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Remote Laboratory Design for a Control Systems Course: An example case of DC Motors' Speed Control

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***Abstract* -- The pandemic has severely affected the quality of education worldwide, especially regarding actual hands-on experience with the laboratory. Therefore, a remote laboratory is the solution to this issue. Controlling the speed of DC motors is included in the control systems laboratory courses syllabus in many universities worldwide. This study aims to develop a real-time remote DC motor control suitable for use in a remote laboratory. The speed control is implemented using TMS320F28379D ControlCard DSP and MATLAB/Simulink. The DC motor is connected to a host computer. Students can control the DC motor remotely on their computers and connect to the host computer using the TeamViewer. Unlike other remote laboratories, where most provide a simulation environment, the proposed platform can give actual hands-on experience. The proposed platform is tested experimentally and compared with the simulation results.**

***Index Terms*—DC-motor control, digital signal processing (DSP), control systems laboratory, and remote laboratory.**

I. Introduction

The pandemic has severely affected the quality of education in the world. Particularly, United Arab Emirates University (UAE-U) has decided to offer distance learning from Spring 2019 to Spring 2022. Hence, the normal teaching activity has begun this semester (Fall 2022). One of the challenges in teaching during the pandemic is delivering laboratory courses. In the Department of Electrical & Communication Engineering (EECE), modifications have been conducted to the syllabus of its laboratory courses. For the course of Instrumentation and Control Laboratory (ELEC433), activities relating to programmable logic controllers (PLC) were replaced by simulation software. Other activities were replaced by video demonstrations, where the instructor experimented, and the student just received the results. A similar case happens in the Electric Energy Conversion Laboratory (ELEC481) course. The risk of problems is more significant in ELEC481 because the students and the instructors deal with high-power equipment. Therefore, the students missed real hands-on experience with the experiments, which could degrade the quality of education for engineering courses the quality of education since the concentration of students decreases significantly. Although the university return to its normal operation, UAE-U should have a plan to mitigate similar disasters in the future.

Remote laboratories exist in the literature. Paper [1] discussed the use of the remote lab for teaching an induction motor. However, the established remote laboratory gave minimal access to its students. It is mainly used to see turn ON-OFF the motor using the PLC. A similar condition happened in [2]. The student can only manipulate the experimental variables utilizing the instructor's graphical user interface (GUI). If the students need to give the values of parameters outside the range of GUI, they need to edit the GUI using Java and LabView. The two software are not familiar to the students at the UAE-U. A remote laboratory course is used in one of the countries in the Middle East [3]. However, their solution provides the simulation only. There was no actual hands-on in the lab. The same system was used in [4]. Another remote lab based on simulation is found [5]–[6]. An actual physical remote laboratory was developed in [7]. However, it used an expensive device, such as a sophisticated data acquisition board. A cheaper solution for the remote lab using Arduino was proposed in [8]. However, the application was merely turning ON-OFF the LED lamps. Based on the existing literature, no solution satisfies the requirement as stated in the research question. This research will try the indigenous solution for establishing a remote laboratory suitable for ELEC433.

Speed control of the DC motor can be designed as one example to implement a remote laboratory suitable for ELEC433. Adjustable speed drives may be operated over a wide range by controlling armature voltage. Nowadays, the advances in technology in power electronics, such as diodes, transistors, and IGBT/MOSFET, along with various analog/digital chips used in firing/controlling circuits, have brought a total revolution in the speed control of DC drives. So, these speed drives have now dominated the area of variable speed because of their low cost, reliability, and simple control and are more accessible for control in innumerable areas of applications.

This paper addresses real-time DC motor speed control using the TMS320F28379D digital signal processor (DSP). The rapid and revolutionary progress in power electronics and microelectronics in recent years has made it possible to apply modern control technology to the area of motor and motion control. All the program can be designed in MATLAB/Simulink that can provide friendly platform for the student. The experimental setup is connected with a host university. The host university is connected with the students' computer using the TeamViewer.

II. Methodology

The schematic of the testbed is shown in Fig. 1. The testbed comprised of the foundation structure, the DC motors, velocity sensors, TMS320F28379D DSP controller and its power switch (DC-DC Boost Converter). The movable flatform is made from light materials and easy to move. The DC motor foundation is supported by strong steel foundation with wheels. The velocity of the rotating DC motor can be obtained from the encoder. The PID controller will be implemented in the DSP controller. It can be programmed using MATLAB/Simulink. Simulink is a block diagram environment used to design systems with multidomain models, simulate before moving to hardware, and deploy without writing code. Therefore, Simulink is more interactive to the user, especially to the students.

The PID controller can be changed and data from the sensors can be read real-time through the USB cable between the DSP controller and Lab PC. This testbed is equipped with a static web camera. The computers will be installed with a TeamViewer software to enable the remote operation of the testbed.

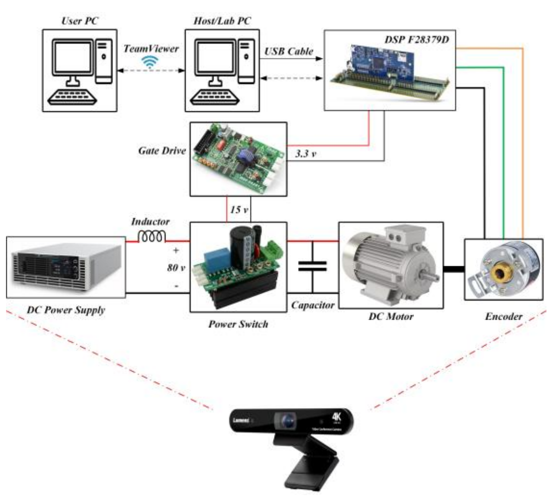

Fig. 1. Schematic of the remote laboratory setup.

Finally, the students enable to conduct experiment remotely. Using the software and the camera, the students will have fully access to the local computer. They can conduct experiment with the same capability compared to the direct experiment using the local controller.

A. Design Speed control of DC-motor in MATLAB/Simulink

Simulink is a software program with which one can do model-based design such as designing a control system for a DC motor speed-control. This section discusses the speed control for DC motor, which is usually used for speed setting and angular position adjustment. The electrical diagram circuit of the direct current (DC) motor using the armature current control method is shown in Fig. 2.

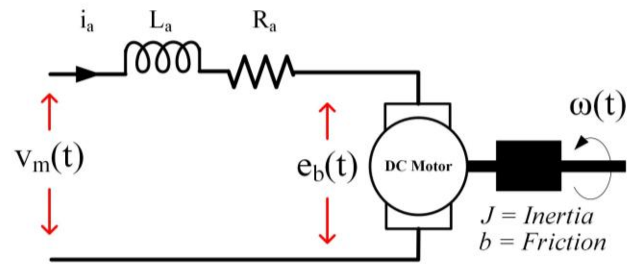

Fig. 2. Electrical diagram for DC motor.

DC motor is used to converter the electrical energy (direct current) into mechanical energy (rotational motion). The motor torque given in equation (1) is results to a constant filed current established in a field coil. While the relation between the input voltage to the armature and armature current is shown in equation (2), also the relationship between back electromotive voltage and motor speed explained in equation (3). Equation (5) shows the relation between motor torque and both load torque and disturbance torque.

$$T_m = K_t i_a(s) \tag{1}$$

$$V_m(s) = R_a i_a(s) + sL_a i_a(s) + e_b(s) \tag{2}$$

$$e_b(t) = K_b \omega(s) \tag{3}$$

$$i_a(s) = \frac{V_m(s) - K_b\omega(s)}{R_a + sL_a} \tag{4}$$

$$T_m = sJ\omega(s) + b\omega(s) \tag{5}$$

$$(sJ + b)\omega(s) = K_t \frac{V_m(s) - K_b\omega(s)}{R_a + sL_a} \tag{6}$$

The speed of DC-motor is proportional to the armature voltage. thus, the DC-DC boost converter is utilized to control the armature voltage. the schematic diagram of DC-DC boost converter is shown in the Fig. 3.

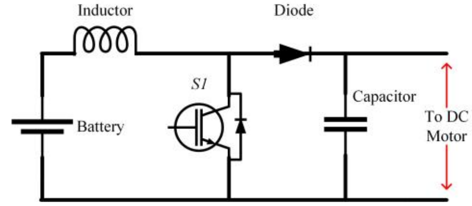

Fig. 3. Schematic of DC-DC boost converter.

The speed control of DC-motor is simulated first in the MATLAB/Simulink. This platform gives initial study of the proposed system. MATLAB/Simulink has given the electrical model, such as voltage DC source, inductor, capacitor, DC-motor and PID block. The design of speed control of DC-motor in MATLAB/Simulink is presented in Fig. 4.

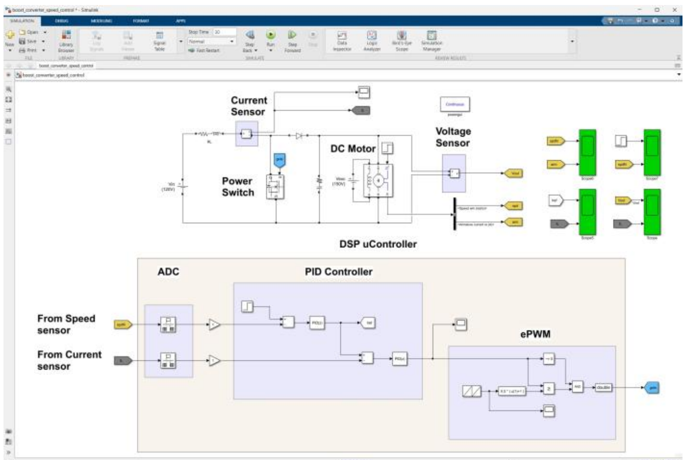

Fig. 4. Design speed control of DC-motor in MATLAB/Simulink.

B. *TMS320F28379D DSP controller.*

This paper addresses real-time DC motor speed control using the TMS320F28379D digital signal processor (DSP). The TMS320F28379D is a dual-core microcontroller, with two 32-bit CPU cores running at maximum clock speed of 200 MHz. it has a rich set of peripherals and interfaces, including up to 24 12-bit ADC channels, up to 12 PWM output, up to 8 ePWM modules, up to 4 quadrature encoder interfaces, up to 3 CAN ports, up to 2 SPI interfaces, up to 3 SCI/UART interface and up to 2 I2C interfaces. The TMS320F28379D is designed to provide high performance and flexibility in real-time control application. It also supported by comprehensive set of development tools and software, including code composer studio (CCS) integrated development environment (IDE), which provides a comprehensive toolset for software development, debugging and programming of the microcontroller (i.e., through the MATLAB/Simulink). Therefore, this microcontroller is friendly user for student. The controller board is shown in the Fig. 5.

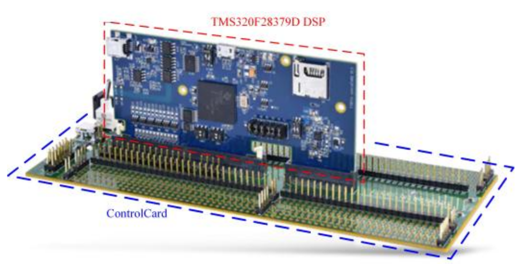

Fig. 5. TMS320F28379D digital signal processor (DSP) ControlCard board.

In each discrete-time-step, the DSP controller board takes some action to generate the digital control signals. The type of action is governed by what we have programmed in this board with the help of MATLAB/Simulink in real-time interface. The TMS320F28379D DSP is integrated with the ControlCard board. This board is a development board for the TMS320F28379D microcontroller that is designed to provide a convenient and easy-to-use platform for evaluating, prototyping, and developing applications. The ControlCARD is a small form factor board that can be plugged into a variety of expansion boards, allowing for easy customization and flexibility.

board monitors the input (i.e. motor current, speed, voltage and so on). The current and voltage input can be read using ADC block while the speed use eQEP block to read the speed. Based on the inputs and the variables that need to be controlled (i.e. motor speed); it takes the programmed action to generate the controlled digital signals. These control signals dictate the magnitude and phase of the PWM voltage source. They are generated by the ePWM block.

C. *Hardware DC-DC Boost Converter.*

The laboratory prototype of DC-DC boost converter for controlling DC motor is shown in Fig. 6. This PCB board provides the terminal for input DC supply and the output DC voltage to control the motor for a desired speed. The DC input voltage is directly generated by using the DC power supply. Then, the capacitance of capacitor being used is 2700 μF and the nominal voltage rating of each of SMs capacitor is 400 V. In this design, the capacitor voltage rating is two times higher than the rated voltage in the output terminal due to a space for safety margin. The converter is connected directly to 80 V DC power supply. In the experiment, the inductance value is 3.5 mH, which can give less enough the current ripple.

Fig. 6. DC-DC Boost converter board.

The speed control programmed in TMS320F28379D ControlCard DSP. The output power from the DSP is relatively small and not enough to trigger the power switch. The power switches such as IGBT or MOSFET are completely off when the gate voltage is below the threshold value, normally in the range of $0 – 4$ V. When the gate voltage reaches approximately $11\ V - 15\ V$, which is above that threshold value, the drain current starts to flow depending on the gate voltage and the rated value is obtained. Therefore, a gate driver circuit is needed to trigger the power switch based on the switching pulses generated from the controller. The circuit of gate drive is shown in Fig. 7, where one set gate drive circuits is assembled in one set of PCB. The gate drive circuits have a low output impedance that can supply relatively large current to the IGBT to attain a switching speed of 10 kHz or more.

An optocoupler is one of the most essential components in the gate driver circuit. It integrates a silicon phototransistor and an infrared light-emitting diode. The gate drive circuit consists of 2 inputs which are 15 *V* DC input and 3.3 V DC input from the controller. The input signal from the controller is applied to the infrared light-emitting diode pins, while the 15 *V* DC supply is passed from the phototransistor pins. It is used to interface the logic circuit with the IGBT gate terminals in order to obtain the required level shifting. Thus, the gate drive provides 100% isolated circuit to secure the controller.

Fig. 7. Gate driver board.

D. DC-motor and Encoder.

This system contains the DC motor that needs to be characterized or controlled. The system has a mechanical coupling arrangement and stand steel foundation. The system also has an encoder mounted on the rotor shaft which is used to measure the speed of DC motor Fig. 8. This can be used for close loop feedback speed-control of the motor. The motor demands a controlled pulse-width-modulated (PWM) voltage to run at controlled speed. The controlled voltage is generated by DC-DC boost converter.

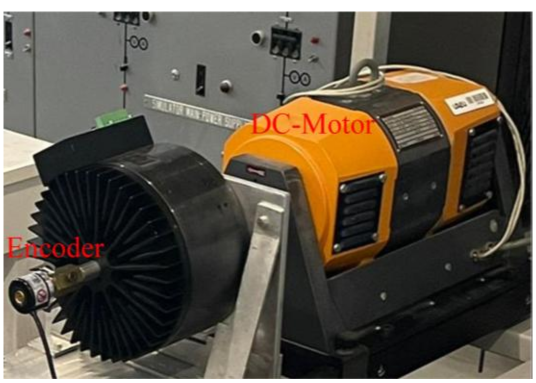

Fig. 8. Set up of DC-motor.

This system uses the quadrature encoder sensor to measure the rotor position. The quadrature encoder sensor consists of a disk with two tracks or channels that are coded 90 electrical degrees out of phase. This creates two pulses (A and B) that have a phase difference of 90 degrees and an index pulse (I). Therefore, the controller uses the phase relationship between A and B channels and the transition of channel states to determine the direction of rotation of the motor. The explanation is illustrated in the Fig. 9.

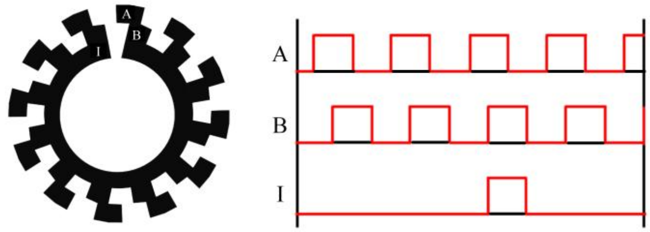

Fig. 9. Schematic of working principle of encoder.

E. Control Desk for TMS320F28379D using MATLAB/Simulink.

The TMS320F28379D is a digital signal controller (DSC) from Texas Instruments, which is designed for control applications that require high performance and real-time processing. The I/O ports of the DSP are accessible from inside the Simulink library browser. Creating a program in Simulink and the procedure to use the I/O TMS320F28379D DSP will be detailed in future experiments. At this stage, let us assume that we have created a control-system inside the Simulink that can control the speed of a DC motor. When you build/Deploy the Simulink control-system, it implements the whole system inside the TMS320F28379D DSP board, i.e. the control-system that was earlier in software (Simulink) gets converted into a real-time system on hardware.

The control desk is a graphical user interface (GUI) that allows the user to interact with the TMS320F28379D-based system. To implement a control desk for the TMS320F28379D, a software tool like MATLAB/Simulink, which provides a set of blocks to interface with the DSC and create a graphical interface. Here several steps to create a control desk using MATLAB/Simulink:

1. Add the required blocks for communication with the DSC, such as the "F28379D Serial Write" block for sending data to the DSC and the "F28379D Serial Read" block for receiving data from the DSC, as shown below.
2. Add the blocks that need to be commands or references, commonly constant block.
3. Build the control-system and deploy it to the TMS320F28379D using the integrated TI C2000 Code Generation Tools.
4. Run the control algorithm on the TMS320F28379D and interact with it through the control desk.

III. Real-Time Implementation of TMS320F28379D DSP

The real-time speed control implementation using TMSS320F28379D is presented here. There are 2 Simulink platform that need to be created, namely the DSP digital control system and DSP control desk platform. First platform is the DSP digital control system of speed control as shown in the Fig. 10. In this Simulink platform there are few necessary blocks to be placed inside the platform such as speed measurement block, PID controller, serial receive, serial send and ePWM. Serials receive and serial send are very important to link these two Simulink platforms, which are DSP digital control system and DSP control desk platform. Therefore, the speed can be controlled and monitored in real-time. This link communicates through the USB/UART cable between the DSP controller and the lab computer.

The design control-system is built/deployed into the TMSS320F28379D DSP controller by clicking the Deploy bottom. The control-system for speed control requires speed measurement, PID controller and ePWM.

The enhanced quadrature encoder pulse (eQEP) module is used for direct interface with a linear or rotary incremental encoder to get position, direction, and speed information from a rotating machine for use in a high-performance motion and position-control system. The used encoder output typically has three signals - channel A, channel B and channel. Connect these signals to the corresponding input pins of the quadrature decoder block. In the eQEP module configuration, set the input mode to quadrature mode and select the quadrature decoder block as the input source.

The cnt port accepts the quadrature encoder counter value. Then, Idx port is enabled when the External index count is checked. Idx port accepts the counter value at last index pulse. The block only accepts scalar unsigned integer based on the Counter size parameter. Finally, θ (position) port accepts the position signal as either scalar fixed point or scalar floating point data type and it converts into speed using the speed measurement block. In this the speed measurement configurations, the blocks is choosed the appropriate measurement type (e.g., speed in radian, degree or per-unit). The sample period is needed to determine how often the speed measurement block will calculate the speed of the encoder. Set this value according to the needs (e.g., For example, a high-speed measurement, set a smaller sample period). The speed measurement configuration is shown in Fig. 11. The last, the output can be filterized for a better result.

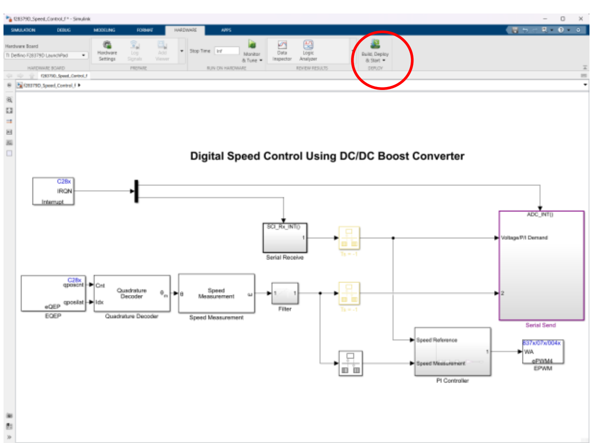

Fig. 10. The control system of speed control of DC motor.

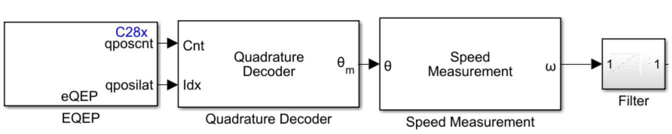

Fig. 11. Block configuration of speed measurement

As mentioned before, the control desk has function to give real-time control and monitoring. The platform of the control desk is presented in the Fig. 12. Configures Serial Communication Interface (SCI) of the DSP controller has funtion to receive data from the USB/UART cable. This enables asynchronous serial digital communications between the MCU and other connected peripherals. Then, the serial Communication Interface (SCI) of the DSP controller transmits data via USB/UART cable. This enables asynchronous serial digital communications between the DSP controller and the control desk.

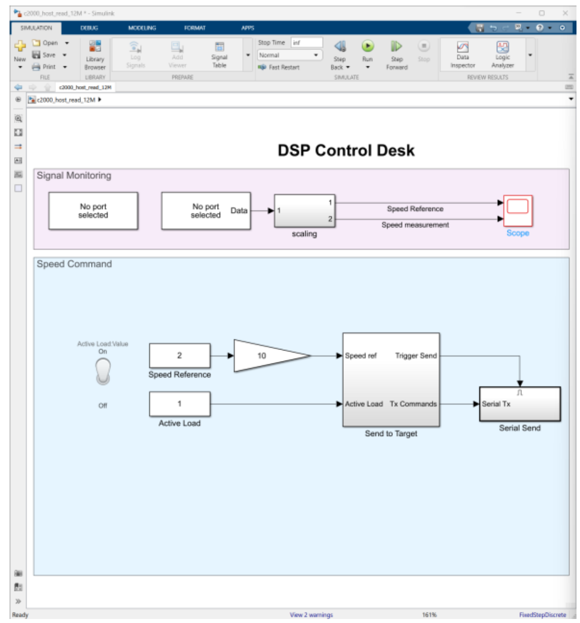

Fig. 12. DSP control desk.

TeamViewer is a popular software tool that enables remote access and control of computers over the internet. It is commonly used for remote support, remote access, and online meetings, and it can also be used for remote laboratory applications.

In a remote laboratory setup, TeamViewer can be used to enable remote access and control of lab equipment, such as oscilloscopes, computer laboratory and other controller devices. This allows students and as well as researchers, to perform experiments and measurements from anywhere in the world, without the need to physically be in the lab.

To use TeamViewer for remote laboratory applications, the lab equipment needs to be connected to a computer that has TeamViewer installed. The computer can then be accessed remotely using another computer or called the user computer with TeamViewer installed, either over the internet or a local network.

Once the remote connection is established, the user can control the lab equipment using the remote computer as if they were physically present in the lab. This can include adjusting the settings of the equipment, taking measurements, and collecting data. The hardware setup is presented in the Fig. 13. It consist of lab PC, user/student PC, the DC-motor, encoder, DC-DC boost converter and TMS320F28379D DSP ControlCARD.

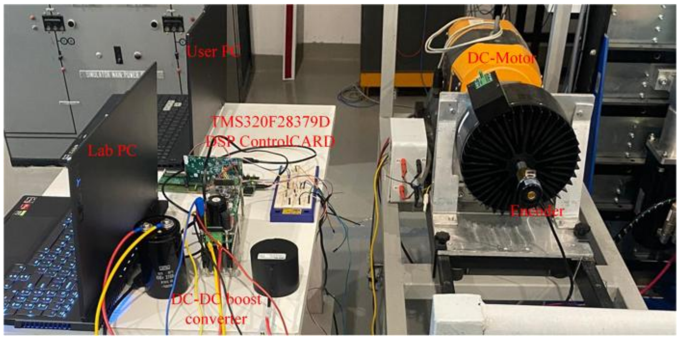

Fig. 13. Hardware setup.

IV. Result & Discussion

The experimental performance results of the proposed remote laboratory for controlling the DC-motor is presented here. To evaluate the performance of the system, a series of measurements has been accomplished. The test can be divided into two. The first is a step change of the speed by giving a few / random voltage by setting the duty-cycle without control-system. The result without control-system is shown in Fig. 14. Secondly, the step change of speed reference is given from the user/student PC through the TeamViewer is shown in Fig. 15 with control-system. These results are absorbed from the user/student through TeamViewer as shown in Fig. 16.

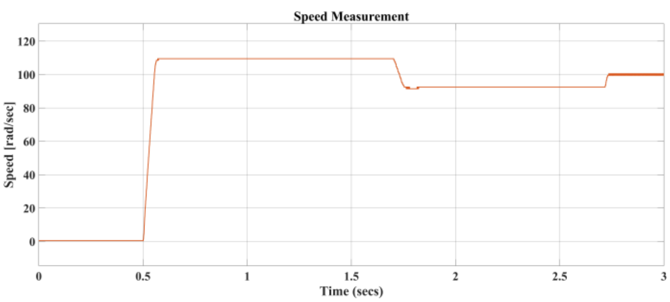

Fig. 14. The step change of the speed without the control system.

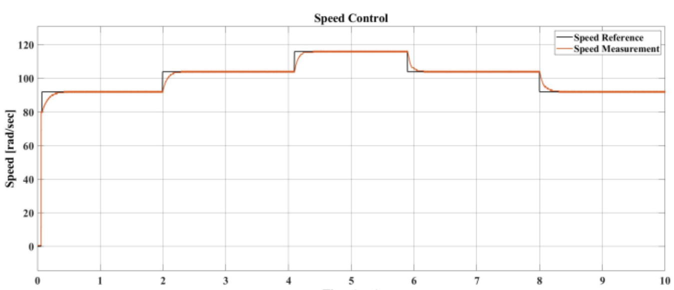

Fig. 15. The step change of the speed with the control-system.

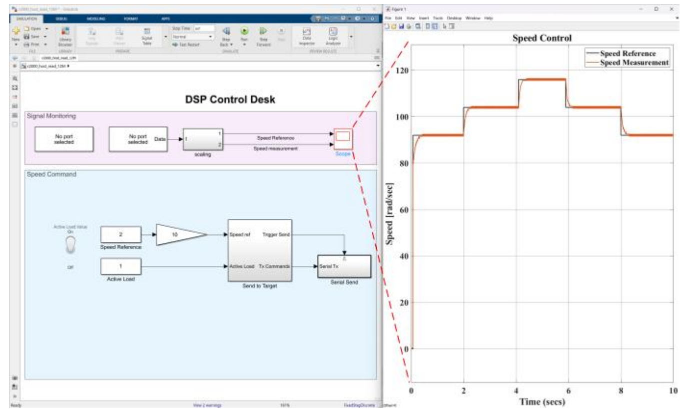

Fig. 16. The control desk platform.

V. Conclusion

The testbed has successfully built that operates remotely and is easily accessed by students, this project offers education of labs online without compromising the knowledge obtained from laboratory activities, it maximizes the students' hands-on experience, and it doesn't constrain the number of students allowed in a lab room. It is low-cost implementation, and it is accompanied by a lab manual which contains concepts of control systems from the modeling to the design. Overall, using TeamViewer for remote laboratory applications can greatly increase the accessibility and flexibility of lab equipment, while reducing the need for physical presence in the lab. This can benefit students, especially those who are geographically distant or have limited access to lab facilities due to pandemic.

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