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Study and Design of Automatic Installations for a Water Pumping Station

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Dedication

To our dear Families

We are infinitely grateful to our family members, particularly our parents for their patience, unwavering support, continuous encouragement, and their belief in us throughout our whole life. We would have never made it this far without them. Most of that work is for you.

We hope this work brings you happiness.

To all our friends of our class, university, in Algeria, and in the world, may God preserve our friendship.

To all our teachers from Saad Dahleb Blida University.

To all those who have trust us.

ملخص

مهمتنا في هذا المشروع الهندسي هي دراسة و تصميم نظام تحكم آلي لمحطة ضخ المياه التي تزود المياه من الوادي إلى محطة معالجة مياه الصرف الصحي. تتكون الدراسة أولاً من تحديد العناصر المهمة بإستخدام مخطط الأنابيب والأجهزة، مع العلم بطبيعة ووظيفة كل عنصر في المحطة، تحديد مبدأ التشغيل، ثم تصميم مخطط التحليل الوظيفي، وإختيار معدات التحكم المناسبة، برمجة الوحدة المنطقية القابلة للبرمجة لسلسلة موديكون ٢٢١ لشنايدر إلكتريك، تصميم الواجهة بين الإنسان و الآلة، اختبار النتائج في جهاز المحاكاة والتنفيذ أخيرًا على مقعد التجريب

كلمات مفتاحية : مشروع هندسي، نظام تحكم آلي، مخطط الأنانبيب و الأجهزة، مخطط التحليل الوظيفي، الوحدة المنطقية القابلة للبرمجة، الواجهة بين الإنسان و الآلة.

Abstract

Our mission in this engineering project is to study and design an automatic control system for a water pumping station that supplies water from a valley to the wastewater treatment plant. The study consists first of the identification of the important elements by using the piping and instrumentation diagram (P&ID), Knowing the nature and function of each component at the station, determining the operating principle, then we design the functional flowchart, and choosing the appropriate control equipment, PLC programming from the M221 series for Schneider Electric, designing HMI, testing the results in the simulator and finally implementation on the test bench.

Keywords : Engineering project, automatic control system, P&ID, functional flowchart, PLC, HMI.

Résumé

Notre mission dans ce projet d'ingénierie est d'étudier et de concevoir un système de contrôle automatique pour une station de pompage d'eau qui fournit l'eau d'une vallée à la station d'épuration. L'étude consiste d'abord à identifier les éléments importants en utilisant le diagramme de tuyauterie et d'instrumentation, connaître la nature et la fonction de chaque élément de la station, déterminer le principe de fonctionnement, puis nous concevons l'organigramme fonctionnel, et choisir l'équipement de contrôle approprié, la programmation de l'automate de la série M221 pour Schneider Electric, la conception de l'IHM, tester les résultats dans le simulateur et enfin l'implémentation sur la maquette.

Keywords : Projet d'ingénierie, système de contrôle automatique, tuyauterie et d'instrumentation diagram, organigramme fonctionnel, automate, IHM.

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List of abbreviations

AC	*Alternating Current.*
AI	*Analog Input.*
AO	*Analog Output.*
ASCII	*American Standard Code for Information Interchange.*
CPU	*Central Processing Unit.*
DC	*Direct Current.*
DI	*Digital Input.*
DO	*Digital Output.*
FIT	*Flow Indicator Transmitter.*
HMI	*Human-Machine Interface.*
I/O	*Input/Output.*
ID	*Identification.*
IEC	*International Electrotechnical Commission.*
IL	*Instruction List.*
IP	*Internet Protocol.*
ISA	*International Society of Automation.*
LIT	*Level Indicator Transmitter.*
LSH	*Level Switch High.*
NC	*Normally Close.*

NO *Normally Open.*

P-ID *Piping And Instrumentation Diagram.*

PH *Potential Hydrogen.*

PIT *Pressure Indicator Transmitter.*

PLC *Programmable Logic Controller.*

PS *Power Supply.*

RAM *Randoom Access Memory.*

ROM *Read Only Memory.*

RTU *Remote Terminal Unit.*

SCADA *Supervisory Control and Data Acquisition.*

TCP *Transmission Control Protocol.*

VFD *Variable Frequency Drive.*

Introduction

Water is the most important thing in this world, which we use for many things in our daily life cooking, drinking, hygiene, industrial processing manufacturing Argo-food, gas and oil, energy production, and agriculture. For a long time, humans try to develop a different technical perspective on pumping water to make this resource more flexible to use in terms of time and location, reduce the cost of consummation, and recycle it to keep it for another use. One of the essential technical aspects of mechanical, electrical, civil, hydraulic, and environmental engineering. For the realization of a pumping water station, the engineers of different fields meet and try to analyze the problem or specification of the project, every engineer tries to propose a solution concerning their field and expertise.

Our mission in this project engineering will be on the automation part, The study consists first of identifying the important elements of the project by using the piping and instrumentation diagram (P&ID) with knowledge of the nature and function of each element in the station, determining the operating principle, selecting the appropriate control equipment, then we design the control elements architecture, the functional flowchart, programming the programmable logical controller (PLC) using EcoStruxur Machine Expert Basic software, we also have to design the station monitoring system using the human machine interface (HMI) by using Vijeo Designer Basic software, In addition, we achieve the connectivity between PLC and HMI using Gateway communication interface. This final year project (FYP) was organized into three chapters:

In the first chapter, we provided an overall overview of the water pumping station, we talked about how any project is organized and the stages it is going through, we show also about the different engineers who can be involved in this kind of project and various scopes and tasks of their work and the skills and capabilities they should have, we focused on automation engineering and on the automation engineer that we represent. In the end, we essentially explained the ethics of engineers and standards.

In the second chapter, we focused on the hardware side of our process where we described the overall structure of automated systems, their parts, and their components, we also talked about the role of components in the operative part, the command part, and the desk part, as well as we have spoken about the protocol of communication used and its types.

In the third chapter, we focused on the software side of our process, where we saw the all steps of studying the process. Furthermore, we introduced the softwares used and explained the development automation part of our project from the creation of the project to completion, and finally, we presented the results and the simulation.

Chapter 1

Project organization and engineering

1.1 Introduction

Project organization is a critical component for the successful completion of any project. Project organization involves establishing the structure and framework for the project, including defining objectives, identifying stakeholders, allocating resources, and developing a timeline. Engineering, on the other hand, is the process of designing, building, and implementing systems and components that meet project requirements.

In this chapter, we will explore the essential principles and practices involved in project organization and engineering. We will discuss the roles and responsibilities of project team members, project life cycle phases, and the importance of effective project management. Additionally, we will explore the various engineering disciplines that are involved in project development, including civil, mechanical, electrical, and automation engineering.

1.2 Project overview

The Water Pumping Station project aims to provide a reliable water supply to a treatment station by drawing water from a valley. The infrastructure will consist of three motor pumps that will operate in a parallel configuration to ensure a continuous flow of water to the treatment station. In addition, there will be a series of distributed tanks to ensure that there is sufficient water storage capacity for times of high demand.

The electrical system will provide power to the pumping station and ensure that the motor pumps operate efficiently and reliably. The instrumentation system will monitor and control the water flow and pressure, ensuring that the water supply is stable and consistent. The automation system will control and optimize the operation of the motor pumps, making sure that they run at optimal efficiency while reducing energy consumption and maintenance costs.

The project will require a multidisciplinary team of engineers, including civil, electrical, mechanical, and automation engineers, to ensure that the infrastructure is designed and implemented to meet the required specifications and standards. The project team will also need to take into account factors such as safety, environmental impact, and sustainability in the design and implementation of the water pumping station.

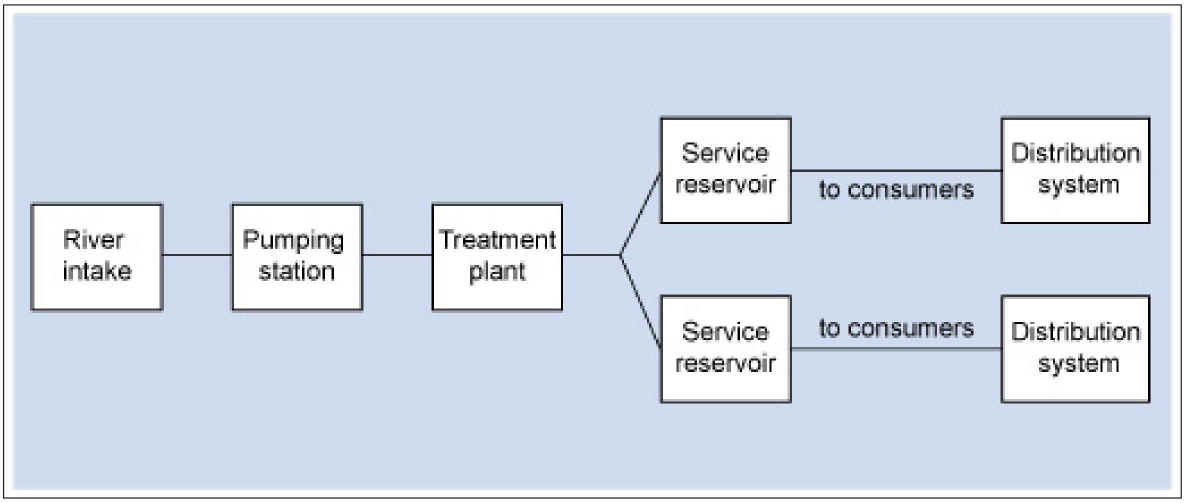


Figure 1.1: The elements of water supply system[1]

1.2.1 Description process

The water arrives through a catchment basin which is located at the river bank, then the water moves through pipes to the lamellar settling tank to remove sludge from the water and separate the solid objects, then the water will be stored in the main tank of the plant with a storage capacity of 250 m3, the preparation and dosing of a coagulant (acid-base solutions) basin in the main tank to regulate the acidity of water.

Water is moved to the secondary reservoir of the treatment plant by pumps according to the need, the process is equipped with an anti-hammer reservoir which allows for protecting the installation of the pipes from over-pressure.

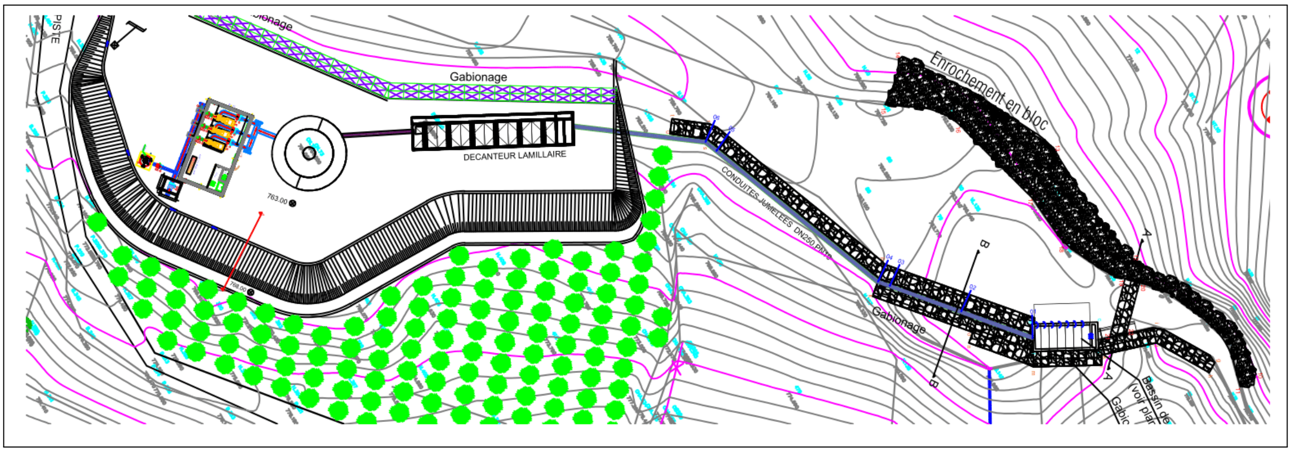


Figure 1.2: Civil plan

1.3 Project life cycle

The project life cycle is a crucial aspect of any project management. It refers to the series of phases that a project goes through from its initiation to its closure. The project life cycle defines the framework for how a project is planned, executed, and delivered to its stakeholders. This concept applies to a wide range of projects, including the construction of a pumping station. A pumping station is a crucial infrastructure that helps supply water to communities and industries. The success of a pumping station project depends on a well-defined and structured project life cycle.

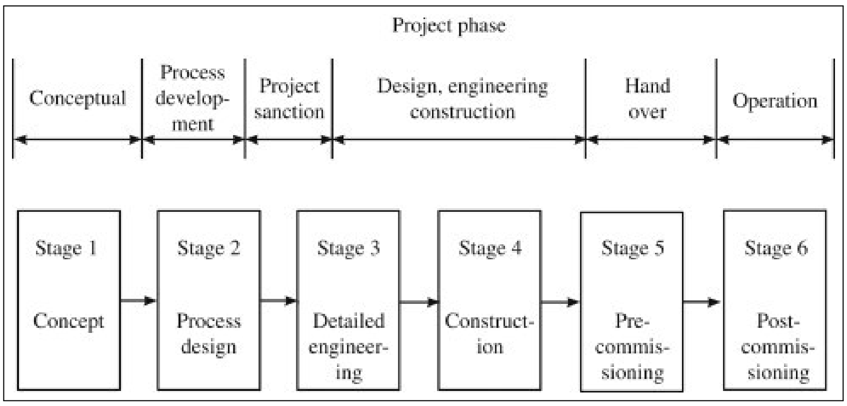


Figure 1.3: Project life cycle diagram[2]

Project Life Cycle is divided into several phases, and in each phase there are roles, the phases are:

1.3.1 Initialization

A project life cycle starts with the initiation phase. This is when the project is first proposed and evaluated to determine its feasibility and potential benefits. During this phase, the project's objectives, the scope of work, and stakeholders are identified, and a high-level plan is developed to guide the project.

Where the owner defines the Scope of work and the consultant starts the preliminary studies of the project based on the Scope of work, At this stage, the first task of the consultant is leading the "Feasibility": study to determine if the technical and economic means are available to carry out the planned project, "Task specification": it consists in making an inventory of the parameters, criteria, and data that will be used to control the project management and the works to be executed.

1.3.2 Design

In this phase, the engineering team will work to develop a detailed design plan for the infrastructure, taking into account the specifications and requirements of the project.

The next step is to perform a detailed engineering design, which includes the sizing and selection of materials, equipment, and instrumentation necessary for the installation. The engineering team will also design the control and automation systems that are required for the efficient and safe operation of the pumping station.

During the design phase, the engineering team will work closely with the project to ensure that the design meets all requirements and specifications. The design phase will also involve extensive testing and simulations to verify the design's performance and identify any potential issues or risks.

1.3.3 Execution

The execution phase is a critical stage where the plans and designs of the project are put into action. During this phase, the construction and installation of the infrastructure and its components are carried out in accordance with the project plan and specifications

The first step is procurement, which involves acquiring the necessary materials, equipment, and services required. This includes pumps, tanks, pipes, electrical components, and automation systems

With the plan in place, the project moves into the execution phase, where the work is performed and the project deliverable is produced. This is often the longest phase of the project life cycle, and it requires close monitoring and control to ensure that the project stays on track.

1.3.4 Commissioning

Once the execution phase is complete, the project team carries out the testing and verification of the installed systems and equipment to ensure they are fully functional and meet the specified performance requirements. The commissioning process typically involves the following steps:

- Pre-commissioning checks: visual inspections and functional checks to ensure that all equipment and systems have been installed correctly and are ready for testing.
- Functional testing: This involves performing a series of tests to verify the performance of the installed systems and equipment, including pumps, valves, control systems, and instrumentation. The tests are conducted in accordance with the project specifications and design requirements.
- Performance testing: This involves conducting a series of tests to verify the performance of the pumping station under different operating conditions. The tests are aimed at verifying the flow rate, pressure, and other parameters of the pumping station and ensuring that they meet the specified requirements.
- System integration testing: This involves testing the integration of the various systems and equipment to ensure that they work together as intended[4]. The tests are aimed at verifying the communication protocols, interlocks, and other control functions of the system.
- Documentation: All tests and results are documented to provide a record of the commissioning process and to ensure that the equipment and systems meet the specified performance criteria.
- Training: Once the commissioning is completed successfully, the operators and maintenance personnel receive training on the operation and maintenance of the pumping station.

The commissioning phase is critical to the success of the project, as it ensures that the completed project meets the required specifications and standards and is fully operational before it is handed over to the end users. Effective commissioning processes help to reduce the risk of project failure, minimize downtime, and ensure that the project delivers the intended benefits.

1.3.5 Operation & Maintenance

In this phase, the operators ensure that the station is working well to keep it efficient and reliable

During the maintenance phase, the project team is responsible for monitoring and maintaining the Station, as well as making any necessary repairs or upgrades to keep the system running at optimal performance levels[4]. The activities involved in this phase are:

- Preventive maintenance: to prevent equipment failure or downtime. This may include regular inspections, cleaning, and maintenance planning.
- Corrective maintenance: The project team addresses any issues or failures that arise during the operation of the project. This may involve repairing or replacing components or systems.

1.4 Project management

Management is the activity in an organization and the coordination of the project in order to achieve defined objectives and goals that manages and controls resources (people, money, time, technology, procedure, etc.) efficiently and effectively. The Management includes developing team objectives and goals, setting up detailed execution plans and procedures, and coordinating with internal and external parties.

A Project Manager is responsible for overseeing the successful completion of a project from start to finish. In the following table 1.1 is an example of a project management worksheet.

The tasks of a Project Manager include:

- Planning and scheduling
- Budget: Managing project costs.
- Quality: Ensures that project deliverables meet the required quality standards

Project Name : Water pumping station	
Project Owner name : Algeria Water Company	
Project Objective: Design, build, and commission a pumping station	
project description: The infrastructure will allow the feeding of a treatment plant with water...	
Project Team	Project Manager name Engineers Office name Construction company name
Project Deliverance	Design and engineering documents Procured equipment and materials Constructed and installed a pumping station Commissioned and tested pumping station Completed operation and maintenance manuals Handover to the client
Project Risks	Delay in equipment delivery or installation Unexpected site conditions during construction Technical difficulties during commissioning and testing Maintenance and operational issues
Project Budget	Design and Engineering: 400,000 DA Procurement: 800,000 DA Construction and Installation: 600,000 DA Commissioning and Testing: 100,000 DA Operation and Maintenance: 100.000 DA Total Budget: 2,000,000 DA
Project Timeline	Initiation: 2 weeks Design: 5 months Execution: 18 months Commissioning: 2 months Closure: 2 weeks

Table 1.1: Example of worksheet project management

1.5 Engineering

Engineering is the application of mathematics, science, and technology to solve complex problems in the design, development, and implementation of a wide range of systems, structures, machines, and processes. It is an essential aspect of the planning, design, and construction of any infrastructure project.

It plays a vital role in ensuring that the project meets its objectives and requirements by applying a systematic approach to problem-solving and critical thinking.

In the case of this project, engineering implies the design and development of the pumping station, including the layout, structure, and systems required to transfer water from the valley to the treatment station. This includes the selection of appropriate materials, equipment, and technologies, as well as the consideration of environmental, safety, and regulatory requirements.

1.5.1 Disciplines

The Water pumping plant project requires the expertise of various engineering disciplines:

- Civil engineer is responsible for designing the layout of site, structure building, and construction of the infrastructure such as the catchment basin and the reservoirs.

- Hydraulic engineer is responsible for the design and operation of the water conveyance system, he uses her expertise to calculate flow rates, pressure, and energy losses to ensure the system's hydraulic efficiency.

- Mechanical engineer is responsible for designing and selecting the mechanical equipment required for the pumping station, such as pumps, motors, valves, and piping systems. They ensure that the equipment is of appropriate size, capacity, and specifications for the intended purpose.

- Electrical engineer is responsible for the design and implementation of the electrical systems that power the equipment in the pumping station. He must ensure that the electrical systems are reliable, safe, and efficient for the electrical systems installation, including the selection of the appropriate motor, power distribution system, switchgear, and control panels. Deliverables of the Electrical Engineering are a one-line diagram (single-line diagram), electrical load list, electrical equipment datasheet, and distribution network drawing.

- Process engineers is ensuring the optimal operating conditions for the system, including the type and amount of coagulant to be added to the water to regulate its acidity.

- Instrumentation engineer is responsible for designing, implementing, and maintaining the control systems and instrumentation that are necessary for the efficient and safe operation of the station. This involves selecting and integrating various sensors, meters, and control devices to measure and regulate key parameters such as flow rate, pressure, and temperature. Including testing and calibrating the instrumentation and control systems to ensure their proper operation during the commissioning phase.

1.5.2 Scope of works and tasks

The scope of work of engineers can vary depending on their area of expertise and the specific requirements of the project they are working on. In general, engineers are responsible for designing, developing, and maintaining systems and processes that meet specific technical requirements.

There are some tasks that engineers perform during a project include:

- Participating in project planning and design meetings to provide technical expertise.
- Creating project plans and schedules that outline the scope of work, timelines, and resource requirements.
- Conducting research and analysis to identify and evaluate various technical solutions that may be applicable to the project.
- Developing detailed engineering drawings, schematics, and specifications that outline the requirements for the project.
- Supervising and coordinating with other engineers, technicians, and contractors to ensure the project is completed on time and within budget.
- Conducting site visits and inspections to ensure the project is being built according to specifications and quality standards.
- Troubleshooting and resolving technical issues that may arise during the project.
- Participating in project closeout activities, including final inspections, testing, and documentation.

1.5.3 Skills

Engineers require a wide range of technical and non-technical skills to perform their mission effectively. Some of the technical skills required for engineers :

- Ability to analyze: Engineers must be able to analyze complex problems and devise effective solutions. They should have a strong understanding of mathematical and scientific principles, as well as critical thinking skills.
- Knowledge of design principles and standards: Engineers must have a solid understanding of the principles and standards that govern their specific area of engineering. This includes a thorough knowledge of math, physics, chemistry, and other sciences.
- Proficiency in computer-aided design (CAD) software: CAD software is used to create detailed drawings, models, and schematics of engineering designs (AutoCAD, SolidWorks, Eplan). Engineers should have a good understanding of CAD software to effectively design and model their projects.

Also, non-technical skills that engineers should have are communication, problem-solving, teamwork, leadership, time management, adaptability, and creativity. These skills are necessary to effectively communicate with colleagues and clients, identify and solve complex problems, work collaboratively with others, manage time and resources effectively, adapt to changing situations, and develop innovative solutions to engineering challenges.

1.6 Automation engineering

Automation engineering is a branch of engineering that deals with the design, development, and implementation of automated systems to improve efficiency, productivity, and quality in various industries. Automation engineers use a combination of hardware and software technologies to create systems that can operate with minimal human intervention, often utilizing sensors, actuators, and control systems. They are responsible for designing and implementing the automation process, including the selection and integration of hardware and software components, programming of controllers and other systems, and testing and maintenance of the automated systems. The goal of automation engineering is to increase efficiency, reduce costs, and improve safety and quality in industrial and manufacturing processes.

In this project, the automation engineer will be responsible for automation and control parts, the tasks that do it in this project are as follow :

- Develop the control system architecture: Design the hardware and software components of the control system, including sensors, actuators, controllers, and communication networks.
- Selecting the appropriate control devices: select the appropriate control devices required to monitor and control the water pumping station's equipment, such as pumps, valves, and motors.
- Designing the human-machine interface (HMI): design the HMI, which is the graphical interface used by operators to monitor and control the water pumping station's equipment and system.
- Developing the control system software: The automation engineer would develop the control system software required to implement the control algorithms and HMI.
- Conduct commissioning and testing of the automation system, including performance verification and functional testing. This ensures that the automation system is working as intended and meets the project requirements.

1.6.1 Deliverables

The deliverable of an automation engineer is a comprehensive control system design. This includes the design of control strategies, the selection of hardware and software components, and the creation of control panel layouts and wiring diagrams. The engineer may also be responsible for programming and configuring the control system software, as well as performing testing and commissioning of the system. Additionally, the automation engineer may develop a maintenance plan for the control system, including scheduled maintenance and troubleshooting procedures.

The ultimate goal of the automation engineer's deliverable is to ensure the efficient and reliable operation of the water pumping station through effective control of its various components and processes.

1.7 Ethics for engineer

Engineering ethics is a set of moral principles and values that guide the behavior of engineers in their professional practice. It involves a commitment to uphold integrity, honesty, fairness, and respect for human life and the environment. Ethics are essential in engineering to ensure that engineering projects and practices are safe, reliable, and sustainable.

They have a responsibility to consider the potential social, economic, and environmental impact of their work. They must prioritize safety and sustainability in their designs, and they must always act in the best interests of their clients and the public. Engineers must also maintain their competence and strive to improve their skills and knowledge throughout their careers.

Ethics will be an essential consideration throughout the project, and the project team will need to ensure that the infrastructure is designed and implemented with the utmost respect for safety, human health, and the environment. The team will need to be aware of the potential social and environmental impacts of the project and work to mitigate these impacts wherever possible.

1.7.1 Standards

A technical standard is an established norm or requirement. It is usually a formal document that establishes uniform engineering or technical criteria, methods, processes, and practices. The documents prepared by a professional group or committee are believed to be good and proper engineering practices and which contain mandatory requirements.

Standards play an important role in the field of engineering as they provide a set of guidelines, principles, and requirements that ensure consistency, reliability, and safety in the design, manufacturing, and operation of products and systems. Standards for engineering cover a wide range of areas such as materials, processes, design, testing, and quality management. These standards are developed by international and national organizations and are used by engineers and companies around the world to ensure that their products and systems meet certain minimum requirements and are of high quality. Adhering to standards is not only important for ensuring the safety and reliability of products, but it can also improve efficiency, reduce costs, and enhance competitiveness in the global market. Therefore, engineers must have a strong understanding of relevant standards and ensure that they are followed throughout the entire engineering process.

In engineering, codes are sets of rules, regulations, and standards that prescribe best practices, safety protocols, and other requirements for the design, construction, and operation of engineering systems and structures. Codes are typically developed by professional organizations, regulatory bodies, and industry groups to ensure that engineering projects are executed in a safe, effective, and efficient manner. Codes cover a wide range of topics, including building codes, fire codes, electrical codes, mechanical codes, and plumbing codes. Compliance with codes is often mandatory and may be enforced through inspections, permits, and other regulatory mechanisms. Following codes helps ensure that engineering projects are designed and built to a high standard of quality and safety, protecting the public and the environment.

We will show in the following table 1.2, the list of standards for automation engineering that are used in the project:

Organization	Standard	Description
International Electrotechnical Commission (IEC)	IEC 61131	Defines a standard for programmable logic controllers (PLCs)
	IEC 61850	Defines a standard for communication networks and systems for power utility automation.
	IEC 61512	Batch control systems.
	IEC 62443	Cybersecurity for industrial automation and control systems.
	IEC 62682	Management of alarm systems for the process industries.
	IEC 61511	Functional safety: Safety instrumented systems for the process industry sector.
International Society of Automation (ISA)	ISA-101	Human Machine Interfaces for Process Automation Systems.
	ISA-95	Enterprise-Control System Integration.
	ISA-5.1	Instrumentation Symbols and Identification .
	ISA-5.2	Binary Logic Diagrams for Process Operations.
	ISA-5.3	Graphic Symbols for Distributed Control/Shared Display Instrumentation, Logic, and Computer Systems.
	ISA-5.4	Instrument Loop Diagrams
	ISA-100	Wireless Systems for Automation.

Table 1.2: Standard for automation engineering

1.8 Conclusion

In this Chapter, we have provided an overview of the project, including a description of the process that helped to understand the functioning of the station. We discussed the phases that the project passes by it. Furthermore, we have talked about the different disciplines of engineering participating in this project and we have focused on automation engineering, tasks, and deliveries. In addition, we explained the aspect of ethics for engineers.

In the next chapter, we will try to focus on the hardware side of our process, where we will talk about the structure of automation systems, their parts and the communication between them, the actuators, instruments, control devices that we used, and the industrial communication used.

Chapter 2

Structure and components of the automation systems

2.1 Introducion

An automation system is made up of several elements and we could say it is automatic if it performs a function alone and always performs the same work cycle (a set of programmed tasks), without human intervention.

In this chapter, we will talk about the structure of automation systems, parts, and components, which are the actuators, sensors, and communication networks that are usually used in the water pumping treatment process and that really we used in our process.

2.2 Structure of the automation systems

An automation system refers to a series of hardware and software components that work together to automatically control a process, equipment, or system. These systems are designed to function with minimal human intervention, making processes more efficient, reliable, and safer.

Automation systems are integral to a wide range of applications, from home appliances and climate control systems to large-scale industrial processes and manufacturing operations. It consists of three main parts which are :

- Operative part.
- Command part.
- Desk part

We summarize the structure of the automation system in the following Figure 2.1 to facilitate analysis, we can represent a system in the form of a diagram identifying the three parts and expressing their relationship.

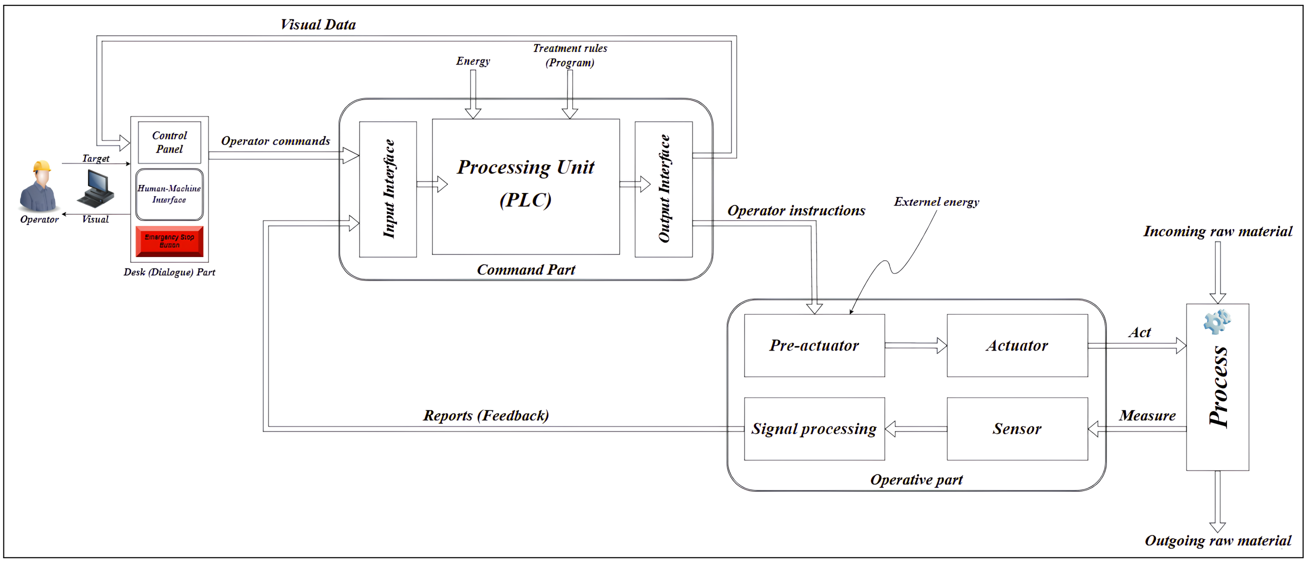


Figure 2.1: Structure of automation system

2.2.1 Operative part

The operative part is defined as all the actuators that act or affect the raw matter (material) from the operative instructions elaborated by the command part as figure 2.2, generally in order to add value, and generate reports (feedback) to the command part. The operative part consists of the following sets:

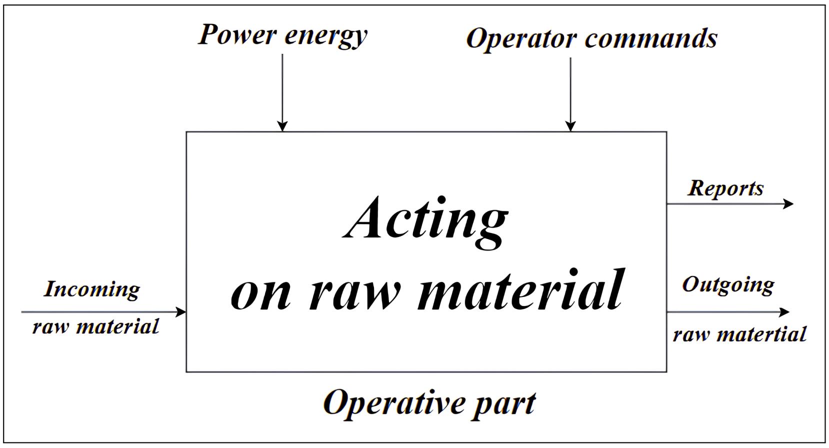


Figure 2.2: Diagram of the operative part

Effectors

The effector is the one element in direct contact with the work material, it makes operations on it and adds value to it by using different energies (mechanical, thermic, or physicochemical. . . etc.) coming from the actuator.

Actuators

Actuators are devices that make something move or operate where receive a source of energy and use it to move something by converting this energy into a mechanical motion. That source of energy can be in three different types :

- Electric actuators: they use electricity to provide motion.
- Pneumatic actuators: they use atmospheric pressure to supply motion.
- Hydraulic actuators: are actuators that are powered by pressurized liquid, compared with pneumatic actuators, hydraulic actuators are more powerful.

The actuator receives different external energies source (electric, pneumatic, or hydraulic) and converts them into mechanical energy or other energies and provides this converted energy to the effector to make its work. It can move something in a straight line (linear) or in a circular motion (rotary).

Pre-actuators

Pre-actuators are devices that distribute the different external energy sources to the actuators after receiving the electrical signals issued by the controller. It is responsible for supplying the actuator with external energy according to the operating instructions received from the command part.

Sensors

Sensors are the figurative eyes and ears of the control process, to be more clear sensors are elements sensitive to physical quantities where take usable information and transform it into electrical signals.

In the world of instrumentation, we define sensors as measuring devices that detect changes in physical, thermal, magnetic, and chemical properties, and produce an electrical output in response to that change. There are two broad categories of sensors :

- Digital sensors: The ones that return true/false signals, these sorts of sensors, are used for anything that we divide into two states.
- Analog sensors: The ones that return a range of values that convert a variable physical quantity into an electrical signal that the control system can understand.

The sensor is responsible for detecting, measuring information, and informing the command part about the execution of the work and the evolution of the system (reports).

2.2.2 Command part

The command part is the part that elaborates the instructions which control the operative part. These orders are elaborated as a result of a logical sequence of instructions and operations to be performed (program), information collected from sensors of the operative part, and from the operator and sent it back to the operative part to the direction of the pre-actuator and actuator. Also, the command part sends the visual data to the operator. A figure 2.3 that shows it.

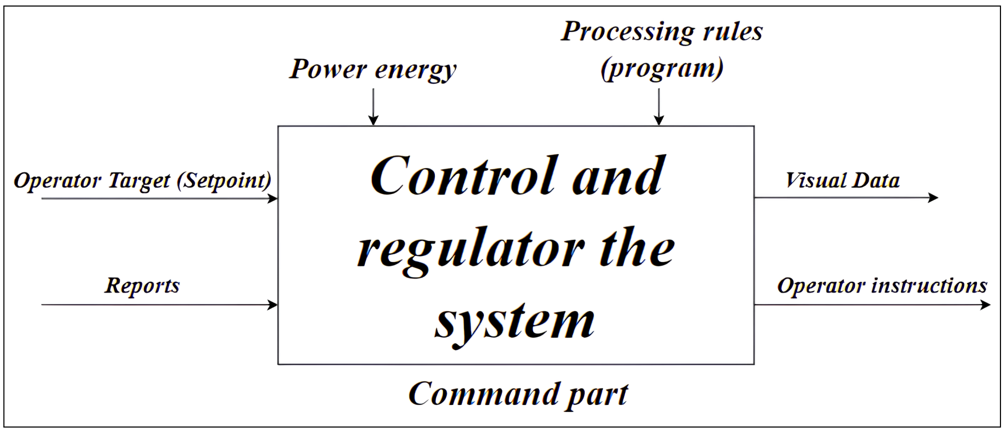


Figure 2.3: Diagram of the command part

2.2.3 Desk part

The desk part is the operator interface or control panel that enables the operator to dialogue with the command part, interact, with and input commands to control the automated system, monitor the system's performance, and make adjustments as needed. The desk part may also provide real-time feedback on the status of the system and alert the operator to any issues, errors, or alarms that require attention.

2.3 Control panel

Control panel, also known as an operator panel, is a user interface that allows operators to monitor and control various processes. It serves as a centralized hub for controlling and monitoring equipment, displaying real-time data, and providing access to critical functions and settings, Figure 2.4 shows our control panel used.

Figure 2.4: Control panel

The control panel contains the following compounds :

2.3.1 Emergency stop button

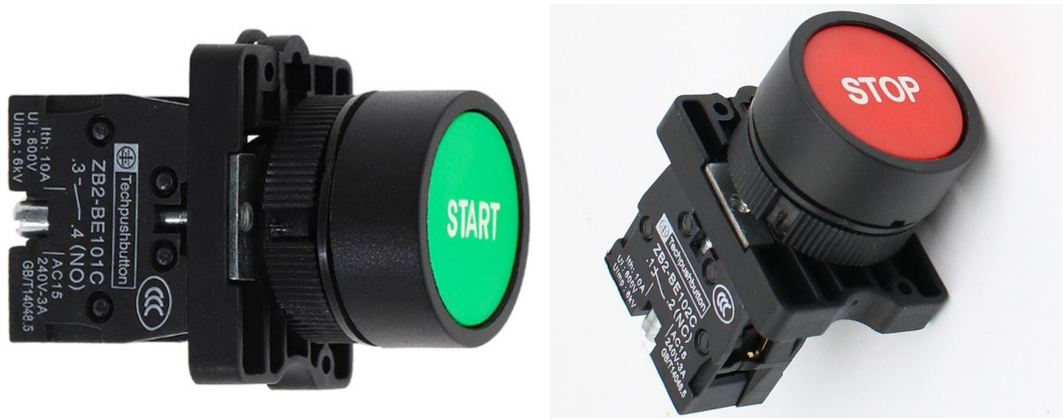
An emergency stop button is a safety device used to immediately halt the operation of machinery or equipment in emergency situations to protect personnel, equipment, and the surrounding environment for that, there are many organizations that imply standards for to use of emergency stop buttons in automated systems as safety devices.

2.3.2 Push buttons

A Push button is a simple electrical switch that is activated by pressing the button, inside the button there is a contact, this contact can be either normally open (NO) or normally closed (NC) figure 2.5 shows these two types.

In the case of NO: under normal conditions, the contact is open, when the button is pressed the contact becomes closed and connected, and when the button is released the contact returns to the original state. This type is used in the start push button.

In the case of NC: under normal conditions, the contact is closed, when the button is pressed the contact becomes open and disconnected, and when the button is released the contact returns to the original state. This type is used in the stop push button.



((a)) Start button [5] ((b)) Stop button [6]

Figure 2.5: Push button types

2.3.3 Selector switch

A selector switch is an electrical switch that has a rotational handle that allows selecting the desired position, so it has multiple positions, each position corresponds to a specific function in the automation system, for example, manual or automatic mode, local or remote mode, etc...

There are two types of selector switches figure 2.6, a selector switch with two positions and a selector switch with three positions.

((a)) Selector two positions [7] ((b)) Selector three positions [8]

Figure 2.6: Selector types

2.3.4 Indicator Lamps

Indicator lamps or indicator lights that provide visual indications to the operator, they are designed to alert the operator about specific conditions, status, and events. These lamps are illuminated in different colors figure 2.7, such as the following [9]:

- Green light means that the system is in a normal operating state.
- Red light can signify warnings, errors, problems, malfunctions, potential hazards, or any critical conditions that require immediate attention.
- Yellow light indicates cautionary or advisory conditions, they may signal a need for attention, or maintenance.
- Blue light signifies that there is an action of the operator is necessary for the continuation of a normal operation.

Figure 2.7: Indicator lights

2.3.5 Human-Machine Interface

HMI is short for Human-Machine Interface, it is a graphical interface, and monitor screen and a visual representation of the system's components, status, and performance, it refers to a screen or dashboard that communicates information, data, and metrics using graphics or visual representations of process equipment and translates complex data into useful information that enables and help the operator to monitor and interact with the automated system, to input commands to the PLC from a certain distance, adjust settings, and know alarms or specific conditions or events. [10].

The water pumping process requires a supervisory system as shown in the table 2.1, for that we use HMI to have good control and to make the process work with excellent performance.

Requirement	Description
Real-time Monitoring	Display of real-time data on pump status, flow rates, and pressure.
Control	Start, stop, and control pump operation and parameters.
Alarm System	Visual and audible alarms for abnormal conditions or faults.
Data Logging	Record and store data for analysis and historical tracking.
Trend Analysis	Graphical representation of data trends and performance indicators.
Remote Access	Ability to access and control the HMI remotely via network connectivity.
Fault Diagnostics	Provide diagnostic information to assist in troubleshooting and maintenance.
Security	User authentication and access control for system security.
Visualizations	Display pump and system diagrams, charts, and trends.
Historical Data Analysis	Analyze historical data to identify patterns and optimize system performance.

Table 2.1: Features of HMI in Water Pumping Station

In our case, we used HMIGXU3512 which represents a range of products Easy Harmony of HMI by Schneider Electric, that meet the requirements of the process in terms of technical characteristics and it has the ability to integrate into the automated system.

The HMIGXU3512 panel has additional features compared to other panels from the same series like HMIGXU3500 and HMIGXU5500 and are:

- USB type A
- Ethernet
- RS-232
- User application 48 MB

Some features [11] for HMIGXU3512 are presented in the list below:

- **Rated supply voltage:** 24 V DC
- **Display size:** 7 inch
- **Display resolution:** 800 x 480 pixels WVGA
- **Display type:** LCD touchscreen
- **Display colour:** 65536 colours

By the following, we tried to identify the parts of this HMI and their functionality.

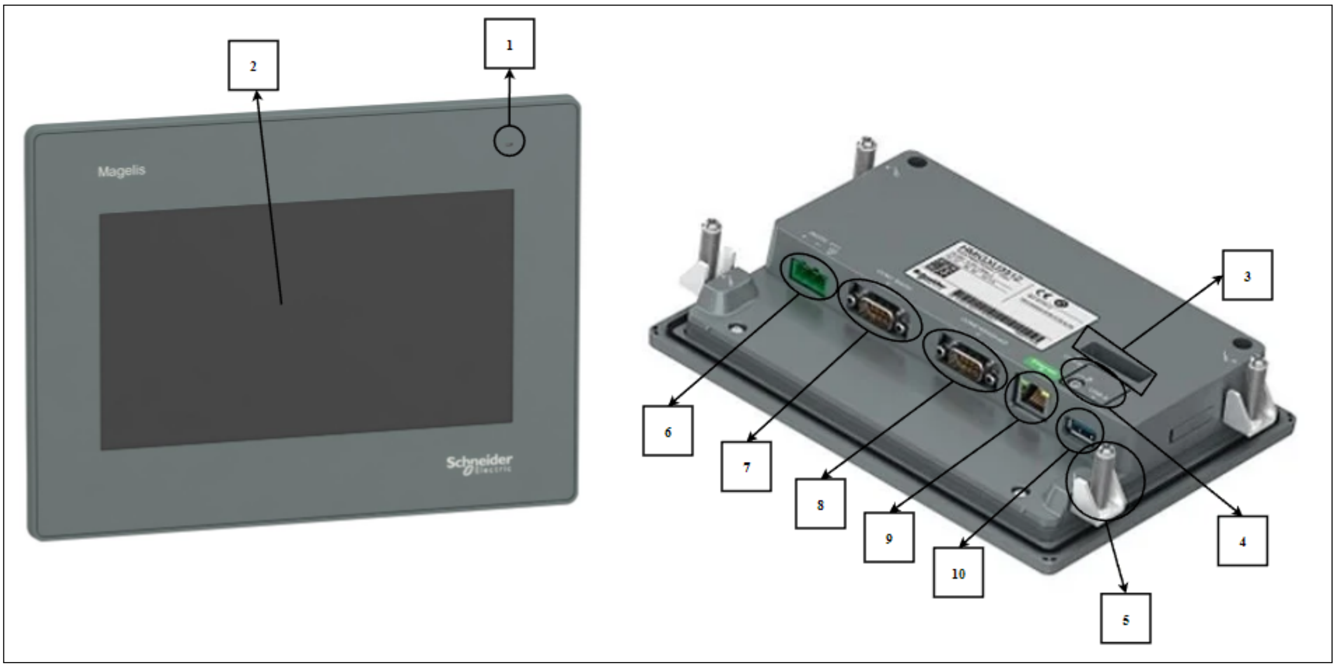


Figure 2.8: HMIGXU3512 Harmony Easy GXU

1- LED indicator

2- Touch panel

3- USB mini-B programming port

4- Locker USB Type A

5- Screw installation fasteners to fix the HMI

6- Power connector to supply the HMI (DC)

7- Serial interface RS-232 for communication.

8- Serial interface RS-422/485 for communication.

9- Port Ethernet for communication.

10- USB Type programming port.

2.4 Actuators

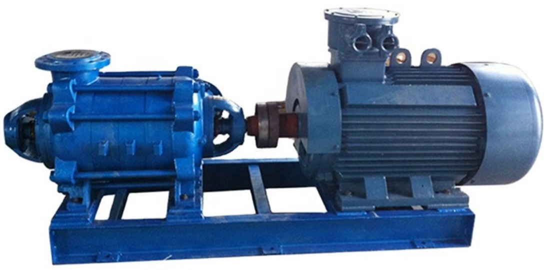
In this project we have different actuator equipment that was selected by hydraulic and mechanical engineers, they are as follows.

2.4.1 Pumps

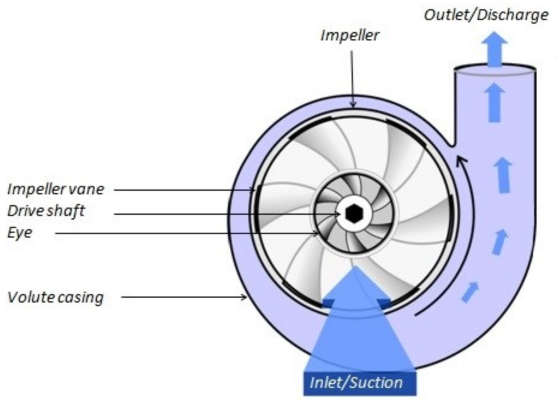
Pumps are mechanical devices designed to move fluids from one place to another. They do this by creating a pressure difference that forces the fluid to move [12]. There are various types of pumps, each suited to a different type of application or working with different types of fluids, in this project, they have chosen a horizontal multistage pump type.

A multistage pump is a centrifugal pump that works by creating a centrifugal force when the motor rotates the impellers so that lead to the pump converting mechanical energy from a motor into energy that moves the fluid.

In our pump model, there are 3 stages, each stage has its own impeller. In a typical setup, a motor drives the 3 impellers which are housed inside a casing filled with the fluid to be pumped. The fluid enters the pump near the center of the rotating impeller and gains energy as it moves outward through the blades of the impellers. When the liquid comes out of the last impeller, it enters a volute chamber which slows the liquid and increases the pressure [12], the figure 2.9 demonstrates this.



((a)) Centrifugal pump [13]



((b)) Working principle [12]

Figure 2.9: Centrifugal pump and working principle

As we are responsible for the control part of this project, we need to know the technical specifications as shown in table 2.2 of this pump in order to select the type of command.

Electrical power supply	Three phases AC
Rated frequency	50 Hz
Rated voltage	400 V
Rated current	384 A
Max power	225.73 KW
Rated speed	1486 r/min
Maximum Flow	210 m3/hr
Maximum Operating Pressure	16 Bar

Table 2.2: Technical features of the pump [3]

2.4.2 Dosing pump

Dosing pump is a positive displacement pump type, designed to inject a chemical or another substance into a flow of water, gas, or steam. Dosing pumps, which are typically small, provide an extremely precise flow rate for maximum control [14], among its advantages are :

- Precision: deliver an exact volume of liquid in a controlled manner. This precision is essential when the exact amount of chemical or other substance being added can significantly impact the outcome of a process.
- Adjustability: The rate at which the pump doses the liquid can usually be adjusted, allowing for flexibility in different situations or as requirements change.
- Chemical Compatibility: designed to be resistant to the chemicals they are dispensing. This is important because corrosive chemicals can damage the pump parts over time.

In this process, it will be used to add a caustic chemical or an acid to a water storage tank to neutralize the PH, in following there are some technical features [15] of the dosing pump to know how to control it:

- Electrical power supply: 3 phases AC, 50 Hz, 1.5KW.
- Flow rate: Adjustable from 0 to 530 L/Hr.
- Pressure: Up to 10 bar.
- Control: Manual or automatic (4-20mA signal).
- Maximum fluid temperature: 80 °C.

2.4.3 Vertical agitator

Vertical agitator, also known as a mixer is a mechanical device used to blend or stir substances together in a tank or vessel. It is the same principle with the pump there is a shaft with impellers and when the shaft is driven by the motor which provides the necessary power to rotate the impellers.

In the process, an agitator was used to mix the chemical products inside tanks in order to facilitate chemical reactions with water. We show in the following technical characteristic [16] of the mixer :

- Motor power: 4 KW, 3 phases AC, 50 Hz.
- Voltage rate: 380 V.
- Operating Speed : 1000 r/min.
- Mixing Capacity: Up to 2000 Liters.
- Maximum Operating Temperature: 80 °C.

2.4.4 Valves

Valves are mechanical devices that control the flow and pressure within a system or process by opening, closing, or partially obstructing various passageways. They are essential components of a piping system that conveys liquids, gases, vapors, slurries, etc. in our process, there are several types of valve that was used (like a gate, butterfly, diaphragm) with different types of command (manual, electric, and pneumatic).

In our case, we will be interested in the valve that has an electric or a pneumatic command which are as follows :

- Knife gate valves are a type of valve that is operated by a pneumatic cylinder, which uses air pressure to move the valve's "gate" or disc, and its feature characteristics are :
  - Pneumatic actuator type: Spring Return.
  - Air Supply Pressure: 4-7 bar.
  - Limit switch position open/close with NO contact.
- Motor Operated Valves type of valve that uses an electric motor actuator for opening or closing, and her feature characteristics are :
  - Supply voltage: 380 V, 3 Phases AC, 50 HZ.
  - Operating Time: 10 seconds (Open to Close).
  - Limit switch position open/close with NC contact.

2.5 Pre-actuators

In this section, we will show the pre-actuators that was used to control different actuator in the process of the water pumping station and there are as follow:

2.5.1 Pneumatic distributors

A pneumatic distributor, also known as a pneumatic valve or air valve, is a device in a pneumatic system that controls the flow of pressurized air. These are used to control the direction of airflow for pneumatic actuators. It can be operated in different ways manually, mechanically, electrically, or pneumatically. In our case, we will use solenoid valves that are operated electrically by PLC.

2.5.2 Relay

A relay is an electromagnetic device used as an interface between the signal coming from PLC and the electrical actuators. It consists of some contacts and a coil wrapped around a magnet. When the coil is energized by an electrical signal from PLC, an electromagnetic field has being created that pushes the contact so it changes its state. If the electrical signal disappears so the contact return to its rest state.

2.5.3 Contactor

Contactor is an electrically controlled switch used for switching a power circuit. It is used to control electric motors, lighting, heating, and other electrical loads. A contactor operates by creating a magnetic field when a control voltage is applied to the coil within the contactor. This magnetic field attracts the contactor's switch points, closing the circuit as the figure 2.10 shows.

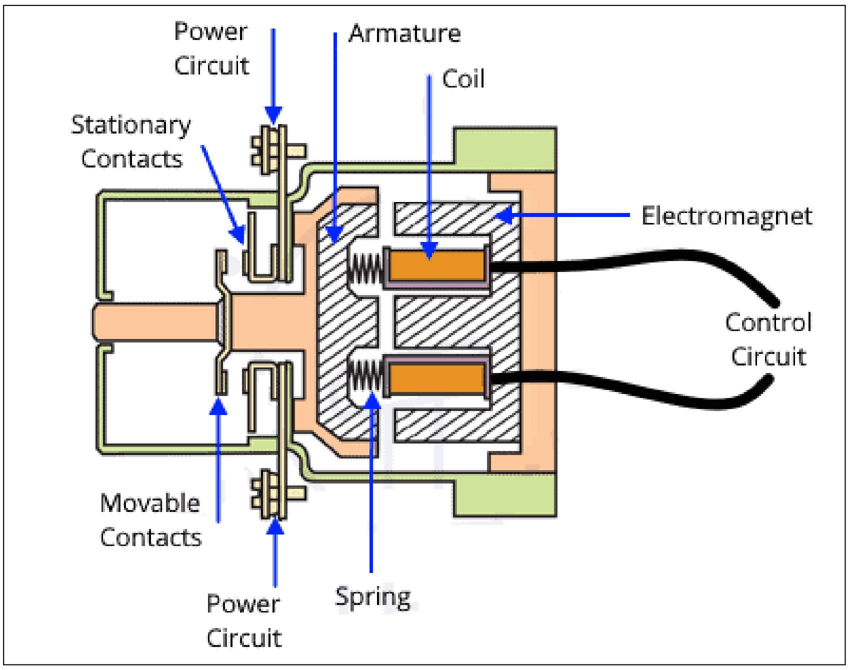


Figure 2.10: Contactor working principle

The contactor and relay are both switches that can be remotely controlled to close or open an electrical circuit. They operate on the same basic principle, but there are differences between them, in the following table 2.3 we will show it.

Feature	**Relay**	**Contactor**
Coil Voltage	Typically low (5V, 12V, 24V)	Usually higher, often 110V to 600V
Contact Current Rating	Lower, often up to tens of amps	Higher, often hundreds of amps
Contact Voltage Rating	Lower, usually up to a few hundred volts	Higher, usually up to several kilovolts
Number of Poles	Usually 1 to 4	Typically 3 or 4, but can be more in special designs
Contact Life	Generally shorter due to less robust construction	Longer, due to more durable design
Auxiliary Contacts	Usually fewer or none	More common, often multiple auxiliary contacts
Size	Smaller	Larger
Overload Protection	Not usually included	Often included
Cost	Less expensive	More expensive

Table 2.3: Comparison between Relay and Contactor

2.5.4 Variable frequency drive

Variable frequency drive (VFD), also known as Variable speed drive is a type of AC motor controller that drives an electric motor that controls the speed and torque output of an AC electric motor by modifying the power frequency and voltage supplied to the motor. It works by converting the incoming AC power to DC power using a rectifier, then converting it back to a quasi-sinusoidal AC power of variable frequency and voltage using an inverter switching circuit as the following figure 2.11 shows.

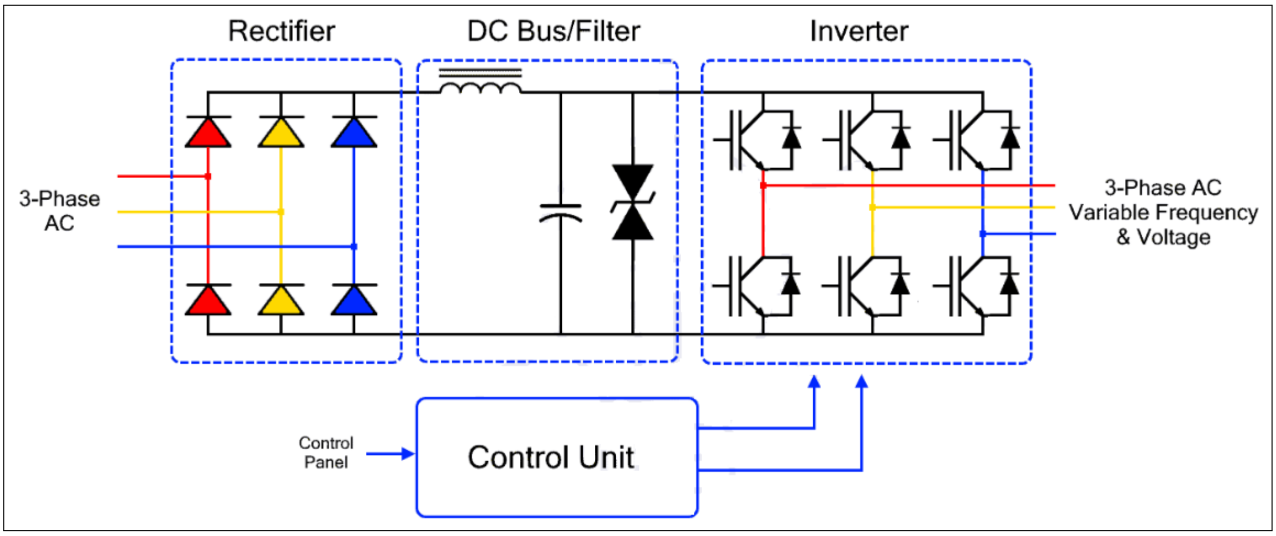


Figure 2.11: Circuit diagram of VFD

VDFs have different applications to use in industrial or in process control such as conveyors, fans, and compressors, in this project of a water pumping station, we will need to control three pumps according to the specifications of the process, the following table

2.4 shows the features of the VFD in this process.

Feature	Description
Energy Efficiency	VFDs enable precise control of pump speed, resulting in significant energy savings by matching pump output to actual demand.
Soft Start and Stop	Provides smooth ramp-up and ramp-down of pump speed, reducing mechanical stress and water hammer effects during start-up and shutdown.
Flow Control	Allows operators to adjust pump speed to maintain the desired flow rate, accommodating varying demand.
Pressure Control	Enables precise control of system pressure by adjusting pump speed, crucial for maintaining specific pressure levels.
Fault Monitoring and Protection	Comprehensive protection features such as overcurrent, overload, and voltage monitoring to prevent damage and enhance system safety.
Remote Monitoring and Control	Supports remote access and adjustment of pump settings, facilitating efficient management and troubleshooting.
System Integration	Easily integrates with other control systems like PLCs or SCADA systems, enabling seamless coordination within the pumping station.
Diagnostic and Reporting Capabilities	Provides real-time data on pump performance, energy usage, motor status, and fault conditions for diagnostics and optimization.
Flexible Operating Modes	Offers various modes including constant pressure, constant flow, and multiple pump control, allowing efficient adaptation to changing system requirements.

Table 2.4: Features of VFDs in Water Pumping Stations

For our solution, we choose ATV630C25N4 which represents a range of products Altivar of VFDs by Schneider Electric, the selection was according to project requirements (performance, budget) and the technical feature of this VFD is as follows.

- Motor power range AC-3: 250 to 500 kW at 380 to 440 V 3 phases.
- Speed drive output frequency: 0.1 to 500 Hz.
- Frequency resolution: 0.1 Hz.
- Acceleration and deceleration ramps: Linear adjustable separately from 0.01 to 9999s.
- Protection type: Short-circuit, Thermal, Safe torque, Motor phase break.
- Communication port protocol: Modbus TCP, Modbus serial, Ethernet.
- Transmission frame: RTU.

Why a VFD and not a soft starter?

In the following, we tried to show the difference between VFD and soft starter.

The two devices are similar in that they control the starting and stopping of industrial water motors (pumps), but have different characteristics.

A soft starter is generally used in applications where there is a large inrush of current that could damage a motor or a pump where the current is slowly applied to the pump which leads to an increase in the speed progressively where it starts up with a nice smooth current until reaches the preset maximum speed. The pump stays working at a fixed speed until we stop the pump, and the same phenomenon happens when the pump starts to stop, where the soft starter slowly reduces the current and gradually reduces the speed until the pump stops, while a VFD controls and can vary the speed of the pump, so we can say a VFD basically is a soft starter with speed control.

As a result, a VFD and a soft starter can do similar functions but, the main difference between the two is that a VFD can vary the speed of a pump.

In our application or process, we need to change the speed of the pumps while they working in order to control the flow rate of water that flows through the pipe to full or empty the two tanks depending on their water levels. So this is why we used the VFD and not the soft starter. But if we control the flow rate by the number of pumps that work we can replace easily the VFD with a soft starter.

However, the VFD is the best choice because it can work as a soft starter with give us an additional option which is speed control during the pumps working, while the soft starter can only control the running and stopping of the pumps.

2.6 Sensors

In this section, we will talk about the instruments that were used in this process to detect and measure different parameters of the process to send it to the command part.

2.6.1 Level indicator transmitter

A Level Indicator Transmitter (LIT) is a combination device that integrates both level indication and level transmitter functionalities into a single instrument. It is designed to provide both a visual indication of the liquid level and a continuous output signal for remote monitoring and control purposes. In our process, we will use it to measure the level of water in tanks to allow command of the pumps automatically.

There are different various measurement principles such as pressure, ultrasonic, radar, or capacitance, to accurately measure the liquid level. In our case, we chose to Ultrasonic sensor to measure the level of liquid according to the advantages as represented in the table 2.5, which concerns the process specifications.

Technical Feature	Description
Measurement Range	The ultrasonic LIT offers a wide measurement range from 0.25 to 15 m.
Accuracy	It provides high accuracy in level measurement, ensuring precise monitoring and control of liquid levels.
Non-Contact Measurement	The ultrasonic LIT utilizes non-contact measurement principles, eliminating the need for physical contact with the liquid.
Output Signal	The ultrasonic LIT offers a configurable output signal, such as 4-20 mA analog signal or digital communication protocols. This allows for easy integration with control systems or SCADA systems.
Environmental Rating	The ultrasonic LIT has a robust environmental rating, such as IP65.
Power Supply	The ultrasonic LIT supports different power supply options, such as 24V DC or 110-240V AC, ensuring flexibility in power requirements.
Continuous Monitoring	It provides continuous and real-time monitoring of the liquid level, allowing for timely response to changing conditions and efficient control of processes.
Diagnostic Capabilities	Diagnostic capabilities, such as self-monitoring, error detection, or sensor health checks, enabling proactive maintenance and troubleshooting.

Table 2.5: Technical Features of an Ultrasonic Level Instrumentation Transmitter

The working principle of an ultrasonic level transmitter involves emitting high-frequency sound waves from the sensor toward the liquid surface. These sound waves then reflect off the liquid surface and return to the sensor. By measuring the time it takes for the sound waves to travel to the liquid surface and back, the sensor calculates the distance and, subsequently, the level of the liquid.

2.6.2 Level switch

A level switch is a device used to detect the presence or absence of a liquid or material at a specific level within a tank, vessel, or pipeline. It is commonly used in industrial applications to monitor and control liquid levels, ensuring proper operation and preventing overflows or dry-run conditions.

The level switch operates based on the principle of contact or non-contact detection, depending on the specific type of switch. In our process, we will use a float level switch to command the valves for opening or closing in automatic mode when the level of water in the tank is high.

2.6.3 Pressure indicator transmitter

Pressure indicator transmitter (PIT) type of sensor is typically composed of a pressure-sensitive surface area made of steel, silicon, or other materials depending upon the analyte's composition. Behind these surfaces are electronic components capable of converting the applied force of the sample upon the pressure sensor into an electrical signal. It is an instrument used to measure and transmit pressure data in industrial processes.The working principle of a PIT involves the following steps:

- **Pressure Sensing:** It is equipped with a pressure sensor, typically based on technologies like strain gauges or piezoresistive elements. When pressure is applied to the sensor, it undergoes a physical deformation that results in a change in electrical resistance or another measurable parameter.
- **Signal Conditioning:** The electrical output from the pressure sensor is processed and conditioned by the PIT's internal circuitry. This includes amplification, filtering, and linearization to convert the raw sensor output into a more accurate and usable form.
- **Pressure Measurement:** The conditioned signal is used to determine the pressure value based on calibration and calibration curves specific to the sensor and PIT model. This allows for accurate measurement of pressure within the specified range.
- **Data Transmission:** The measured pressure value is converted into an electrical signal that can be transmitted to external devices or systems. This can include analog signals, such as 4-20 mA or 0-10V DC, or digital communication protocols like Modbus, Profibus, or HART.
- **Display:** The PIT may have a built-in display to show real-time pressure readings. This allows for local monitoring and quick visual indication of the pressure level.

PIT will be used to monitor and control the water pressure in pipes to ensure safe installation with the following features:

- Pressure range: 0 to 16 bar.
- Accuracy : +/- 0.5% .
- Output signal: 4-20 mA, 2 wire.
- Power supply: 10-30 VDC.

2.6.4 Flow indicator transmitter

Flow indicator transmitters (FIT) also known as flow meters are instrumental devices used to measure the flow rate of a fluid, such as water, in a pipeline. They provide accurate and real-time information about the quantity of fluid passing through a specific point. There exist various types of flow meters in industrial processes to control different equipment, in our process, we have electromagnetic flow meters that will use to command the speed of pumps depending on treatment plant requirements.

Electromagnetic flow meters operate based on Faraday's law of electromagnetic induction. They utilize a magnetic field generated by coils placed around the pipe and electrodes inserted into the fluid. As the conductive fluid flows through the pipe, it generates a voltage proportional to the flow velocity, which is detected by the electrodes as

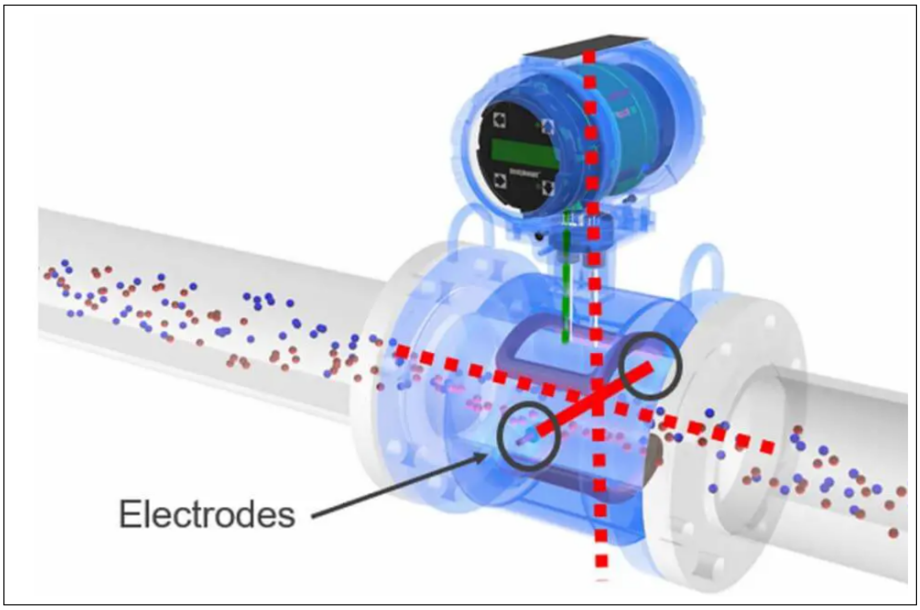


Figure 2.12: Principle of work electromagnetic FIT.

shown in figure 2.12.

The technical feature of this FIT are :

- Flow range: 0.2 to 10 m/s. - Pressure Rating: Up to 16 bar.

- Output Signal: 4-20 mA analog.

2.6.5 PH meter

PH meter is an instrument used to measure the acidity or alkalinity of a solution, PH is the unit of measure that describes the degree of acidity or alkalinity. It is measured on a scale of 0 to 14. PH transmitter is an analog sensor, also known as redox (ORP) designed for continuous monitoring of PH in industrial process and water monitoring, measuring the PH of a solution, and displaying the result on a built-in screen.

In addition, in our process to prepare the solution, it has also been used to control the dosing pumps that are dosing the chemicals where the PH meter transmits the PH value to the PLC that gives the instruction to the dosing pump to add the acid or alkaline base to the solutions, agitators to mix the solutions, and valves to open.

2.7 Programmable Logic Controller

A Programmable Logic Controller is a digital computer programmed to control and monitor processes in industrial automation systems by executing a sequence of instructions (program). It specialized type of computer designed to withstand harsh industrial environments and perform real-time control functions. It is the main element in the command part because it contains the program from which orders and instructions are elaborated according to data received from reports from sensors and set points from the operator. Data is sent to the pre-actuator through the output unit.

Basically PLC hardware is classified into two different types which are compact or fixed PLC and modular or rack-mounted PLC.

Compact PLC

This PLC type has a fixed number of I/O points. There are several built-in modules in the same unit such as a power supply, CPU, I/O interface, communications interface, and other components, these modules are integrated in a compact chassis, as shown in figure 2.13. Compact PLC is a space-saving and cost-effective solution for applications with limited space or smaller-scale control requirements, the characteristics of compact plc are in the following table 2.6.

Feature	**Description**
Size	Compact and space-saving design
I/O Points	Limited number of I/O points
Functionality	Essential control and monitoring capabilities
Communication	Support for various protocols (e.g., Modbus, Ethernet/IP)
Scalability	Expandable with additional modules
Cost-Effectiveness	Affordable solution for small-scale applications
Ease of Use	User-friendly programming software

Table 2.6: Features and Characteristics of Compact PLC

Figure 2.13: Example of PLC compact 'M221'

Modular PLC

A modular PLC, also known as a rack-mounted, is a type of PLC that offers a modular architecture for flexible and scalable automation solutions. Unlike compact PLCs, modular PLCs allow for the expansion and customization of the system by adding or removing modules based on the specific requirements of the application, the characteristics of modular plc are in the following table 2.7.

Feature	**Description**
Modularity	Ability to add or remove modules for customization
Scalability	Expandable to accommodate growing system requirements
Hot Swapping	Ability to add or remove modules while the system is running
Distributed Control	Support for distributed control and coordination
Wide Range of I/O	Various I/O options for different signal types
Communication	Integration with other devices and systems through protocols
Modular Programming	Organization of control logic into modular sections

Table 2.7: Features and Characteristics of Modular PLC

In a rack-mounted programmable logic controller (PLC) system, the PLC modules are typically housed within a rack or chassis. The rack provides a physical framework for organizing and connecting the modules. Here are some PLC modules that can be installed in a rack as shown in figure 2.14 :

- Power supply (PS) provides power to the PLC by converting the available incoming AC power to the DC power required by the CPU and I/O modules to operate properly. Usually, the output voltage is 24 VDC.
- CPU Module: The CPU module is the central processing unit of the PLC system. It contains the microprocessor and memory necessary for executing control programs, handling communication, and managing system tasks.
- Input/Output(I/O) modules also called signal modules (SM), they are connected to digital or analog field devices.
- Communication processor (CP) or communication module (CM) is an optional module, it can be used for providing an additional communication port for communication protocols. Also, it's used for networking communication and exchanging data between multiple PLC, HMI, SCADA, and other systems.
- Function module (FM): offer additional functionalities or specialized features. They can include high-speed counter modules for precise counting applications, motion control modules for controlling motors, temperature measurement modules for monitoring and controlling temperature, or safety modules for implementing safety functions.
- The interface module (IM) is an optional module used for rack-to-rack communications in multitier configurations (extensions).

In the following table 2.8, we will show the different features between Compact and modular PLC.

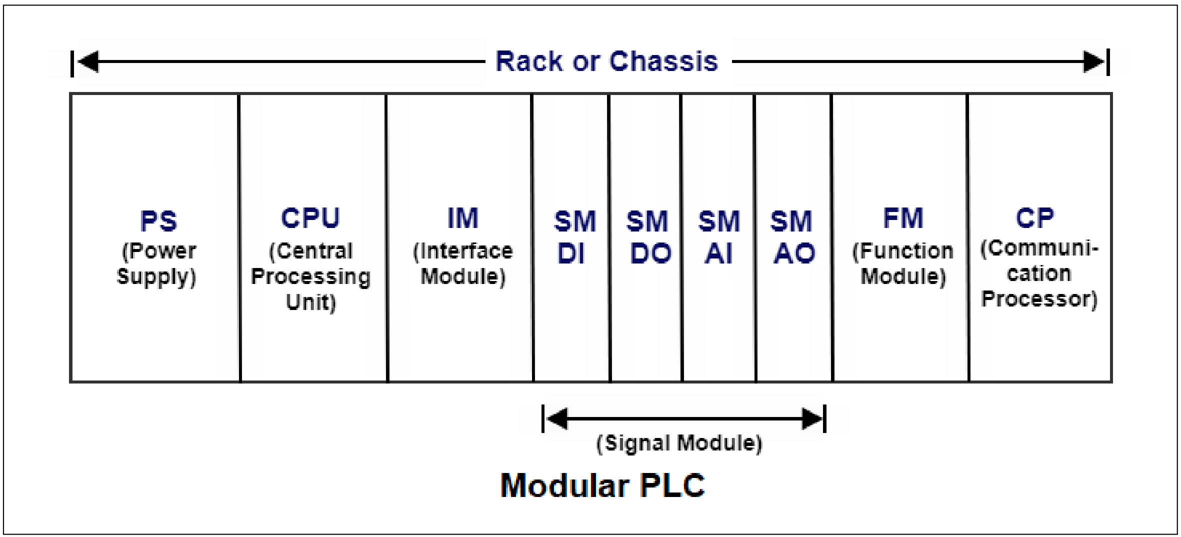


Figure 2.14: Modular PLC bloc diagram

Feature	Compact PLCs	Modular PLCs
Size	Small and compact	Larger, rack-mounted
I/O Points	Limited number	Scalable, more I/O options
Flexibility	Limited expansion options	Expandable, customizable
Hot Swapping	Not usually supported	Supported for module changes
Distributed Control	Limited distributed capabilities	Suitable for distributed control
Communication	Basic communication options	Support for various protocols
Cost	Generally more cost-effective	Higher initial investment

Table 2.8: Comparison between Compact and Modular PLC

2.7.1 Internal structure of the PLC

The internal architecture of a PLC is designed to manage control and automation operations. It comprises several key components that work together to ensure the PLC's efficient operation. Here are the main elements of a PLC's internal structure figure 2.15:

- Memory: The PLC has memory for storing control programs, data, and variables required for system operation. This includes random access memory (RAM) for temporary storage of running data, and read-only memory (ROM or flash) for permanent storage of programs and system parameters.
- Central Processing Unit (CPU): The CPU is the brain of the PLC and is responsible for executing control programs, managing I/O operations, and overall system coordination. It contains a microprocessor, memory, and various communication interfaces with other components.
- I/O interfaces: The CPU interfaces with input and output modules to receive signals from external devices and send control signals to actuators. It communicates with these modules through dedicated interfaces, ensuring proper data exchange and synchronization.
- Power supply: The PLC is powered by a power supply that converts the input

voltage into a voltage suitable for powering the system. The power supply provides a stable, regulated voltage to the PLC's various components.

- Communication Interfaces: The CPU may have built-in communication interfaces, such as Ethernet ports or serial communication ports, to enable communication with other devices or systems. These interfaces allow for data exchange, remote monitoring, and integration with external systems.

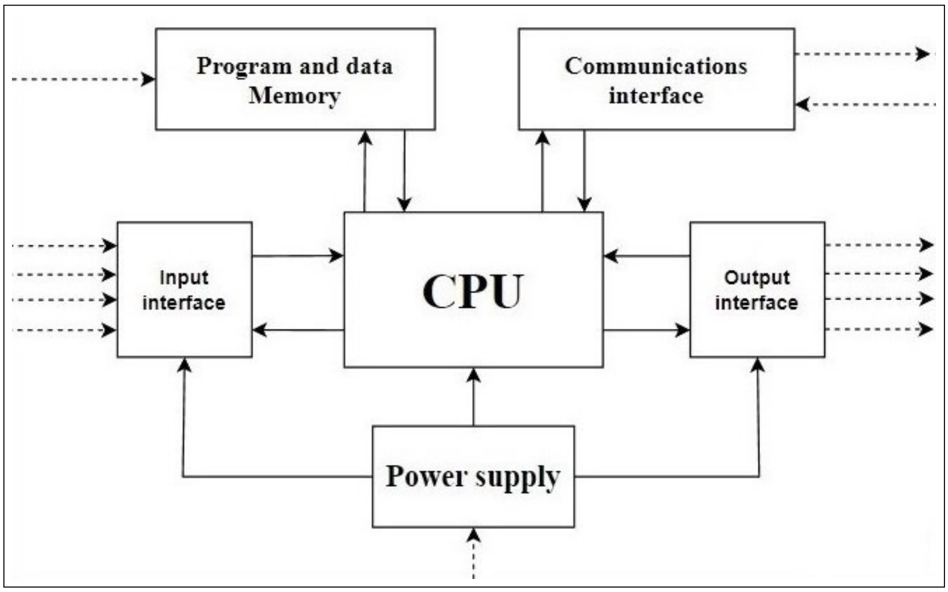


Figure 2.15: internal structure of the PLC

2.7.2 Criteria for selecting a PLC

When choosing a PLC for a specific application, it's important to consider various criteria to ensure compatibility with requirements of the process. Here are some key criteria:

- CPU requirement: The CPU speed, memory size, scan time, and rate.
- I/O Requirements: Determine the number and types of input and output (I/O) points needed for the process.
- Communication protocols: The PLC should support the communication protocols that are needed to connect with other devices.
- Power supply: The PLC and its cards of I/O should match the available power source (incoming power).
- Cost: Determine the overall cost of the PLC system, including the initial hardware investment, software licenses, and maintenance costs.

2.7.3 Overview M221 PLC

In our project, we are using M221 PLC with the exact reference TM221C40R which is a range of product Modicon PLCs from Schneider Electric. It is a compact and versatile controller and offers a space-saving, cost-effective automation solution, is easy to integrate into existing systems, additional I/O modules and communication modules can be easily added to accommodate future requirements, and provides flexibility for system expansion. It is designed for small to medium-scale automation applications such as water pumping processes.

Its characteristics are compatible with the process specifications, and they are as follows [17]:

- rated supply voltage: 100...240 V AC, frequency: 50Hz.
- Discrete I/O number: 40 (DI 24, DO 16 Relay NO).
- Analogue input number: 2, signal 0 to 10 V with resolution 10 bit.
- Discrete output voltage: 5...250 V AC
- Discrete output current: 2 A.
- Discrete input logic: Sink or source (positive/negative).
- Discrete input voltage: 24 V DC.
- Memory capacity: 256 kB for user application and data RAM with 10000 instructions.
- Communication port protocol: USB port, serial link: Modbus master/slave - RTU/ASCII.
- Transmission rate: 1.2...115.2 kbit/s (115.2 kbit/s by default) for bus length of 15 m for RS485.

We summarize the TM221C40R external structure with the following figure 2.15

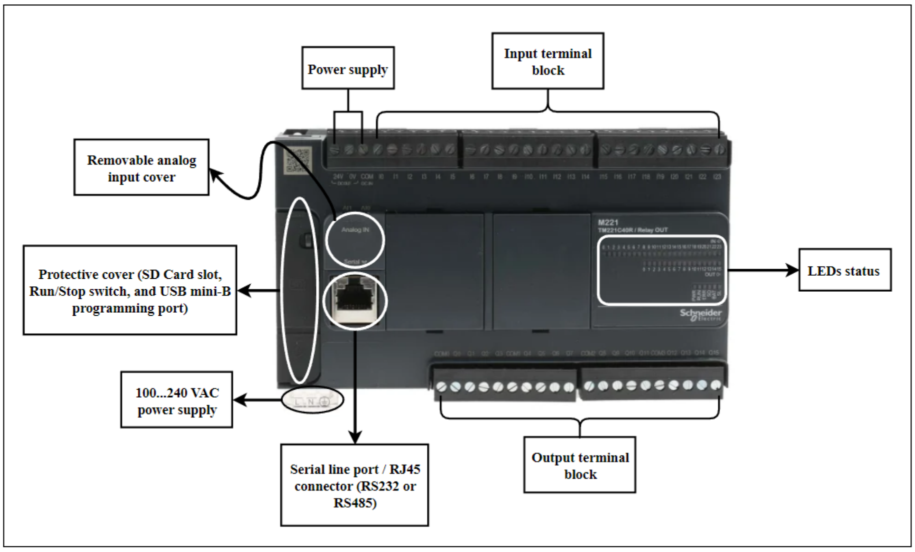


Figure 2.16: TM221C40R model external structure

2.8 Industrial communications and control protocols

Industrial protocol communication plays a crucial role in modern industrial automation systems, enabling efficient and reliable data exchange between various devices and components. These protocols provide standardized methods for communication and ensure interoperability among devices from different manufacturers. Industrial protocols are designed to meet the specific requirements of industrial environments, including real-time communication, robustness, and scalability[18]. They facilitate the exchange of data related to process control, monitoring, diagnostics, and configuration, allowing seamless integration of devices such as PLCs, HMIs, sensors, actuators, and other automation equipment.

Common industrial protocols include Modbus, Profibus, Profinet, EtherNet/IP, DeviceNet, and OPC. These protocols utilize different communication media, such as Ethernet, serial connections, or fieldbuses. By implementing industrial protocols, organizations can achieve efficient communication, centralized control, improved productivity, and enhanced decision-making capabilities, leading to optimized industrial processes and increased operational efficiency[18].

In our project, we used the Modbus serial protocol and Modbus TCP/IP between control devices as figure 2.17 show that.

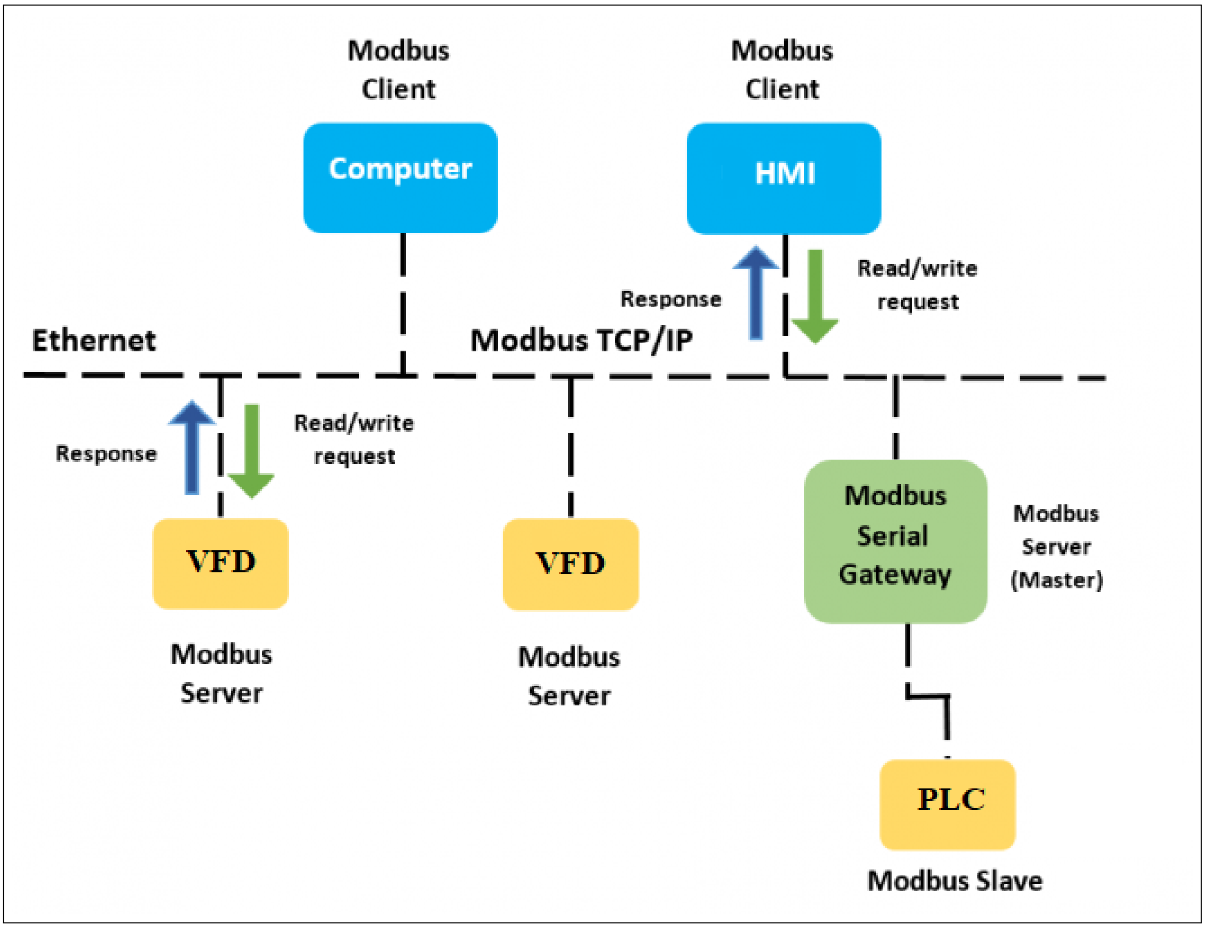


Figure 2.17: Network architecture of the station

2.8.1 Modbus Serial

Modbus is a communication protocol developed by Modicon systems. First introduced in 1979, Modbus was created for use with its programmable logic controllers [19]. The protocol allows devices to intercommunicate irrespective of network distribution or computer architecture. It has since become a standard communication protocol in the industry, and it is now a commonly available means of connecting industrial electronic devices.

2.8.2 Features of the Modbus serial

- Bus topology
- Theoretical number of subscribers 247, can be lower depending on the manufacturer and the limitation of the physical layer.
- Semi-duplex transmission.
- Physical medium can be supported: twisted pair, coaxial.
- Base-band transmission from 50 to 19200 bits/s.
- Supports connections to RS232, RS422, RS485.
- Master/slave protocol access method.

2.8.3 Message structure of Modbus serial

Modbus messages are specifically structured to ensure coherent communication between the master and slaves. The master sends a message consisting of the following[19]:

1. Slave Address (1 byte): This field is used to address the slave device. There can be multiple slave devices connected to one master device. The address field identifies which device should pay attention to the message. The address range is from 1 to 247 for slaves, and 0 for a broadcast message where all slaves should respond.
2. Function Code (1 byte): This field informs the addressed slave device about what kind of action to take. For example, read data, write data, etc.
3. Data Field (N bytes): The data field contents will vary based on the function code. For instance, if the function code is indicating a read command, the data field would include the starting address and the number of items to be read. If the function code is indicating a write command, then the data field would contain the address to start writing to and the values to be written.
4. Error Check (2 bytes): This field is used for error checking of the entire message. This error check field follows the data field.

2.8.4 Types of Modbus serial transmission

Two types of coding can be used to communicate on a Modbus network. All the equipment present on the network must be configured according to the same type.

Modbus RTU

The Modbus RTU communication is of serial type and is done via the serial interfaces RS232, RS485, or RS422. The coding of the information is done in binary. The Modbus RTU is among the most widely used industrial protocols. If communication is via RS232, there can only be one master and one slave in this case. master and only one slave. On the other hand, if the communication is carried out via the RS485 or RS422, there can be several slaves [19].

The Modbus RTU frame consists of a sequence of hexadecimal characters and Figure 2.18 showing composition of the frame and we will explain as follows [19]:

1. Start: A Modbus RTU frame begins with a silent interval of at least 3.5 character times. This is known as a Start of Frame. In practical terms, it's a gap of silence to ensure the receiver recognizes the start of a new message.
2. Slave Address (1 byte): This is the ID of the device that the message is intended for. It can be a value from 1 to 247. When the slave device sees its address, it processes the message and responds.
3. Function Code (1 byte): This field determines the type of action the slave device should take, such as reading from or writing to the coils or registers.
4. Data Field (n bytes): This contains additional information that the function code needs to perform its task. For example, if the function code requests a read, this field would include the start address and quantity of coils or registers to be read.
5. CRC Check (2 bytes): At the end of each Modbus RTU message is a CRC (Cyclic Redundancy Check) error-checking field. This is used by the recipient to detect any transmission errors.
6. End: The end of a Modbus RTU frame is marked by a silence of at least 3.5 characters times. This is referred to as the End of Frame.

		Protocol Data Unit (PDU)			
Start	Slave ID	Function code	Data	CRC error check	Stop
3.5 Bytes	1 Byte	1 Byte	n Bytes	2 Bytes	3.5 Bytes
	Application Data Unit (ADU)				

Figure 2.18: Structure frame Modbus serial RTU

The maximum data size is 256 bytes. All the information contained in the message is expressed in hexadecimal. Each byte composing an RTU frame is coded on 2 hexadecimal characters (8 bits) and the transmission will be as follows [19]:

- Without parity control: Start, 8 bits of data, 2 bits of stop.
- With parity control: Start, 8 bits of data, 1 bit of parity, 1 bit of stop.

Modbus ASCII

Modbus ASCII is a type of Modbus communication protocol that sends data in ASCII format. It is less efficient than Modbus RTU in terms of data throughput, but it is also less sensitive to transmission errors. Here is a detailed frame of Modbus ASCII that show in figure 2.19 [19]:

1. Start of Frame: Each message (frame) starts with a colon (":").
2. Slave ID (1 byte, represented as 2 ASCII characters): This is the address of the device that the message is intended for. It is represented as two ASCII characters.
3. Function Code (1 byte, represented as 2 ASCII characters): This specifies the type of action the slave device should take, such as reading or writing to its registers. It is represented as two ASCII characters.
4. Data (n bytes, represented as 2n ASCII characters): The actual data of the message is encoded in ASCII format, where each byte of data is represented as two ASCII characters. The contents depend on the function code.
5. Error Check (2 bytes, represented as 4 ASCII characters): Modbus ASCII uses a Longitudinal Redundancy Check (LRC) for error detection. This is calculated by adding up the bytes in the message (excluding the start-of-frame colon and the end-of-frame CRLF), taking the two's complement of the least significant byte of the sum, and then representing the result as two ASCII characters.
6. End of Frame: This is signified by a Carriage Return and Line Feed pair (CRLF).

Start	Address	Function	Data	LRC	End
;	2chars	2chars	N * 1 chars	2chars	CR, LF

Figure 2.19: Structure frame Modbus ASCII

2.8.5 Modbus TCP/IP

Modbus TCP/IP is simply the Modbus RTU protocol with a TCP interface that runs on Ethernet. it messaging structure is the application protocol that defines the rules for organizing and interpreting the data independent of the data transmission medium. TCP/IP refers to the Transmission Control Protocol and Internet Protocol, which provides the transmission medium for Modbus TCP/IP messaging [20].

Simply stated, TCP/IP allows blocks of binary data to be exchanged between computers. It is also a world-wide standard that serves as the foundation for the World Wide Web. The primary function of TCP is to ensure that all packets of data are received correctly, while IP makes sure that messages are correctly addressed and routed [20].

2.8.6 Features of Modbus TCP/IP

Modbus TCP/IP has numerous technical features that make it suitable for use in industrial control systems:

- Free topology (Bus, star, tree, or ring).
- Base-band transmission from 10 to 100 Mbits/s.
- Physical medium can be supported: Twisted Pair (Copper), Fiber Optic, Wireless.
- Supports connections to Ethernet
- Method of access to the medium Carrier Sense Multiple Access Collision Detect (CSMA/CD).
- Client/ Server communication model.
- Support a large number of connected devices.

2.8.7 Structure message of Modbus TCP/IP

Modbus TCP/IP uses the MBAP (Modbus Application Protocol) header which is specific to Modbus TCP/IP. It encapsulates the Modbus Protocol Data Unit (PDU) into the data field of a TCP frame.

Here's a breakdown of a Modbus TCP/IP frame as show in figure 2.20 [21]:

1. Transaction Identifier (2 bytes): This is used for transaction pairing, matching the request with the response. This value is typically incremented for each new message from the client.
2. Protocol Identifier (2 bytes): This field is used to identify the protocol. For Modbus over TCP/IP, this value is 0.
3. Length Field (2 bytes): This field defines the remaining length of the message following this field. It's the count of bytes in the subsequent fields.
4. Unit Identifier (1 byte): This was included for Modbus to allow for the possibility of using it in conjunction with a bridging entity able to forward Modbus requests to multiple slaves. This could be a Modbus TCP to Modbus RTU gateway for example. In a direct client-server connection, this is usually set to 0.
5. Function Code (1 byte): This field is part of the Modbus PDU and is used to tell the server which type of action to perform. Examples include reading and writing from discrete coils or holding registers.
6. Data Field (n bytes): This is also part of the Modbus PDU. It contains additional information for the function to be performed (like the starting address and quantity of items for read functions) and it will contain the data received in a response message.

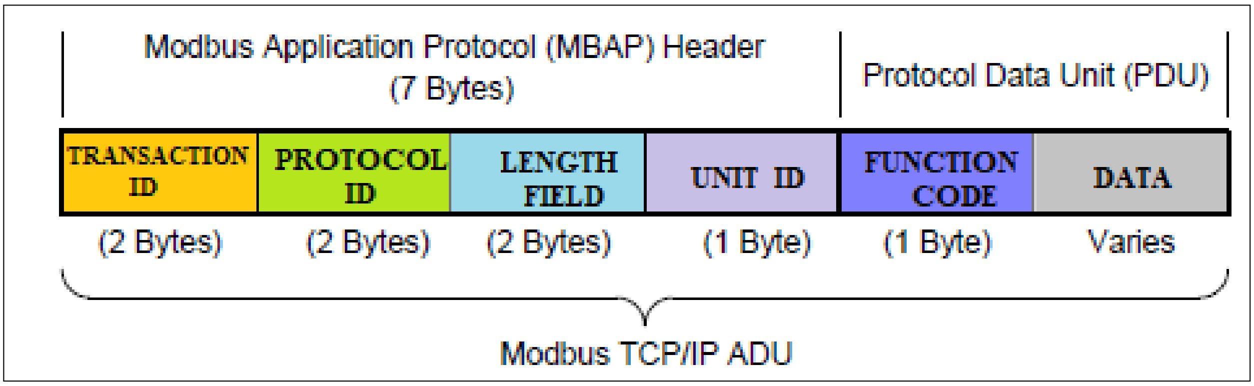


Figure 2.20: Structure frame Modbus TCP/IP

2.8.8 EGX150 Gateway

Gateway is a network device, it allows to connects two different networks that use different protocols. It translates one protocol into the other, enabling communication between devices that otherwise wouldn't be able to understand each other.

In our project, we used Link150 Ethernet gateway from Schneider Electric as shown in figure 2.21. It is a communication device that provides connectivity between Ethernet (Modbus TCP/IP) and Modbus serial line devices, allowing Modbus TCP/IP clients to access information from serial slave devices. It also allows serial master devices to access information from slave devices distributed across an Ethernet network [22].

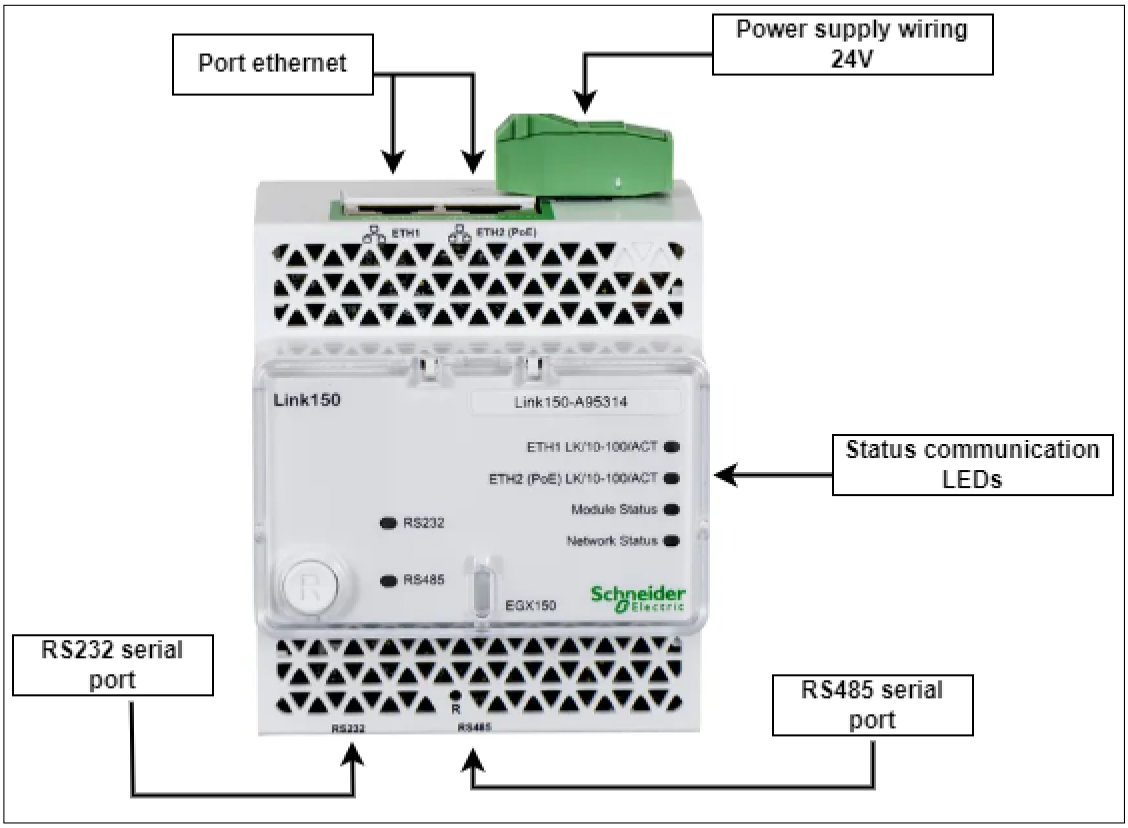


Figure 2.21: Link-150 Ethernet Gateway

As we needed this Gateway to improve the quality of communication and the speed of data transfer so the following features are very important for us [23]

- **Protocol:** Modbus, Serial, HTTP, Modbus TCP/IP, FTP, SNMP.
- **Number of ports:** 2 Ethernet ports and 2 (1 available at a time) Serial ports
- **type of Serial ports:** RS-232 or RS-485 (2-wire or 4-wire), depending on settings
- **type of Ethernet ports:** 10/100BASE-TX (802.3af) port
- **Maximum number of connected devices:** 32 (directly) and 247 (indirectly)
- **Baud rates:** 19200 bps (factory setting), 2400 bps, 4800 bps, 9600 bps, 38400 bps, 56000 bps, 57600 bps.
- **Power supply:** 24 V DC (-20/+10 %) or Power over Ethernet (PoE Class 3 IEEE 802.3 af) at 15 W.
- **Consumption:** 24 V DC, 130 mA at 20 °C PoE 48 V DC, 65 mA at 20 °C

2.9 Conclusion

In conclusion, in this chapter, we focused on the hardware side of our process in each part of the automation system and their components, we also introduced the PLC TM221C40R used from various sides such as external structure, its features, its importance, and the advantages that it provides. We also talked about the HMIGXU3512 and its characteristics, and finally, we submitted also the Gateway as a medium for communication and improvement of the quality of communication and the speed of data transmission.

In the next chapter, we will try to focus on the software side of our process either PLC or HMI, and the communication between them.

Chapter 3

Design and develop automation part of the process

3.1 Introduction

In this chapter, we will talk about the study and design steps for the automation part of our process, where we will begin with the identification of equipment by the piping and instrumentation diagram (P&ID), then we will size the devices according to the equipment that will be controlled in the process, after that we will configure PLC and HMI to be able to communicate, the next step is starting the development the logic of the process control by programming the PLC and designing the HMI interface according to the project specifications, and finally we will finish by testing the program which has been developed and implemented on the test bench.

3.2 Study requirement of process

The water pumping process has different equipment to be controlled, to understand the process operation, we should use a P&ID document which is usually designed by a hydraulic engineer, we also use the datasheet of equipment to extract information such as technical characteristics that will help us to configure and program the PLC.

First of all, what is a P&ID?

A P&ID stands for piping and instrumentation diagram, it is a schematic representation of the process flow within an industrial facility and is commonly used in industries such as oil and gas, chemical, power generation, and manufacturing. It illustrates the interconnections between various equipment, piping, instrumentation, and control systems used in the process as shown in figure 3.1.

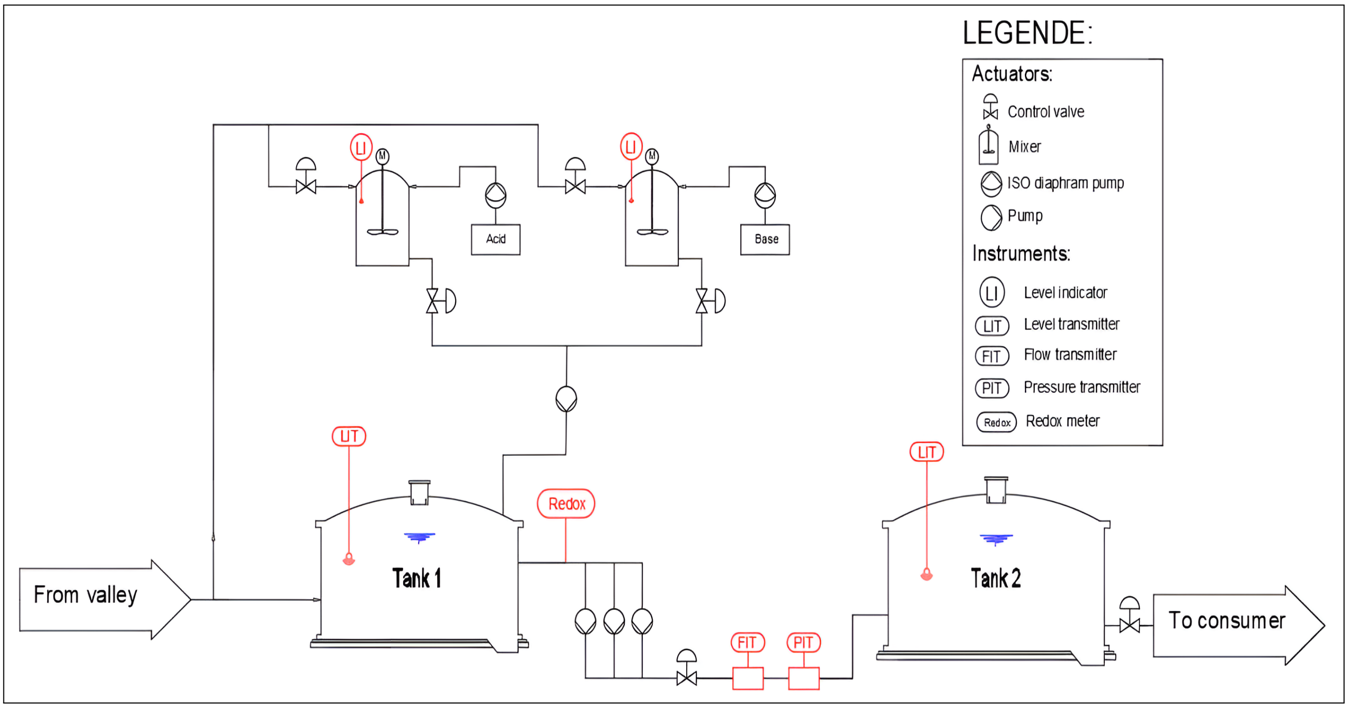


Figure 3.1: P&ID of the water pumping station

What is the principle of working of our process?

According to the Piping and instrumentation diagram, the working principle of our process is to transport water from the first tank to the second tank through three pumps, where two pumps run continuously and one pump is on standby. The number of pumps running is controlled according to the level in both tanks which is measured by LIT. There is another part we can call the solution preparation station, At this plant, a solution will be prepared with a given PH by pumping different chemicals (Sulfuric acid, sodium hydroxide) in two small preparation tanks and it will be pumped to tank 1 that will be measured in it the PH degree of the water by PH meter that control the dosing pumps in order to add acid or base to tank 1. When we have a moderate solution, we can transfer it to tank 2 for distribution to consumers. Furthermore, we will mention some important points to understand more:

- We used FIT to display the flow rate in the pipes and we can control it by the number of the pumps running and their speed.
- We used PIT for the security system in order to preserve the state of the pipes.
- The agitators' role is to accelerate the reaction between the water and chemicals.

3.2.1 Sizing number of I/O equipment

According to the P&ID and datasheet of equipment, we have extracted the list and the number of inputs and outputs that show in the tables 3.1 and 3.2 as follows:

Actuators					
Equipment	**Number**	**I/O Signals**			
		DI	DO	AI	AO
Pumps	4	4	1	/	1
Dosing pumps	2	4	1	/	/
Vertical agitators	2	4	1	/	/
Valves	6	2	1	/	/

Table 3.1: List and number of actuators

- Pumps, dosing pump, and vertical agitator have 4 signals of digital inputs (DI) which represent the following faults cases:
  - Feedback of running (Contactor or VFD).
  - Motor circuit breaker
  - Phase failure relay.
  - High-temperature detector (PTC).
- Digital output (DO) represents a signal of command that comes from PLC to run the pumps, dosing pump, vertical agitator and to open the valves.
- Analog output (AO) represents a signal (4-20 mA) of the speed command for pumps through VFDs.

Instruments					
Equipment	**Number**	**I/O Signals**			
		DI	**DO**	**AI**	**AO**
Level indicator transmitter (LIT)	2	1	/	1	/
Flow indicator transmitter (FIT)	1	1	/	1	/
Pressure indicator transmitter (PIT)	1	1	/	1	/
PH sensor	1	/	/	1	/
Level switch (LSH)	2	1	/	/	/

Table 3.2: List and number of instruments

- Digital inputs (DI) represent fault signals, where some advanced transmitters have built-in diagnostic features or communication protocols that allow them to detect and report their own faults or failures to the PLC.
- Analog inputs (AI) represent feedback signals transmitted by the instruments to the PLC, where LIT, FIT, and PIT transmit a signal of 4-20 mA while the PH meter transmits a signal of 0-10 V.

We have sized the total I/O signals and we have added 20% on the total I/O signal numbers to have a reserve in case of modification or addition of new equipment as shown in the table 3.3 below.

Signal I/O	**DI**	**DO**	**AI**	**AO**
Total number + 20%	60	17	6	5

Table 3.3: Total number of I/O signals

In our project we used TM221C40R PLC which has 24 DI, 16 DO, and 2 AI, according to the number of I/O signals of equipment, we need to add extension I/O modules to the PLC to cover all the needs as shown in the table 3.4 and the figure 3.2.

I/O modules	**Description**	**Number of modules**
TM3DI16/G	Digital input extension modules have 16 channels with 24 Vdc, 1 common line, logic type sink or source.	2
TM3DM8R/G	Digital input and output extension module has 4 channels inputs, and 4 channels 2A relay outputs with 24 Vdc.	1
TM3AI4/G	Analog input extension module has 4 channels of 12 bits.	1
TM3AQ4/G	Analog output extension module has 4 channels of 12 bits.	1
TM3TM3/G	Analog input and output extension module with 2 channels analog input of 16 bits and 1 channel analog output of 12 bits	1

Table 3.4: Description extension modules I/O

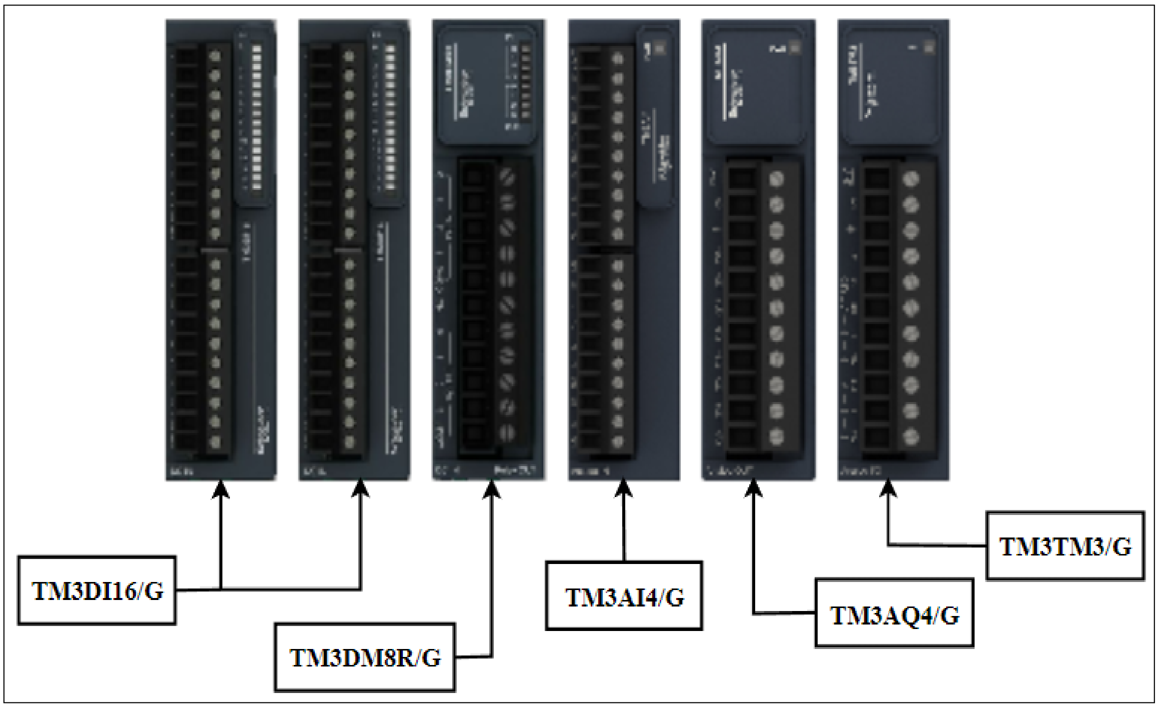


Figure 3.2: Extension I/O modules

3.3 Hardware configuration

It involves the physical installation, connection, and configuration of various hardware devices to ensure proper functionality and communication within the system.

3.3.1 Control elements architecture

After we have sized the I/O numbers of equipment and selected the extension I/O modules, we choose the pumps driver (VFDs) which will be compatible with its characteristics, where we chooses the ATV630 to vary the speed of the pumps during their work, we have three pumps so we choose three VFDs, now we can design the control elements architecture of the process which contents the network of communication protocol as shown in figure 3.3.

It is clear by the architecture that the role of the gateway is converting between two different protocols which are from Modbus serial to Modbus TCP/IP in our case, by this method we improve the quality and the speed of data exchange between PLC, HMI, and VFDs.

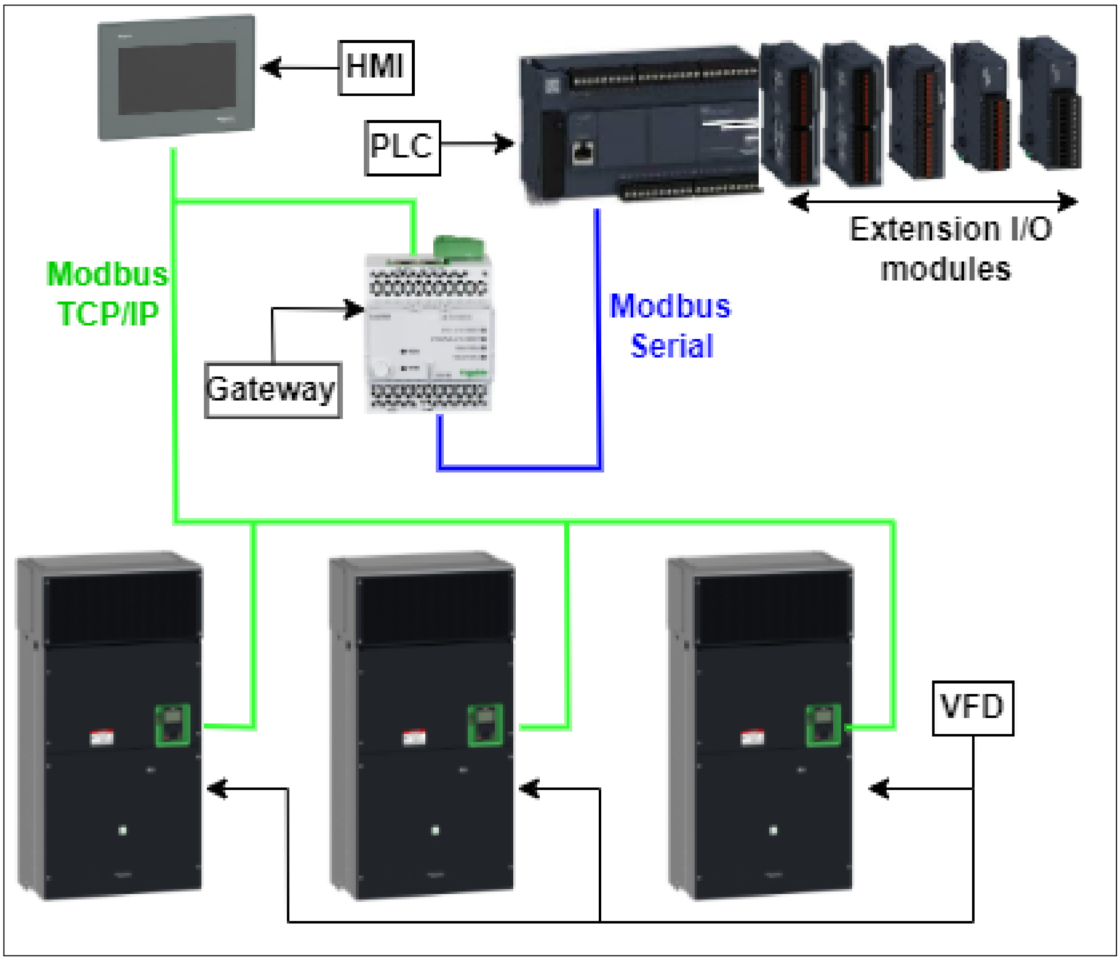


Figure 3.3: Control system architecture

3.3.2 I/O Modules Configuration

Configuring the I/O modules by assigning addresses, specifying input/output types, calibrating analog signals, setting up communication protocols, and configuring other relevant parameters to match the system requirements.

- Assign I/O Addresses: Each I/O module has a unique address or identifier. Configure the I/O addresses based on the system's addressing scheme and the specific I/O module model. Assign addresses to each I/O point within the module, distinguishing between input and output points.

- Configure Input Parameters: Set up the input parameters for each I/O point. This includes specifying the input type (analog, digital), signal range, scaling factors, filtering options, and any necessary signal conditioning. Ensure that the configuration aligns with the characteristics of the connected sensors or field devices.

- Configure Output Parameters: Set up the output parameters for each I/O point. Define the output type (analog, digital), signal range, resolution, response times, and any necessary signal conditioning. Consider the specifications of the connected actuators or field devices to ensure proper control and actuation.

The transmitters that we used, will be configured in module analog input as signal 4-20mA and range value 0 to 32000 as shown in figure 3.4.

Analog inputs

Used	Address	Symbol	Type	Scope	M..	M...	Filter	Filter Unit	Sampling
✓	%IW3.0	LIT1_INPLC	4 - 20 mA	Normal	0	3200	0	x 10 ms	1 ms/Channel
✓	%IW3.1	LIT2_INPLC	4 - 20 mA	Normal	0	3200	0	x 10 ms	1 ms/Channel
	%IW3.2	FIT_INPLC	4 - 20 mA	Normal	0	3200	0	x 10 ms	1 ms/Channel
	%IW3.3	PIT_INPLC	4 - 20 mA	Normal	0	3200	0	x 10 ms	1 ms/Channel

Figure 3.4: Configure analog input module

3.3.3 Network configuration

Network configuration is a crucial step in setting up an automation system to ensure proper communication and data exchange between devices. we have used different devices that will be configured as follows.

PLC configuration

The PLC TM221C40R that we used, has only accepted Modbus serial protocol for that we will configure it as follows:

- Serial line settings:
  - Baud rate: 19200.
  - Parity: even.
  - Stop bit: 1.
  - Physical medium : RS-485.
- Protocol settings:
  - Transmission mode: RTU
  - Addressing: Slave number 5

HMI configuration

The HMI HMIGXU3512 that we will use accept two different protocol Modbus serial and Modbus TCP/IP, in case we choose Modbus TCP/IP according to their advantages and will configure it as follow :

- Assignment of the IP address: 172.20.63.15.
- IP protocol: TCP.
- Double word order: Low word first.
- ASCII display byte order: Low byte first.

Gateway configuration

Gateway is the device that allows linking a different protocol that we will configure through a Link 150 web page and it will be as follows:

1. Connect the gateway with the PC through an Ethernet cable.
2. Open a web browser: Launch a web browser on a computer that is connected to the same network as the gateway device.
3. Enter the gateway's IP address: In the address bar of the web browser, enter the IP address of the gateway device figure 3.5.

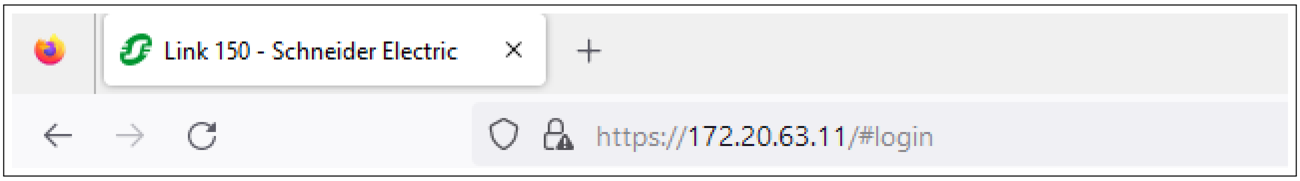


Figure 3.5: Access to the web page of the gateway

4. Login to the web interface: if required, enter the login credentials to access the gateway's web interface figure 3.6.

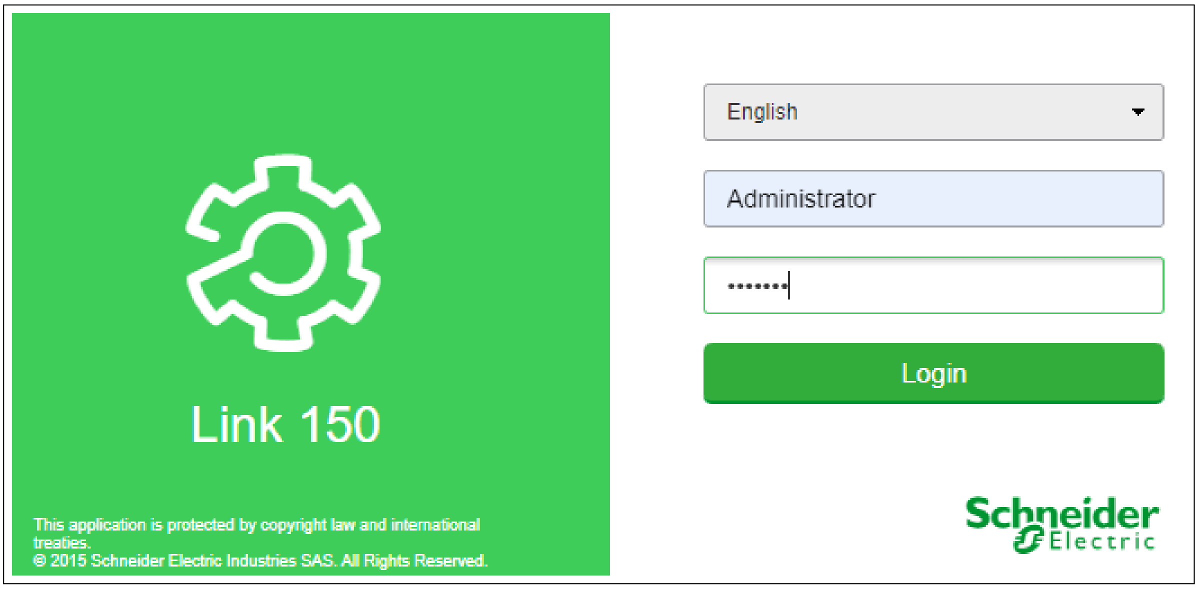


Figure 3.6: User login

5. Configure Communication Protocols: after we have accessed the gateway web page, we will set up the gateway according to the same PLC and HMI configuration as follows.
   - Affecting the address IP "172.20.63.11" to the Ethernet port of the gateway.
   - Setting the serial port of the gateway as the Master and RS-458-2W as the physical interface.
   - Setting the transmission line 19200 bit/s, even parity, stop bit 1.

6. Test communication: Verify the communication between the gateway and other devices in the network to check the data exchange, connectivity, and synchronization with the connected devices, such as the PLC or HMI as shown in figure 3.7.

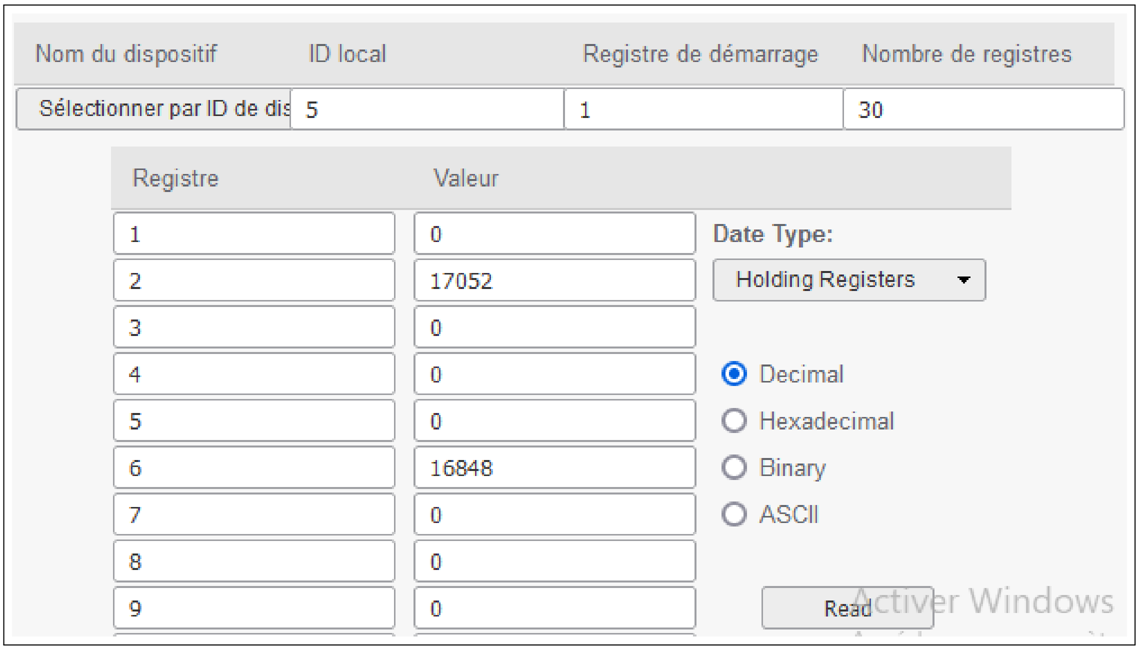


Figure 3.7: Test data exchange between devices

3.4 PLC program development

In this section, we show the software plc programming overview and explain how did we develop a program of process.

3.4.1 Software PLC overview

SoMachine Basic is a software development environment specifically designed for programming Schneider Electric's M221 PLC. It provides a user-friendly interface and a range of tools for creating, configuring, and troubleshooting automation projects. SoMachine Basic is part of the EcoStruxure Machine architecture, which offers a complete solution for machine control and automation.

Here are some key features of SoMachine Basic :

- Integrated Development Environment: it provides an integrated development environment (IDE) that allows users to create and edit automation projects. The IDE includes a graphical programming editor, configuration tools, and a project management interface figure 3.8.
- Graphical Programming: The software supports multiple programming languages, including ladder diagram (LD), instruction list (IL), and function block diagram (FBD). The graphical programming interface makes it easier to design and visualize the control logic.

- Device Configuration: SoMachine Basic enables users to configure and set up M221 and M221 Book logic controllers, as well as other connected devices. It provides tools for defining I/O points, configuring communication parameters, and managing device settings.
- Library of Function Blocks: The software includes a library of pre-defined function blocks that can be used to implement common control functions. These function blocks provide ready-to-use components for tasks such as motor control, PID loops, sequence control, and communication protocols.
- Simulation and Testing: It offers simulation capabilities that allow users to test their control logic before deploying it to the actual hardware. Users can simulate inputs, outputs, and process variables to verify the behavior and performance of their automation projects.
- Remote Access and Monitoring: The software supports remote access and monitoring of automation projects. It enables users to connect to the logic controllers and monitor real-time data, perform diagnostics, and make modifications remotely.
- Diagnostic and Troubleshooting Tools: It provides diagnostic tools to assist with troubleshooting and maintenance. It offers features such as online debugging, runtime monitoring, and event logging to aid in identifying and resolving issues.
- Integration with EcoStruxure Platform: SoMachine Basic seamlessly integrates with the wider EcoStruxure architecture and ecosystem. It enables data sharing and interoperability with other Schneider Electric products and solutions, including HMI panels, SCADA systems, and cloud-based services.

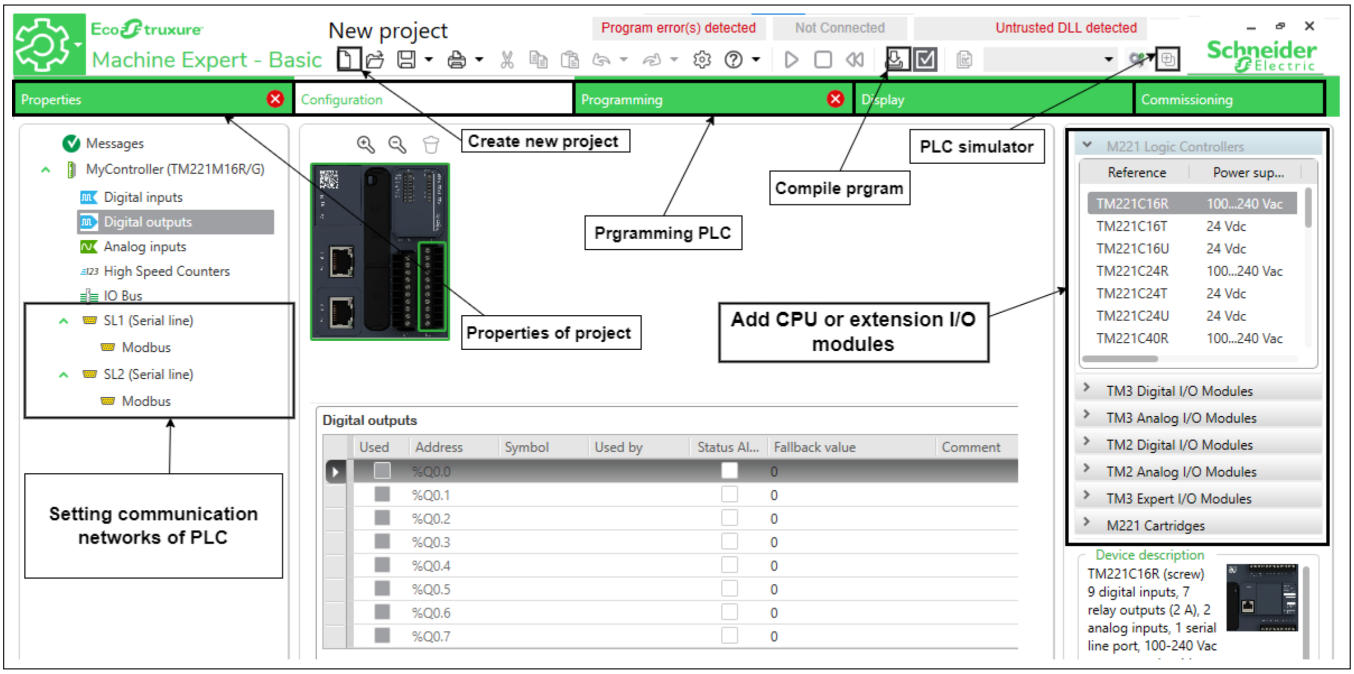


Figure 3.8: View of SoMachine-Basic

3.4.2 Process requirement

In this process of the water pumping station, there are different places and modes of control:

- Mode Local:
  - Operators can manually start or stop the pumps, adjust setpoints, and perform maintenance tasks directly at the local control panel.
  - Local mode allows for immediate intervention, manual control, and quick response to any issues or abnormalities detected at the station.
- Mode Remote:
  - Operators can remotely monitor the status of the pumps, water levels, flow rates, and other relevant parameters from a central control room, reducing the need for physical presence at the station.
  - Remote mode facilitates centralized management, data logging, and alarm handling, allowing operators to respond to alarms or faults promptly.
  - Operators can remotely adjust pump control settings, set operational schedules, and access historical data for analysis and optimization.
- Manual Control Mode:
  - In manual control mode, operators have direct control over the operation of the water pumping station.
  - Operators can manually start or stop the pumps, adjust setpoints, and control other parameters using local control panels or interfaces.
- Automatic Control Mode:
  - For an automatic mode to start working, all equipment must be in the normal state (safety).
  - The pumps start running if the condition of the water level in tank 1 is more than 20% and valve 1 is open.
  - Valve 1 is opening when the level of water in tank 2 is less than 80%.
  - The pump must be stopped if there is any fault indicated by the motor circuit breaker, phase failure relay, or temperature detector high.
  - If the pump was running and suddenly fails, another standby pump must be started.
  - Tank 1 is equipped with a PH meter to measure the acidity of the water for the adjustment of chemical products.
  - If the value of PH meter was measured less than 6.5, valve 2 will open, and pump 4 be run to add base solution.
  - If the value of PH meter was measured more than 8.5, valve 4 will open, and pump 4 be run to add acid solution.
  - The chemical solutions are prepared through a vertical agitator in preparation tanks to mix the water and chemical products that inject by the doses pump.

According to the specifications, we have designed an automatic mode functional flowchart as shown in figure 3.9.

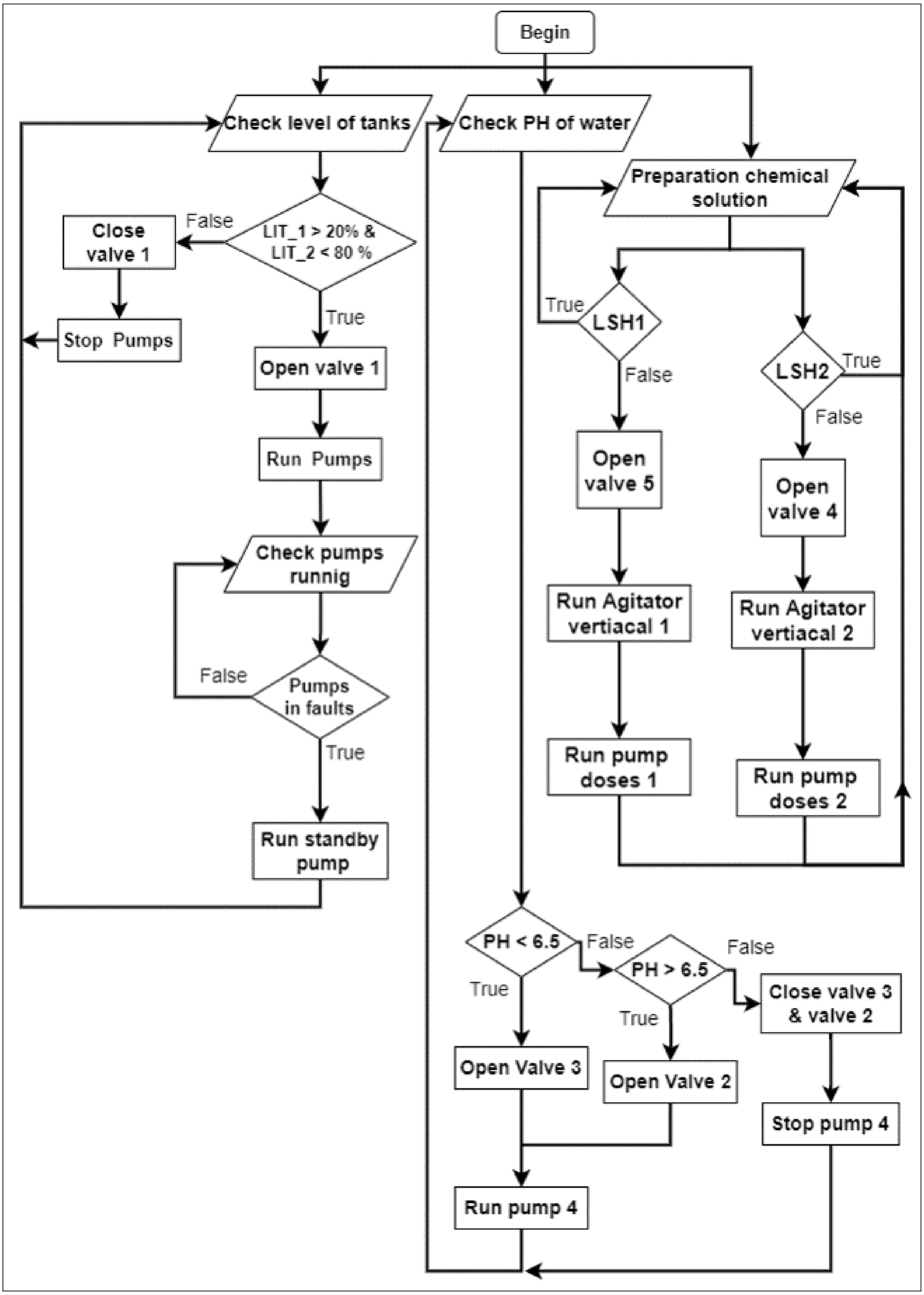


Figure 3.9: Flowchart of process in automatic mode

3.4.3 Equipment control blocks

After we have designed a flow chart, we will now develop a program in PLC to operate the process of the water pumping station using ladder language to programming.

- Firstly we create blocs for every equipment to facilitate the programming as the figure 3.10 represents the bloc program of a pump to control and manage the operation of a pump. It encapsulates the logic and functionality required to start, stop, monitor, and protect the pump. Figure 3.11 represent the intern bloc program of the pump.

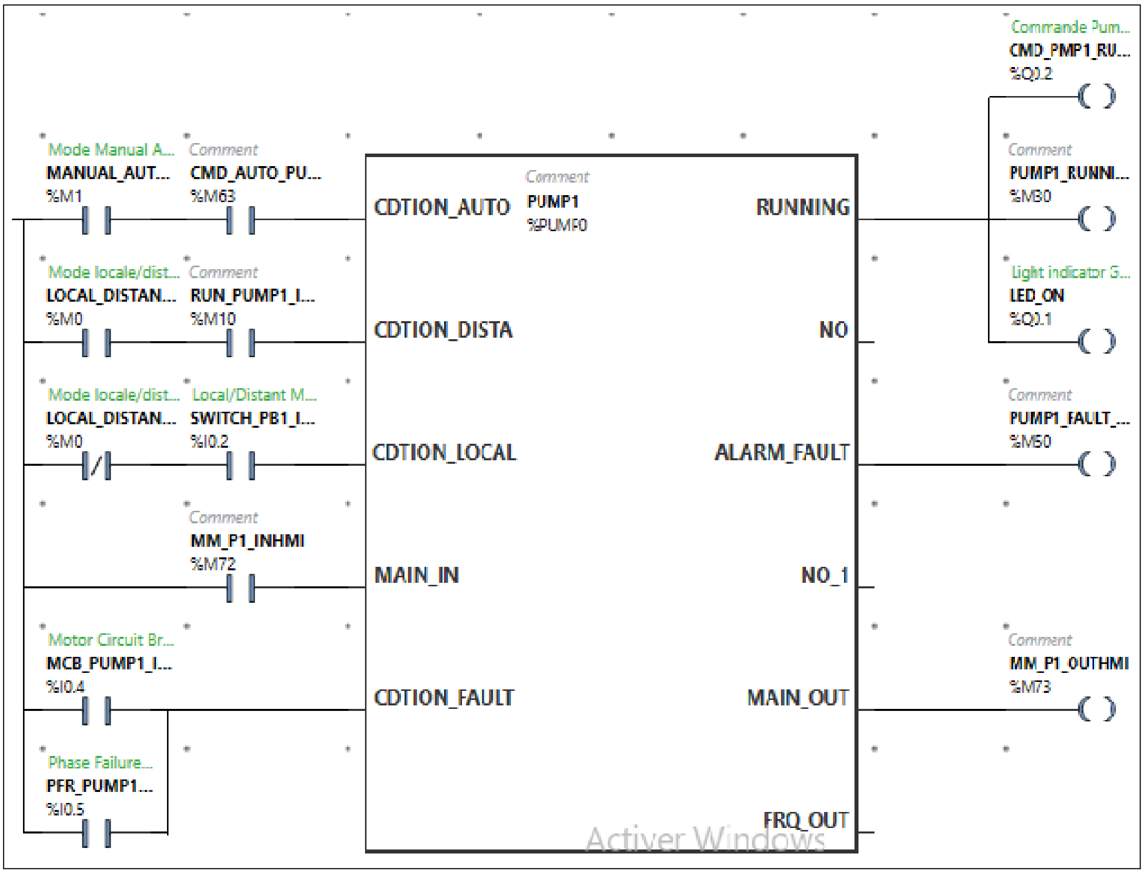


Figure 3.10: Bloc function of pumps

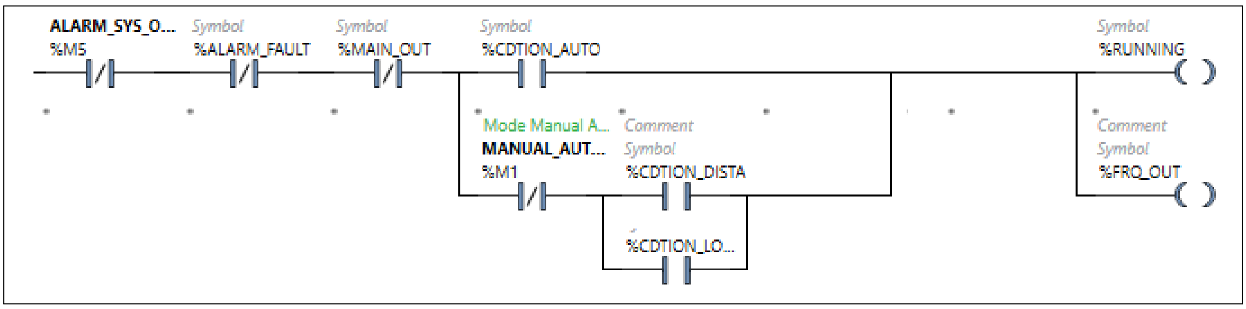


Figure 3.11: Intern bloc program of pump

We will duplicate this block in the main program to control the 3 pumps, but each pump has different conditions for operating in each mode.

- In the second we create a scale function bloc for the instruments to convert or scale input signals from a level sensor into meaningful engineering units or values. It is typically used to map the raw sensor readings to a specific range or units that represent the actual level measurement, as shown in figure 3.12.

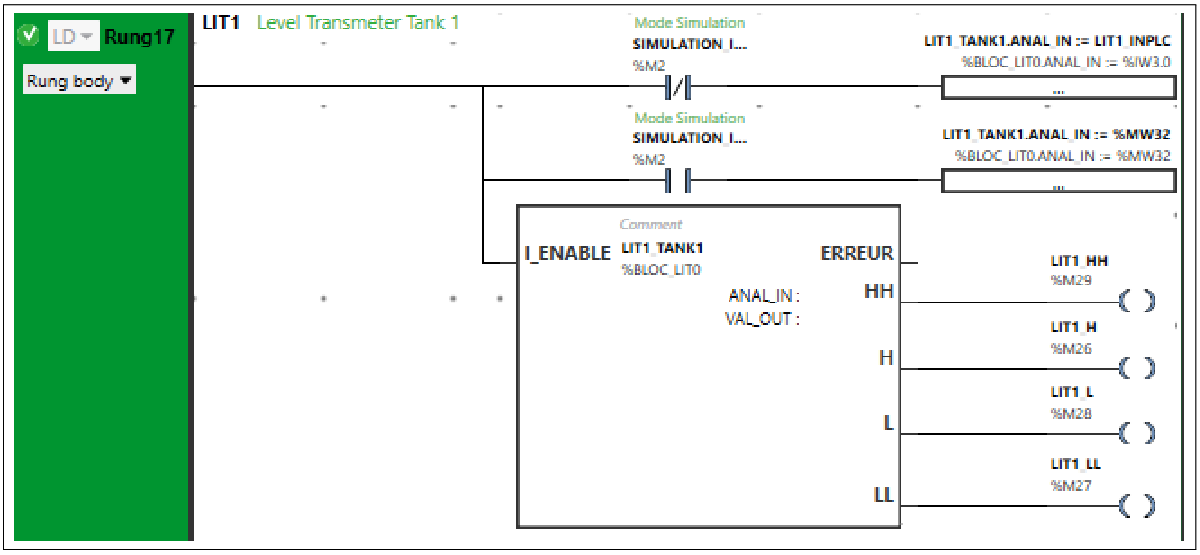


Figure 3.12: Function bloc of LIT

Figure 3.13 represent the intern scale function bloc of LIT, the scale function is based mainly on mathematical operations that convert integer to float type variable and scale an input value to a desired output value through a proportional relationship, for example, if the input range is 0 to 32000 and the desired output range is 0 to 100, a linear scale block will divide the input value by 100 to obtain the corresponding output value which will be usable as an input condition in other function blocks.

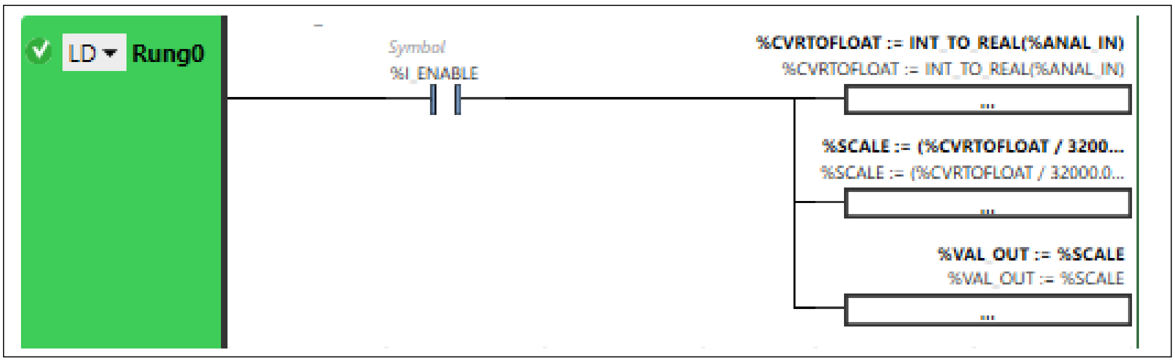


Figure 3.13: Intern bloc function of LIT

- After we have created control blocks for each equipment now we will develop the logic and sequencing of operations within the control system. Define the sequence of events and actions that need to occur for proper system operation. This includes programming interlocks, alarms, and control strategies to ensure the safe and efficient functioning of the equipment.

3.5 Design HMI interface

In this section we talked about HMI design software and how did we develop the interface using different tools according to process requirements.

3.5.1 Software HMI overview

Vijeo Designer is a software application developed by Schneider Electric that is specifically designed for creating and configuring human-machine interfaces (HMIs) for industrial automation systems. It provides a comprehensive set of tools and features to design, simulate, and deploy interactive graphical interfaces that enable operators to monitor and control various processes in real-time as shown in figure 3.14 .

Here are some key aspects of Vijeo Designer:

- Graphical Interface Design: Vijeo Designer offers a wide range of graphical elements such as buttons, icons, images, and animations, allowing designers to create interactive and user-friendly interfaces.
- Dynamic Screen Navigation: Vijeo Designer allows the creation of dynamic navigation structures within the HMI.
- Alarm Management: The software provides tools for configuring and managing alarms and events. Operators can define alarm thresholds, priorities, and response actions.
- Simulation and Testing: Vijeo Designer offers simulation capabilities, enabling designers to test and validate the HMI screens and functionalities before deploying them to the actual hardware.

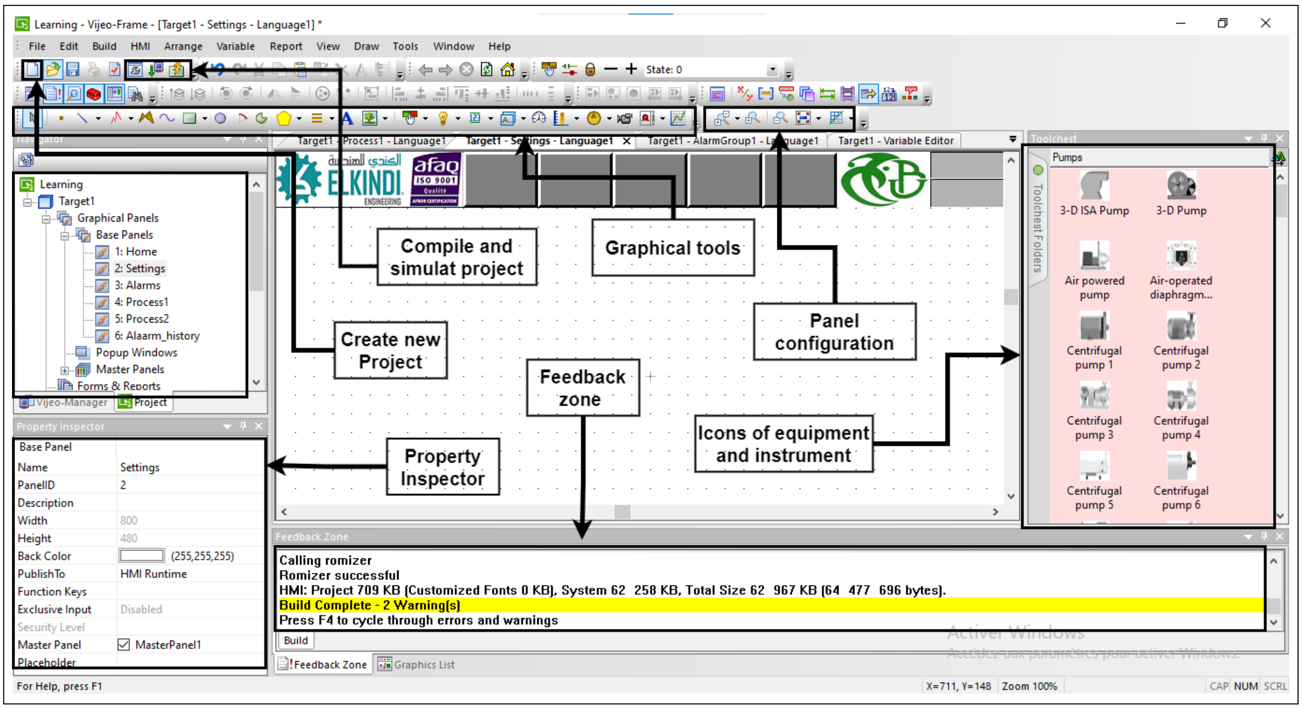
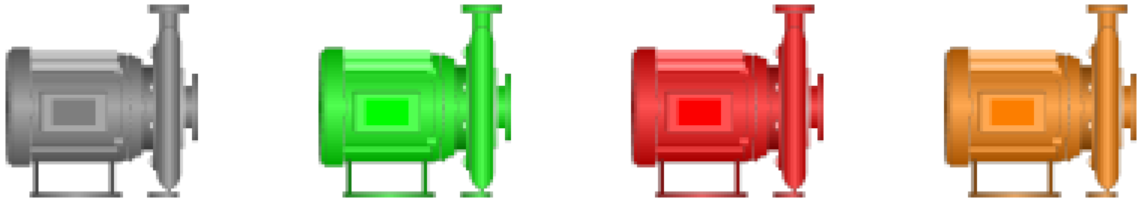


Figure 3.14: View of Vijeo Designer

3.5.2 Design steps HMI

We will design HMI according to the requirement of the process for that we follow the steps as following:

1. Firstly we will design the global process view as in the P&ID diagram, the main process view contains the main equipment that will be controlled if the equipment has a different situation, it must appear to the operator with a different color as shown in figure 3.15.



((a)) Stand-Off ((b)) Running ((c)) Fault ((d)) Maintenance

Figure 3.15: Pumps situation

2. Secondly, we will add the indications of the various instruments used in the process to display the values measured by the different transmitters.

3. In addition, we're going to add other views that will allow you to view the history, alarms, and configuration of process parameters figure 3.16.

Alarm Group Setting... Add...

	Variable	Alarm Group	Data Source	Device Address	Message
1	PLC_ModbusEquipm...	AlarmGroup1	External	%M5	Alarm System ON
2	PLC_ModbusEquipm...	AlarmGroup1	External	%M6	Emergency button has been pressed
3	PLC_ModbusEquipm...	AlarmGroup1	External	%M29	Level of water is very high in Tank 1
4	PLC_ModbusEquipm...	AlarmGroup1	External	%M27	Level of water is very low in Tank 1
5	PLC_ModbusEquipm...	AlarmGroup1	External	%M43	Level of water is very high in Tank 2

Figure 3.16: Alarm group setting

4. Finally, we will configure access to the various views and control parameters by configuring access levels figure 3.17.

Group	Security Level	Password/Fingerprints	Download Security	Data Manager Security
Engineers	3	Password	Allowed	Read/Write/Delete
Operators	1	Password	Allowed	Read/Write
Technicians	2	Password	Allowed	Read/Write

Figure 3.17: Access control levels configuration

3.6 Test and results

Once we have developed the process program, we will test it in the simulator and then on the test bench. In this section, we will show the commissioning and result of our work.

In SoMachine software, we can simulate the control logic and behavior without the need for physical hardware. The simulation feature allows testing and verifying the program's functionality before deploying it to an actual PLC. Here is a general overview of how to simulate the program in SoMachine:

- Open the Project: Launch SoMachine software and open the project.
- Configure the Simulation Settings: Navigate to the "Configuration" tab or menu.
- Select Simulation Mode: Choose the desired simulation mode.
- Define I/O: In the I/O configuration, define the input and output variables used in the program figure 3.18.
- Configure Initial Values: Set the initial values of variables, inputs, and outputs as needed for the simulation figure 3.19.
- Start the Simulation: Start the simulation by selecting the appropriate option in the toolbar or menu.
- Monitor and Debug: Use the built-in monitoring and debugging to observe the program execution, check variable values, and troubleshoot any issues figure 3.20.

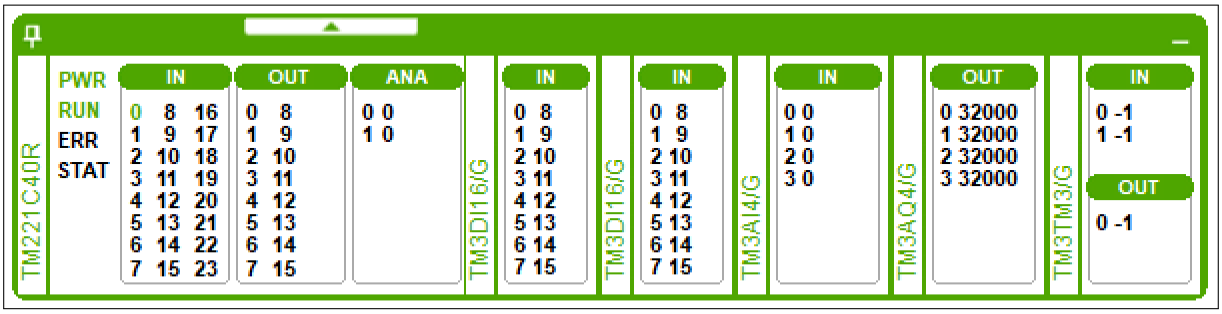
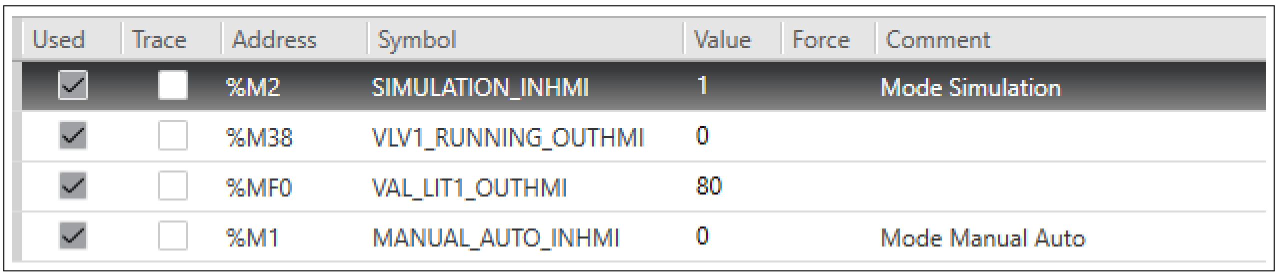


Figure 3.18: I/O simulator soMachine



Used	Trace	Address	Symbol	Value	Force	Comment
☑	☐	%M2	SIMULATION_INHMI	1		Mode Simulation
☑	☐	%M38	VLV1_RUNNING_OUTHMI	0		
☑	☐	%MF0	VAL_LIT1_OUTHMI	80		
☑	☐	%M1	MANUAL_AUTO_INHMI	0		Mode Manual Auto

Figure 3.19: Configure the initial of values variables

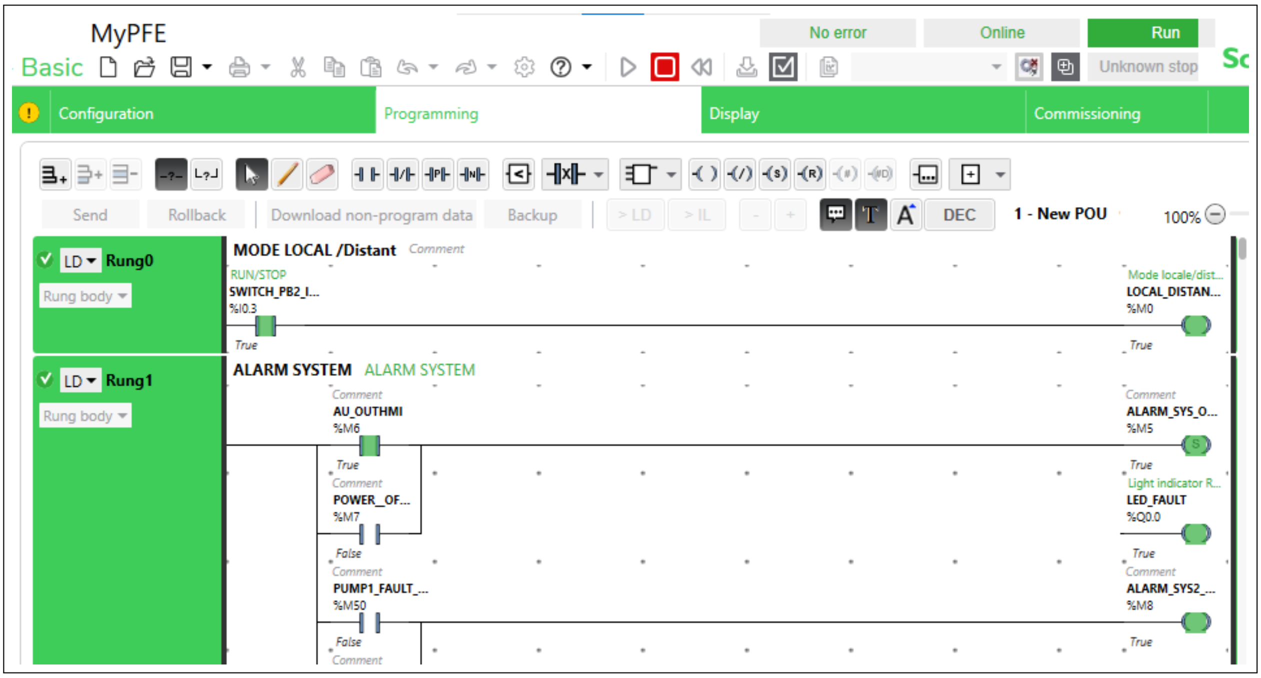


Figure 3.20: Online visualization program PLC

After we have tested the PLC program that we developed on the SoMachine simulation, now we are going to test the interface of HMI that we have designed on the Vijeo designer. Figure 3.21 represents a synoptic view of water pumping in the process and figure 3.22 represents the synoptic view of the solution preparing station and chemicals pumping in Tank 1.

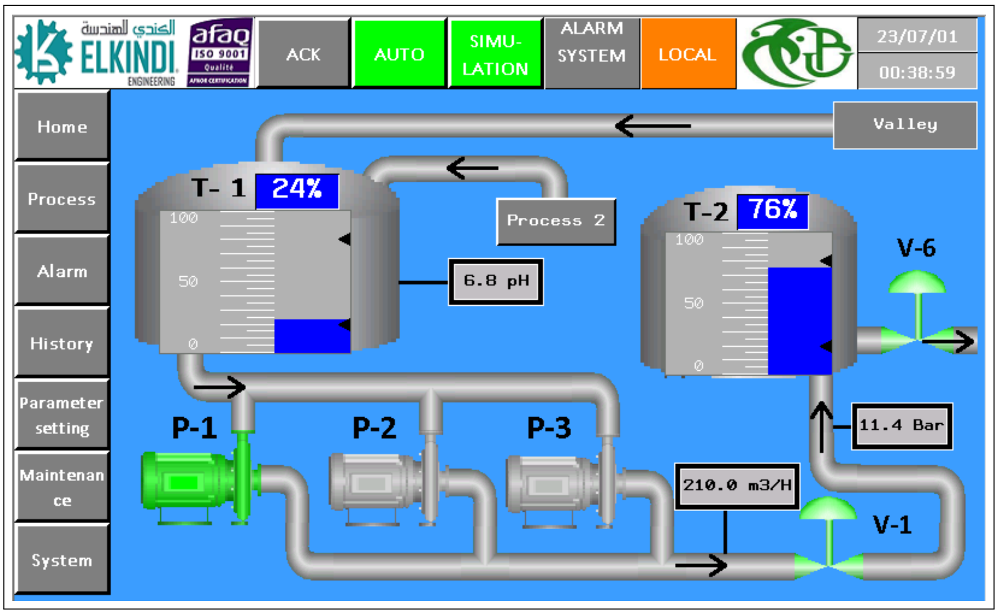


Figure 3.21: Process 1: water pumping station screen HMI

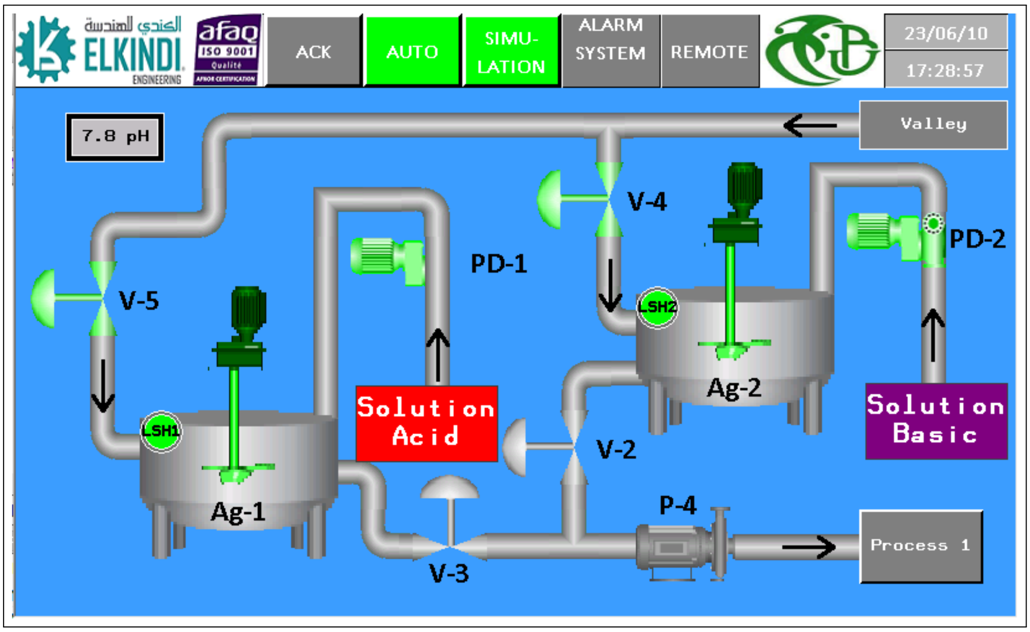


Figure 3.22: Process 2: solution preparing station screen HMI

Figure 3.23 represents an alarm view that is actively indicated to the operator and figure 3.24 represents a history alarm view.

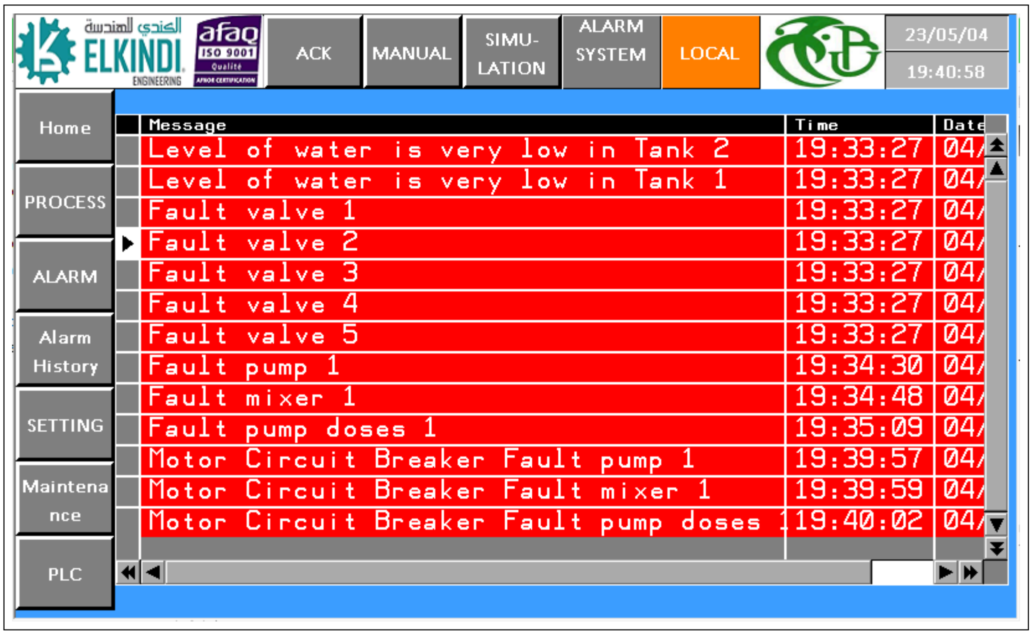


Figure 3.23: Alarm screen HMI

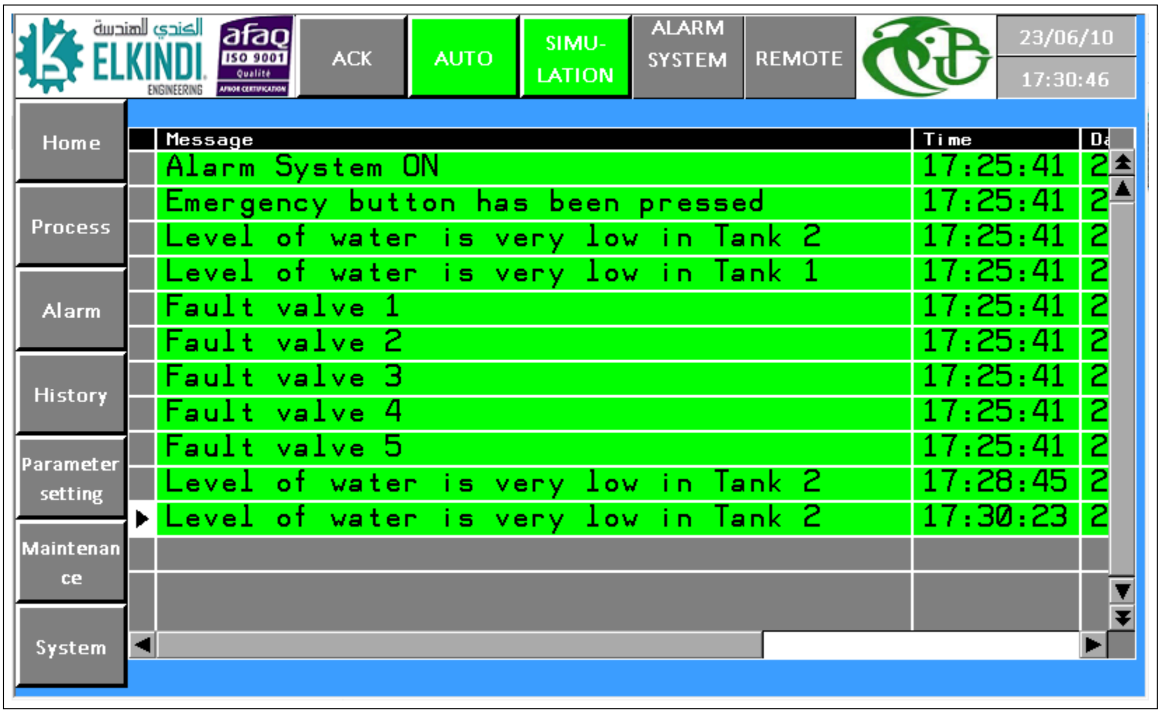


Figure 3.24: History alarm screen HMI

Figure 3.25 represents the parameters setting process view in HMI.

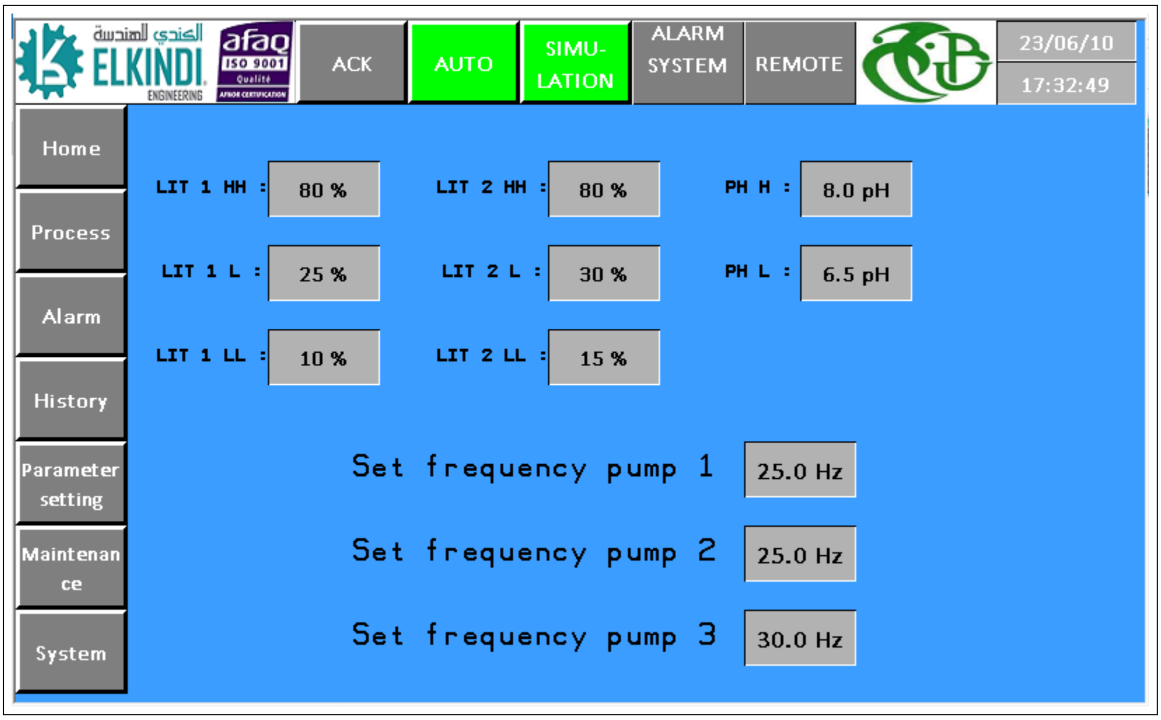


Figure 3.25: Setting screen HMI

After we have tested the HMI on the simulator, we can now upload the program file and HMI design file to the devices on the test bench.

3.7 Conclusion

In this chapter, we explained the steps to study and design the process control, beginning by identifying the requirements of the process to sizing the number of I/O, we also configured to make communication between PLC and HMI, and we developed a PLC program according to the requirement of the process and we designed interface of HMI. Finally, we commissioned using the simulator of SoMachine to check the integrity of the PLC program and we implemented it on the test bench.

Conclusion

Our final year project was to study and design the automation part of the water pumping station. Throughout this project, we have gained valuable insights into the importance of automation control in water management systems and the potential benefits it can bring. By thoroughly analyzing the requirements and challenges of water pumping stations, we have been able to develop an effective automation solution that optimizes the operation and performance of the station. The integration of PLCs, HMIs, sensors, and control strategies has allowed for precise monitoring, accurate data collection, and efficient control of the pumping process.

First of all, we started with some documents to understand the philosophy of this kind of project, through our research and analysis, we have identified the key instruments and technologies used in water pumping stations for the automation part that we were concerned with as automation engineers, such as level sensors, flow meters, pressure meters, valves, and VFDs. These instruments have proven to be critical in maintaining the desired water levels, ensuring optimal flow rates, and preventing equipment damage or failures. We noticed also that usually, they used various modes in the programming side such as local mode, remote mode, manual control mode, automatic control mode, and simulation mode.

Furthermore, we have explored the communication and networking aspects of automation systems, recognizing the significance of establishing robust and secure networks to facilitate data exchange, remote monitoring, and real-time decision-making. The use of supervisory systems and remote monitoring software has provided us with the ability to monitor and control the water pumping station from a centralized location, enhancing operational efficiency and responsiveness.

During the implementation phase of our project, we encountered various challenges and obstacles, especially on the communication side. However, through careful planning, collaboration, and problem-solving, we were able to overcome these hurdles and successfully deploy our automation solution. This hands-on experience has further enhanced our understanding of the practical aspects of automation engineering and project management.

We can develop this project by adding other options such as a start-up management option so that we have the ability to control which pump runs first every time we need to run the pumps, this technique is an algorithm we can add to the program in order to improve the life span of the pumps.

In conclusion, this project was a great opportunity to implement our knowledge and take an experience in this kind of industrial project such water pumping station, also it was a gateway to see professional life, in addition, the final year project allows us to learn about new things and acquire new skills such as some new software, familiarize our-self with new PLC band which is Schneider Electric and their softwares, also we have taken an experience of work by AutoCAD and Draw.io software.

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