PLC based PID control for induction motor drive using VFD

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In today's rapidly developing and changing landscape, PLC technology, widely used in the field of industrial automation, offers users various solutions. In industry, management, and scientific technical jobs, the execution of tasks without human labor is achieved through automation and machines. In this context, Asynchronous motors are preferred over other electrical machines due to their lower cost and being the most widely used machine in the industry. In this study, the control of an Asynchronous motor was realized using a PLC with a VFD driver. In the established experimental system, the speed of the Asynchronous motor was controlled using a Proportional Integral Derivative (PID) controller algorithm. Different control PID values were experimented with constant speed trials to achieve the best results. The obtained results were interpreted through system graphs.

Keywords: *PLC, Induction motor, PID, VFD.*

1. Introduction

The Programmable Logic Controller (PLC) is widely used in industrial automation systems. The first commercial PLC, initially intended to replace relay control systems, was developed by the Modicon company in 1969 [1, 2]. In those years, this device, developed to be used in place of relay control circuits, only contained basic logical processing commands. In the following years, advancements in technology led to the development of sensor technologies, motion control systems, communication systems, and environmental peripherals, becoming essential in defense, health, communication, energy, and industrial automation [3]. Processor technology developments are implemented in PLCs, with multi-core processors, FPGA, and DSP usage varying according to brand models [4]. New PLCs have become more functional both in terms of programming capacities and size. While previous models used manual programming consoles, new PLC models support command execution necessary for writing a control algorithm using a computer [5]. Sensors, actuators, valves, relays, motors, encoders, and other devices used in automation, instrumentation, mechatronics, and control technologies communicate with PLCs. Depending on the communication protocols used, information flow enables data acquisition, data processing, and data analysis. Commonly used protocols include ProfiBUS, ProfiNET, CanBUS, ModBUS, and DeviceNET. Industrial Ethernet supports communication speeds of 10/100/1000 Mbit. Various programming algorithms are used when programming PLCs, such as command-line sequencing, ladder diagrams, function block diagrams, graphical programming, and structural control language [6].
When investigating recent literature studies, it is observed that Maryam Mammadlı synchronized step and servo motors with SCADA-based PLC in an application involving speed control using S7-1200. They accessed the system through the SCADA system and controlled both the step motor and servo motor. Their work did not include an application for speed and torque control of an asynchronous motor with VFD [7]. Mustafa Bektaş conducted a study on the PLC-based control and torque measurement of a Motor Test Bed. The motor test bed was controlled, and they used a frequency converter to activate the asynchronous motor. The use of an optical reflex sensor was employed to detect the direction of rotation and measure torque. The study did not implement an application for the control of an asynchronous motor with VFD and encoder using PLC S7 1200 [8]. Deniz Akçura conducted a study on garage door control with PLC and asynchronous motor. In this work, an application for an industrial system, a sectional garage door, was realized using PLC and a 3-phase asynchronous motor. Their study did not include an application for speed and torque control of an asynchronous motor with an encoder [9]. Lokman Baran achieved the control and monitoring of the power factor of a three-phase asynchronous motor with PLC. They used PLC S7 200 to implement reactive power compensation in a system where four asynchronous motors were active at different times [10]. Bülent Naci

Güler conducted speed control of DC motors using PID management in PLCs. Their work did not involve speed and torque control of asynchronous motors [11]. İbrahim Yücedağ implemented a PLC-based application for starting rotor-wound asynchronous motors. They prepared the PLC program using MODÎCON A020 PLUS PLC device DOLOG AKL. Speed-torque, speed-rotor voltage, and speed-rotor current curves were plotted with the values obtained in the application. A small but powerful motor was used in the study [12].
This study involves the speed and torque control of a three-phase asynchronous motor using PID with VFD AC drive and encoder assistance. Siemens S7 1214C DC/DC/DC series PLC is used. The system consists of five mechanical components: PC, PLC, VFD (Drive), encoder, and asynchronous motor. The control of the PLC and VFD Drive is carried out with DAC.

2. Details of PLC and PID controller

The Programmable Logic Controller (PLC) technology, widely used in industrial automation, continues to rapidly develop and change, providing users with solutions in various aspects. A complex system can be controlled effectively using a PLC. For the desired system control, the gain, integral, and derivative time parameters are found, and control is achieved using the PID software, which is widespread in industrial control systems [13]. In this context, Asynchronous motors are preferred due to their lower cost compared to other electrical machines and being the most widely used machine in the industry. An Encoder, producing signals based on the movement of the shaft of the asynchronous motor, can monitor how many pulses are generated in each revolution [14]. Variable-frequency drives (VFDs) are used in many areas of the industry to control motor speeds and various activities during motor operation [15].
The Proportional Integral Derivative (PID) controller algorithm consists of the coefficients Kp, Ki, and Kd [16, 17]. The block diagram of the PID controller is given in Figure 1. In the proposed study, different values were tested to find the optimal coefficients. Thus, speed and torque control of the asynchronous motor were achieved, obtaining the desired speed and torque control with the smallest error.

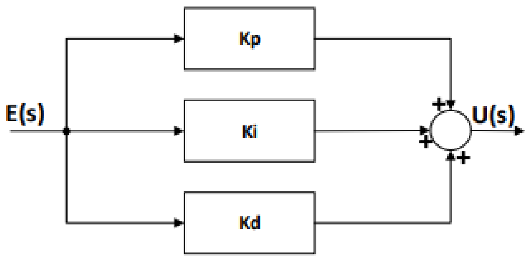

***Figure 1**. The block diagram of the PID controller.*

The block diagram of the proposed system model is provided in Figure 2. In V/f control, the motor speed is controlled by altering the applied voltage (V) and frequency (f) to maintain a constant ratio. The V/f ratio has been kept constant to ensure nominal torque at all speeds up to the fundamental speed of the motor. Using the V/f constant, power and speed are controlled by changing the voltage (V) value in Equation 1 and the frequency (f) value in Equation 2. Additionally, torque control can be achieved as per Equation 5.

$$P = IxVx\cos\phi \quad (1)$$

$$n_s = \frac{120f}{P} \quad (2)$$

$$n_r = (1-s)n_s \quad (3)$$

$$w_r = \frac{2\pi}{60} n_r \quad (4)$$

$$T = \frac{P}{w_r} \quad (5)$$

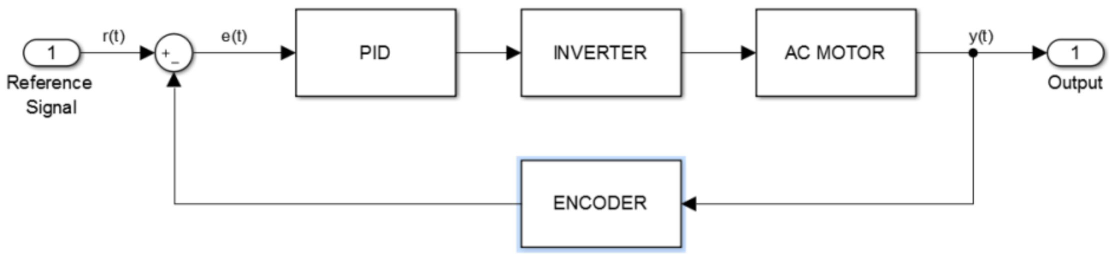

***Figure 2**. The block diagram of the proposed system.*

3. Design of PLC based PID controller of induction motor

In every PLC manufacturing company, different nomenclature types are used for addressing. Internal and external addresses in the PLC are crucial for software. Internal addresses are used within the PLC and cannot be physically traced, connected, or monitored. Storage or status-holding addresses are defined within the PLC for digital or analog values. External addresses are also defined as physical addresses. External addresses hold the positions of circuit elements such as contacts, relays, valves, and limit switches as bit addresses. Digital input addresses include information such as start, stop, emergency stop, limit switch, normally closed contact, and normally open contact, which can alter the flow of the operation. A different input address is assigned for each circuit element in the PLC. Similarly, digital output addresses are used to operate valves, relays, or contactors and have the "ON/OFF" status information. If the used output address is active, it is expressed digitally as "1," and if it is inactive, it is expressed digitally as "0." The programming logic can be modified while the software is running. A visual representation of ladder diagram (LAD) logic, abbreviated as LAD, is provided. Transitions between programming logics are made through the properties window on the software page.

One of the most efficient methods for operating asynchronous motors is the Variable Frequency Drive (VFD) control method, also known as "V/F method." The "V/F method" adjusts the voltage and frequency applied to the motor to maintain a constant ratio of frequency to voltage. Understanding the "V/F control method" requires examining how asynchronous motors operate. Speed control of three-phase asynchronous motors can be achieved using VFDs with PID parameters through PLC. PID parameters, Traditional Proportional-Integral-Derivative (PID) controllers, are widely used in industrial control applications due to their simple mathematical modeling, ease of operation, good robustness, high reliability, stabilization, and the elimination of steady-state errors.

The PLC S7 1200, VFD and asynchronous motor with an encoder connected to the shaft used in the proposed system are given in detail in Figure 3.

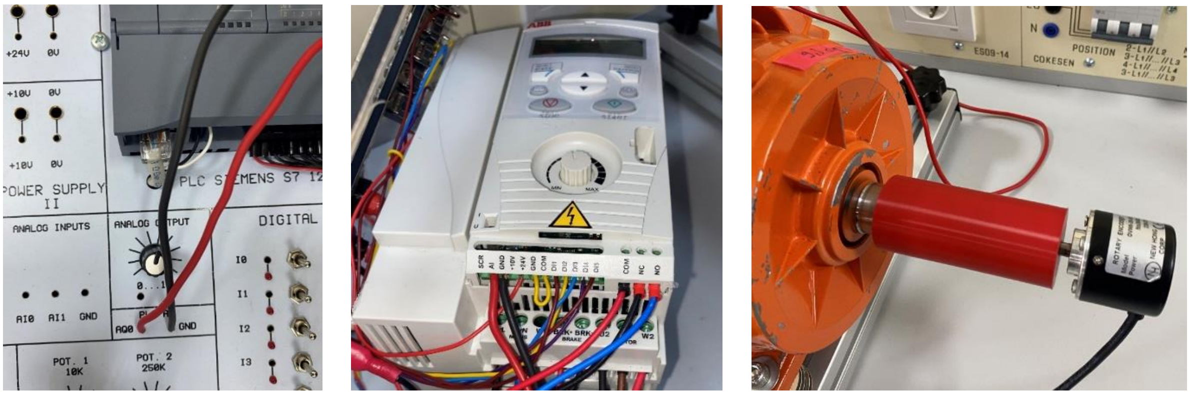

***Figure 3**. The experimental setup of proposed system.*

The proposed project was written using the ladder diagram method by the TIA Portal Program. As seen in Figure 4, a PLC software diagram was created step by step in the TIA portal program interface.

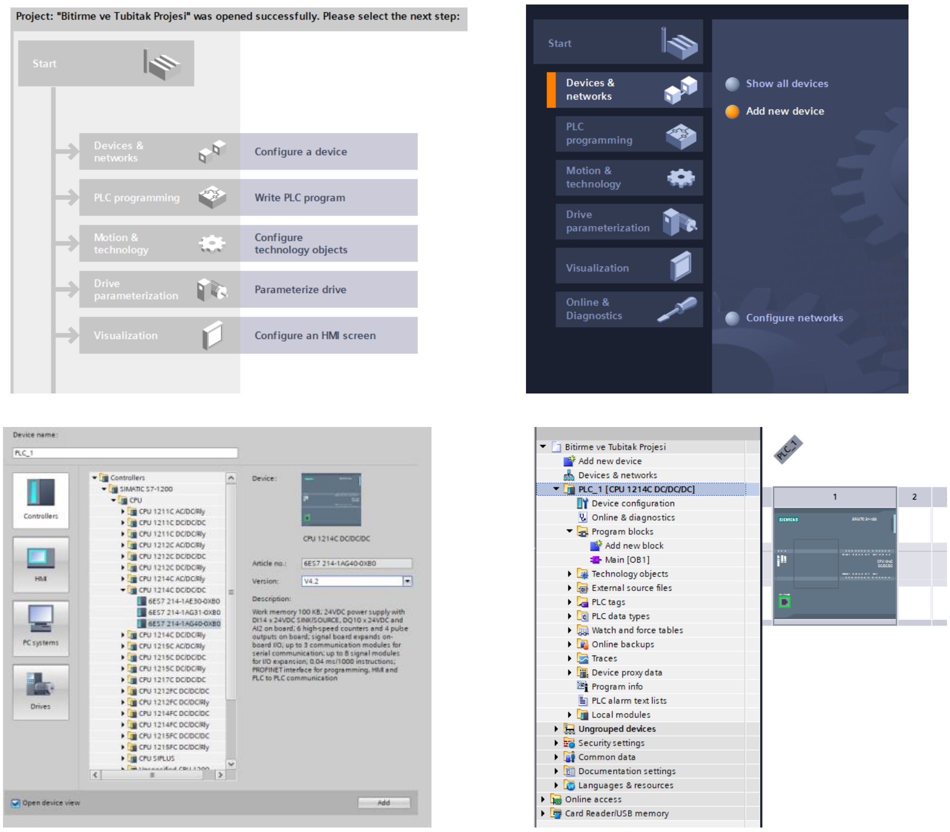

Figure 4. *TIA portal interface for PLC programming.*

HSC (High Speed Counter) was added to the network and transferred the pulse information coming from the leg connections of the encoder, thus the generated pulse information was counted. HSC 6 is set for HSC selection. Since the Encoder used has two outputs, A and B, it was selected as A/B in the function and set as up counter. The A/B outputs of the encoder were connected to pins I0.0 and I0.1 of the PLC and selected as input. The input address of HSC 6 is ID1020. The data at ID1020 has been converted from DInt to Real. The real data was assigned to the MD100 address and the pulse information of the encoder was read. The encoder used in the system produces 2000 pulses per second. Therefore, the data in the MD100 address is divided by 2000 every second and multiplied by 60 to reach the number of rotate per minute (rpm). Figure 5 shows the HSC selection stages for the encoder.

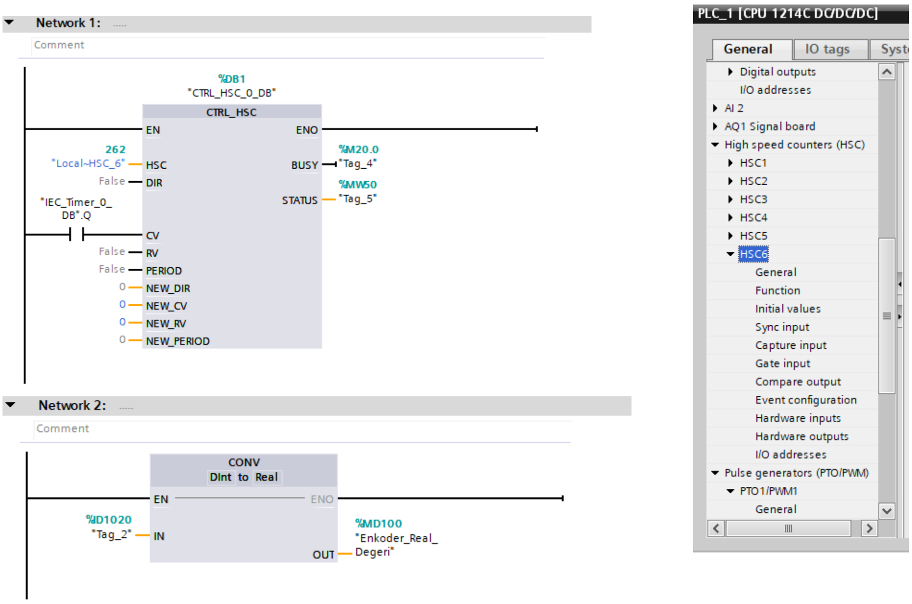

Figure 5. *HSC selection for encoder.*

The PID block will be used in the system control, so the TIA Portal interface should transition to the Cyclic_Interrupt block. The Cyclic Interrupt block is used to execute a program outside the normal scanning time. The desired RPM value for the asynchronous motor's operation is assigned to the Setpoint. The output of the RPM value is assigned to the QW80 analog output address. The control type is set to Speed. Inputs are configured as Input, and Output_per(analog). To ensure that the PID block operates and settles to the set value when the PLC is in run mode, the mode parameter of the PID block is set to 3. Since PI control is performed, 0 is entered instead of the "D" parameter. PID block settings are given in Figure 6.

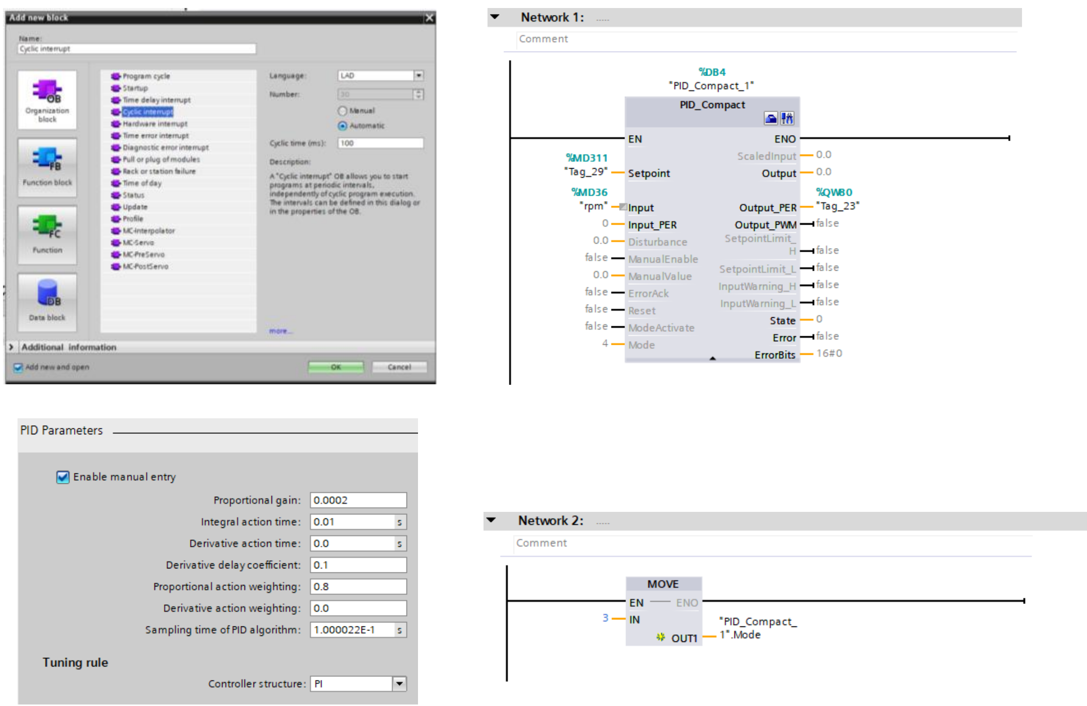

Figure 6. *PID block settings.*

4. Experimental results and discussion

The ABB ACS150 model driver used in the design of the system has one phase input and three phase output. DAC application is required to enable the PLC to communicate with the driver and to adjust the frequency by providing 0-10V voltage. DAC connections: 0-10V is supplied from the AI and GND inputs of the VFD using the AQ0 and GND outputs of the PLC. After performing the parameter settings of the VFD, the LOC/REM button is pressed to drive the motor according to its parameters, the driver is pulled from Local mode to REM mode and PID commands are waited for the system to operate. Figure 7 shows the results obtained when the rpm value is set to 750 rpm.

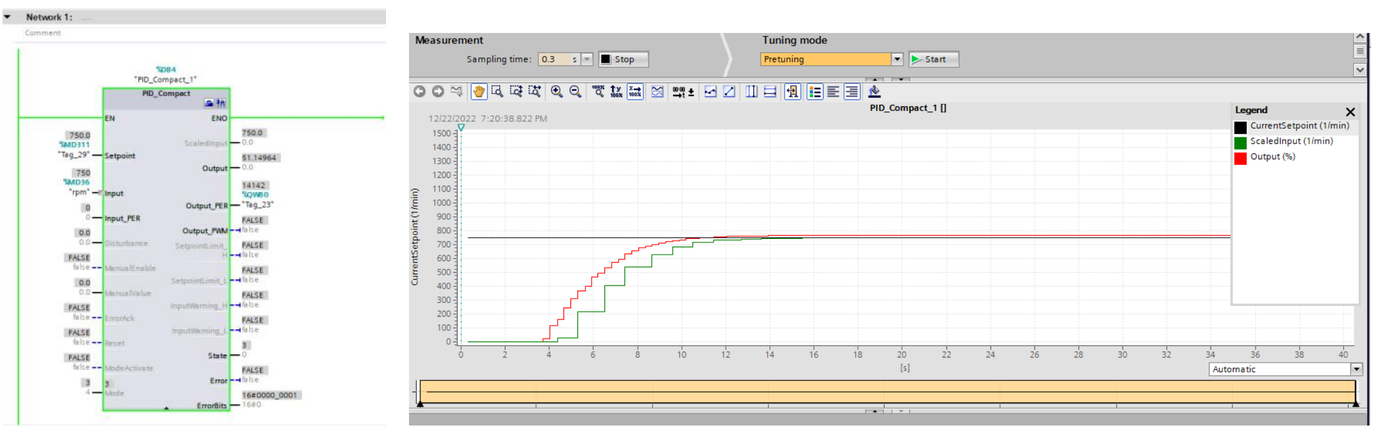

Figure 7. *The results at RPM value 750rpm.*

Figure 8 and Figure 9 show the results obtained when the rpm value was set as 1000 rpm and 1500 rpm, respectively.

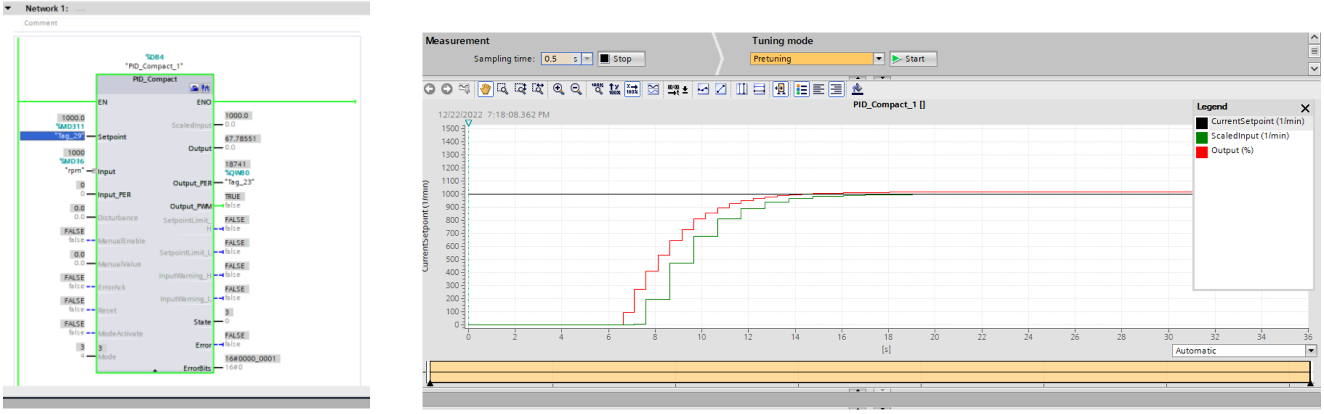

***Figure 8**. The results at RPM value 1000rpm.*

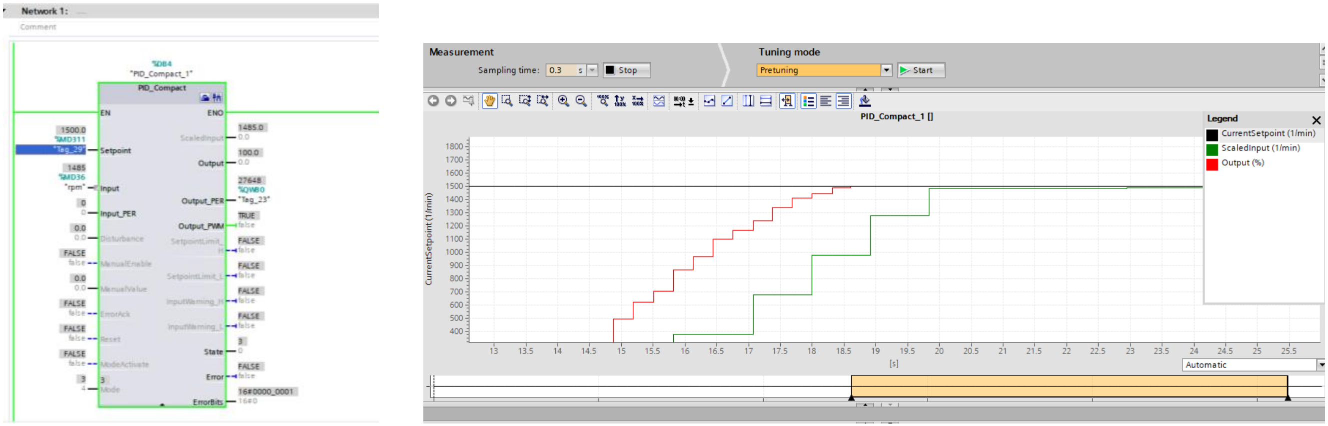

***Figure 9**. The results at RPM value 1500rpm.*

5. Conclusion

In this study, the speed control of the Asynchronous Motor was carried out with PID in the Ladder diagram software in the TIA-PORTAL V15.1 program, using the S7 1200-1214C Siemens PLC microcontroller. Before performing PID control, the VFD driver was connected to the PLC. The parameters inside the VFD driver are adjusted according to the characteristics of the asynchronous motor. Since the VFD driver does not have a profinet connection, a Digital-Analog Converter application was implemented. With the Digital-Analog converter application, digital values between 0-27648 were converted into analog voltage between 0-10V. Thus, communication is achieved between PLC and VFD driver analog outputs. The PID block in the interface of the PLC was adjusted according to the desired values in the project, considering the characteristics of the asynchronous motor. PID constantly compares the input value applied to the driver with the actual speed information coming from the encoder and balances the output value against changing loads. Proportional-integral-derivative parameters are set in PID control in PLC. In PID control, positive graphical results were obtained by minimizing errors through trial and error parameters in Pretuning mode. In PID control, control is achieved by keeping the speed of the asynchronous motor constant according to the desired set point value and by adjusting the parameters in the fastest way and with the least error. Speed control of the asynchronous motor has been successfully achieved with PLC.

REFERENCES

[1] Brusso, B. C. “50 Years of Industrial Automation [History],” *IEEE Industry Applications Magazine*, 24(4), 8-11. 2018, doi: 10.1109/MIAS.2018.2820440.

[2] Stankovski, S., Ostojić, G., Baranovski, I., Tegeltija, S., & Smirnov, V. "Robust automation with PLC/PAC and edge controllers," *IFAC-PapersOnLine*, 55(4), 316-321, 2022, doi: 10.1016/j.ifacol.2022.06.052

[3] Colombo, Armando Walter, et al. "A 70-year industrial electronics society evolution through industrial revolutions: The rise and flourishing of information and communication technologies," *IEEE Industrial Electronics Magazine*, 15., 115-126, 2021, doi: 10.1109/MIE.2020.3028058.

[4] Chmiel, M., Mocha, J., Hrynkiewicz, E., & Milik, A. "Central processing units for PLC implementation in Virtex-4 FPGA," *IFAC Proceedings Volumes*, 44(1), 7860-7865, 2011, doi: 10.3182/20110828-6-IT-1002.01830.

[5] Doumanidis, C., Xie, Y., Rajput, P. H., Pickren, R., Sahin, B., Zonouz, S., & Maniatakos, M. "Dissecting the Industrial Control Systems Software Supply Chain," *IEEE Security & Privacy*, 221(4), 39-50, 2023, doi: 10.1109/MSEC.2023.3266775.

[6] Vadi, S., Bayindir, R., Toplar, Y., & Colak, I. "Induction motor control system with a Programmable Logic Controller (PLC) and Profibus communication for industrial plants—An experimental setup," *ISA transactions*, 122, 459-471, 2022, doi: 10.1016/j.isatra.2021.04.019.

[7] Mammadli, M. "SERVO Motor Speed Control with SCADA Based PLC," *Master's thesis, İstanbul Üniversitesi-Cerrahpaşa Lisansüstü Eğitim Enstitüsü*, İstanbul, 2020.

[8] Bektaş M. "PLC Based Control of a Motor Test Bed and Torque Measurement," *Master's thesis, University of Applied Sciences Ravensburg*, Weingarten, 2014.

[9] Akçura, D. "PLC ve Asenkron Motor ile Garaj Kapısının Kontrolü," *Master's thesis, Yıldız Teknik Üniversitesi Fen Bilimleri Enstitüsü*, İstanbul, 2010.

[10] Baran L. "A PLC Based Monitoring and Control of Power Factor of a Three Phase Induction Motors," *Master's thesis, Gazi Üniversitesi Fen Bilimleri Enstitüsü*, Ankara, 2009.

[11] Güler, B. N. "PLC'lerde pıd yönetimi kullanılarak DC motor hız denetimi," *Master's thesis, Kocaeli Üniversitesi, Fen Bilimleri Enstitüsü,* Kocaeli, 1999.

[12] Coşkun, İ., & Yücedağ, İ. "With PLCs and PLC Wound Rotor Induction Motor Starting," *Sakarya University Journal of Science*, 2(2), 121-128, 1998.

[13] Kolaj, W., Mozaryn, J., & Syfert, M. "PLC-PIDTuner: Application for PID tuning with SIMATIC S7 PLC controllers," *21st international conference on methods and models in automation and robotics (MMAR)* pp. 306-311, 2016.

[14] Al Andzar, M. F., & Puriyanto, R. D. "PID Control for Temperature and Motor Speed Based on PLC," *Signal and Image Processing Letters*, 1(1), 7-13, 2019, doi: 10.31763/simple.v1i1.150.

[15] Kumar, J., Mani, V. S., & Ghazi, S. M. "IoT based VFD control using PLC," *AIP Conference Proceedings*, vol. 2427, no. 1, 2023, doi: 10.1063/5.0101140.

[16] Çayir, M., & Özbay, H. "Solar Sulama Sistemleri için MPPT tabanlı Üç Fazlı Evirici Tasarımı," *Mühendislik Bilimleri ve Araştırmaları Dergisi*, 5(2), 243-254, 2023, doi: 10.46387/bjesr.1295798.

[17] Özbay, H., & Karafil, A. "Direct Active-Reactive Power Control of Three Phase PWM Rectifier," 8(3), 616-631, 2020, doi: 10.29109/gujsc.735266.