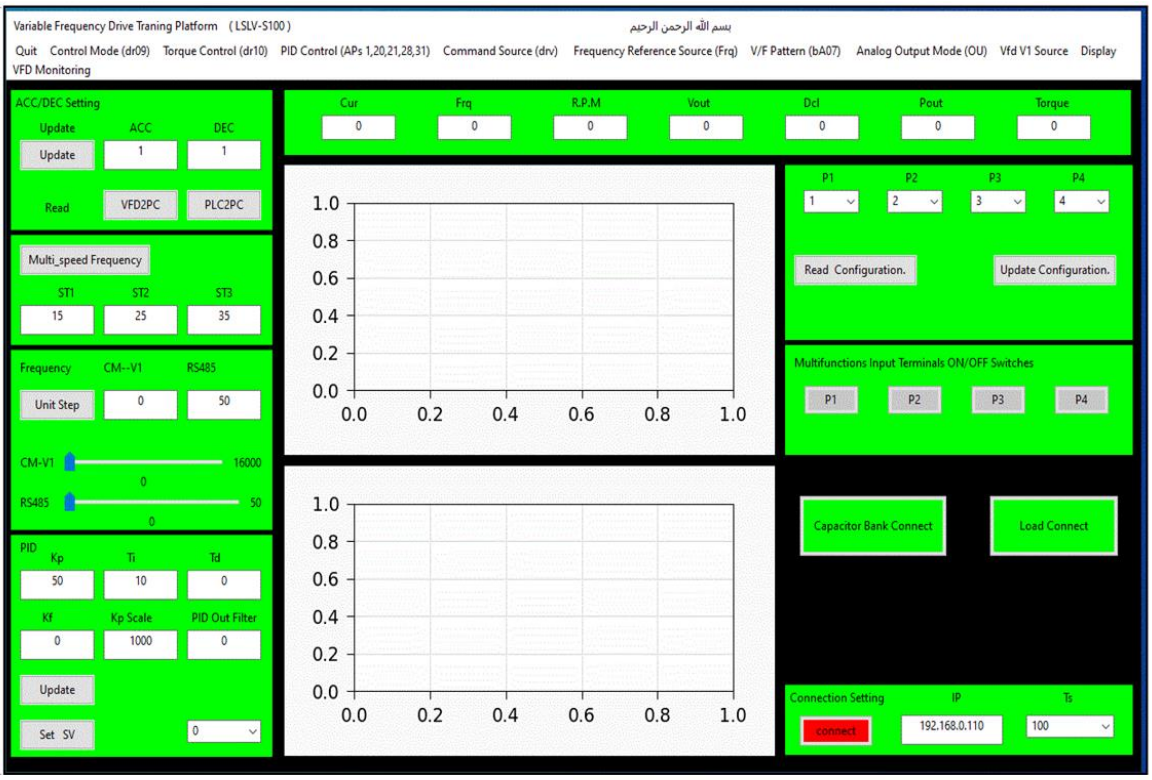

Figure 3. Operation screen

The VFD’s parameters reading and setting is executed by the WxPython user program through the event driven concept. The WxPython user programed controls the conditional flags and the PLC memory areas listed in Table 2 to set or read the VFD’s parameters via the PLC as shown in Figure 4. The PLC uses its high-speed counter instruction to calculate the motor running speed and feed this speed to WxPython user program. It also uses it digital to analog and analog to digital facilities to control the VFD (via its V1 terminal) and read its analog output (AO). The real time mentoring and recording of the VFD’s output variables (voltage, frequency, current, DC link voltage, and torque) and the motor shaft speed are executed making use of the WxpPython timer event.

Table 2. The PLC and the VFD Modbus memory address

Index	Conditional Flag	PLC Memory Start address	S100 Start address -1	Data Size	Parameters
0	%MW118.8	%MW12	0X3030F	8	Current, Frequency, r.p.m, feedbackspeed, Vout, DC link voltage, power, and torque
1	%MW119.9	%MW120	0X41105	2	Command and frequency reference sources
2	%MW119.1	%MW126	0X0004	1	Command frequency
3	%MW119.2	%MW140	0X41540	5	P1 to P5 terminals function settings
4	%MW119.3	%MW40	0X31540	5	P1 to P5 terminals function reading
5	%MW119.4	%MW30	0X30006	2	Acceleration and deceleration times reading
6	%MW119.5	%MW130	0X40006	2	Acceleration and deceleration times setting
7	%MW119.6	%MW190	0X41F04	3	St1,St2, and St3 setting
8	%MW119.7	%MW195	0X41108	1	Control mode
9	%MW119.8	%MW196	0X41109	1	Torque control enable
10	%MW119.9	%MW197	0X41107	1	Torque reference setting
11	%MW119.10	%MW198	0X41206	1	V/F pattern
12	%MW118.0	%MW199	0X41813	1	PID reference source
13	%MW118.1	%MW200	0X41814	1	PID Feedback source
14	%MW118.2	%MW201	0X41800	1	Application function selection
15	%MW118.3	%MW202	0X41815	6	PID’s parameters setting
16	%MW118.4	%MW210	0X41812	1	PID reference setting
17	%MW118.5	%MW211	0X4181B	1	PID mode
18	%MW118.6	%MW212	0X4181E	1	PID output inverse
19	%MW118.7	%MW213	0X41600	1	Analogue output mode

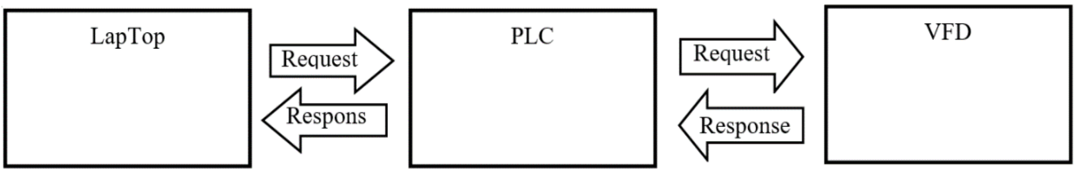

Figure 4. Master-slave and query-response between the laptop, PLC and VFD

3. PERFORMANCE TEST’S EXAMPLES

The proposed platform has been tested for linear V/F pattern operation as shown in Figures 5, 6, 7, square2 reduction V/F pattern operation as shown in Figure 8, open loop operation as shown in Figure 9, and closed loop or PID loop operation as shown in Figure 10. Figure 5 displays the performance under linear V/F ratio with 10 sec acceleration time (ACC) and 1 sec deceleration time (DEC). The figure shows the linear relation between the VFD output frequency and output voltage and also shows how the ACC and DEC parameter settings affect the speed of reaching the rated speed and the zero speed. Large acceleration ensures soft increase in the shaft speed and the VFD output voltage r.m.s value and frequency, and an absence of the current overshoot. Sharp (small time) deceleration causes sharp decrease in the shaft speed and VFD output voltage r.m.s value and frequency but appearance of current overshoot due to the electrical breaking required to narrow the deceleration period. Figure 6 displays the performance under linear V/F ratio with 1 sec acceleration time and 10 sec deceleration time. These settings cause sharp transition from the standstill to the steady state for shaft speed, the voltage r.m.s value and frequency and appearance of some current overshoot in the motor starting current. However, ensures soft deceleration in the shaft speed, voltage r.m.s value and frequency. Figure 7 displays the performance under linear V/F ratio with 10 sec acceleration time and 10 sec deceleration time. For these settings both the acceleration and deceleration process are soft. Figure 8 displays the performance under square2 reduction V/F ratio with 10 sec acceleration time and 10 sec deceleration time. This figure shows nonlinear acceleration deceleration patterns to sustain torque throughout the whole frequency range. Figure 9 shows the VFD’s performance under open loop control mode of operation. In this test, the VFD drives three-phase induction motor, which drives an induction generator (induction motor with excitation capacitor bank). Under this mode of operation, the generation continued for 400 W resistive load and failed to continue for 500 W unit step loading because of the uncorrected drop in the shaft speed. Figure 10 shows the VFD’s performance under PID mode of operation. In this case, the generation continued for 500 W unit step loading because the speed drop is quickly corrected by the PID loop.

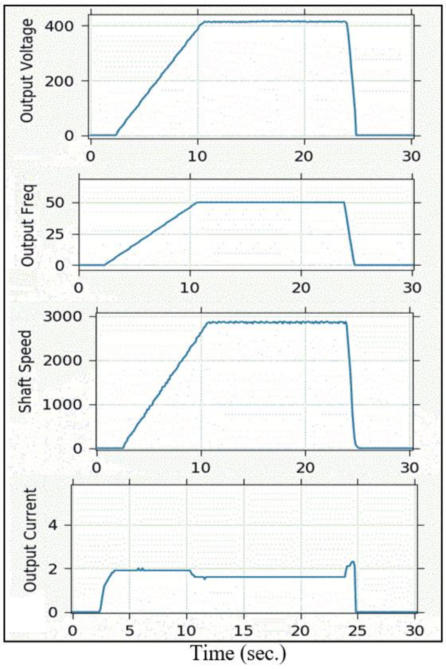

Figure 5. Linear V/F with ramp ACC and sharp DEC

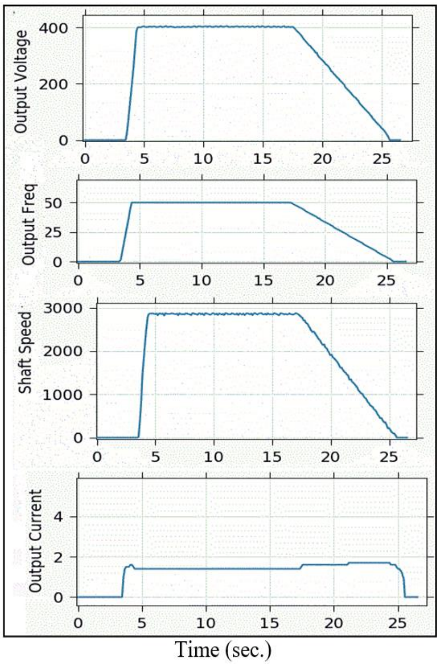

Figure 6. Linear V/F with sharp ACC and ramp DEC

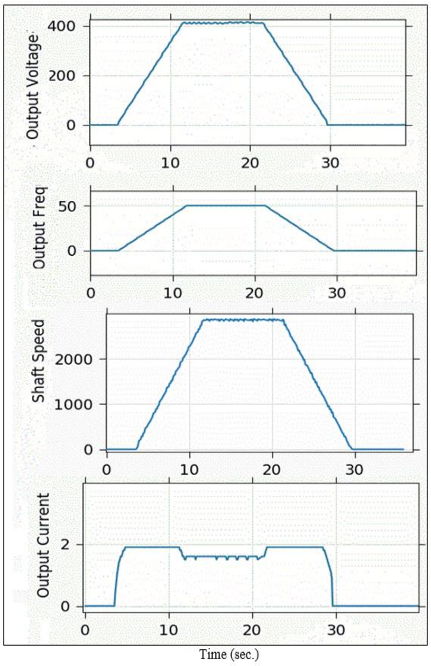

Figure 7. Linear V/F with ramp ACC and ramp DEC

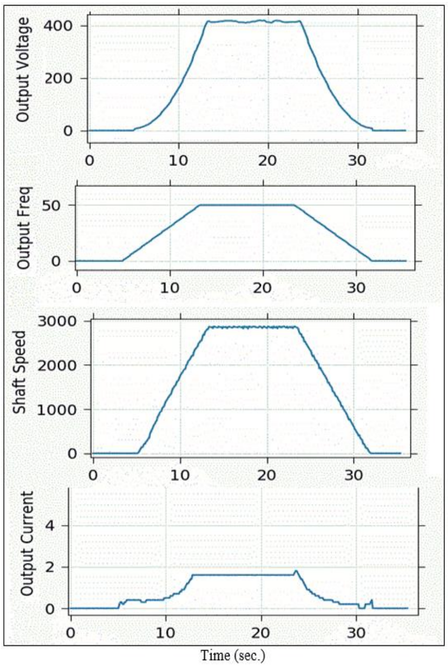

Figure 8. Square2 V/F with ramp ACC and ramp DEC

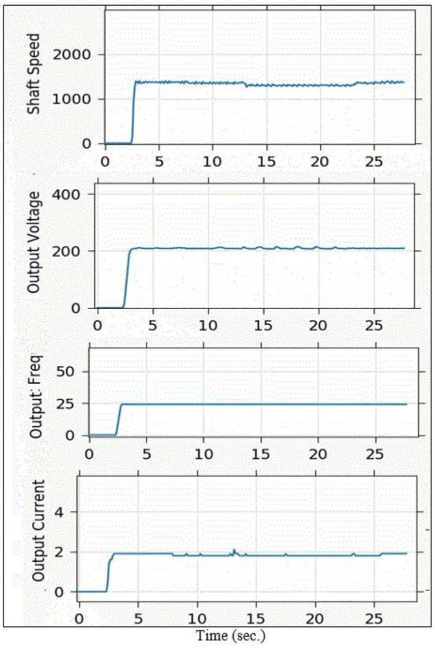

Figure 9. Open loop with 400 W resistive load

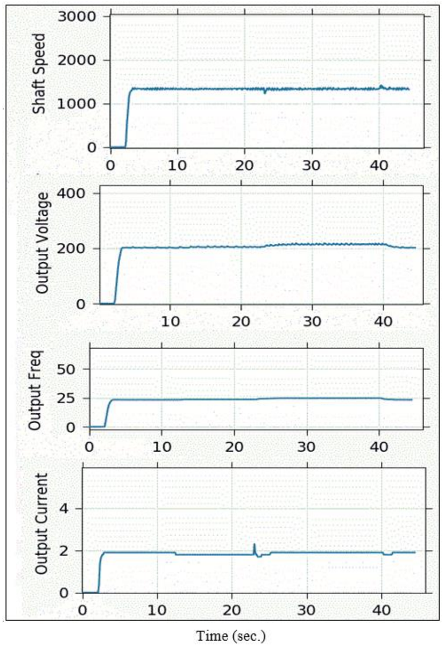

Figure 10. PID loop with 500 W resistive load

4. CONCLUSION

In this paper, PC/PLC based VFD training platform using WxPython and PyModbus has been introduced. The platform design depended: i) the timer class to coordinates the cyclic handshaking between the PC and the PLC; ii) the graphical features of WxPython to develop the required interfacing between the user and the VFD using menu devices (radio and check items), button devices (button and toggle buttons), text devices (static and Ctrl texts items), panel devices to work as containers, combo box items, and plot panel items to display the recorded data as trend graph; iii) Modbus/TCP Client of PyModbus to enable the communication between the PC and the PLC; iv) Modbus RTU communication to establish the communication between the PLC and the VFD; v) the PLC high-speed counter to measure the motor shaft speed using incremental type shaft encoder; vi) the PLC digital to analog modules to control the VFD output frequency via its analog input terminals; and vii) the PLC analog to digital modules to read the VFD analog output. Through the adoption of the graphical features of WxPython, this work introduces a user-friendly and cost effective educational platform through which the users can understand and practice the configuration of the various parameters of the VFD unit. The real time monitoring and history recording facility of this work strengthen the user understanding. The experiments conducted ensure that the user can use this platform to practically understand the effect of the various parameters of LS S100 variable frequency drive unit. In addition, this platform is used to control the speed of induction motor whether in open or closed loop (normal or process PID) mode of operations and see the difference between the two modes.

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