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Theme

Design and Implementation of a Didactic Test Bench Based on PLC s7-1200

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Abstract

Our project aims to design and implement a practical learning tool (didactic test bench) using a PLC (Programmable Logic Controller). This didactic tool benefits students of automation, instrumentation, and embedded systems to experiment their practical works as it provides hands-on experience alongside the theoretical knowledge. This project go through three stages, the first stage involved the selection and gathering of all components used to build our practical didactic tool, followed by the design and implementation in the second stage, finally, the last stage is devoted to the testing and validation through two experiments: Speed control of a DC motor based on PI controller and water level control based ON/OFF controller.

Keywords: Didactic test bench, PLC s7−1200, TIA portal, PID, DC Motor, water level control.

ملخص

يهدف هذا المشروع إلى إنجاز واختبار أداة تعليمية عملية باستخدام وحدة تحكم منطقية قابلة للبرمجة (PLC). الأداة المنجزة موجهة إلى طلبة تخصص الهندسة الكهربائية، ليتمكنوا من إنجاز وتجسيد الأعمال التطبيقية التي تعنى بالتحكم الصناعي الآلي وذلك لترسيخ المكتسبات النظرية. يمر هذا المشروع بثلاث مراحل، تضمنت المرحلة الأولى اختيار وتجميع جميع المكونات المستخدمة لإنجاز هذا المشروع، يليها مرحلة التصميم والتنفيذ، المرحلة الأخيرة مخصصة للاختبار والتحقق من أن المشروع المنجز يعمل من خلال تجربتان: التحكم في سرعة محرك التيار المستمر باستخدام المتحكم التناسبي التكاملي (PI) والتحكم في مستوى المياه باستخدام نمط تحكم (on/off).

الكلمات المفتاحية: منصة الاختبار التعليمي, PID-1200، TIA Portal، PLC S7, محرك DC, التحكم في مستوى المياه

Résumé

Le but de ce projet est la conception et la réalisation d'un banc d'essais didactique à base d'un automate programmable industeriel (API). Cet outil didactique déstiner aux étudiants de la spécialité d'automatique, instrumentation et systèmes embarqués dans l'objectif d'expérimenter leurs travaux pratiques, en leur offrant une expérience pratique en complément de leurs connaissances théoriques. Le déroulement de ce projet est dévisé en trois phases: La première phase consiste à sélectionner et choisir les différents composants que nous avons utlisé pour construire notre outil d'apprentissage pratique, en tenant compte à la fois du coût et de la qualité. suivie de la conception et de la mise en œuvre dans la deuxième phase. Enfin, la dernière phase est consacrée aux tests et à la validation à travers deux expériences : la commande de vitesse d'un moteur à courant continu basée sur un régulateur PI et la régulation du niveau d'eau basée sur un contrôleur de type TOR.

Mots clés: Un banc d'essais didactique, API s7−1200, TIA portal, PID, moteur à courant continu, contrôle de niveau d'eau.

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First and foremost, I would like to praise Allah the Almighty, the Most Gracious, and the Most Merciful for His blessing given to me during my study and in completing this thesis. May Allah's blessing goes to His final Prophet Muhammad (peace be up on him).

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Finally, I have a great expectation that my study will be beneficial and useful for anyone who is interested in reading this final project, may Allah accept it from us as sadaqah jariyah.

BOUDELAA Lina

Laghouat University, June 2023

In the first place and above all else, I am grateful to Allah for His blessings throughout my academic journey and in completing this thesis. May God's blessings be upon the seal of the prophets, Muhammad, and peace be upon him.

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Finally, I hope that my study will benefit and assist anyone interested in reading this final project. May Allah accept it from us as an ongoing act of charity.

BENMOUSSSA Mouhamed Tahar

Laghouat University, June 2023

Contents

List of Figures

List of Tables

Abbreviations

Here is the sorted list of abbreviations in alphabetical order:

- **CP**: **C**ontrol **P**art.
- **CPU**: **C**entral **P**rocessing **U**nit.
- **EMF**: **E**lectromotive **F**orce.
- **FBD**: **F**unction **B**lock **D**iagram.
- **FC**: **F**unction **C**all.
- **HMI**: **H**uman **M**achine **I**nterface.
- **IEC**: The **I**nternational **E**lectrotechnical **C**ommission.
- **IL**: **I**nstruction **L**ist.
- **I/O**: **I**nput and **O**utput.
- **LAN**: **L**ocal **A**rea **N**etwork.
- **MPI**: **M**ulti **P**oint **I**nterface.
- **OB**: **O**rganization **B**lock.
- **OP**: **O**perative **P**art.
- **PC**: **P**rogrammable **C**omputer.

- **PID control**: **P**roportional, **I**ntegral, **D**erivative control.
- **PLC**: **P**rogrammable **L**ogic **C**ontroller.
- **PN/IE**: **P**rofinet/**I**ndustrial **E**thernet.
- **PWM**: **P**ulse **W**idth **M**odulation.
- **SFC**: **S**equential **F**unction **C**hart.
- **SP**: **S**upervision **P**art.
- **ST**: **S**tructured **T**ext.
- **TCP/IP**: **T**ransmission **C**ontrol **P**rotocol/**I**nternet **P**rotocol.
- **TIA portal**: **T**otally **I**ntegrated **A**utomation **P**ortal.

General Introduction

Industrial automation and control systems are vital for modern processes. They improve efficiency, precision, and reliability by monitoring and regulating variables like temperature, pressure, flow rate, speed, etc. As industries adopt advanced technologies, the need for sophisticated automation and control solutions has greatly increased.

Our thesis focuses on the design and construction of a test bench for industrial processes using PLC technology, with a focus on hardware development and software programming, aiming to understand automation principles for efficient and reliable solutions. This master thesis is divided into three chapters:

- **In chapter one** We begin by giving an overview of automation and control systems and their importance in industrial settings. We focus on studying the fundamental components of these systems, such as sensors, actuators, programmable logic controllers (PLCs), human-machine interfaces (HMIs), and communication networks.

- **The second chapter** is devoted to the construction of our test bench that simulates real-life industrial scenarios. This test bench serves as a platform for implementing and evaluating automation and control systems. The chapter explains the hardware components that we have used, their functions, and how they are incorporated into the test bench. It also covers the design considerations and practical aspects of building a dependable and adaptable test bench.

- **The third chapter** we present the software tool and programming methods used to develop automation and control systems. This chapter focuses on TIA Portal software and explains how to create software projects, set hardware parameters, and write programs using ladder logic. Practical examples on a test bench, such as controlling the speed of a DC motor and managing water levels in a tank, demonstrate the capabilities and effectiveness of the automation solutions developed.

This thesis equips readers with the knowledge and skills to design and implement industrial automation and control systems. By examining hardware, software, and practical application on a test bench, it advances automation technology in various industries.

Chapter 1

Introduction to Automation Systems

Contents

1.1 Introduction

Human have been searching for well-being since the beginning of time, this evolutionary desire is the basis for the exponential progress in science in general, and automation in particular. Humans began by thinking, designing and creating. When it became necessary to increase the quantity as well as the quality of manufactured goods, the automation of tasks then appeared, replacing humans in arduous, dangerous and repetitive actions. [1]

In this chapter, we will present an overview of automation systems, including their basics and key aims, as well as their architecture, which consists of different parts and components that operate together to automate a process.

1.2 What is an automation system?

Automation systems refer to the use of multiple machinery and software technologies in order to automate certain operations ranging from simple repetitive tasks to complicated processes by following pre-programmed instructions with no human interventions but still under human supervision. Nowadays, Automation plays a significant role in various fields; we can find it for example in:

- Industry :manufacturing (figure 1.1), healthcare, transportation, construction...
- Everyday life: Elevators, traffic lights, vending machines, and others.

Figure 1.1: Example of an Automated system in the industry of manufacturing

1.3 Objectives of automation

The little contact that occurs between humans and machines made possible for automation to revolutionize the manufacturing processes and improve the productivity of various fields in industry. In addition, automation systems are characterized by flexibility and precision guaranteeing higher quality of outputs through the ability to detect the slightest changes compared to the desired standards.

1.4 Structure of automation systems

The architecture of automation systems comprises of three essential parts: control (CP), operating (OP), and supervision (SP). Every element within these parts is properly set up and harmonized to accomplish specific functions whilst maintaining a high degree of efficiency and accuracy (figure 1.2).

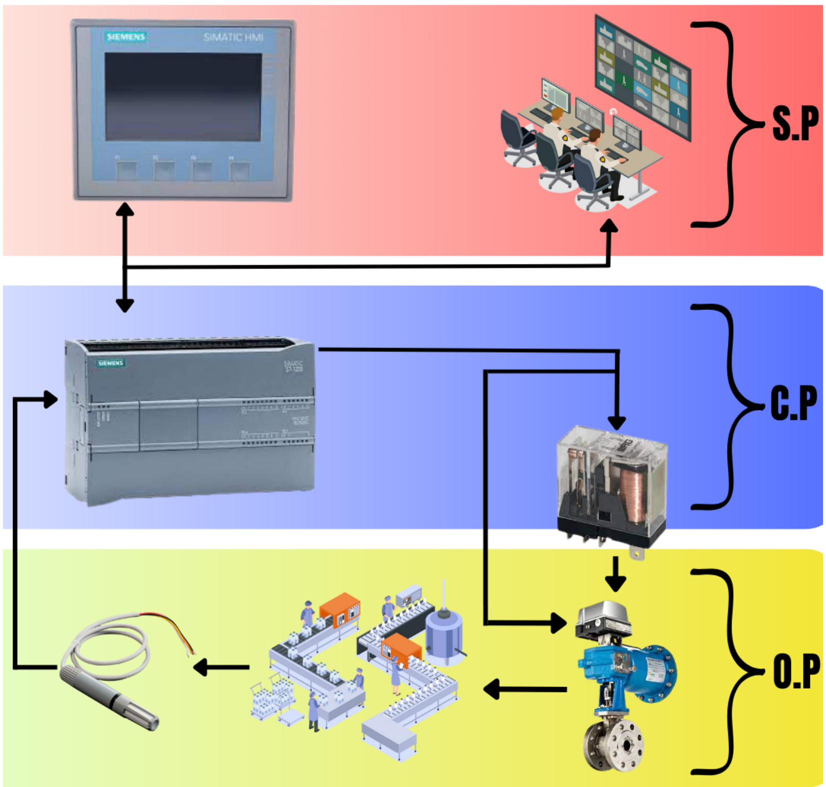

Figure 1.2: Different parts of an automated system

1.4.1 Control part

a. Definition

This part is responsible of giving orders to the operative part and it consists of an essential component, known as the controller, or PLC (Programmable Logic Controller), as shown in Figure 1.3 .

Figure 1.3: Programmable logic controller SIMATIC S7-1200 by Siemens.

b. Programmable Logic Controller (PLC)

A Programmable Logic Controller (PLC) also referred to as a programmable controller (PC), serving as the system's brain that coordinates all the elements within the system. It is a type of computer that help to automate numerous processes in the industrial fields, making it the predominant choice for process controls due to its capability to operate in aggressive environments.

The PLC consists of essential components, in which are: the power supply, the CPU, input and output interfaces, as well as communication interfaces. as illustrated in figure 1.4. Its main functionality is to give commands and make decisions based on a set of instructions provided by an automation engineer or an operator. Despite the existence of other programming languages like Structured Text (ST), Instruction List

(IL), Function Block Diagram (FBD), and Sequential Function Chart (SFC) defined by the **IEC 1131 international standard**. The PLC is programmed with the most dominant language in automation called ladder logic through a variety of software platforms such as Tia portal/step7 for Siemens products.[2]

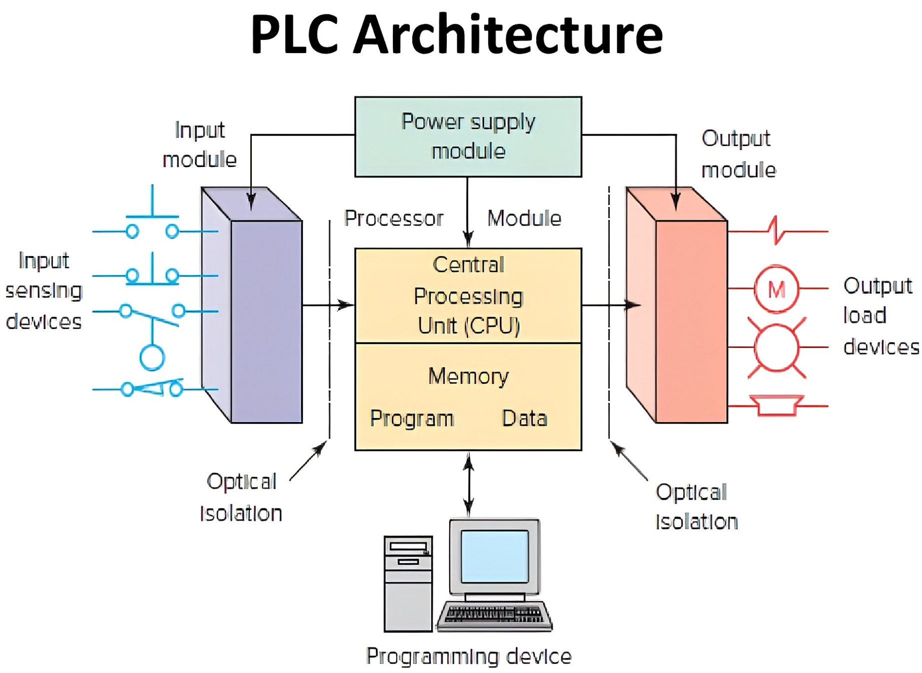

Figure 1.4: The architecture of PLCs

The controller interfaces with various sensors that assure the acquisition of information, including level, temperature, pressure or proximity sensors. Through input modules, which allow the PLC to gather as much data from the system, and know its actual state, in order to respond accordingly. Some input modules of the PLC respond to digital signals, which are either on or off, and other inputs respond to analog signals, which represent a variation of voltage or current range. It also has digital/analog output modules that ensure the transmission of command signals to the operative elements and adjust variables such as pressure, lighting, temperature, speed, etc. This remarkable technological device has helped achieve the "one operator, many processes" system and increased production efficiency two and three times [3].

1.4.2 Operative part

a. Definition

This is the effective part of the system, it is responsible for physically executing the instructions given by the PLC and utilizes several hardware technologies and machinery including actuators, pre-actuators, sensors and other equipment that work in tandem to complete different tasks with utmost precision and accuracy [4]

b. Sensors

Sensors are devices that collect information on the status of process variables in real time and provide it to the control part as signals; they are typically used as inputs for PLCs. We can obtain sensors for different purposes such as measuring pressure, temperature, speed and others. And they can generate either digital or analog signals, as in figure 1.5

- Digital sensors: This type delivers a logical output; it can be either 0 or 1. Example: proximity sensors, limit switches.[4]

-Analog sensors: This type gives real values of physical variable. Example: temperature sensors, pressure sensors.

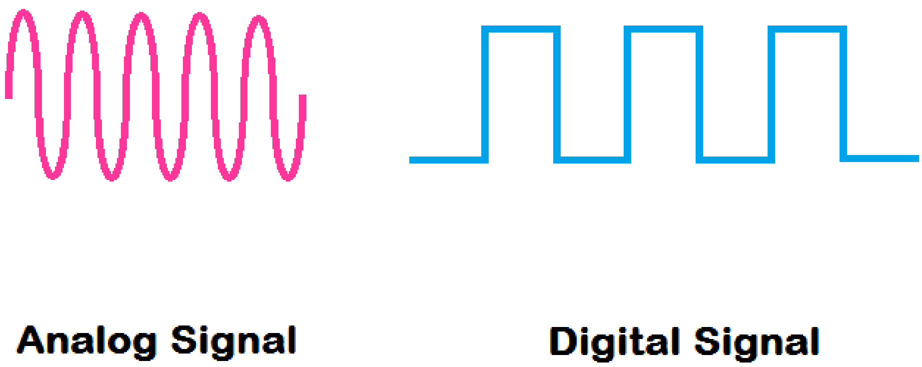

Figure 1.5: Analog vs digital signals

c. Actuators

Actuators are components that play a crucial role in translating energy from one form to another; they convert electrical, pneumatic or hydraulic energy into mechanical motions. That can be either linear or rotational force. Which can be used to position a component, control fluid flow, or apply a force to another machine or system [4]. Actuators come in variety of types, for instance:

- Electric actuators

Motors: Used for generating rotational movement in order to power machinery such as ventilators, pumps, and belt conveyors.

- Hydraulic actuators

Hydraulic cylinders: Used to produce linear motion by turning hydraulic pressure into mechanical energy.

- Pneumatic actuators

Pneumatic Valves: Used control the flow of compressed air. Air cylinders: similar to hydraulic cylinders but operated with compressed air.

d. Pre-actutators

Pre-actuators are intermediary devices between the control signals generated by the PLC and the actuators responsible for physical motions. These devices amplify, shape or adjust the control signals to allow them to meet the specific requirements of connected actuators, because the control part is typically unable to directly distribute the energy required for the actuator. **As an example:**

- The Control part operates at a very low voltage **(i.e., 24 volts DC)**, while the Operative Section requires a higher voltage **(i.e., 400 volts AC)** for powerful motors.

- The Control part is electrically powered, while the Operative Section relies on pneumatic energy. Therefore, the pre-actuator is responsible for distributing a high-energy supply that is suitable for the actuator, based on the low-power control signal received from the PLC.

- Contactors are the pre-actuators for electric motors.

- Distributors are the pre-actuators of hydraulic and pneumatic cylinders [5].

1.4.3 Supervision part

Supervision control is imperative in any automation system. It involves monitoring and overseeing both the process and the controller and ensures that the system is functioning correctly and at its optimal level. The rising complexity of production systems has also impacted the level of automation,the necessity for greater amounts of information and the ability to connect the operator with other subsystems of the production chain requires the use of appropriate technologies such as Human-Machine interface or HMI for short, it is an integral part of the automated system which allows the operator to enter the loop through a graphical display screen and facilitate the connection of human actions to the inputs of an algorithm control inside the PLC [6] ,[7].

Figure 1.6: The implementation of HMI panels in industry fields

The adoption of a Human-Machine Interface (HMI) in industrial fields (figure 1.8) offers several significant advantages, including:

- HMI plays a vital role in establishing a friendly visual environment between the operator and the technology. It is considered as the access point to the automation control system. Controlling through finger touch has replaced the use of physical tools and made traditional manual procedures obsolete. [8]
- This supervisory interface provides real-time data and alerts or errors regarding any deviations or anomalies in the process and present data in visual format

such as graphs, bars, flashing lights and so on, so that the operators can identify issues, monitor the system and take corrective actions promptly before it leads to significant problems.

- A well designed HMI screen according to industrial standards ensures operator satisfaction and minimum or no human errors in controlling large and complex systems making the interaction flawless and smooth, and this is achieved through multiple aspects such as: screen layout, color representation, graphics, pictures, text, data values, alarms, navigation, and others. (figure 1.7) [8]

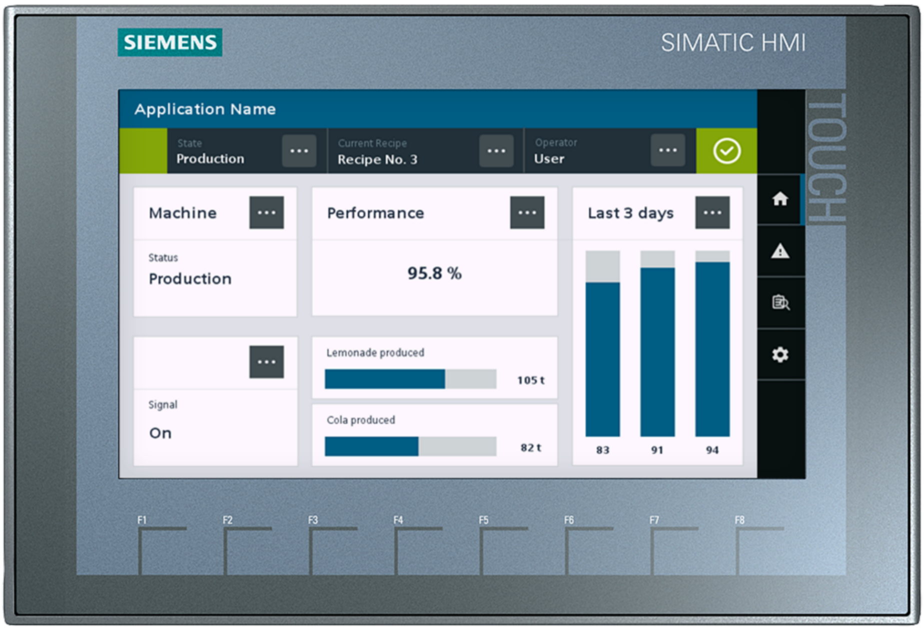

Figure 1.7: HMI screen design

1.4.4 Communication interfaces

With the increasing level of automation in the industry more and more every year, there is a growing need to enhance the interconnection between different PLCs and other industrial equipment, such connections require suitable communication interfaces to facilitate seamless signal and data exchange among various devices of the system. Along with the demands and requirements for upgrading the industry from hard wired signals to communications protocols.

Communication protocols come in different types, and one of the commonly used protocol is EtherNet, it is type of network used in building automation systems, allowing devices to connect and communicate with one another over short distances within a local area network (LAN). Other protocols specialized for high-speed communication between devices, particularly in Siemens automation systems, including Profinet and MPI. In addition, wireless communication technologies such as Wi-Fi can be added to increase flexibility and reduce cabling requirements. Routers and switches are also used in ensuring data flow and correct device connection. and permit an optimized network design with greater performance, flexibility, and security. [9]

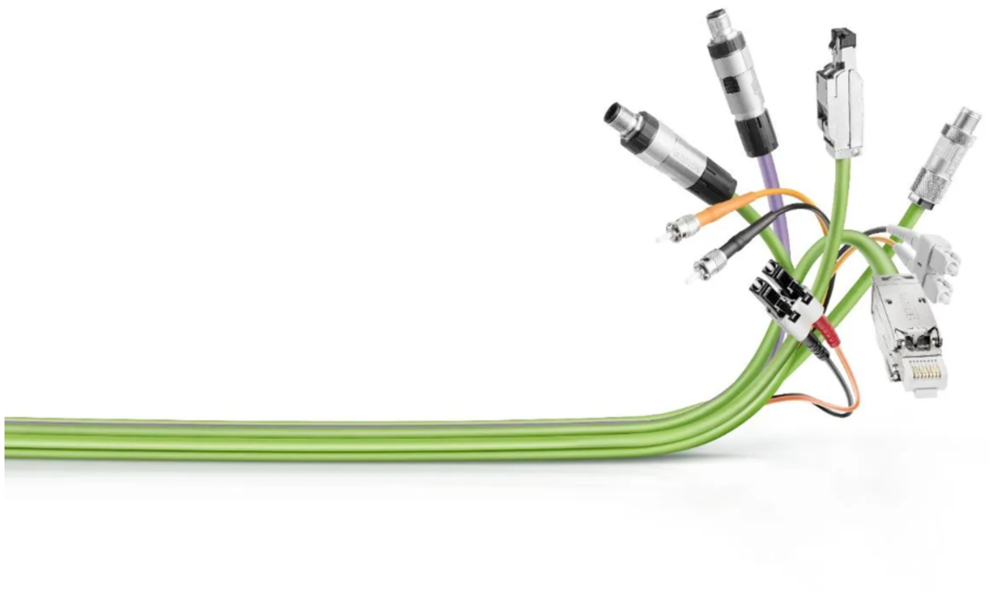

Figure 1.8: Communication cables

1.5 Conclusion

In this chapter, we have introduced the world of automation by defining automated systems, as well as their key goal which is not only limited to increase productivity and efficiency but it is also important to build systems with safety precautions for both human beings and equipment. we finished with explaining each part of the automated system from the part where the operator give commands to the part of signal treatment and execution.

In the next chapter, we will present how we designed and constructed our test bench based on PLC SIMATIC S7-1200.

Chapter 2

Design & Conception of the Didactic Test Bench

Contents

2.1 Introduction

This particular chapter is dedicated to illustrating the various components of an educational test bench focused on instructing individuals in automation systems with particular emphasis given to the Siemens S7-1200 PLC. It offers practical hands-on experience in the field of industrial automation and control by covering a variety of topics including component functions and integration, configuration of the Siemens PLC S7-1200, construction of human-machine interfaces, and testing and validation protocols. A concluding summary is provided which succinctly summarizes the impact of the test bench's design. For computer engineers seeking to specialize in automation and industrial control, this chapter serves as an extensive guide. It offers a detailed overview of the planning, construction, validation, and programming of the educational test bench with an aim to enhance the skills and knowledge of the reader, with the ultimate goal of improving career opportunities.

2.2 Test bench configuration and components

The setup and components of the didactic test bench are key features that influence its functioning and usefulness as a teaching platform in the area of automation systems. This section will give a full explanation of the main components and their responsibilities in the test bench arrangement.

2.2.1 Power Supply Model S-240-24 24V/10A and Protective Switch

a. The power supply:

PS model S-240-24 24V/10A is an essential component that provides a stable and reliable source of power to the test bench. It has a maximum output power of 240W and runs with good efficiency. With its universal AC input/full-range capability, this power supply is compatible with various electrical systems (figure 2.1 -figure 2.2). [10]

Figure 2.1: Power supply model S-240-24 24v/10a

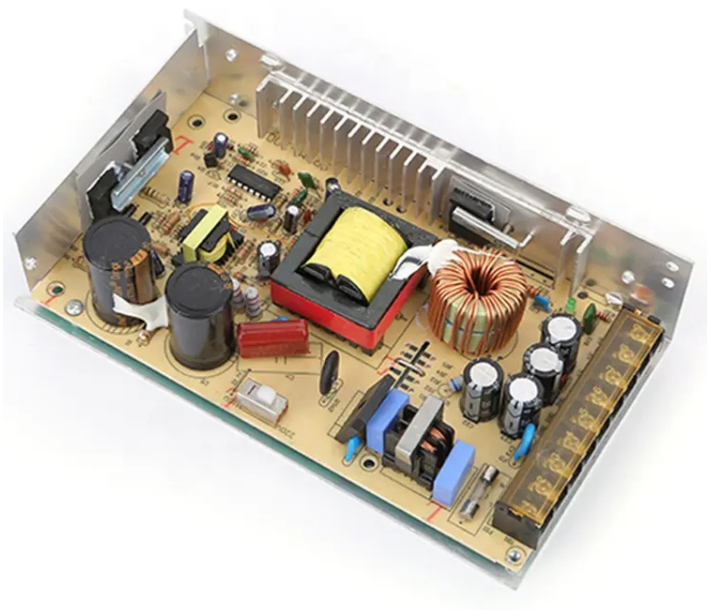

Figure 2.2: Inside power supply model S-240-24 24v/10a

Key Features of the Slypro Power Supply 24V/10A and why do we use it:

- **Output Voltage**: The Slypro power supply delivers a consistent output voltage of 24V DC, ensuring a reliable power source for the test bench and its components.

- **Active Power Factor Correction**: The power supply is equipped with built-in active PFC functionality, which enhances energy efficiency by minimizing reactive power and reducing harmonic distortion.

- **Protection Features**: To safeguard the test bench and its components, the Slypro power supply incorporates multiple protection mechanisms. These consist of overvoltage, overcurrent, overshot circuit, and overtemperature protection. These features prevent damage to the equipment and ensure the safety of both the user and the test bench.

b. Protective switch:

The Protective Switch serves as a vital safety device within the test bench configuration. Its main role is to protect the system as a whole from electrical surges and overloads. The power supply disconnection is swiftly executed by the protection switch in case of electrical faults or abnormal conditions, effectively minimizing potential risks (figure 2.3).

Figure 2.3: Protective switch

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Importance of the Protective Switch:

a. **Safety Assurance:** By promptly interrupting the power supply upon detecting a fault, the protective switch ensures the safety of both the user and the equipment connected to the test bench.

b. **Equipment Protection:** The switch safeguards the test bench components from potential damage caused by electrical surges or overloads. It acts as a reliable line of defense against unexpected electrical incidents.

Integration of components The slypro power supply model s-240-24 24v/10a and the Protective Switch are integrated seamlessly into the test bench's configuration. The main source of electricity, the power supply provides controlled and steady electrical energy to the whole system. The protective switch acts as a critical intermediary between the power supply and other test bench components, monitoring and safeguarding against electrical faults.

2.2.2 Human machine interface (HMI) - KTP700

The HMI KTP700 is a human-machine interface designed specifically for interaction with the Siemens S7-1200 1214c DC/DC/DC PLC. With a 7-inch widescreen display boasting a resolution of 800 x 480 pixels, the KTP700 HMI showcases impressive performance features. Its design prioritizes user-friendliness and programmability, positioning it as a prime option for individuals, whether they be students or professionals, interested in exploring the realms of industrial automation and control systems. With support for the Profinet communication protocol, the HMI KTP700 ensures fast and reliable communication between the HMI and the PLC. Additionally, it offers a range of communication ports, including USB, Ethernet, and RS485, giving users the flexibility and simplicity of use needed for diverse uses (figure **??**).

Figure 2.4: Industrial human machine interface - KTP700

2.2.3 Siemens S7-1200 1214c DC/DC/DC PLC

The Siemens S7-1200 1214c DC/DC/DC PLC, among the highly regarded PLCs in the market, attains well-deserved prominence. This PLC model specifically caters to small and medium-sized applications, featuring a sleek and compact design integrated with digital and analog Input/Output (I/O) modules. Powered by a high-speed processor, it boasts affordability, versatility, and a user-friendly interface, making it a remarkable asset in industrial landscapes. With 14 digital inputs, 10 digital outputs, and two channels of analog input that accept 0-10 V DC signals, the S7-1200 PLC converts analog input signals into processable digital signals. Its user-friendly design and ease of programming render it an ideal choice for students and professionals interested in industrial automation and control systems (figure 2.5). [11]

Figure 2.5: PLC S7-1200 1214C

Figure 2.6 represents the wiring diagram of s7-1200 1214c DC/DC/DC.

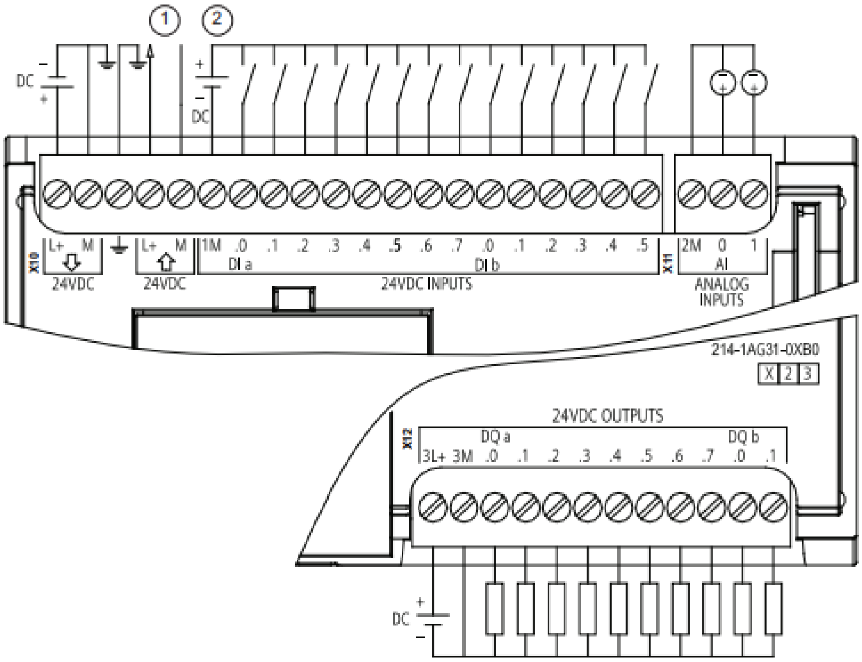


Figure 2.6: CPU 1214C wiring diagram

a. Programming with TIA portal software

Effortlessly programming the S7-1200 1214c DC/DC/DC PLC is made possible through the intuitive TIA Portal software. This programming interface provides a comprehensive library of pre-built functions and blocks, significantly reducing programming time and enhancing overall efficiency. Moreover, the software's simulation mode enables thorough testing and debugging of programs before real-world deployment, thereby increasing reliability and mitigating potential risks (figure 2.7).

Figure 2.7: TIA Portal Programming

b. Communication and integration

The communication capabilities of the S7-1200 1214c DC/DC/DC PLC are not to be overlooked. Equipped with multiple communication options like Modbus, Profibus, and Ethernet, the PLC seamlessly interacts with other devices in an industrial setup. This inherent flexibility facilitates effortless integration into existing industrial automation systems, simplifying installation, configuration, and operation processes 2.8.

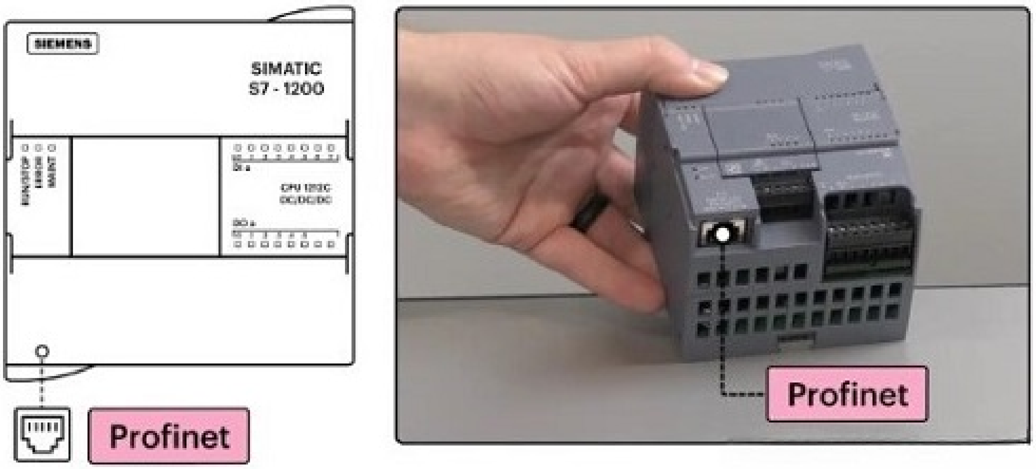


Figure 2.8: S7-1200 communication ports

In summary, the Siemens S7-1200 1214c DC/DC/DC PLC stands as a powerful and versatile solution for industrial applications. With its compact design, integrated digital and analog I/Os, intuitive programming software, and diverse communication options, it enables seamless control over small to medium-sized industrial processes. This PLC model plays a paramount role in industrial automation, leading to heightened productivity, enhanced process quality, and significant reductions in labor costs. Its ability to handle various industrial applications makes it a popular choice, providing increased productivity, improved quality, and reduced labor costs in industrial automation.

2.2.4 Input/Output (I/O) interface

Through digital and analog I/O modules and for smooth communication that improves automation system performance, I/O Interface connects sensors, and actuators, with PLC. This interface empowers the PLC to establish seamless connections, allowing for effective communication and integration in both digital and analog formats. It converts sensor and actuator signals into digital formats for the PLC to process and transforms digital signals into commands to control system actuators. As a fundamental building block within the domain of industrial automation, the I/O interface is crucial for regulating and mechanizing industrial operations. In the didactic test bench, it is an essential element enabling the PLC to interface with diverse components and make informed decisions based on real-world measurements.

Inputs and outputs: In our case there are 3 normalized analog inputs connected to a potentiometer used to connect it with a speed detector. There are also two analog inputs and 7 digital inputs, which include four normalized inputs and start/stop buttons and ESD (Emergency Shut Down). There are 9 digital outputs with 6 normalized outputs and green, red, orange lights that refer to start, stop, and ESD. From the internal structure of the PLC S7-1200 CPU 1214C in 2.6:

- Q0.1 is for PWM
- Q0.4 Green led
- Q0.6 Red led
- Q0.7 Orange led
- I0.3 Start
- I0.5 Stop
- I0.6 ESD
- IW64 for DC tachogenerators
- IW66 for Level transmitter (4-20 mA)

In our test bench model, we are using various digital/analog inputs and outputs, As shown in the image below:

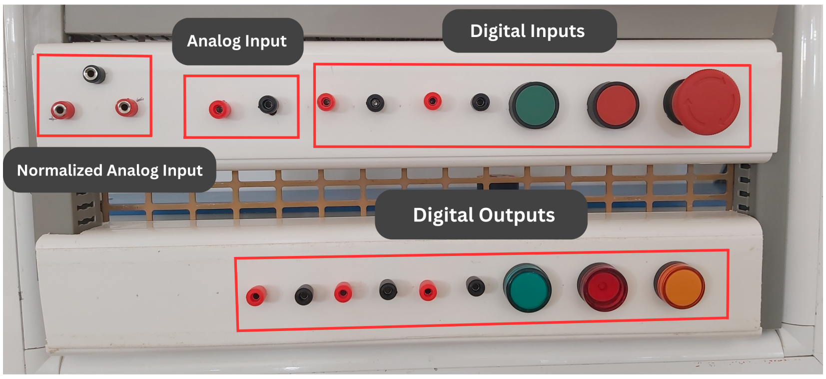


Figure 2.9: Digital Inputs

Conversion and processing of analog inputs:

The S7-1200 PLC, including the CPU 1214C, features built-in inputs exclusively designed to handle analog signals ranging from 0-10V. This capacity empowers the PLC to read analog input signals originating from sensors or devices that generate either voltage or current output. Subsequently, the analog signals undergo conversion into digital signals, enabling the PLC to efficiently process them and facilitate precise control and monitoring within the didactic test bench.[12]

2.3 Test bench design and integration

The integration and development of our educational test setup, which utilizes the PLC S7-1200 and automates the speed control and water level, encompass various components and configurations. Included in the configuration of the test bench are components such as a power supply model S-240-24 (24V/10A) along with a safety switch. Additionally, an interface for input/output (I/O) operations, the Siemens S7-1200 1214c DC/DC/DC PLC, and the HMI model KTP700. The setup also encompasses the DC Motor CC10, an extra I/O interface, the Profinet communication protocol, a wiring diagram, and the control circuit for the DC motor through a DC-DC buck converter the command of the latter isolated by optocoupler (hcpl3120).

The design and integration of the test bench involve constructing a physical support structure to stabilize the DC Motor and the Hdl 300 sensor while integrating different components and configurations. A power supply and I/O interface connect the PLC with the sensors and actuators. The Siemens S7-1200 PLC enables automation with the KTP700 HMI user interface for operator interaction.

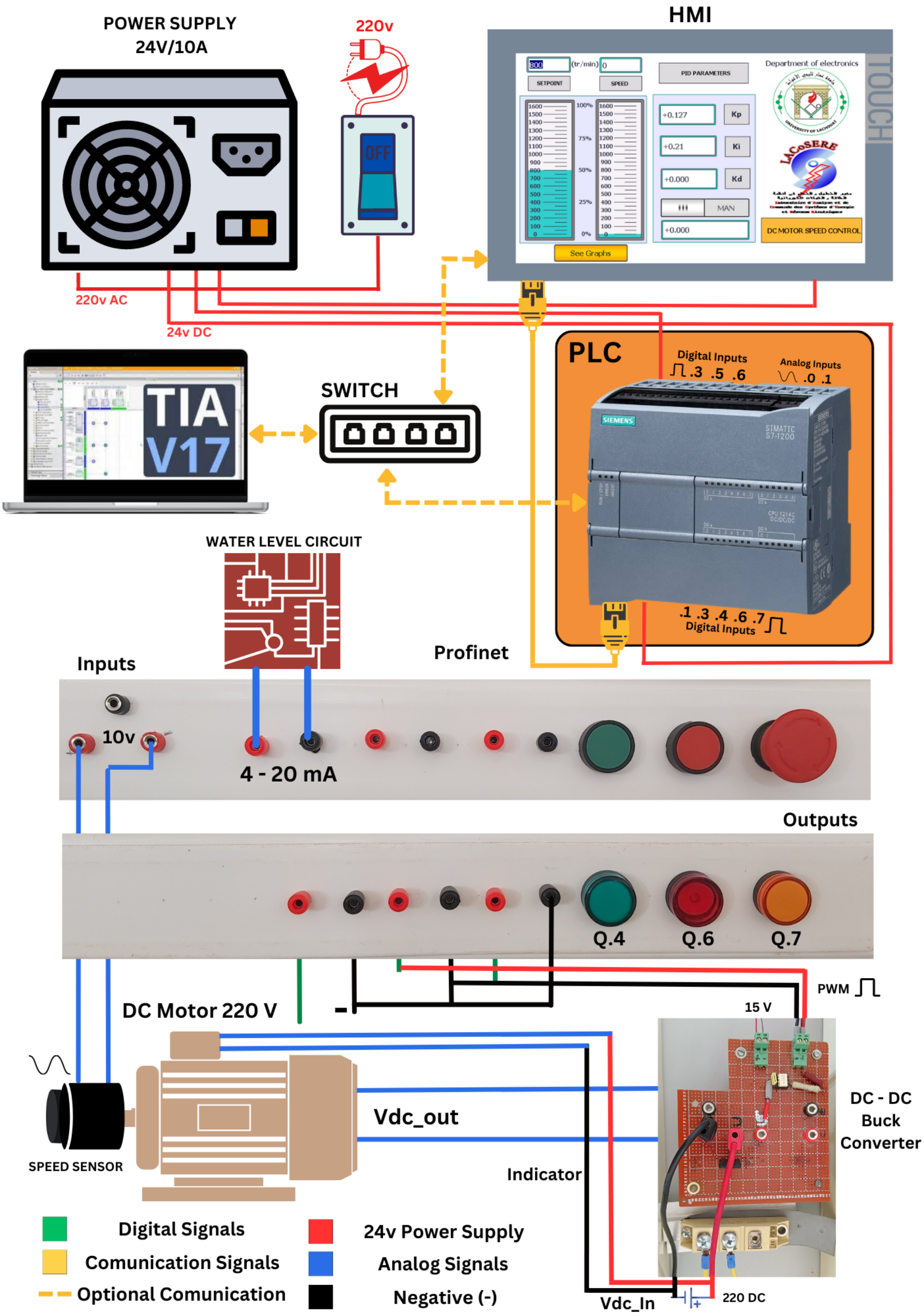
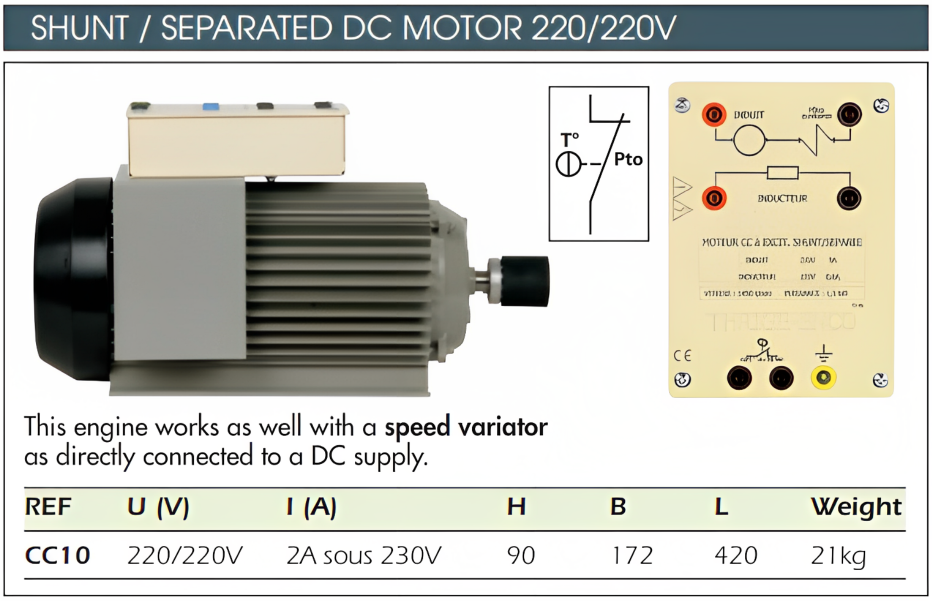


Figure 2.10: General Scheme of Test Bench

To establish connections among the various components within the test bench, a wiring diagram is employed. Additionally, the control circuit for the DC Motor, is responsible for regulating the motor's speed, while the water level transmitter is subjected to normalized analog input. The I/O interface, in conjunction with the Profinet communication protocol, facilitates seamless communication between the test bench components and the PLC.

2.3.1 Shunt/Separately DC motor cc10

In our test bench, the SHUNT/SEPARATELY DC MOTOR CC10 SPEED holds immense importance as it combines the benefits of shunt and separately excited DC motors to achieve precise speed control and optimal performance. By manipulating the current flowing through the field or armature windings, the motor's torque-speed characteristics can be altered. The torque equation $T = F \times r$ of this motor resembles that of a separately excited DC motor. Belonging to the category of self-excited motors. The shunt winding, composed of numerous turns of fine copper wire, ensures a constant field current. Speed regulation in shunt DC motors is achieved by adjusting the current supplied to either winding. Within the realm of 3-phase asynchronous motors, the SHUNT/SEPARATELY DC MOTOR CC10 SPEED plays a crucial role in facilitating precise speed control. [13] [14]



REF	U (V)	I (A)	H	B	L	Weight
CC10	220/220V	2A sous 230V	90	172	420	21kg

Figure 2.11: Dc motor cc10 speed

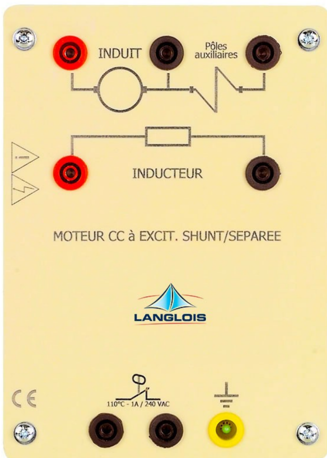
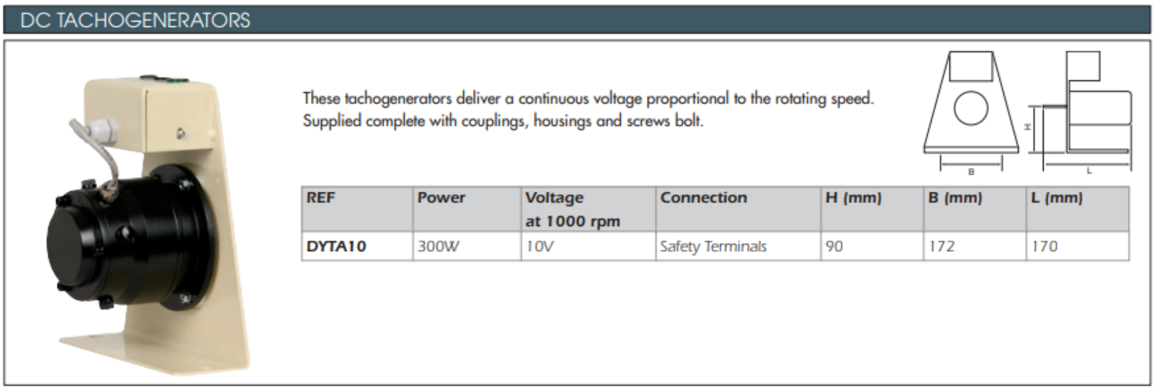


Figure 2.12: DC Motor CC10 Characteristics

2.3.2 DC Tachogenerators

Our dc motor's speed is assessed utilizing the dc tachogenerator. It produces "EMF" wich is proportional to the flux and speed to be measured. The small output voltage can be measured with dc voltmeters and the polarity of the output voltage indicates the direction of rotation. It is applied to measure the speeds of motors, and equipment such as conveyor belts or machine tools. It is a true speed measuring device relying on the basic principle of generator to gather speed information based on voltage [15] [13].



DC TACHOGENERATORS

These tachogenerators deliver a continuous voltage proportional to the rotating speed. Supplied complete with couplings, housings and screws bolt.

REF	Power	Voltage at 1000 rpm	Connection	H (mm)	B (mm)	L (mm)
DYTA10	300W	10V	Safety Terminals	90	172	170

Figure 2.13: DC Tachogenerators Characteristics

2.3.3 DC motor control

To regulate the velocity of a DC motor, the given dc-dc buck converter below utilizes numerous constituents like a DC power supply, an inductor, a resistor, and a diode. The objective of this circuit is to handle the motor's speed by modifying the voltage across it. To turn the motor on and off, it employs an IGFET switch, and the resistor represents the motor's load. Additionally, the diode shields the circuit from the back EMF generated by the motor. The potentiometer is used to create a varying potential difference across the gate of the Mosfet switch, which adjusts the voltage across the motor accordingly. The source pin of the IGFET switch tracks the value of the created potential difference and modifies the voltage across the motor in response. This sequence of powerful pulses enables the motor to run without stalling, delivering improved torque even at lower speeds. [16]

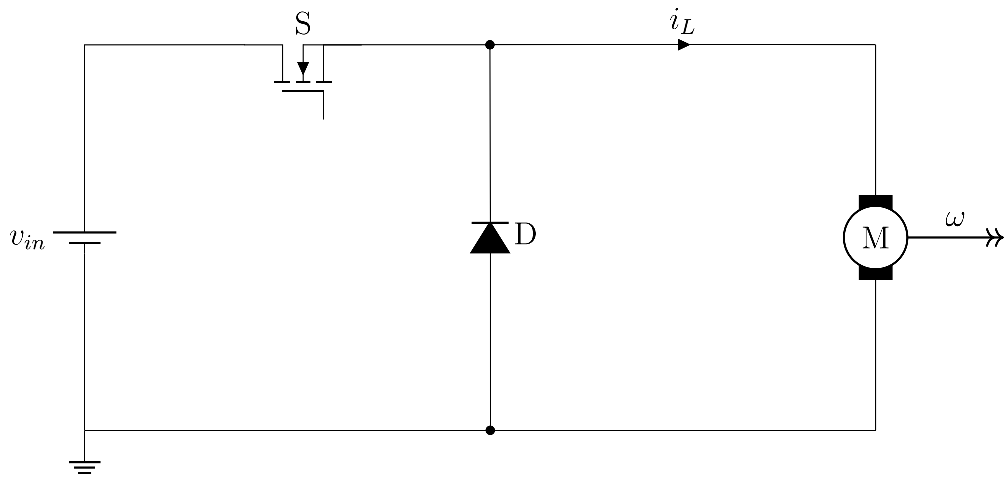


Figure 2.14: DC-DC Buck Converter

Control circuit reference scheme, to show connection details:

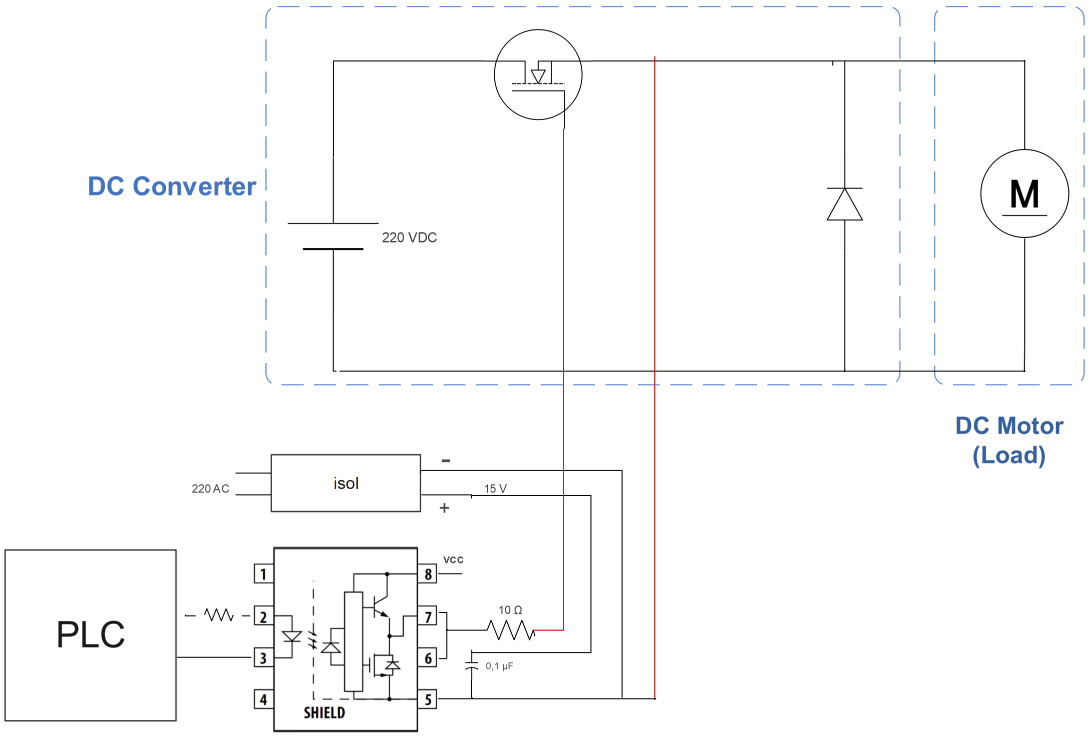


Figure 2.15: Control circuit of DC motor

HCPL-3120 Motor control applications benefit from the HCPL-3120 optocoupler's ability to deliver rapid gate drive for IGBTs and MOSFETs. It comprises an IC with a power output stage, optically coupled to a GaAsP LED. Notable characteristics of this device include exceptional noise immunity, high rejection of common-mode disturbances, and operation within a wide temperature range (-40°C to +100°C). Applied extensively for power supplies, and industrial control systems, as well as motor control, like in our project's motor control circuit [17].

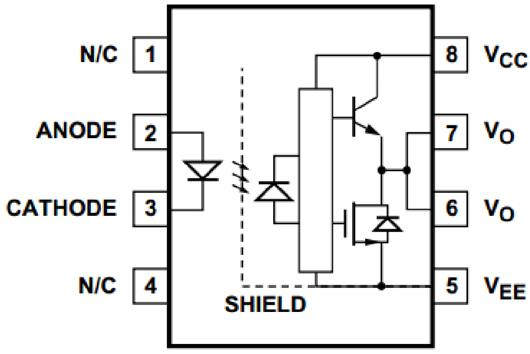


Figure 2.16: HCPL-3120 Optocoupler

2.3.4 Custom analog input for water level control

In our test bench we set a custom analog input dedicated for water level control as the second payload of our test bench, Analog inputs dedicated as shown in ??. And it include the circuit shown below With a 24V power source and connected in parallel with a 500 ohm resistor it extends to the analog input. We use current-to-voltage converter with 500 ohm load to connect sensor's 4-20 mA current output to controller's 0-10V analog input module.

Water Liquid Level Transmitter Sensor Hdl 300 with a sturdy stainless steel construction and simple calibration process, our HDL300 liquid level transmitter sensor precisely detects liquid levels of up to 5m. It utilizes high-performance silicon piezoresistive material in its pressure sensitive core to measure hydrostatic pressure, which in turn allows for the calculation of liquid height. The sensor provides compatibility with diverse control systems by means of its 4-20mA output enabling seamless integration into various setups.

Figure 2.17: Liquid Level Transmitter Sensor Hdl 300

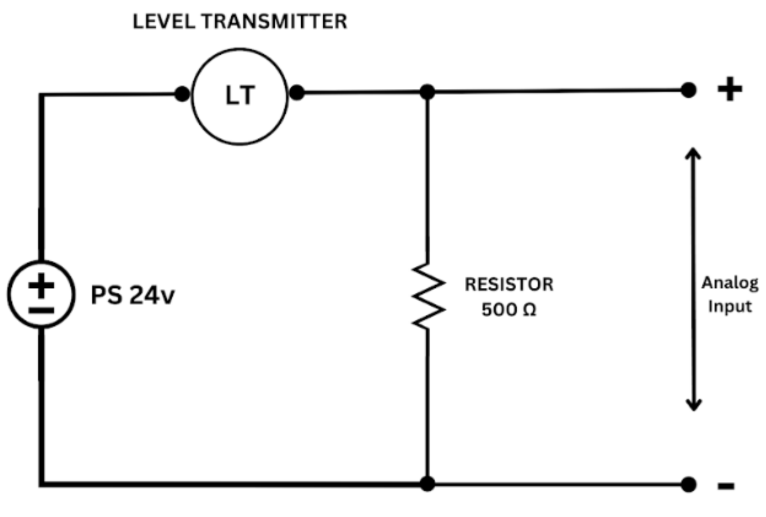


Figure 2.18: Water Level Circuit

The test bench's design prioritizes operator safety and the reliable operation of the equipment. Adhering to the specifications and requirements of both the DC Motor, water level transmitter and the PLC S7-1200, the design should be meticulously executed. Integration of the various components must be conducted in a manner that guarantees the smooth operation of the test bench and enables the automation of the DC motor or water level detection.

2.4 Economic study of the project

The economic study for the Didactic Test Bench Design and Implementation project shows positive results. The estimated total cost is around 310,000.00 DA (31 million centimes), including equipment procurement and design expenses instead of more than 2,000,000.00 DA (200 million centimes)[18] Benefits include cost reduction for universities, student exposure to real-world experience, and job creation.
here are the details of the costs:

Elements of our test bench	**Price in DA**
PLC	110,000.00 DA
HMI	190,000.00 DA
Power supply	4,700.00 DA
Design (prototype)	4,500.00 DA
Other Additional Elements	4,150.00 DA
Total Price	**313,350.00 DA**

Table 2.1: Price list of test bench elements.

Our target is business owners across industries, And we can also establish an institute that focuses on teaching everything related to automation. Our target here will be students and anyone interested in automation. the project faces risks like a limited supply of key components. The study considers most aspects demonstrating the project's feasibility and positive impact on Algeria's industrial sector.

2.5 Conclusion

The focus of this chapter is to present a comprehensive introduction to an instructional test platform designed for automation systems, specifically the Siemens S7-1200 PLC. It encompasses an examination of the various constituents of the test platform, such as the power supply, protective switch, I/O interface, and HMI KTP700, as well as their functionalities. Emphasis is placed on the significance of comprehending these elements in the process of designing and implementing automation systems. Furthermore, the discussion extends to the Siemens S7-1200 1214c DC/DC/DC PLC and its significance within the realm of industrial automation. Also our project can enhance efficiency, lower expenses, and fulfill market demands. Serving as a fundamental basis for the subsequent chapter, this chapter equips readers with a profound comprehension of programming, testing, and validation protocols.

Chapter 3

Programming and Testing

Contents

3.1 Introduction

After discussing the fundamental components of our test bench in the previous chapter, we will now focus on the software tools used to program our chosen systems and test the didactic test bench that we have developed.

In this chapter, we will first give a brief definition of TIA portal, and a guide through the process of creating a project and configuring hardware, as well as testing our systems with the test bench and observing the interaction between the software and hardware and see if they function as intended.

Also in this chapter and as results, we test our realized test bench through two experiences: "speed control of DC motor" and "water level control".

3.2 PLC programming

3.2.1 Tia Portal: Introduction and Overview

Totally integrated automation portal, or TIA portal for short, is a software and tools package developed by Siemens. It is specifically designed to simplify the programming of PLCs of the S7-1500, S7-1200, S7-300, and S7-400 families and Human-Machine interfaces of Siemens. as well as offering the ability to configure hardware parameters such as : IP address, type of communication, firmware version, and others.

TIA Portal is an all-in-one platform that includes the Step7 software for PLC programming and WinCC flexible for Human-Machine Interfaces. it offers a neat programming environment for engineers and programmers due to the well structured blocks and simplified program interface. [19]

3.2.2 Setting up the Programming Environment

After successfully installing the software on your computer, here's the step-by-step hands-on guide to build a project in TIA portal:

- **Step 1: Launch TIA PORTAL**

  After launching the software by clicking on the icon of TIA Portal, The portal view will be the first thing that appears on your screen as shown in figure 3.1

  To create your first project click on "Create new project", and write its name in "project name" section, you can also change the path of the project or keep the default location, and finally click on "create".

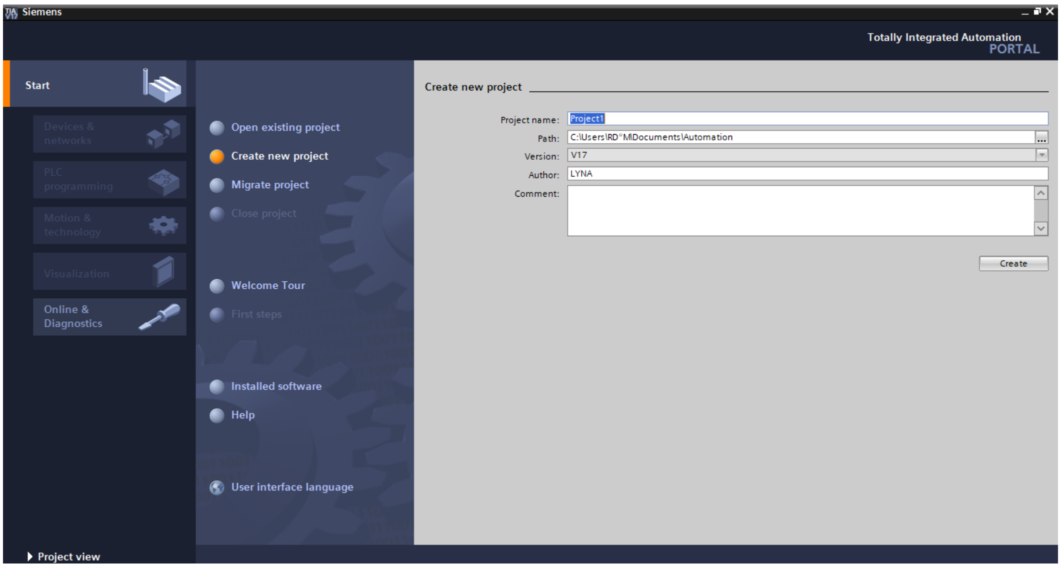


Figure 3.1: The portal view of TIA portal

Now in the "device and networks" section, click on "Add new device" → "Controllers" and choose the CPU based on the reference of your device, and select its matching firmware version as shown in figure 3.2, follow the same steps when choosing the HMI, click on "HMI" icon and select the desired panel.

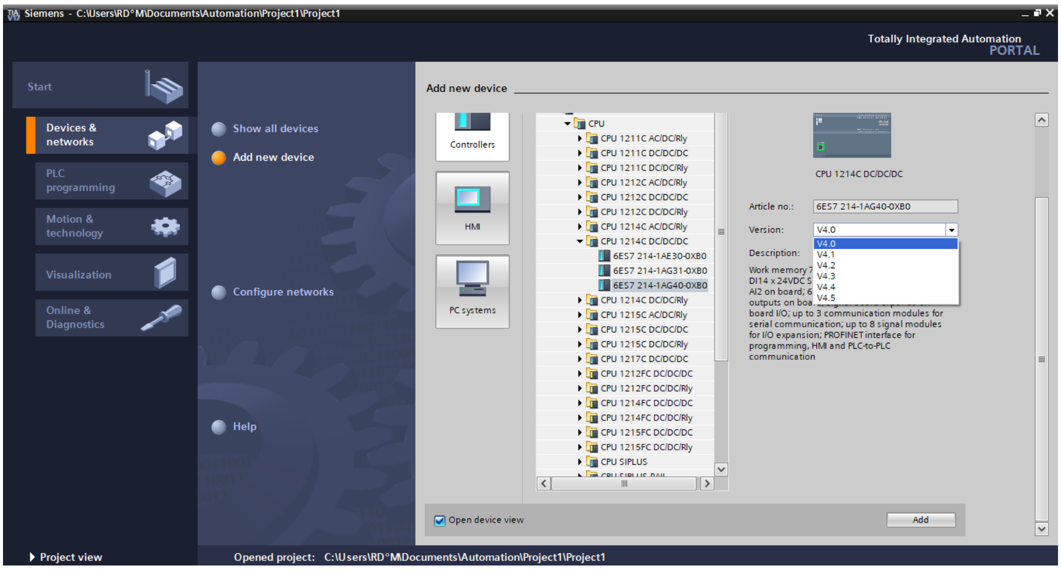


Figure 3.2: Device and networks: CPU selection

In our case we have chosen : SIMATIC S7-1200 CPU 1214c DC/DC/DC, ref: 6ES7 214-1AG40-0XB0 and firmware version: v4.03.01 as indicated in the data sheet of our PLC. and for the HMI : KTP700 Basic PN, ref:6AV2 123-2GB03-

0AX0 and firmware version: 15.1.0.0

- **Step 2: Configuring the Hardware**

  To ensure the communication and connection between the PLC and HMI, we need to set the IP address of each device and place them on the same network, so they can establish a connection and exchange data effectively.

  To assign an IP address for the PLC, navigate to "Device configuration" in the project tree, double click on the PLC to open the proprieties of the device, and then go to the "Ethernet address" within the "profinet interface" section and enter the desired IP address. as shown in figure 3.4

  Follow the same steps to assign the IP address for the HMI, and remember to use unique and compatible IP addresses that are within the same network range.

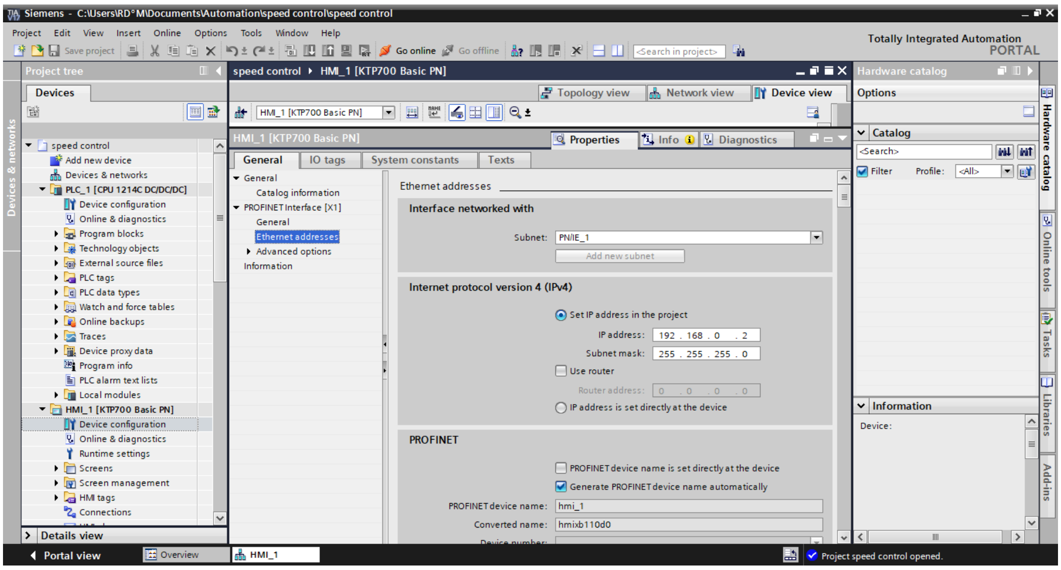


Figure 3.3: Assigning IP address for PLC

For simulation purposes, it is important to mention that we can establish a connection between PLC and HMI, by simply clicking on the Ethernet port and then dragging and releasing it on the other port that we want to create a connection with.

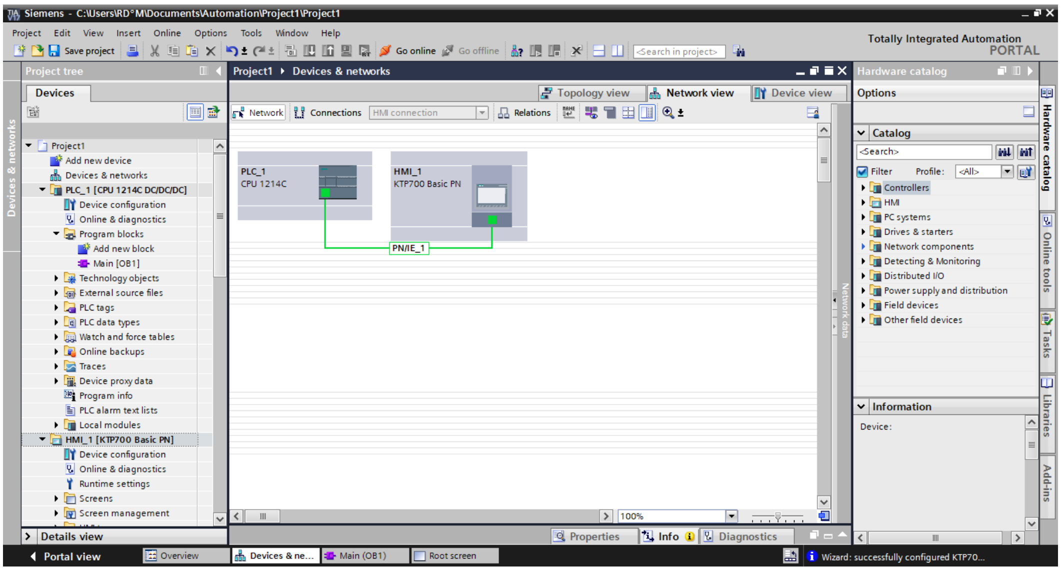


Figure 3.4: Visual representation of Ethernet connection between PLC And HMI

In order to establish communication between the PLC/HMI and the programming computer, we should also configure the IP address of the computer to be on the same network as the other devices, to do so, we need to follow these steps:

In "network and sharing center" within the parameters of the computer, navigate to "adapter settings", identify the Ethernet adapter corresponding to your connection type, click on "Internet Protocol Version 4 (TCP/IPv4)" and enter the IP address, as illustrated in figure 3.5

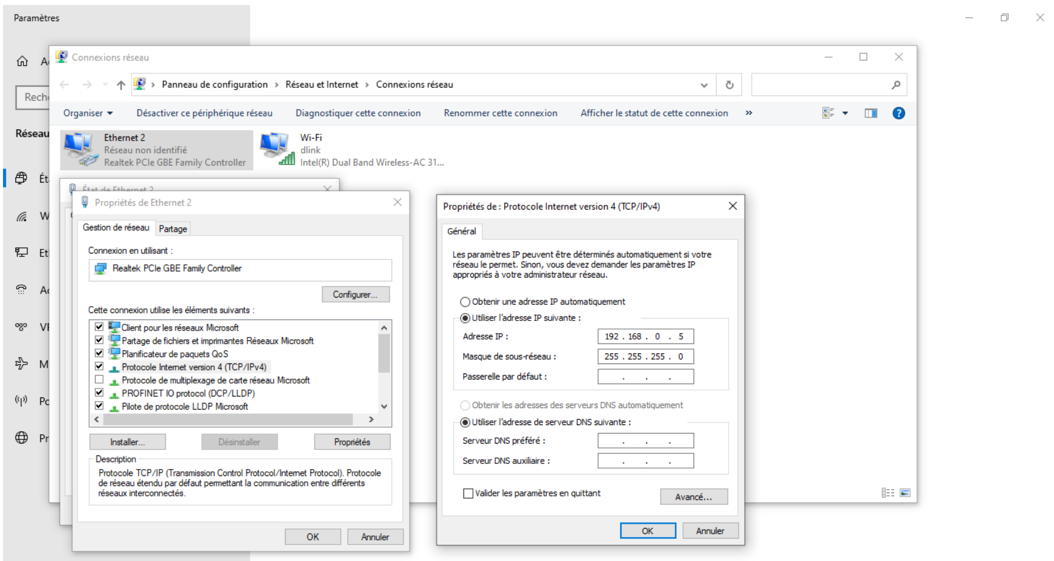


Figure 3.5: Assigning IP address to the computer

- **Step 3: Writing the Program Logic**

  To write your program in TIA portal, navigate to "Program blocks", expand the main organization block "Main [OB1]" which will lead you to the program editor in the project view. Next and with the help of the basic instructions provided by TIA portal, you can build your program in few steps.

  The illustrated figure 3.6 provided as an example of a ladder logic program that turns ON and OFF a Green LED, using two push buttons with input addresses I0.0 , I0.1 and the address Q0.0 as an output to represent the Green LED, and each address is listed in "tag tables"

  When the "ON" push button is pressed, and "OFF" push button is not pressed, the LED can be activated and remain in that state until push button "OFF" is pressed to reset the LED.

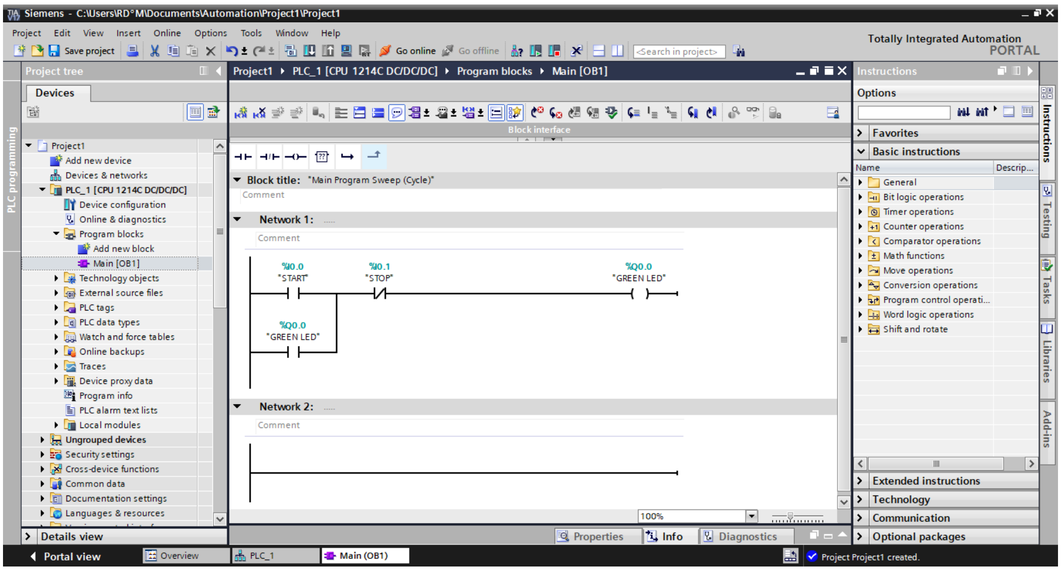


Figure 3.6: Program example in step7 Tia portal

- **Step 4: Downloading the Program to the PLC**

  To download the program and test it with the connected physical devices, simply click on the download button located in the tool bar on top, and then select connection type in the "type of the PG/PC interface" in our case it is PN/IE, which indicates Profinet protocol, and also select the "PG/PC interface" that represent the programming computer, and then start a quick scan in order to detect the accessible devices connected to your local network and once detected load the program to the PLC.

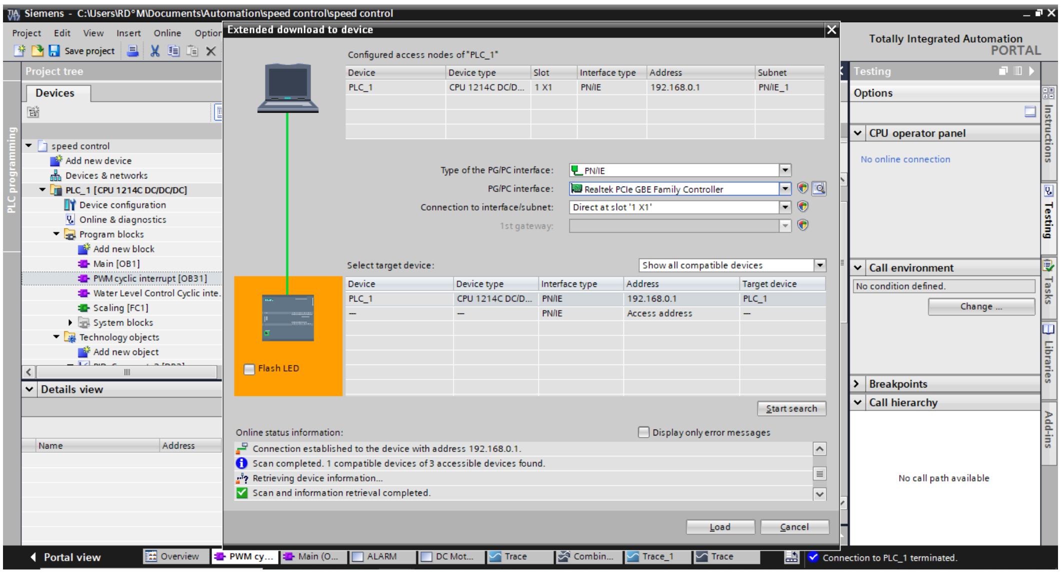


Figure 3.7: Downloading program to PLC

3.3 Examples on the Test Bench

Now that we have learned how to get started with TIA portal software, its time to move forward and test and simulate real life systems using our didactic test bench. this practical experience allows us to put our theoretical knowledge to use, and helps us evaluate the functionality and performance of the automation solutions we built.

For this project, we have developed two different automated systems,**"Speed control of a DC motor"** and **"Water level control of a tank"**, which are going to be explained in details and tested with our pedagogic test bench to ensure their proper functionalities.

3.3.1 Speed control of a DC motor using PID controller

The main objective of this system is to control the speed of a DC motor using PID algorithms integrated in the PLC's program. Controlling systems using PID has long been a technique reserved for industry, leaving students with limited theoretical knowledge, however, This system was designed with specific intention to allow them to observe the impacts of PID control on a real-world system.

a. PID controller

A proportional–integral–derivative controller (PID) is the most common control algorithm in industry used to improve the performance of a control system.

As its name indicates, PID controller consists of three fundamental coefficients: proportional (Kp), integral (Ki) and derivative (Kd) adjusted to achieve better performance. The control system, receives feedback data from the plant through sensors that measure the actual value of the parameters that require control such as, temperature, speed, pressure, etc. and compares it to the setpoint which is the desired value of the process variable. The PID then compute the desired actuator output by calculating proportional, integral, and derivative responses and summing those three components to compute the output. The control system is illustrated in figure 3.8 representing the block diagram of the closed control loop with a PID controller.

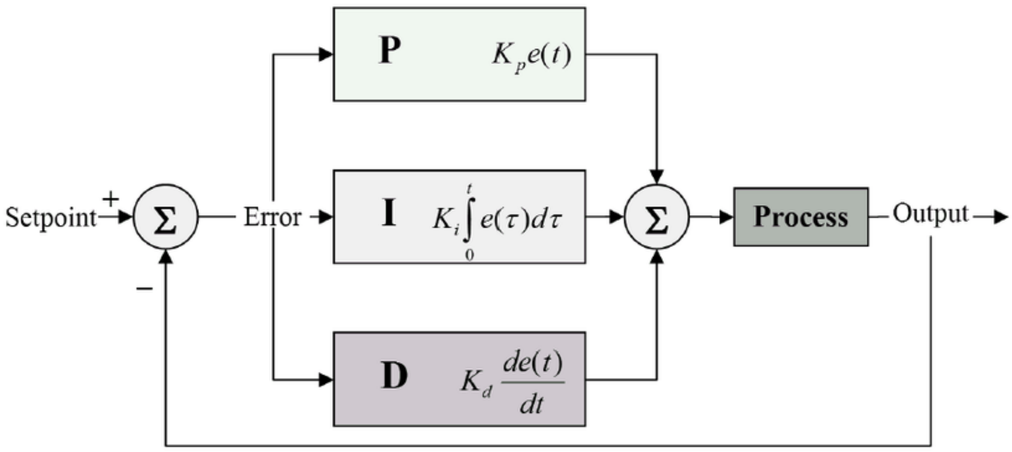


Figure 3.8: Block diagram of a closed loop control system with a PID controller

The figure 3.9 illustrates the response of a closed loop control system when applied to it a step function as the desired amplitude command variable (Setpoint), This control system aims to move the controlled physical parameter to the fixed desired value with minimal error. the output response can be distinct by certain characteristics :

- **Rise time:** It's the time required for the system to rise from 10 % to 90 % of its steady state value or final value.
- **Overshoot:** It is the amplitude of the first peak that represents the amount by which the process value exceeds the desired amplitude.
- **Settling time:** It is the time that takes the process value to settle and stabilize within an acceptable pre-defined error value.
- **Steady state error:** It is the final variation between the desired input and the process value.

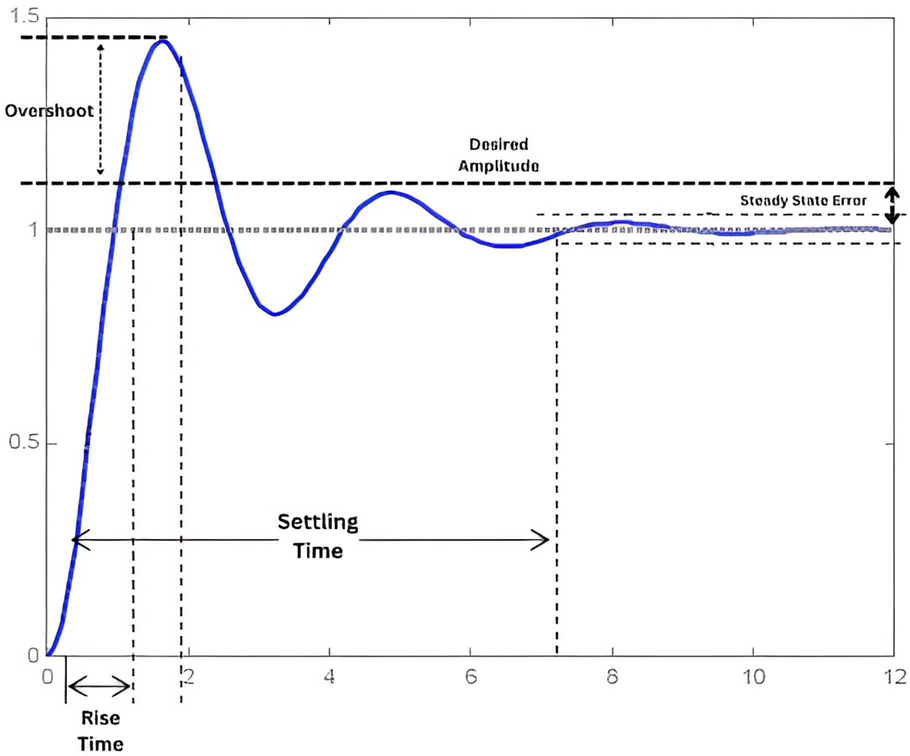


Figure 3.9: Response of a closed loop control system with a PID controller

Each PID parameter has effects on the system if increased seperatly, as illustrated in table 3.1 [20].

The proportional gain Kp increases the response rate time of the system and minimizes but doesn't eliminate the steady state error.

The integral gain Ki increases the response rate time of the system and eliminates the error.

The derivative gain Kd, decreases the overshoot and increases stability of the system.

Parameters	**RT**	**OS**	**ST**	**SSE**	**Stability**
Increasing Kp	Decrease	Increase	Small increase	Decrease	Degrade
Increasing Ki	Decrease	Increase	Increase	Large decrease	Degrade
Increasing Kd	Small decrease	Decrease	Decrease	No effect	Improve if kd small

Table 3.1: Effects of PID parametrs in a closed loop system

With :

RT : Rise Time; **OS** : Overshoot; **ST** : Settling Time; **SSE** : Steady State Error.

b. System requirements

The speed of the motor is read by a speed sensor (figure 2.13), that sends real time speed values to the analog input of the SIMATIC s7-1200 PLC, the PLC then receives the data and processes it with the integrated program located within the controller, then decides the appropriate control action to achieve and maintain the desired speed (Setpoint) entered by the operator through the HMI panel.

The command provided by the controller is typically generated in a form of a pulse width modulation (PWM), firstly sent from the PLC's digital output as either 24V for logical 1 or 0V for logical 0 to a DC/DC buck converter through an optocoupler (figure 2.16), which is an electronic component powered with 15V, and does the isolation for safety purposes of two circuits : the PLC device and the system.

The DC/DC buck converter (figure 2.14) does the regulation of the motors power input by transforming a fixed dc input into a lower controlled dc output and thus controlling its speed.

The speed of the DC motor corresponds to the image of the output voltage of DC/DC buck converter, which represents the average value of the PWM control signal, based on:

$$Vout = \alpha . Vin$$

With :

- Vout: Output voltage of DC/DC buck converter which represents the desired voltage level required to achieve the desired motor speed.

- α: Duty cycle that represents the average value of the PWM signal.

-Vin: Input voltage supplied to the DC/DC buck converter.

The figure below illustrates the speed control scheme of a DC motor using PI controller.

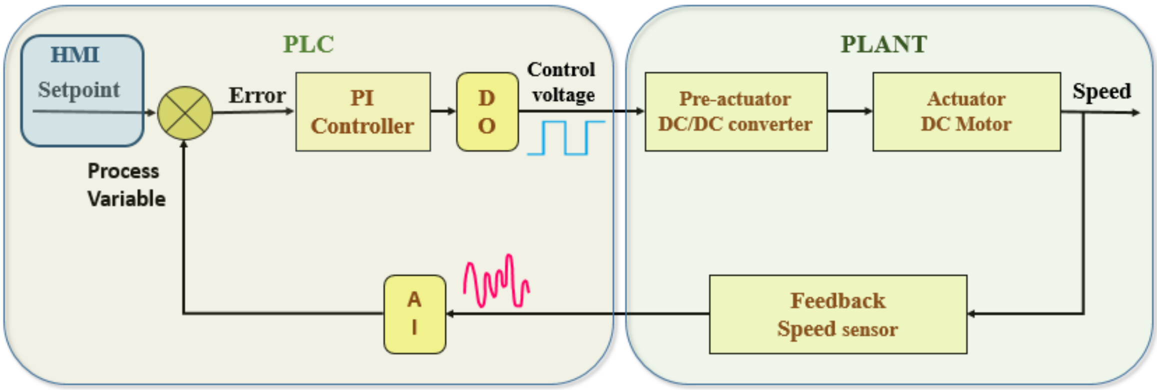


Figure 3.10: Block diagram of DC motor's speed control using PI controller

c. The system's program logic in TIA portal

- **PID Compact**

  The program we have implemented in TIA portal to control the speed of our DC motor is simply the instruction of PID compact. This instruction provides a PID controller with integrated tuning function for actuators.

  To ensure responsiveness and accuracy of the speed control system with minimal delay, it is necessary to place the PID compact in "Cyclic interrupt [OB30]" as the PID instruction needs to update at a specified time interval and also "cyclic interrupt" block has the highest execution priority as comparing to other organisation blocks including the "main" block. in addition, its cyclic time is adjustable based on the specific needs of the system in study, if the system requires rapid changes, the execution cycle must be short in order to have faster responses and vice versa. [20]

The PID algorithm operates according to the following equation:

$$y = K_p[(b.w - x) + \frac{1}{T_i.s}(w - x) + \frac{T_d.s}{a.T_d.s + 1}(c.w - x)]$$

with :

y : Output value of the PID algorithm;

K_p: Proportional gain;

s : Laplace operator;

b : Proportional action weighting;

w : Setpoint;

x : Process value;

T_i : Integral action time;

a : Derivative delay coefficient (derivative delay T_1= a×T_d);

T_d : Derivative action time;

c : Derivative action weighting.

The diagram shown in figure 3.11 illustrates the inside block scheme of PID compact control loop.

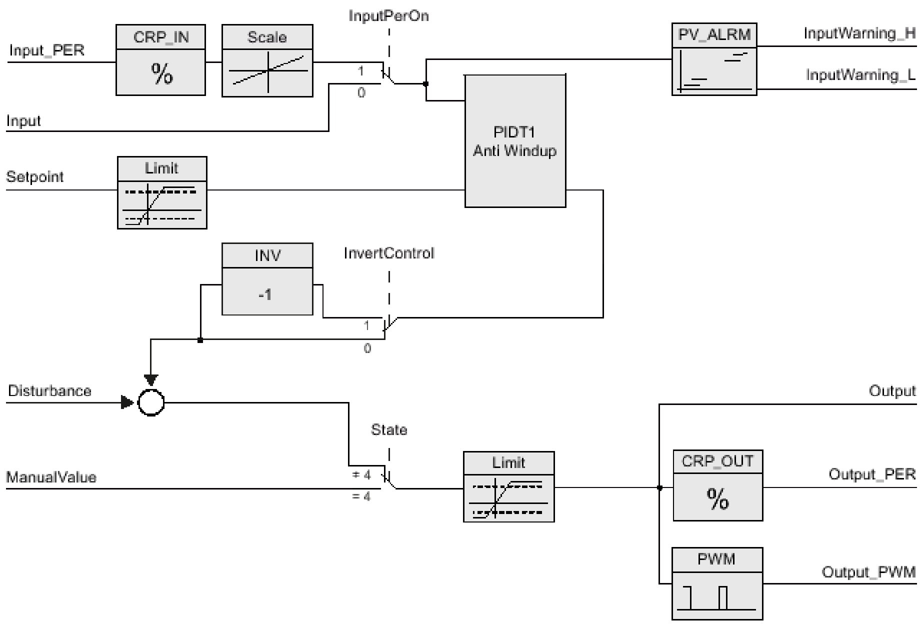


Figure 3.11: Block scheme of PID Compact

The diagram below(figure 3.12) illustrates the integration of the parameters into the PID algorithm:

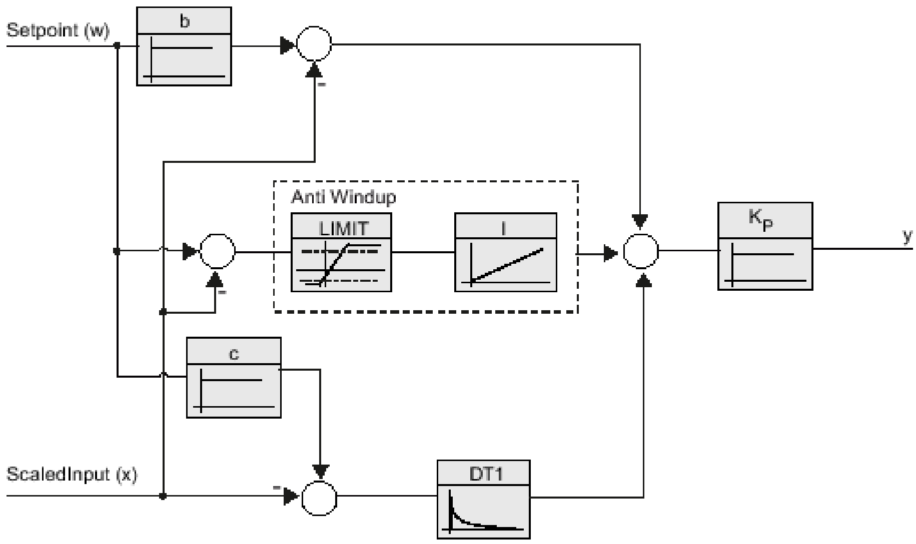


Figure 3.12: PID with anti−windup

- **Program description**

Our PID compact has two inputs, figure 3.15, the first one taking the internal address %MD40 and referred to as **"Setpoint"**, which is the desired speed value entered by the operator through the HMI screen. and the second input %MD3 is the **"Feedback"**, that is directly connected to the speed sensor providing the PLC with real time speed values. The PID compact instruction takes the value of these two inputs, using the pre-programmed PID algorithm within the block, it calculates the appropriate output based on the error which is the difference between the setpoint and the feedback, and generates a PWM signal command through the PWM digital output of the block %M0.7, as in figure 3.15

To convert the voltage output range of the speed sensor measured in voltage from 0 to 10V, into a display range of 0 to 1600 rpm for our DC motor, we utilize the conversion instructions available in TIA portal that we have programmed in a function block FC[1], as illustrated in figure 3.13, and called in the main block. figure 3.14.

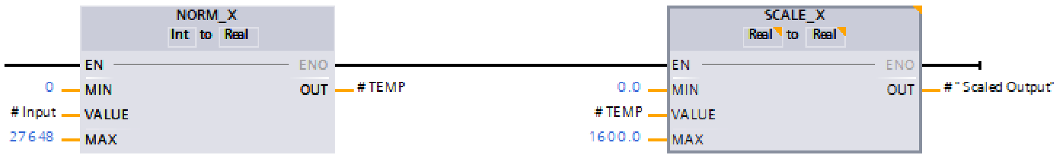


Figure 3.13: Standard scaling function block

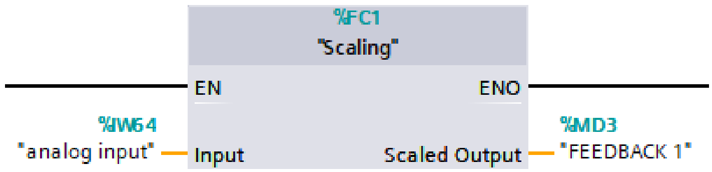


Figure 3.14: Feedback scaling block

The NORM_X is utilized to normalize the value of the analog tag %IW64 connected directly to the speed sensor by using the min and max parameters to define the physical limits of the analog input, we put "27648" as the maximum normal range value of the analog signal transferred to the CPU by analog modules and 0 as the minimum, the result at the OUT output is between 0 and 1. So, as an example: half of the motor's maximum speed 800rpm will give us an output of 0.5. the scaling instruction SCALE_X is used to scale the value at the VALUE input by mapping it to a specified value range (0 to 1600), so 0.5 from the instruction NORM_X will give us 800 output scale.

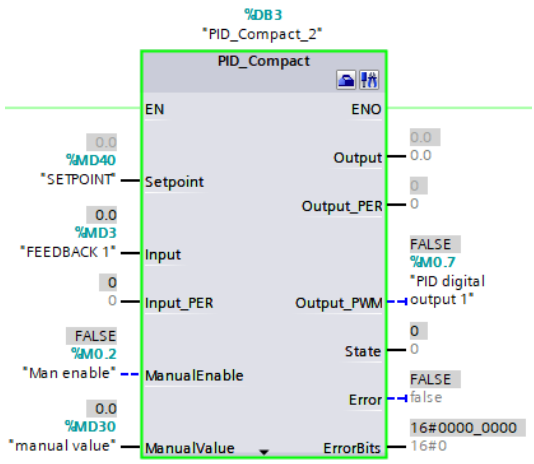


Figure 3.15: The program block of the dc motor speed control system

As our focus is on automation rather than theoretical design of the PID controller, we do not need to calculate the PID parameters manually, we have simply used tuning methods built-in into the PID compact function block accessible in Siemens TIA portal, that calculates Kp, Ki and Kd coefficients automatically depending on the control system. To enable this method, navigate to "Technology objects" → "PID compact [$DB3$]" → "Commissioning".

The commissioning window (figure 3.16), provides two autotuing methods: Pretuning and Fine tuning. During pre-tuning the Kp and Ki parameters are calculated, as we are using a PI controller, and then during fine-tuning, the parameters are adjusted further for enhanced performance.

Following the tuning procedure, we arrived at the final parameter values:

$$\text{Kp} = 0.27 \text{ and } \text{Ki} = 0.21.$$

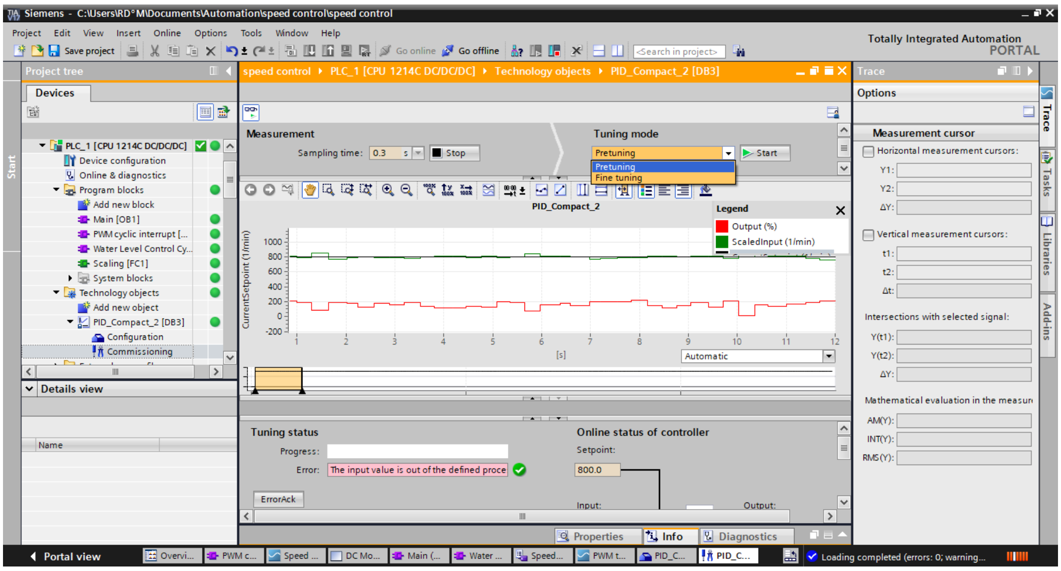


Figure 3.16: Tuning methods

- **HMI screen**

  We have developed a SCADA interface that can be monitored either by a personal computer or our Siemens KTP−700 HMI screen as shown in the figure below.

  The HMI screen includes an input field where the operator can enter the desired speed, and a display field to show the actual speed value, acting as the feedback of the motor. And both, the setpoint and the speed are visually represented in a bar graph. Moreover, we have displayed PID parameters for easy access and adjustment, and also, we added a switch for easy Manual/Automatic switching, there is also a field where the operator can enter a manual input speed. additionnaly, there is a button that allows us to access to the graphical interface where graphs of the setpoint and the output are traced.

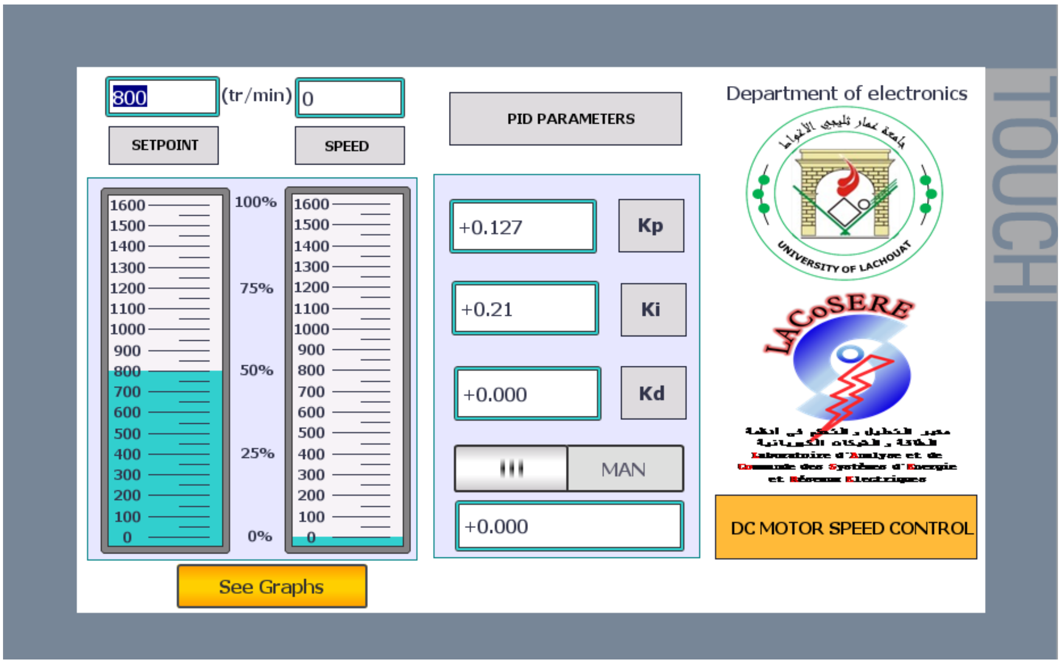


Figure 3.17: The HMI screen of the speed control system

3.3.2 Water level control of a tank

In practical applications, there are plenty of water level control systems that can be implemented to suit different needs, one of the most common ones are those with overflow control to prevent water exceeding the maximum level of a tank or a storage. However, the system we have developed shares similarities with the overflow control systems mentioned earlier but is designed with less complexity while using advanced industrial equipment to help us achieve effective water level control.

a. System requirements

Our system is mainly composed of the test bench serving as a crucial component in this project, because it contains the most important device which is the PLC, in addition to that, there are other elements in the system that work together to achieve the desired control, including: water level sensor, an electric valve and finally a tank.

In this system the process variable is the water level from the tank which is measured with a level sensor that is specifically designed to be fully submerged in the water allowing it to give us the entire water level with high accuracy.

The sensor is directly connected to the controller's analog input module, however, this module requires an input voltage range of 0-10V but the sensor outputs a current ranging from 4-20 mA, in order to interface these two inputs we need to use current to voltage converter by implementing a 500 ohm load resistance, as illustrated in figure 3.18

Chapter 3/figubknbre/ampstovolts.jpg

Figure 3.18: 4-20mA to 0-10V conversion circuit

By introducing a 500 Ohm load resistor into the loop circuit in the figure on top, it becomes possible to produce a voltage across the resistor ranging from 2 to 10V, corresponding to the sensor's current output variation of 4 to 20mA. So, now the PLC has the capability to give the appropriate commands to the electric valve and control the alarm system based on the program integrated within it.

Side note: The resistor's value is simply calculated with Ohm's law:

$U = R \cdot i \rightarrow R = \frac{U}{i} = 500$ ohm

b. System's program logic in TIA portal

- **Program description**

  Our program, has an input referred to as **"Water level analog input"**, connected to the analog signal coming from the water level sensor. This input takes the analog range values of the PLC starting from 0 to 27648. To provide the operator with a clear and a more understandable level display (in our case ranging from 0-100%), it is essential to go through a scaling function, similar to what was done with the speed sensor input in the previous system. However, after converting the current of the sensor to voltage output 2-10V instead of 0-10V, the PLC reads 20% as an initial value of the water level. in order to correct the offset caused by the sensor's output, we thought of adjusting the minimum input value of the NORM_X instructions block to 5530, which corresponds to 20% of the maximum limits, as illustrated in figure 3.19

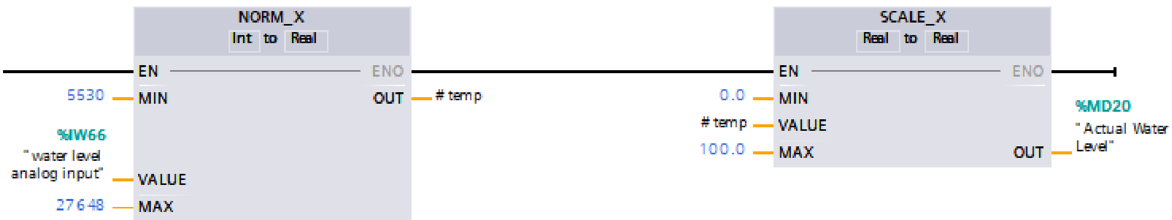


Figure 3.19: Level scaling block

The main project of the system in TIA portal is shown in figure 3.20, programmed with ladder logic, the first instruction is the SR flip flop block, utilized to set or reset the tag **%M1.4** that opens or closes the electric valve addressed with the internal address **%M1.2**

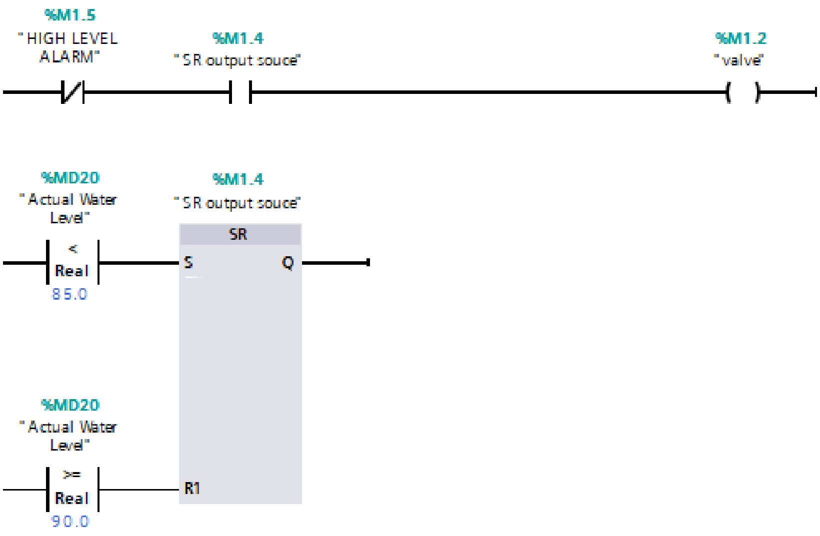


Figure 3.20: The program logic of water level control system

The operand "SR output" is set and the valve is open when the following condition is fulfilled:

– The actual water level is inferior than 85%

The operand "SR output" is reset and the valve is closed when the following condition is fulfilled:

– The actual water level is greater than or equal to 90%

We also implemented to the program an alarm instruction, shown in figure 3.21. as a preventive action to avoid the risk of water overflow. When the water level reaches or exceeds 90%, a series of actions is triggered ensuring the system is functioning on its safe operating conditions.

Firstly, the electric valve responsible for controlling water closes, stopping any further tank filling. Simultaneously, an alarm is displayed on the HMI screen alerting the operator to the high level situation.

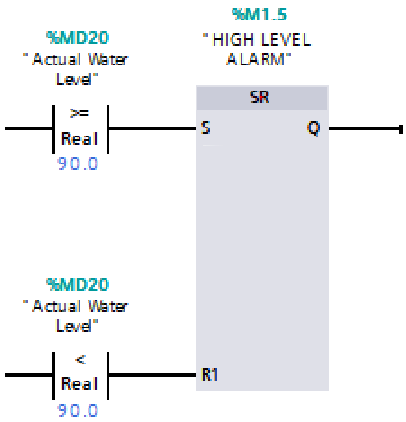


Figure 3.21: High level Alarm program block

- **HMI screen**

  For this system, we have also designed a SCADA interface that provides the operator with comprehensive overview of the system's status. figure 3.22

  The HMI screen is well designed ensuring a clear visualization of the water level in the tank through the graphical representations, the user can easily read the water level at a glance. In addition to that, we have implemented a numerical display to provide more precised numerical values of the level. Moreover, the state of the electric valve is represented with a flashing light indicator, when the valve is open, the indicator lights green, and when the valve is closed, it lights red. Another great feature is the alarm, that is triggered when the water level reaches or exceeds the dead-band preventing water overflow.

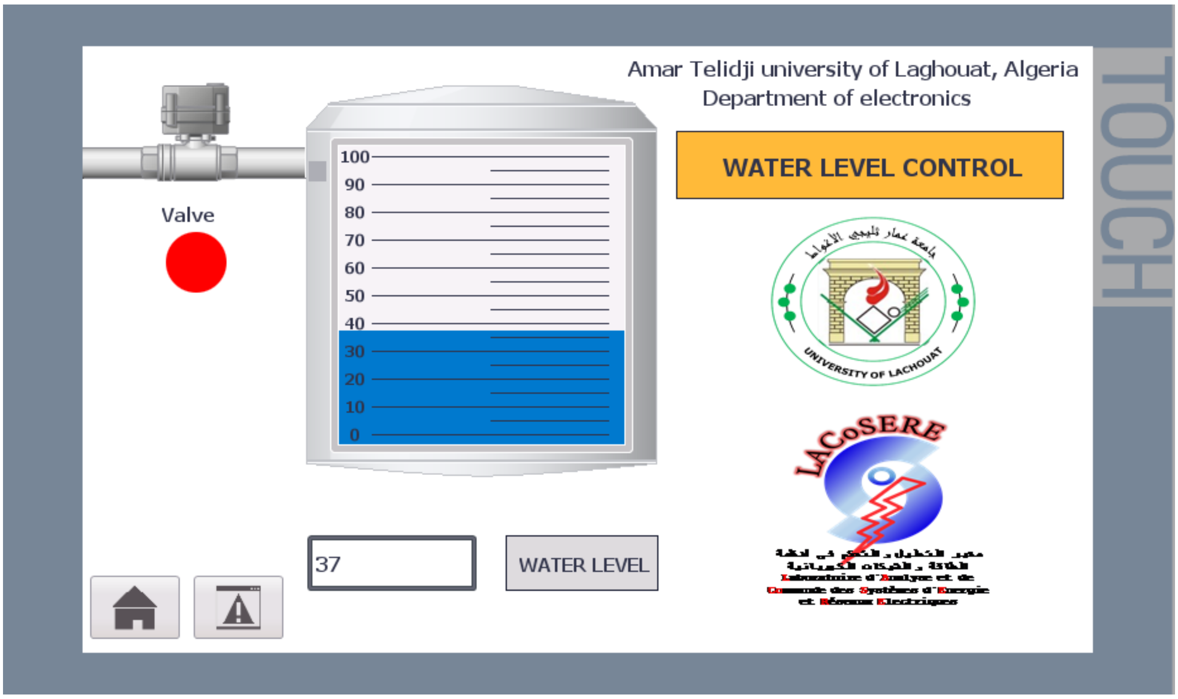


Figure 3.22: The HMI screen of the speed control system

3.4 Conclusion

In this chapter, we presented an overview of TIA portal software, and offered a step by step tutorial on how to create a program. Following that, we explored the first system developed specifically to put our didactic test bench on the test, this system is "the speed control of DC motor using PID controller". We firstly, started by introducing the theoretical concept of PID controller in general then, we moved on to the practical side of the project, we discussed the system requirements and explained in details the program logic as well as the HMI design and how it functions.

Finally, we explained the second system, which is "the water level control of a tank", we outlined the system requirements as well as the program logic discussing the functionality of the water level sensor, the valve, the implementation of alarms, and we finished with the design of the HMI screen which provided the operator with a clear visualisation and easy system monitoring.

General Conclusion

The project presented in this master thesis is part of the work carried out within the Automatic Complex Systems Team of the LACoSERE laboratory in the Laghouat university . It focuses on the design and conception of a didactic test bench based on PLC S7-1200, with the aim of providing our faculty laboratory with a PLC controlled training tool composed of elements that are frequently used in industrial processes, in favor of students who should be able to acquire proper education and practical knowledge.

Firstly, we have introduced an overview of automation systems, including their fundamental objectives in industrial processes and a detailed description of their structure, establishing the necessary basics to gain a better understanding of the functionalities and capabilities of automation systems.

Then, we offered a detailed presentation of the different parts of the experimental setup, which were used to construct our didactic test bench, by providing a comprehensive description of each element, as well as their individual functionalities and contributions to the system.

In the last section, we presented the basics of programming with TIA portal software, providing a guide through the process of configuring hardware and creating a program for the first time, then, we moved to the testing of our test bench through two experiments, namely speed control of DC motor using PID controller and ON/OFF water level control and successfully ensured that the test bench operates as intended and meets its objectives.

In conclusion, the development of this project has been a rewarding and enriching experience despite all the challenges and difficulties we've encounter, we have gained a practical knowledge in configuring hardware and programming PLCs and HMIs, as well as establishing communication between PLC, HMI and the programming computer. We have also learned the wiring of the controller's I/O and other different components of the test bench. Throughout the testing process of our systems, we have gained deeper insights into the control process of a DC motor, witnessing the impact of PID parameters on the system's speed and how they can influence the response characteristics and minimize errors. And from the water level control system, we have learned the conversion of 4-20mA sensor signal to a readable 0-10V range and how to control a level without exceeding the limits by implementing alarm functionalities.

This test bench holds immense value for students of our university, as it provides them with an experimental setup to apply theoretical concepts in various disciplines including: PLC hardware and software labs, HMI SCADA labs, and diagram and instrumentation labs. In addition to that, the flexibility of the test bench offers students the opportunity to learn and test other applications in multiple areas, such as renewable energy systems, agriculture systems, robotics, etc.

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