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Automation and Supervision of a Solar Desalination Plant based on Programmable Logic Controller

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بسم الله الرحمن الرحيم

Dedication

To my dear and beloved father "Abdel hafid",

as a token of my deep affection.
To my dear and beloved mother "Siham", as a token of my deep affection.

To my sister "Aya" and my brother "Ahmed" for their support.
To all the members of my family.
To all my friends, especially: " Nadjib", "Mouhamed " "Zakaria" , "Abedel Mounam","Houssam","Ammar"," Amine","Amer".

To my friend and also teammate "Mouslim"
To my classmates of the 2024–2025 cohort.
To all the people I love.

I dedicate this modest

Oussama

Dedication

To my dear and beloved father " Abdel Hamid ",
as a token of my deep affection.
To my dear and beloved mother " Jamila ",
as a token of my deep affection.
To my sisters: Soumaya and Zohra
for their moral support.
To my brothers: Tarek and Reda
To all the members of my family.
To all my friends, especially: , Mouhamed , Zakaria,
Abedel Mounam ,Houssam ,Al Arabi ,Amine
,Hachim ,Ammar.
To my friend and also teammate Oussama
To my classmates of the 2024–2025 cohort.
To all the people I love.

I dedicate this Modest work.

Mouslim

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Table of Abbreviations

Abbreviation	Designations
RO	Reverse Osmosis
PLC	Programmable Logic Controllers
SW	Seawater
BW	Brackish Water
BWRO	Brackish Water Reverse Osmosis
NF	Nanofiltration
UF	Ultrafiltration
MF	Microfiltration
MSF	Multi-Stage Flash Distillation
MED	Multi-Effect Distillation
FO	Forward Osmosis
CIP	Clean-In-Place
SCADA	Supervisory Control and Data Acquisition
IoT	Internet of Things
HMI	Human-Machine Interface
I/O	Inputs/Outputs
PROFIBUS	Process Field Bus
PROFINET	Process Field Network
PS	Power Supply
CPU	Central Processing Unit
TCP	Transmission Control Protocol
IP	Internet Protocol
LED	Light Emitting Diode
SM	Signal Modules
CM	Communication Modules
MC	Memory Card
IEC 61131-3	International Electrotechnical Commission Standard 61131-3
LD	Ladder Diagram
IL	Instruction List
FBD	Function Block Diagram
ST	Structured Text
SFC	Sequential Function Chart

TIA Portal	Totally Integrated Automation Portal
WinCC	Windows Control Center
PC	Personal Computer
BOOL	Boolean
INT	Integer
RS	Set-Reset
NO	Normally Open Contact
NC	Normally Closed Contact
TON	Timer ON Delay
PPM	Parts Per Million

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ملخص

يتناول هذا العمل أتمتة وحدة لتحلية المياه والإشراف عليها باستخدام تقنية التناضح العكسي، الأكثر استخدامًا في مجال تحلية المياه، والتي يتم التحكم والإشراف عليها على التوالي بواسطة وحدة تحكم منطقية للبرمجة من شركة سيمنز *S7-1200 (PLC)* وواجهة آلة بشرية *(HMI)*. بعد الدراسة والتحليل المعمق لدفتر الشروط و للمواصفات، تم تطوير برنامج تحكم باستخدام برنامج TIA portal V15 وبرمجته باستخدام Ladder ثم نقله إلى *PLC* المبرمج الالي الصناعي لتلبية المواصفات وإدارة التشغيل الآلي لتحلية المياه المدروسة و الطاقة الشمسية كمصدر للطاقة. ثم تم تقديم وصف تفصيلي لتقنيات الأتمتة المختلفة للأنظمة الصناعية، وبشكل أكثر تحديدًا التقنية القائمة على استخدام وحدات سيمنز. تم تخصيص جزء كبير للبرمجة باستخدام برنامج بوابة TIA ، مع تسليط الضوء على الخطوات التي يجب اتباعها لإنشاء مشروع التشغيل الآلي، وتهيئة الأجهزة، وتطوير البرامج والمحاكاة. وبالإضافة إلى ذلك، تم تطوير وتصميم واجهة بين الإنسان والآلة بواسطة برنامج *Wincc* المرن المدمج في برنامج بوابة *TIA Portal V15* لتمكين المشغل من المراقبة والتحليل والإشراف على سلوك النظام في الوقت الحقيقي.

الكلمات المفتاحية: الأتمتة، التحكم، التناضح العكسي، *PLC*، *S7-1200*، *TIA Portal*، *WinCC*، الطاقة الشمسية.

Abstract

The present work deals with the automation and supervision of a water desalination unit based on reverse osmosis technique, the most used in water desalination, controlled and supervised respectively by a Siemens programming logic controller (PLC), S7-1200 and a human machine interface (HMI). After an in-depth study and analysis of the specifications, a program was developed using TIA portal V15 software and programmed with Ladder and supplied by a photovoltaic source of energy which was then transferred to the PLC to meet the specifications and manage the automatic operation of the considered water desalination. A detailed description of the different automation technologies for industrial systems, and more specifically the technology based on the use of Siemens modules, was presented. A large part is devoted to programming with the TIA Portal software, highlighting the steps to be followed for creating an automation project, hardware configuration, program development and simulation. In addition, a Human-Machine Interface has been developed and designed by the *Wincc* flexible software integrated into the TIA portal V15 software to enable the operator to visualize, analyses and supervise the behavior of the system in real time.

Keywords: Automation, Control, Reverse Osmosis, PLC, Siemens S7-1200, TIA Portal, WinCC, Solar

Résumé

Le présent travail traite de l'automatisation et de la supervision d'une unité de dessalement d'eau basée sur la technique de l'osmose inverse, la plus utilisée dans le dessalement de l'eau, contrôlée et supervisée respectivement par un automate programmable Siemens S7-1200 et une interface homme-machine (HMI). Après une étude et une analyse approfondies du cahier des charges, un programme a été développé à l'aide du logiciel TIA portal V15 et programmé avec Ladder et l'énergie solaire comme source d'énergie, puis transféré à l'automate pour répondre au cahier des charges et gérer le fonctionnement automatique du dessalement de l'eau envisagé. Une description détaillée des différentes technologies d'automatisation des systèmes industriels, et plus particulièrement de la technologie basée sur l'utilisation de modules Siemens, a été présentée. Une grande partie est consacrée à la programmation avec le logiciel TIA Portal, mettant en évidence les étapes à suivre pour la création d'un projet d'automatisation, la configuration du matériel, le développement du programme et la simulation. En outre, une interface homme-machine a été développée et conçue par le logiciel flexible Wincc intégré dans le logiciel TIA Portal V15 pour permettre à l'opérateur de visualiser, d'analyser et de superviser le comportement du système en temps réel.

Mots-clés : Automatisation, Contrôle, Osmose inverse, PLC, Siemens S7-1200, TIA Portal, WinCC, Énergie solaire.

General Introduction

Water plays a central and critical role in all aspects of life, in the national environment, in our economies, in food security, in production and in politics. Water is a major factor in each of the three pillars of sustainable development, economic, social and environmental. Water is invaluable resource in our ecosystem, essential for our survival and environment. It is after all, a fundamental part of all our cells.

The most valuable and significant natural resource on Earth is water. It keeps all life going. Without water, life cannot exist. Water is essential not only for humans but also for the ecosystem as a whole. Water covers about 71% of Earth's surface. Sadly, freshwater accounts for only 3% of the available water. Glaciers and ice caps that have frozen over account for approximately two-thirds of the freshwater. Groundwater and surface water account for the remaining small amount [1].

It is essential for life and health. Water is essential for leading a life of dignity. It is known to be abundant on earth, but it mainly occurs in the form of seawater (97%). However, seawater contains nearly 100 times more salt than the limit set by the WHO (World Health Organization) for human consumption [2].

Out of more than 7 billion human beings, more than 1.1 billion do not have access to drinking water today, and more than 2.6 billion do not have a sanitation system [3]; to remedy this problem, the Algerian authorities have decided that one of the adequate solutions for our country, which has a coastline of 1600 km, is the desalination of seawater. Therefore, seawater desalination has become an industry in Algeria, and like all industries, technological developments and the need for competitiveness increasingly lead to the automation of production systems Several reverse osmosis plants have already been implemented in coastal cities such as Algiers, Oran, and Skikda, contributing significantly to the national water supply[4].

Seawater desalination has emerged as one of the most technologically advanced and sustainable ways to alleviate water scarcity, particularly in arid and semi-arid countries, as a result of the growing demand for fresh water worldwide brought on by urbanization, population increase, and rising consumption rates. In order to make saline water fit for industrial, agricultural, or drinking purposes, salts and dissolved minerals must be removed [5].

One of the most popular and effective desalination techniques in the world is reverse osmosis (RO). It is renowned for using less energy than thermal methods and for having a great capacity to remove contaminants. By applying high pressure to saline water, the method retains salts and impurities while enabling only clean water molecules to flow through semi-permeable membranes.

Automation is now crucial to the operation and monitoring of desalination facilities due to developments in industrial technology. Automation increases system reliability, boosts performance, and lowers human error. The Programmable Logic Controller (PLC), one of the most efficient automation tools in this industry, allows precise and quick control of every processing step, including controlling automatic cleaning cycles, checking water quality, and controlling pressure. Such an automated system is well suited not only for major coastal desalination facilities, but also for remote arid regions in Algeria where saline groundwater sources are prevalent and require purification.

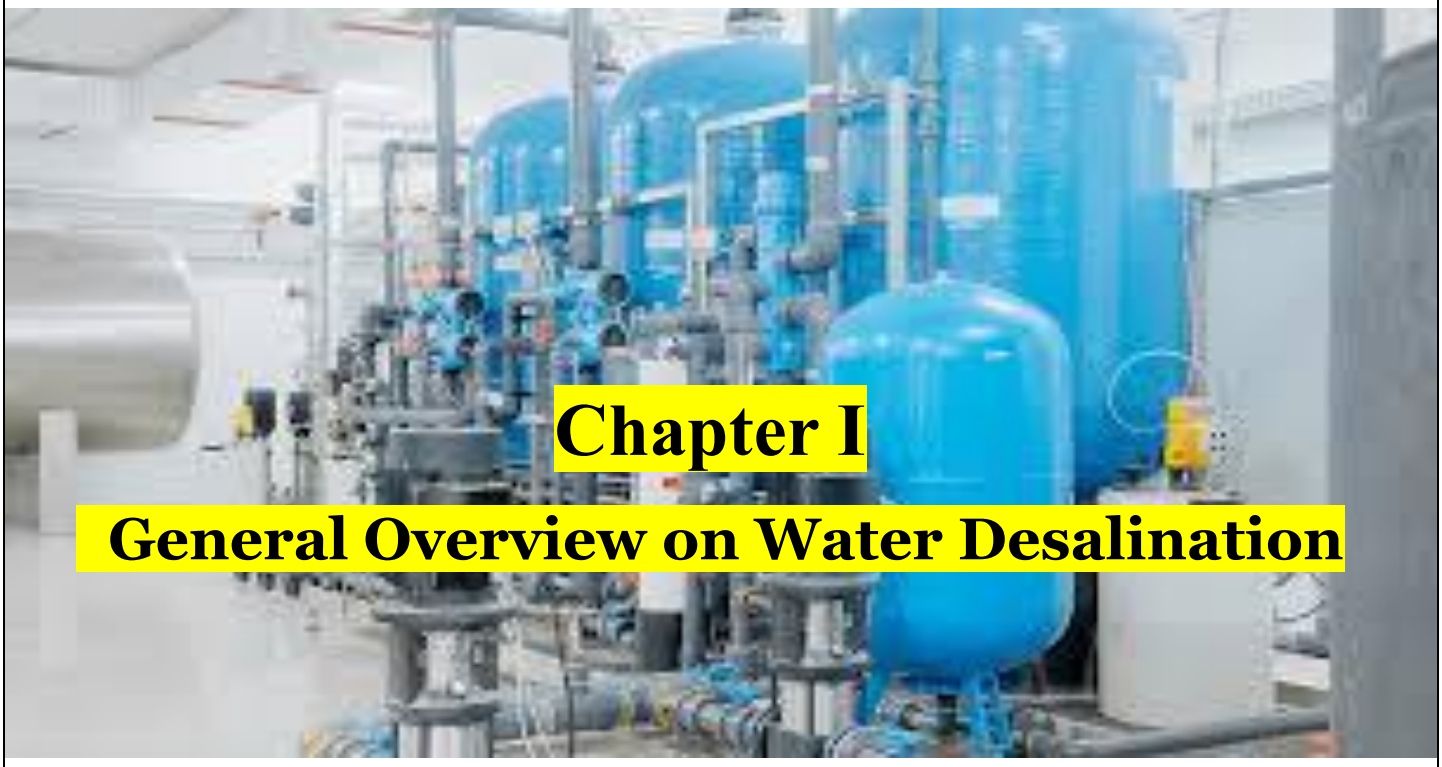
In this regard, the Siemens S7-CPU-1200 in the TIA Portal V15 environment is used to build and execute a control and supervision system for a reverse osmosis-based seawater desalination unit.

A Human-Machine Interface (HMI) is also integrated to guarantee the desalination unit operates safely and effectively while providing ongoing operational variable monitoring in compliance with the specified parameters [6].

The main objective of the present dissertation is the control and the supervision of a solar water desalination plant based on Programmable Logic Controllers (PLC)-S7-1200 and Human machine interface (HMI) which is provides a tailor-made solution in terms of adaptation and flexibility.

To achieve this objective, the present dissertation is structured into four main chapters as follows:

- Chapter One: Presents an overview of water desalination, focusing on reverse osmosis technology its components, working principle, advantages and challenges as well as the importance of automated control in these systems.
- Chapter Two: The technical elements of industrial automation are covered in this chapter, including input/output modules, processing units, PLC architecture, and automated system components. Additionally, it presents the programming languages such as Ladder Diagram, Function Block Diagram, and Structured Text that are utilized in PLCs in accordance with the IEC 61131-3 standard. This chapter provides a thorough overview of programming and control technologies.
- Chapter Three: covers the design and implementation of a solar-powered seawater desalination system, including the use of Siemens TIA Portal, hardware setup, Ladder Logic programming, energy management for fixed and mobile units, and sizing of solar components with related schematics..
- Chapter Four: Focuses on developing an HMI interface to display operational data visually, using WinCC within TIA Portal, enabling the operator to monitor system performance and analyze faults in real-time, followed finally by a general conclusion and perspectives with future directions for the development of automated and environmentally friendly desalination systems.



Chapter I

General Overview on Water Desalination

I.1. Introduction

Water desalination is a vital solution to address water scarcity, especially in arid regions. It involves removing salts from saline water sources such as seawater and groundwater using various technologies. The most notably Reverse Osmosis (RO), known for its efficiency and lower energy consumption compared to thermal methods.

This chapter presents the various types of saline water and key desalination methods, with a focus on the importance of controlling RO systems using Programmable Logic Controllers (PLC) to ensure operational efficiency, optimize energy use, and improve water quality [7].

I.2. Desalination

Water Desalination is a process aimed at removing salts and dissolved substances from saline water such as seawater or brackish groundwater to convert it into fresh water suitable for drinking, agriculture, or industrial use. This process involves various technologies such as reverse osmosis (RO) and thermal distillation, with the choice of method depending on the water source and its salinity level. Desalination is considered a strategic solution to address freshwater scarcity, especially in arid and semi-arid regions, and plays a vital role in supporting water security and achieving sustainable development [7] .

I.3. History of desalination

The Greeks and Romans were the first to attempt desalination of water, employing crude techniques like boiling seawater and collecting the steam to produce fresh water. Desalination technology advanced significantly with scientific advancements, particularly in the 20th century as the need for drinking water in arid and semi-arid regions soared. Oil rich nations, especially those in the Arabian Gulf, began implementing contemporary methods like reverse osmosis (RO) and thermal desalination in the 1950. Since then, scientific advancements have increased the efficiency of desalination procedures and decreased their operating costs, making it one of the primary solutions to water scarcity [8].

I.4. Desalination water around the world

One of the most important methods for addressing freshwater scarcity in arid and semi arid regions of the world is desalination. Due in significant part to their limited natural freshwater supplies, the Middle East especially Saudi Arabia, the United Arab Emirates, and Kuwait leads the globe in the production of desalinated water. Other nations, such as China, Australia, Spain, and the United States (particularly California), have increased their investments in desalination technologies in recent decades to improve water security and guarantee sustainable growth. The bulk of the more than 20,000 desalination facilities that are now in operation use thermal-based techniques including multi stage

flash (MSF) and multi-effect distillation (MED), as well as reverse osmosis (RO). Desalination is anticipated to become more prevalent as conventional water sources continue to be strained by factors like climate change, industrial demand, and population increase worldwide. [9]

I.5. Desalination plant in Algeria

Desalination is considered a strategic option in Algeria to address the growing challenges related to water security, particularly in light of climate change and the decline of traditional water resources. The country has witnessed significant expansion in this field, currently operating 19 seawater desalination plants along its coastal strip, with plans to increase the number to 43 by 2030. The total production capacity of these plants is approximately 3.7 million cubic meters per day, covering more than 40% of the population's drinking water needs, with the ambition to raise this share to 60% in the coming years. Among the most prominent of these plants are: The Mostaganem (Mactaa) plant in Oran one of the largest in Africa, with a production capacity of up to 500,000 cubic meters per daythe El Hamma plant in Algiers, and the Beni Saf plant in Aïn Témouchent. Most of these plants rely on reverse osmosis (RO) technology to enhance water independence [9].

I.6. Types of Saline Water Suitable for Desalination

I.6.1. Seawater (SW)

Seawater is one of the most commonly used saline water sources for desalination due to its vast global availability. It contains a high concentration of dissolved salts, ranging between 35,000 and 45,000 parts per million (ppm), making desalination a complex process that requires advanced technologies. High pressure reverse osmosis (RO) and thermal distillation techniques are used to remove salts and convert seawater into potable or industrial water. However, these processes consume large amounts of energy, impacting the operational costs of desalination systems [10].

I.6.2. Brackish Water (BW)

Brackish water has a lower salt concentration than seawater, typically ranging between 1,000 and 10,000 ppm. It is found in underground wells and inland lakes and is often used for drinking, agriculture, and industrial applications. Desalination of brackish water requires less energy-intensive methods compared to seawater, such as low pressure reverse osmosis (BWRO) and nanofiltration (NF). These technologies offer cost effective solutions, particularly in regions suffering from freshwater shortages [11].

I.6.3. Highly Saline Water / Hypersaline Water

Highly saline water refers to sources with salt concentrations exceeding 50,000 ppm, such as the Dead Sea and some salt lakes. Desalinating this type of water is more challenging due to the high salt content, necessitating the use of highly efficient technologies like multi stage flash distillation

(MSF) or high pressure reverse osmosis. These processes require significant energy consumption, leading to higher desalination costs and limiting their widespread use compared to other types of saline water [12].

I.6.4. Industrial Saline Water

Industrial saline water originates from manufacturing processes, including petrochemical industries, mining, and power plants. This type of water may contain high salt concentrations as well as toxic chemical contaminants, requiring advanced treatment technologies. Reverse osmosis with pre treatment chemical processes or evaporation-based distillation is used to remove salts and harmful substances, ensuring compliance with environmental standards before reuse or discharge. Treating industrial saline water is essential for environmental protection and reducing the negative impact of industrial waste disposal [13].

I.6.5. Saline Groundwater

Saline groundwater is found in arid and desert regions, where certain underground water reservoirs contain high concentrations of dissolved salts and minerals, typically ranging between 1,000 and 20,000 ppm, depending on the geological composition of the source. Low pressure reverse osmosis (BWRO) or nanofiltration (NF) technologies are used to effectively desalinate this water. These systems provide a sustainable solution for producing potable and agricultural water while minimizing energy consumption and operational costs [14].

I.7. Water Desalination Methods

The process of desalinating saline or brackish water to make it fit for industrial or human consumption involves eliminating dissolved salts, minerals, and other contaminants. Desalination has emerged as a crucial remedy for the growing global need for fresh water brought on by population development, climate change, and industrial expansion, particularly in areas with limited freshwater supplies. Desalination is a process that uses a variety of technologies to remove impurities and salts from water. While some techniques rely on thermal energy for evaporation and condensation, others employ physical barriers like membranes. New methods that increase sustainability and efficiency have recently been introduced by developments in nanotechnology and renewable energy.

Understanding the advantages and disadvantages of each desalination method is crucial for selecting the most suitable approach based on economic feasibility, energy consumption, environmental impact, and water quality requirements. The major desalination techniques include:

I.7.1. Reverse Osmosis (RO) Desalination

I.7.1.1. Description

One of the most used desalination techniques is reverse osmosis. It works by forcing brackish or saltwater through semi permeable membranes under high pressure, which lets only water molecules through while keeping out salts, minerals, and other impurities. RO systems are frequently employed in small scale residential or commercial applications as well as large scale municipal desalinization facilities.

I.7.1.2. Operating the Reverse Osmosis (RO) Technique

I.7.1.2.1. Working Principle

This technique uses semi permeable membranes to allow fresh water to pass through while blocking salts and other contaminants. Saline water is pushed through the membranes under high pressure, separating the salts and impurities.

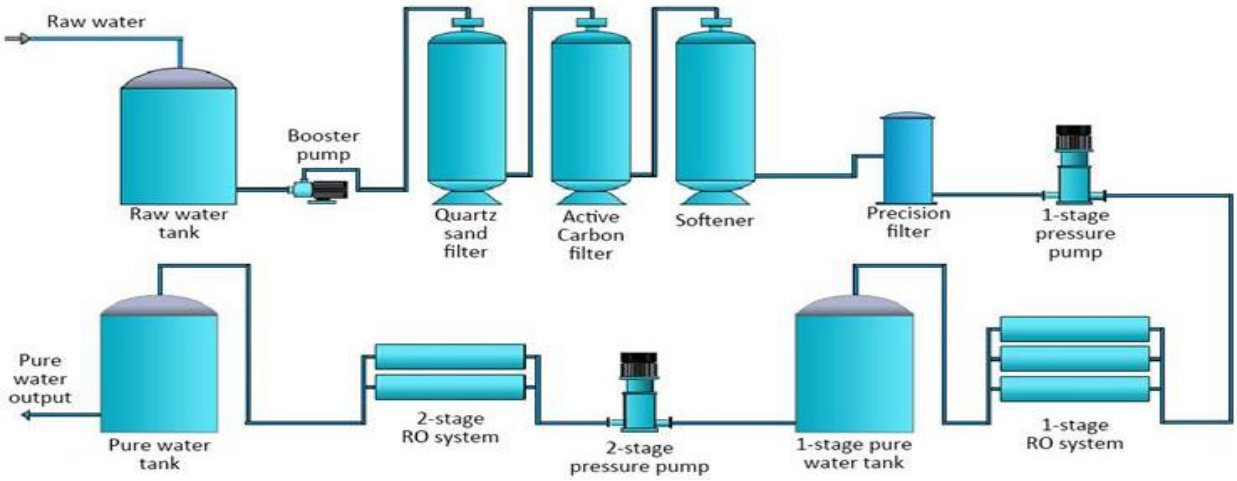


Fig. I.1. Reverse osmosis Technique [15]

I.7.1.2.2. Operation Stages

- **Pre treatment**
    - Removal of large impurities such as sand and clay using mechanical filters.
    - Addition of chemicals to prevent scale buildup and reduce corrosion effects.
    - Removal of chlorine or oxidizing agents that could damage the membranes.
- **High Pressure Pumping of Saline Water**
    - High-pressure pumps (around 55-80 bar) force the water through the RO membranes.

- Energy recovery devices are used to reduce electricity consumption and improve efficiency.

- **Separation of Fresh Water from Saline Water**
    - Freshwater passes through the membranes, while concentrated brine is discharged as waste.

- **Final Treatment :**
    - pH levels are adjusted, and essential minerals such as calcium and magnesium are added to make the water suitable for drinking.
    - The freshwater is stored in tanks and distributed through networks [16].

I.7.1.3. Advantages

- **High Efficiency in Salt Removal:** RO systems are capable of removing up to 99% of dissolved salts and contaminants, resulting in fresh water of superior quality.
- **Reduced Energy Use Compared to Thermal Methods:** RO uses a lot less energy than distillation procedures because it doesn't involve heating water**.**
- **Reduced Operational Costs**: RO systems typically have lower maintenance and operating costs than thermal desalination, even with significant initial investment prices.
- **Scalability:** RO technology is a flexible option for a range of water requirements because it can be used in small, medium, and large

I.7.1.4. Disadvantages

- **Membrane Replacement and Maintenance**: Because RO membranes are prone to fouling and scaling, they must be cleaned or replaced on a regular basis, raising operating expenses.
- **High Energy Consumption:** RO systems require a high pressure, which uses a lot of electricity even if it's less than distillation.
- **Problems with Brine Disposal**: RO generates a lot of brine, or concentrated saline wastewater, which needs to be disposed of properly to protect marine life [17].

I.7.2. Distillation Desalination (Thermal Methods)

I.7.2.1. Description

Distillation is a time-honored and dependable process of desalination, which involves heating saline water to the point of evaporation, therefore separating salts and contaminants:

- **Multi Stage Flash Distillation (MSF):** Water is heated and rapidly flashed into steam across multiple chambers, improving efficiency.
- **Multi Effect Distillation (MED):** Water is boiled in a sequence of chambers, each at a progressively lower pressure, to optimize energy use.

I.7.2.2. Operating the Distillation Technique (MSF & MED)

I.7.2.2.1. Working Principle

This method involves heating saline water until it evaporates, then condensing the vapor to obtain fresh water, leaving behind the salts and impurities in the boiling chamber.

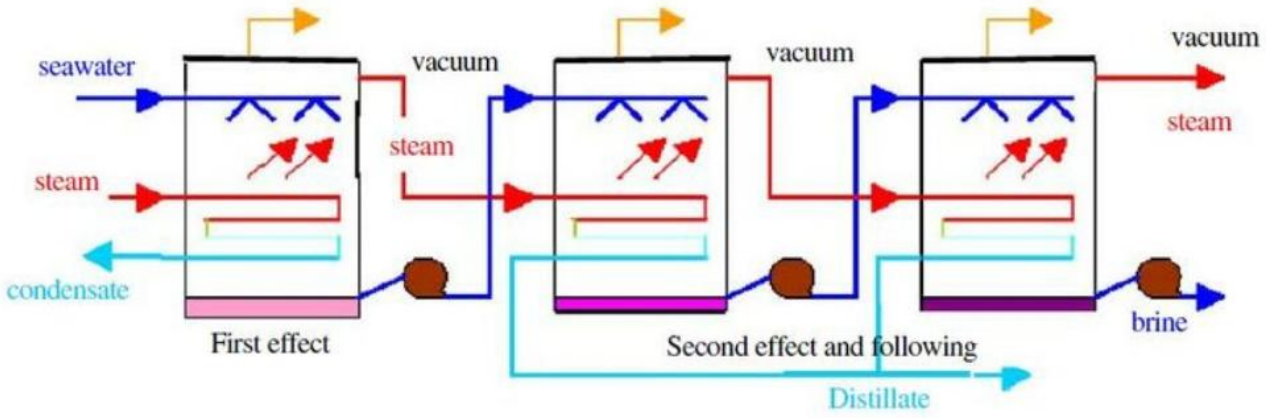


Fig. I.2. Distillation Technique [18]

I.7.2.2.2. Operation Stages

- **Initial Heating of Saline Water**
    - Water is heated using a heat source such as natural gas, steam, or solar energy.
    - In **Multi-Stage Flash Distillation (MSF)**, saline water is heated to high temperatures and then passed through multiple chambers with lower pressures, causing rapid evaporation ("flashing").

- In **Multi-Effect Distillation (MED)**, water evaporates in sequential stages, where condensed steam from each stage is used to heat the next stage, improving energy efficiency [19].

- **Condensation of Vapor to Obtain Freshwater**
  - The vapor passes through condensers cooled by seawater, leading to condensation and the formation of pure freshwater.

- **Disposal of Remaining Brine**
  - The concentrated brine is discharged into the sea or processed to extract valuable minerals.

- **Purification and Distribution of Freshwater**
  - Water quality is adjusted, and necessary minerals are added before distribution [19].

I.7.2.3. Advantages

- **High Water Purity:** Distillation produces extremely pure water, free from not only salts but also most contaminants and pathogens.
- **Long Equipment Lifespan:** Distillation systems, when properly maintained, can have long operational lifespans compared to membrane-based systems.
- **Effective for High Salinity Water:** Unlike RO, which struggles with very high salinity, distillation is effective even for extremely saline water sources like the Red Sea or the Persian Gulf.

I.7.2.4. Disadvantages

- **High Energy Consumption:**The heating and cooling cycles in distillation require large amounts of thermal energy, making it expensive unless waste heat or renewable energy is used.
- **High Capital and Maintenance Costs:** Constructing and maintaining distillation plants is expensive due to complex infrastructure and energy demands.
- **Large Land and Space Requirements:** Distillation plants require extensive space for multiple chambers and auxiliary equipment [20].

I.7.3. Freezing Desalination

I.7.3.1. Description

This method involves lowering the temperature of saline water until ice crystals form. Since pure water freezes first, the ice is separated and melted to obtain fresh water, while the remaining liquid contains the concentrated brine.

I.7.3.2. Operating the Freezing Desalination Technique

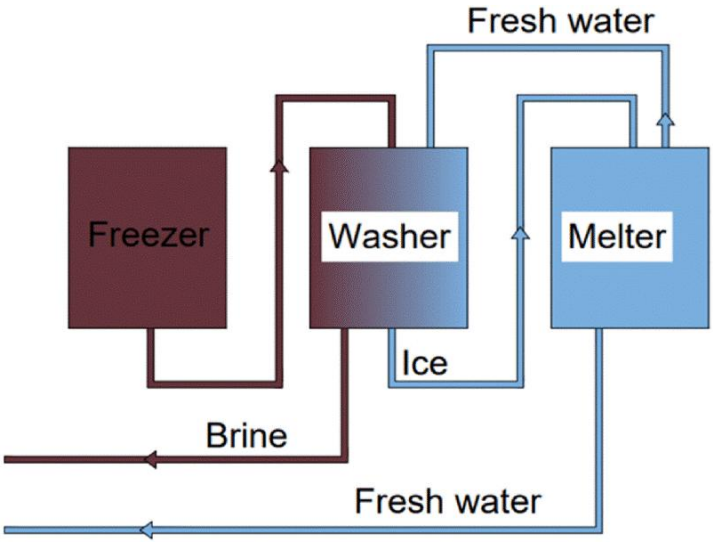


Fig. I.3. Freezing Desalination Technique [21]

I.7.3.2.1. Working Principle

This method relies on the fact that ice formed when cooling saline water does not contain salts. The ice is then melted to obtain fresh water.

I.7.3.2.2. Operation Stages

- **Freezing Saline Water :**
  - The temperature is gradually lowered until ice begins to form.
  - The cooling rate is carefully controlled to prevent salt entrapment within the ice.
- **Separating Ice from the Remaining Saline Water**
  - Techniques such as centrifugation or washing are used to remove any residual salt or impurities from the ice.

- **Melting the Ice**
    - The ice is gently heated to obtain fresh water.
- **Purification and Storage of Freshwater**
    - Water is purified and mineral levels are adjusted before use [22].

I.7.3.3. Advantages

- **Lower Energy Use Compared to Distillation:** Since freezing requires less energy than boiling, this method is potentially more energy-efficient
- **Minimizes Corrosion Issues:** Unlike high-temperature processes, freezing does not corrode equipment, leading to lower maintenance costs.
- **Produces High Purity Water:** The process results in fresh water with minimal impurities.

I.7.3.4. Disadvantages

- **Technical Challenges in Ice Separation:** It is difficult to efficiently separate ice from the brine without contamination.
- **Complex Equipment Requirements:** Specialized freezing and separation systems increase costs and technical complexity.
- **Higher Operating Costs:** Although energy use is lower than distillation, the overall costs remain high due to the difficulty in maintaining freezing systems [23].

I.7.4. Solar Desalination

I.7.4.1. Description

Solar desalination utilizes the sun's energy to evaporate saline water, and the vapor is then condensed into fresh water. This can be done using :

- **Solar Stills:** Simple enclosed systems that mimic the natural water cycle.
- **Solar Powered Reverse Osmosis:** RO systems powered by solar energy to reduce reliance on conventional electricity.

I.7.4.2. Operating the Solar Desalination Technique

I.7.4.2.1. Working Principle

Solar energy is used to evaporate saline water, then condense the vapor to obtain fresh water.

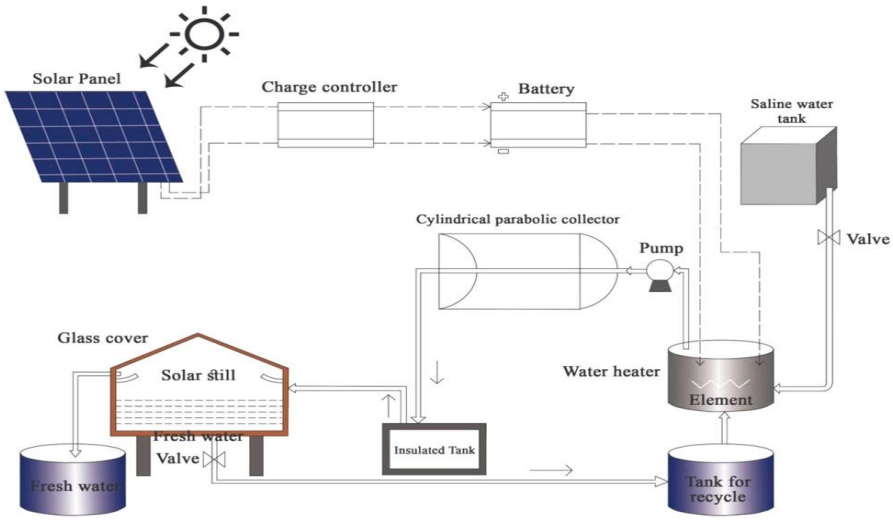


Fig. I.4. The Solar Desalination Technique [24]

I.7.4.2.2. Operation Stages

- **Solar Energy Collection**
  - Solar panels are used to heat the saline water directly or generate electricity to power evaporation pumps.
- **Solar Evaporation**
  - Saline water is placed in basins or closed systems where it evaporates under sunlight.
- **Condensation of Vapor to Obtain Freshwater:**
  - The vapor condenses on cold surfaces, such as glass or cooled metal, and is collected as freshwater.
- **Water Treatment and Distribution**
  - Water quality is adjusted to ensure it meets required standards [25].

I.7.4.3. Advantages

- **Renewable and Sustainable:** Solar energy is abundant and free, making this method highly sustainable in sunny regions.
- **Low Operating Costs:** Once installed, solar desalination requires minimal energy costs, reducing long-term expenses.
- **Ideal for Remote Locations:** This method is particularly useful in isolated areas where conventional desalination plants are impractical.

I.7.4.4. Disadvantages

- **Limited Output:** Solar desalination systems typically produce smaller quantities of water compared to industrial-scale methods.
- **Weather Dependency:** Efficiency is heavily dependent on sunlight availability, making it less effective during cloudy or rainy periods.
- **High Initial Investment:** The setup of solar collectors, panels, and thermal systems requires a significant upfront cost [26].

I.7.5. Forward Osmosis Desalination

I.7.5.1. Description

Forward osmosis (FO) is a desalination method that utilizes a semi permeable membrane to separate freshwater from saline water. This process relies on osmotic pressure differences between two solutions, drawing water through the membrane while leaving salts and impurities behind.

I.7.5.2. Operating the Forward Osmosis Technique

I.7.5.2.1 Working Principle

Forward osmosis occurs naturally due to the difference in osmotic pressure between a high-concentration "draw solution" and the saline water. Water molecules move across the membrane toward the draw solution, leaving behind salt and contaminants. The fresh water is then separated from the draw solution to obtain clean water.

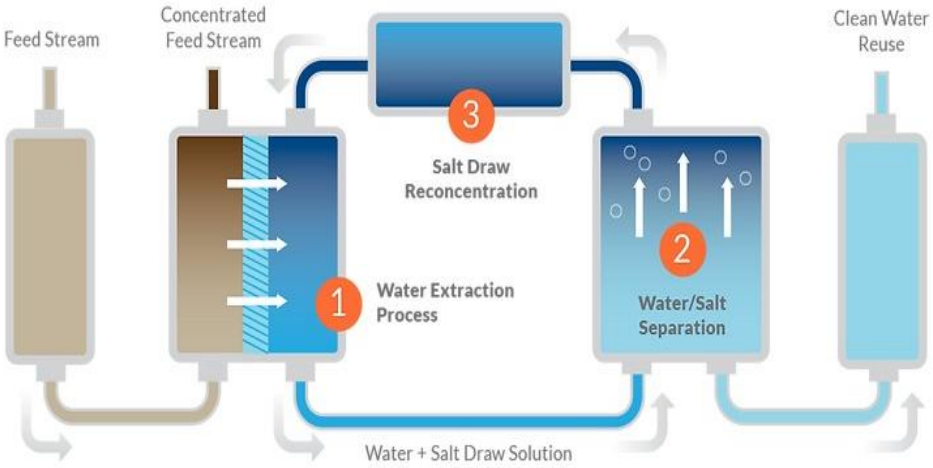


Fig. I.5. the Forward Osmosis Technique [27]

I.7.5.2.2. Operation Stages

- **Water Transport Through the Membrane:**
  - Saline water is placed on one side of a semi-permeable membrane.
  - A highly concentrated draw solution is placed on the other side, creating an osmotic gradient.
  - Water naturally moves through the membrane, leaving behind salts and impurities.
- **Separation of Fresh Water from the Draw Solution**
  - The water rich draw solution is processed to extract fresh water.
  - This can be achieved through techniques such as membrane filtration, thermal separation, or chemical precipitation.
- **Purification and Post Treatment :**
  - The fresh water is further purified and adjusted for mineral content before being stored or distribute [28].

I.7.5.3. Advantages

- **Low operating pressure means safer equipment:** Lower pressure reduces stress on components and decreases the risk of damage or failure.

- **Less Fouling and Scaling:** FO membranes are less prone to clogging, resulting in longer system lifespan and lower maintenance costs.
- **Ability to Use Waste Heat or Low-Grade Energy:** The process can be integrated with other systems that produce excess heat, improving efficiency.

I.7.5.4. Disadvantages

- **Need for Draw Solution Recovery:** The method requires an additional process to separate clean water from the draw solution, adding complexity.
- **Limited Large-Scale Applications:** FO is still in the early stages of commercial adoption and requires further optimization for widespread use.
- **Potential Costs of Draw Solution Regeneration:** The chemical or thermal separation of the draw solution can be expensive, depending on the method used [29].

I.8. The best and most popular way to desalination water

The most popular and effective technique for desalinating water is reverse osmosis (RO), which involves passing water through semi permeable membranes while applying high pressure to eliminate pollutants and salts. Compared to other processes like thermal distillation, which relies on water evaporation and vapor condensation and includes Multi Stage Flash (MSF) distillation and Multi Effect Distillation (MED), this technology is extremely effective and has reduced operating expenses. Large desalination plants frequently employ thermal distillation, but this process uses a lot of energy. Reverse osmosis is a more sustainable alternative, particularly when renewable energy sources are used [30].

I.9. The Osmosis

Osmosis is a natural physical process in which water molecules move from a low concentration solution to a high-concentration solution through a semi permeable membrane, in order to equalize the solute concentrations on both sides of the membrane. This membrane allows only water molecules to pass while blocking salts and other substances. Osmosis is essential in many biological functions, such as water absorption in plants and fluid movement within the cells of living organisms, and it forms the scientific basis of the reverse osmosis technology used in water desalination[31].

I.10. Reverse osmosis System Components



Fig. I.6. Reverse osmosis System Components [32]

Table.I.1. Table of Reverse osmosis System Components

Number	Component
1	Electrical supply, protection and control panel
2	Inlet pressure
3	Working pressure
4	Pump pressure
5	Equipment on/off switch
6	Permeate (osmosis) water flow
7	Drain water flow
8	Recirculation flow
9	Reject regulator
10	Recirculation regulator
11	Low pressure switch
12	High pressure pump and motor
13	Membrane housing
14	Water inlet
15	Flushing valve
16	Conductivity and temperature meter
17	Osmosed (permeate) water outlet
18	Drain outlet
19	Inlet solenoid valve
20	20-inch, 5-micron pre-filter

I.11. The History of Reverse Osmosis (RO)

The actual development of reverse osmosis technology started in the 1950 when Sidney Loeb *and Srinivasa Sourirajan at the University of California, Los Angeles created polymeric membranes that could remove salts from water under high pressure. Jean-Antoine Nollet had started studying the osmosis phenomenon in 1748. Using cellulose acetate membranes created at UCLA, the first commercial reverse osmosis factory was set up in Coalinga, California, in 1965. John Cadotte later created interfacial polyamide membranes in the 1970, which served as the basis for the membranes that are now present in a large number of desalination facilities. Since those early innovations, no significant advancements have been made, despite continuous gains in membrane efficiency in areas like flow, rejection, and pressure needs. Recent advances in nanotechnology and nanocomposite membranes, however, present new opportunities to boost membrane performance and efficiency while also boosting their resistance to chlorine. This might lower costs and enhance desalination plant performance [33].

I.12.The membrane



Fig. I.7. The membrane [34]

The membrane in the reverse osmosis process is a semi permeable material used to separate pure water from salty water through a pressure driven physical process. In this process, pressure is applied to the salty water, pushing it through the membrane, which allows only water molecules to pass while blocking salts and larger particles. The membrane is a crucial component in this process as it determines the efficiency and quality of water purification [35].

I.12.1. Types of Membranes Used in Water Desalination

Membrane technologies are among the most efficient methods for water desalination, offering various solutions to suit different salinity levels and treatment requirements. Reverse Osmosis (RO) membranes remain the most widely used due to their high salt removal efficiency, while Nanofiltration

(NF) and Ultrafiltration (UF) membranes are used for treating moderately saline water or as a pretreatment stage before reverse osmosis [36]. Below are the main types of membranes used in water desalination:

I.12.1.1. Reverse Osmosis (RO) Membranes

Reverse osmosis membranes are among the most commonly used membranes for water desalination, capable of removing up to 99% of dissolved salts and contaminants. This technology applies high pressure to force saline water through a semi-permeable membrane, allowing pure water molecules to pass through while retaining salts and other impurities. These membranes are used for seawater desalination, brackish water treatment, and potable water production. They are divided into two main types: Seawater RO (SWRO) membranes, which can withstand high salinity levels, and Brackish Water RO (BWRO) membranes, designed for treating moderately saline water [37].

I.12.1.2. Nanofiltration (NF) Membranes

Nanofiltration membranes are a suitable option for processes that require partial salt removal, operating at lower pressures than RO membranes, which helps reduce energy consumption. These membranes are effective in removing divalent ions such as calcium and magnesium, making them ideal for water softening applications. They are also used in treating groundwater and removing organic pollutants and pesticides from surface water [38].

I.12.1.3. Ultrafiltration (UF) Membranes

Ultrafiltration membranes have larger pores compared to nanofiltration and reverse osmosis membranes, making them effective in removing suspended particles, bacteria, and viruses without requiring high pressure. These membranes are primarily used as a pretreatment stage before reverse osmosis, helping to improve system efficiency and prevent membrane fouling. They are also applied in treating surface water, rivers, and wastewater reuse systems [39].

I.12.1.4. Microfiltration (MF) Membranes

Microfiltration membranes are used to remove large suspended particles such as sediments and bacteria, though they are not capable of removing viruses or dissolved salts. For this reason, they are often used as a preliminary stage before ultrafiltration or reverse osmosis, contributing to improved water quality and reducing clogging in finer membrane systems. This technology is applied in industrial water treatment plants and for general water purification [40].

I.12.2. Components of Reverse Osmosis Membrane (RO)

The reverse osmosis membrane consists of several layers that work together to achieve high efficiency in the water purification process. Below is a detailed explanation of the main components of the membrane:

I.12.2.1. Active Layer

This layer is responsible for removing salts and impurities from water. It directly contacts the salty water and its role is to allow pure water to pass through while rejecting salts and contaminants. This layer is typically made of Interfacial Polyamide, which has a high capacity for rejecting salts due to its effective chemical structure. This layer is the most important in the process as it determines the membrane's efficiency in reverse osmosis.

I.12.2.2. Support Layer

This layer provides structural support to the active layer, contributing to the membrane's stability under high pressure during the reverse osmosis process. The support layer is usually made of materials such as polyester or polypropylene, which are strong and durable while maintaining the membrane's flexibility. This layer helps the membrane withstand high pressure during the process without affecting its efficiency.

I.12.2.3. Microporous Layer

Located at the bottom of the membrane, this layer helps distribute water evenly across the surface of the membrane. The microporous layer prevents the accumulation of excess pressure on the upper layers, improving the distribution of water and increasing the efficiency of filtration. It also protects the other layers from degradation due to high pressure or other mechanical stresses.

I.12.2.4. Protective Layer

Some modern membranes may have an additional layer that is resistant to chemicals such as chlorine or biological contaminants. This layer helps extend the life of the membrane and improve its efficiency by preventing negative effects that could cause damage or reduce its performance. This protective layer provides additional protection and helps maintain the membrane's efficiency for extended periods [41].

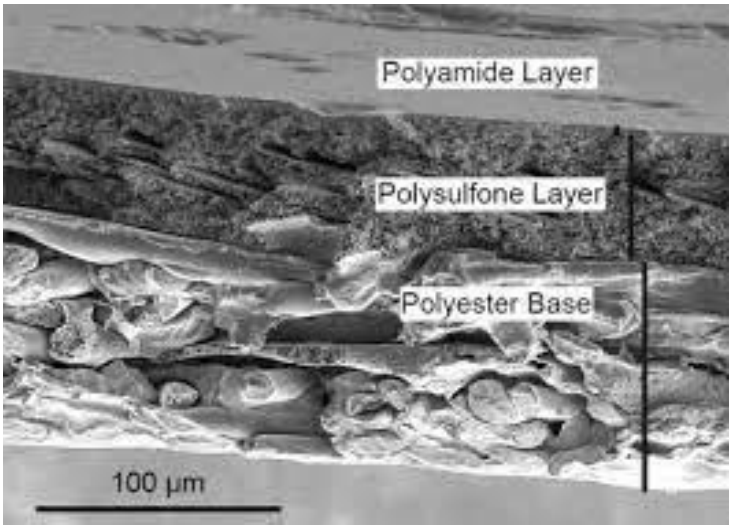


Fig. I.8. Microscopic image of a semi-permeable membrane [42]

I.13. Common Challenges in Operating a Reverse Osmosis (RO) System

Reverse osmosis (RO) systems require precise control to ensure operational efficiency and maintain the quality of the produced water. However, they face several challenges that can impact their performance. One of the most significant challenges is fluctuations in water pressure, as sudden changes can lead to membrane damage or reduced separation efficiency. Additionally, the system requires continuous monitoring of flow rates and electrical conductivity to ensure the effective removal of salts and impurities. The operation of pumps and valves also demands high precision to prevent energy wastage and minimize the consumption of chemicals used in pre treatment processes. Moreover, it is crucial to ensure a rapid response to any variations in the quality of the incoming water, as delays in adapting to these changes can result in a decline in the quality of the produced water or system malfunctions [43].

I.14. The importance of automation in Reverse Osmosis (RO) Systems and the role of PLC in control

Automation plays a crucial role in enhancing the efficiency and performance of reverse osmosis (RO) systems by ensuring precise control over operational processes and reducing the need for human intervention. Automated control helps in regulating water pressure and flow automatically, which protects membranes from damage caused by sudden fluctuations. Additionally, automation enables continuous monitoring of the quality of the produced water through advanced sensors, ensuring compliance with health and industrial standards. Furthermore, automation contributes to improving energy efficiency by operating pumps and valves based on actual demand, thereby reducing operational costs. It also assists in early fault detection through alarm systems and data analysis,

minimizing unexpected downtimes and extending equipment lifespan. Additionally, automation facilitates the management of automatic membrane cleaning processes (CIP), ensuring long-term system efficiency. One of the key advantages of automation in RO systems is the ability to integrate the system with remote monitoring technologies, allowing engineers and operators to control operations from anywhere via SCADA systems or Internet of Things (IoT) technologies. Automation also enhances the system's response to operational changes, such as variations in raw water quality or pressure, by dynamically adjusting settings to ensure stable performance [43].

I.15. Programmable Logic Controller is a Good Choice for Automating RO Systems

A Programmable Logic Controller (PLC) is one of the best solutions for automating reverse osmosis (RO) systems due to its flexibility and high reliability in industrial environments. PLCs are capable of executing real time control operations, allowing precise adjustments of operational parameters. Additionally, they offer ease of programming and maintenance, as software codes can be easily updated and modified according to system requirements. PLC also supports integrated control over all system components, including pumps, valves, sensors, and measurement devices, ensuring synchronized and efficient operation. Furthermore, it integrates seamlessly with SCADA systems to display data and analyze performance in real time, aiding in accurate operational decision making. Moreover, PLCs are highly resistant to harsh environmental conditions, such as humidity and high temperatures, making them ideal for use in water treatment and desalination plants. Thanks to these advantages, PLC is the optimal solution for automating RO systems, as it provides precise and reliable control, reduces operational errors, and ensures system stability and efficiency in the long run [43]

I.16. Conclusion

Water desalination stands out as one of the most vital technological solutions to address water scarcity, especially in arid and semi-arid regions suffering from limited natural freshwater resources. This chapter provided a comprehensive overview of the different types of saline water sources and the major desalination technologies used to treat them. Reverse osmosis (RO) was highlighted as the most efficient and widely adopted method, alongside other approaches such as thermal distillation, freezing, solar desalination, and forward osmosis.

The chapter also emphasized the critical role of automation in modern desalination systems, particularly through the use of Programmable Logic Controllers (PLCs). Automation not only enhances operational efficiency and precision but also helps reduce energy consumption and ensures consistent water quality.

This foundational knowledge sets the stage for the next chapter, which delves into advanced concepts of automation, system design, control architectures. These tools are essential for the development of smart, efficient, and scalable desalination plants.



Chapter II

Advanced Concepts in Industrial Automation and Programmable Logic Controllers

II.1. Introduction

One of the key pillars that has greatly aided in the advancement and improved effectiveness of industrial operations is industrial automation. Reducing human interference, improving accuracy, and speeding up production have all helped achieve this. Because of its strong ability to operate industrial processes and machines in a flexible and effective way, the Programmable Logic Controller (PLC) is one of the most important parts of automation systems. The overall layout of automated systems will be covered in this chapter, along with a thorough rundown of the various parts of control units, including the operational unit, control unit, and Human Machine Interface (HMI).

The function of PLCs in industrial control, including their types, traits, and benefits over conventional systems, as well as the programming languages specified by the IEC 61131-3 standard, will receive particular attention. In order to prepare for the next chapter, which will concentrate on the practical implementation in a water desalination system, this chapter aims to lay the theoretical groundwork required to comprehend how these technologies might be incorporated into actual industrial applications[44].

II.2. Automated Systems

An automated system is a structured set of components designed to perform a series of programmed tasks without the need for direct human intervention. These systems are commonly found in various domains, such as automatic level crossings, motorized garage doors, or industrial production lines.



Fig.II.1. Automated System [45]

II.3. Automation

Automation is a response to the growing need to perform complex tasks more quickly and efficiently while reducing human intervention. This technology allows manual processes to be transformed into automated operations through sophisticated software and systems. The evolution of automation has led to a significant increase in the number and diversity of products, covering areas such as planning, console message management, backup, restoration, and performance optimization.

One of the major advantages of automation lies in its ability to make services more available and responsive, while minimizing human errors that can lead to accidents or malfunctions. It also enhances system security by implementing backup mechanisms that ensure continuity of operations even in the event of a failure. The goal of automation is to make machines and installations autonomous, so they operate efficiently with minimal human intervention and a low error rate. Depending on the complexity of the installations, different levels of automation can be achieved, allowing for productivity optimization and cost reduction [46].

II.4. The objective of automation

The main objective of automation is to replace traditional hard-wired logic systems with programmable electronic devices that are well-suited for industrial environments. These systems perform automation functions to control pre-actuators and actuators based on logical, analog, or digital inputs, while also enabling real-time monitoring of industrial processes.

Automation aims to improve productivity and enhance product quality by streamlining operations and reducing human intervention. It also helps eliminate physically demanding tasks, making maintenance work easier and more efficient. Safety is significantly increased for both installations and personnel, thanks to automated monitoring and control. Additionally, automation contributes to material savings and energy efficiency by optimizing resource usage. It is particularly effective in eliminating repetitive tasks and adapting to specific production contexts, all while maintaining consistent quality across processes [47].

II.5. The different types of industrial automation

Industrial automation is a term used to describe the application of technology to control industrial processes, which is what happens when tasks for human workers are done or assisted by machines through factory automation. Industrial processes can be controlled manually, but with industrial automation, machines can be controlled through the use of computers and other electronic devices.

There are four main types of industrial automation: fixed automation, programmable automation, flexible automation, and integrated automation [48].



Fig.II.2. Industrial Automation [49]

II.5.1. Fixed Automation System

Fixed automation is the simplest type of industrial automation. In a fixed automation system, the machines are permanently set up to perform a specific task. Once the task is completed, the machine is reset and waits for the next task. Fixed automation systems are used in industries where the tasks are repeated over and over again.

A fixed automation system is also known as hardwired automation. This type of industrial automation is used for high-volume production, repetitive tasks, and products with a long-life cycle. The system includes all active components (hardware) and passive components (software). With fixed automation, the application process is mostly simple and involves an assembly dictated by programmed commands. Though it is tricky to accommodate changes in the product design with this type of automation, it does aid in cutting time and labour costs by automating mechanical tasks. Flexible automation system are mass production factories. Often used when performing a set task, fixed automation is best utilized for large volume, continuous production. Fixed automation systems, also known as hard automation, are designed to complete a single set of tasks repeatedly. Fixed automation systems typically are used for discrete mass production or continuous flow systems. An example of a fixed automation system is an automated conveyor belt in the auto manufacturing industry that moves objects with minimal effort, increasing efficiency which uses the following technologies

-Programmable Logic Controller (PLC) based systems

-Human Machine Interface (HMI), which provides operators with information about the current state of the process through display screens [50] .

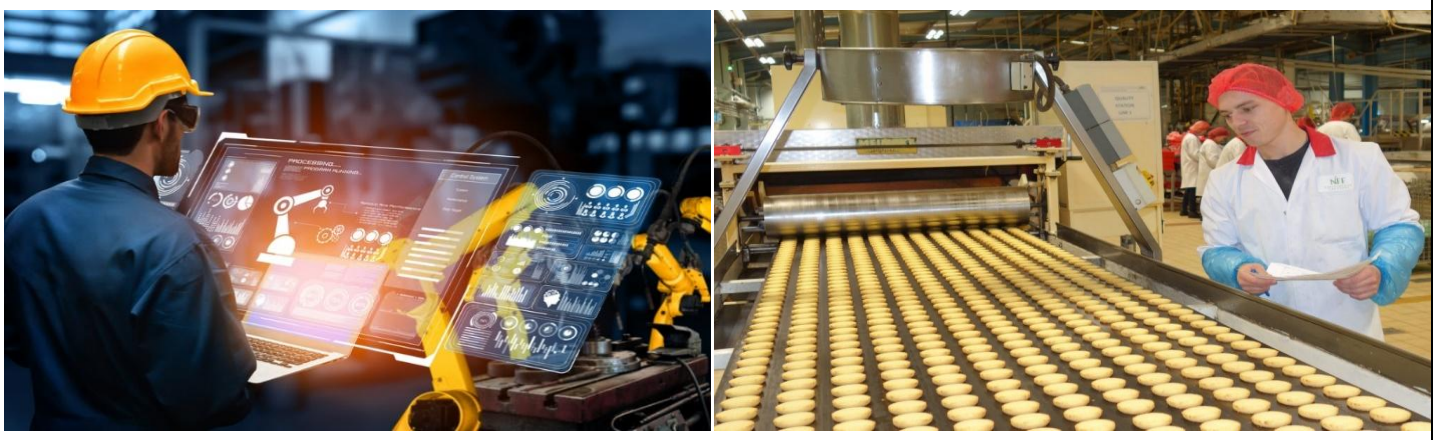


Fig.II.3. Fixed Automation [51]

II.5.2. Programmable Automation System

Programmable automation is more complex than fixed automation. In a programmable automation system, the machines can be programmed to perform a variety of tasks. This allows factories to produce a wider range of products thanks to the way that the sequence of operations and machines involved can be changed. Programmable automation systems are used in industries where the tasks vary from one batch to the next.

Programmable automation systems are controlled by commands delivered by a computer program. Because of this, the automated processes can vary based on the instructions sent to the computer by the designer's code. Programmable automation is commonly used in settings where similar items are produced using the same automated steps and tools. For example, paper and steel rolling mills use the same steps to create many different types of products. It is used for batch production; programmable automation is ideal for lower volume production runs where more changeovers take place [52].

II.5.3. Flexible Automation System

A flexible automation system is the most commonly used form of industrial automation. It utilizes programmable logic controllers (PLCs), which are electronic devices that can be programmed to automate a wide range of control tasks in manufacturing, mining, utilities, and other industries. Flexible automation typically uses a network topology with one or more primary controllers communicating with several units (also called remote terminal units). The primary controller directs the operation of each unit to perform specific tasks. Flexible automation: Flexible automation offers more process flexibility and automated changeovers, helping to reduce downtime and increase customization of products.

In a flexible automation system, the machines can be programmed to perform a variety of tasks, but they can also be adjusted to change the way they perform those tasks. This allows factories to produce a wider range of products, and to make changes to their production line quickly and easily. Flexible automation systems are used in industries where the products vary from one to the next [53].

II.5.4. Integrated automation

Integrated automation systems involve totally automating manufacturing plants with minimal human involvement. Computers can be used to design parts, test the completed designs and then fabricate the new parts. Integrated automation can be used with continuous process manufacturing and batch process manufacturing.

Integrated automation is the most complex type of industrial automation. In an integrated automation system, the machines are all connected to a central computer. This allows the factory to control all aspects of production from a single location. Integrated automation systems are used in industries where the products are produced in small quantities and where changes to the production line need to be made quickly and easily. As automation advances, integrating machines and software into one system for real-time monitoring is becoming more popular. Integrated automation allows for fully automated production lines that increase flexibility and connect the entire production floor [53].



Fig.II.4. Integrated automation [53]

This type of industrial automation system is best for batch production, where in the volume of production is medium to high. However, incorporating new configurations in this type of automation takes a lot of work. Therefore, new products and reconfiguration of operations require a lengthy process and a long setup. The control programme can be reprogrammed for each batch based on the instructions provided and the necessary processing tasks and sequencing. This process takes time because, in most cases, the equipment must be reconfigured from batch to batch. Some examples of programmable automation systems include computer numerical controlled machinery, programmable logic controllers, and industrial robots [54].

II.6. The key differences between industrial automation systems

Each of these types of industrial automation has its own advantages and disadvantages.

- Fixed automation systems are the simplest and cheapest to install, but they are limited in the number of tasks they can perform. Programmable automation systems, on the one hand, are more expensive to install than fixed automation systems, but they allow factories to produce a wider range of products.
- Flexible automation systems can be the most expensive to install, but they allow factories to produce a wider range of products and to make changes to their production line quickly and easily.
- Integrated automation systems can also be expensive to install, but they allow factories to control all aspects of production from a single location, which offers the most customizability.

  In factory automation, the type of industrial automation system that best works will depend on the specific needs of the factory. However, in general, programmable automation systems are the most versatile, flexible automation systems are the most efficient, and integrated automation systems are the most efficient and provide the greatest control over production [55].

II.7. SCADA

SCADA (supervisory control and data acquisition) is a tool which is made of computer systems. It enables for the gathering and analysis of real-time data, and is used to monitor, control and supervise equipment.

These are planted in manufacturing facilities in order to supervise equipment such as telecommunication, water, gas and waste. If there is a problem with these, such as failure in telecommunication equipment, the SCADA system provides information with where the problem has occurred and determines how critical the failure is [56].

II.8. Benefits of Industrial Automation

Automation offers several advantages that can increase operational efficiency. From reducing costs to increase output to improved product quality, companies across many different industries are seeing the value of automating their production operations. The various technologies used in industrial automation have evolved over the years thanks to the advancement of the industrial internet of things (IIoT). IIoT has opened many avenues for firms to leverage the benefits of automation solutions. In this section, we have outlined some of the most basic advantages of automation solutions and there are many benefits of industrial automation, including [57] .

- **Enhanced quality**

Automation in the industrial sector leads to improved quality of products which are much less prone to errors made by human operators. The spot-on precision provided by automation technology is unmatched regarding the quality of products. In addition, it results in higher consistency throughout the production batches.

- **Better efficiency and higher output**

Automation robotics have much higher output value, and their working pace is much higher than human operators. Moreover, robots are capable of working 24/7, which increases their production time.

- **Cost efficient**

It is obvious that the cost of employing robots to perform the same functions as human labour will cost much less comparatively. The only expenses after the initial cost of a robot are upkeep and the energy required during execution. Compared to operator salaries and benefits, the cost savings accumulate over time. Furthermore, robots optimize the process and improve quality, resulting in less waste and even more cost savings.

- **Safer operation**

Employing robotics ensures operator safety as well. Industrial automation eliminates the need for workers to perform unsafe tasks such as working around hazardous chemicals, picking up heavy objects, working in unpleasant atmospheres, etc.

- **Increased productivity**

Automating your production can help to identify bottlenecks or faults in your system, solving issues before they come significant problems. Additionally, robots can reduce errors as well as streamline processes that allow for continuous operation.

- **Higher quality products:**

Through repeatability and validation, automation devices can ensure a consistent quality of your product reducing waste and rework.

Deciding which type of automation to use for production can be tricky. This chart below shows what options might be best to consider, depending on the variety and demand of the product.

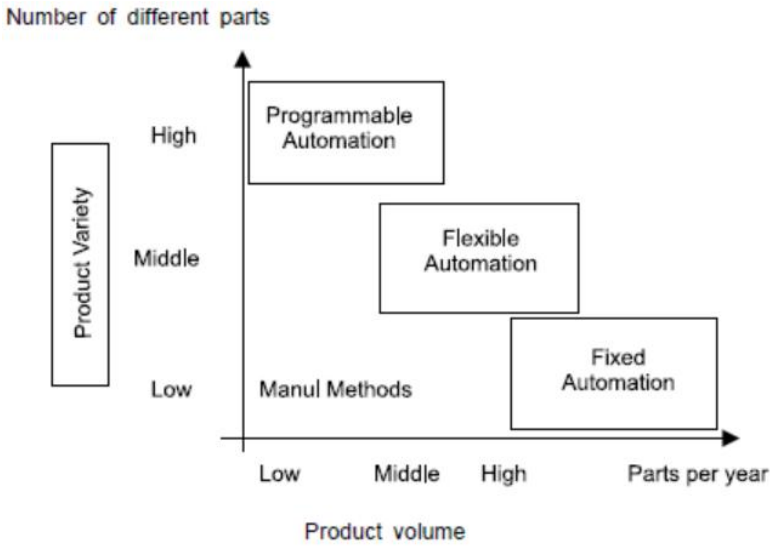


Fig.II.5. Product Variety and Production Quantity for Three Automation Types [57]

II.9. The Main Advantages of Automation

Because of its many benefits, automation is crucial to contemporary production systems. It lowers the chance of accidents and physical exhaustion by taking the place of people in repetitive, hazardous, or physically taxing jobs. Automated systems reach efficiency levels that are hard to attain manually, offering continuous, quick, and reliable performance. Automation is also a cost-effective solution for industries since it lowers labor costs and improves product quality through accurate and consistent operations. Additionally, it satisfies the expanding industry need for high system uptime and productivity. Cost savings, higher productivity, dependability, availability, and improved performance are the most often mentioned advantages of automation. Automation is therefore essential to the growth of industry and to supplying the demands of a constantly expanding population [58].

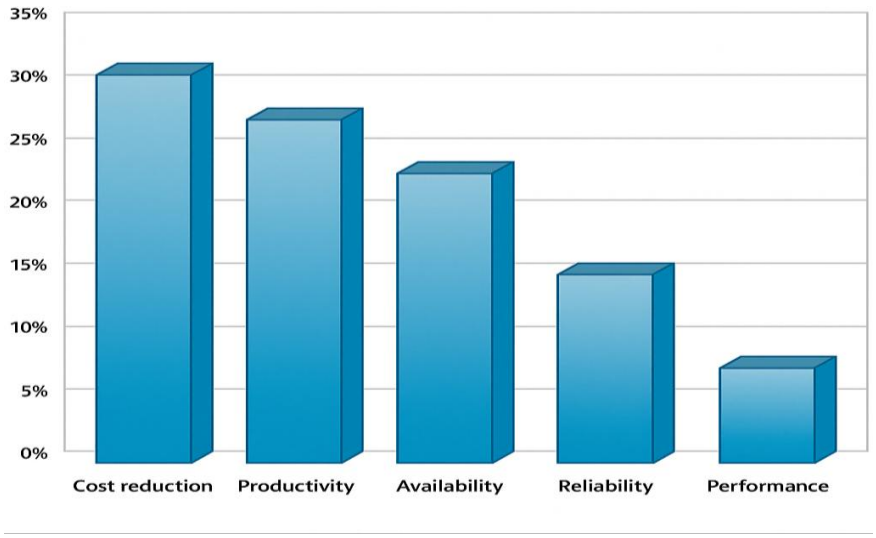


Fig. II.6. The main advantages of automation [59]

II.10. Structure of an automated system

An automated system is typically composed of three essential components: the control unit, the operative unit, and the human-machine interface (HMI). Each of these parts plays a vital role in ensuring the overall functionality and efficiency of the automation process [60].

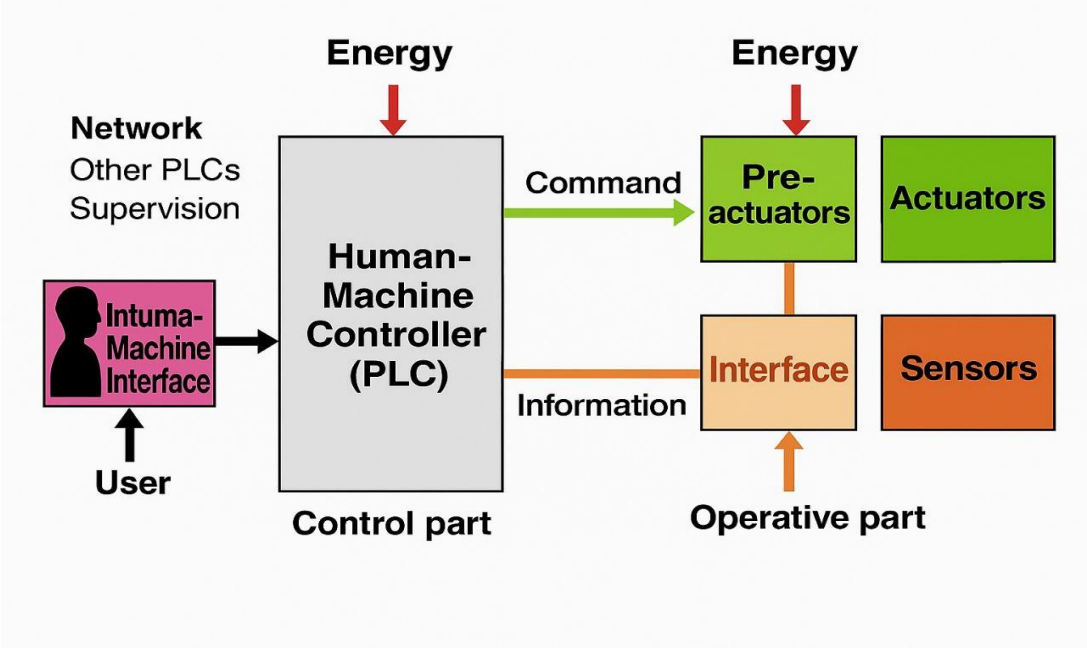


Fig. II.7. Functional Block Diagram of an Industrial Control System [61]

II.10.1. The Operative Unit

This part includes the physical components that carry out the actual process. It consists of :

- **The production unit** , which performs the manufacturing or transformation required in the industrial process.
- **Pre-actuators**, which are auxiliary devices like contactors or pneumatic distributors that support the operation of actuators.



Fig.II.8. Pre-actuators [62]

- **Actuators**, which convert external energy sources into mechanical energy to drive the production unit, such as electric motors or hydraulic cylinders.



Fig.II. 9. Actuators [63]

- **Sensors**, which detect physical variables (like temperature, pressure, or position) and convert them into signals understandable by the control unit.



Fig.II.10 Sensors [64]

These components work together to perform the physical operations of the system, while continuously sending feedback to the control unit for real time decision making [65].

II.10.2. The Control Unit

This unit is the brain of the system. It includes:

- **Input interfaces**, which adapt the signals from sensors or user commands into a format the system can process.
- **Processing unit** (e.g., PLC, microcontroller, or industrial computer), which receives data from the sensors and executes a predefined program to control the system's behavior.
- **Output interfaces**, which convert the processed data into commands that control the pre-actuators, visual indicators, or alarms.

Through this structure, the control unit ensures that the system operates according to the defined logic, responding to changes in the environment or system conditions [66].

II.10.3. The Human-Machine Interface (HMI)

This component allows interaction between the user and the system. It includes:

- **Display units and alarms**, which provide real-time information (visual or auditory) about the system's status.
- **User input devices**, like push buttons or touchscreens, that let the operator send commands or make adjustments.

The HMI plays a crucial role in monitoring, control, and troubleshooting, providing a bridge between human operators and the automated system [67].

II.11. General Information about Programmable Logic Controllers

II.11.1. History

Programmable Logic Controllers (PLCs) are electronic control devices used in industries to automate processes and systems. These systems first emerged in the late 1960 in the United States, driven by the automotive industry's (General Motors) need for more flexible control solutions. Engineers developed PLCs as an alternative to traditional hard-wired control systems, offering more adaptability and ease of programming. PLCs represent a significant advancement in industrial automation, providing solutions that can be customized and programmed as needed. Today, PLCs range from small units designed for simple machines with limited inputs/outputs, to large, multifunctional systems capable of managing complex processes with thousands of inputs/outputs. As a result, PLCs have become the preferred choice in many industries due to their flexibility and efficiency in controlling operations [68].

II.11.2. Choosing a Programmable Logic Controller

Choosing a Programmable Logic Controller (PLC) is mostly a company's or group's decision, and prior experiences and business relationships are already a significant beginning point. Big businesses usually want two manufacturers in order to foster competition and provide them with the option to switch if one of them performs worse than the others. However, too much equipment diversity might have detrimental effects, and maintenance staff need to be trained on this equipment. A PLC that supports many programming languages can guarantee optimal circumstances for troubleshooting and fine-tuning. Additionally, owning programming software can save money on both the software's purchase and employee training. Furthermore, it is preferable to have tools that enable program simulation. Quantifying the requirements in terms of:

- **Business relationships and past experience**: Companies are often selected based on prior experience and existing business relationships. Large companies typically prefer to work with two manufacturers to encourage competition and avoid relying on a single supplier.
- **Maintenance team training**: It is essential to train technical teams on the specific equipment to prevent issues that may arise from using a wide variety of systems.
- **Compatibility with different programming languages**: The PLC should support multiple programming languages to make maintenance and development easier and more efficient.
- **Software and support tools**: Having appropriate programming software can reduce costs associated with software purchases and staff training. Simulation tools are also important for testing programs before implementation.
- **Number of inputs/outputs (I/O)**: The required number of I/Os must be considered. A high number may require additional modules or extension devices.
- **Type of processor**: The processor should match the system's needs in terms of memory capacity, processing speed, and special functions it can provide.
- **Special functions or modules**: Specialized modules such as axis control units or weighing systems can help offload tasks from the main processor and improve overall system performance.
- **Communication capabilities**: The PLC should be able to communicate with other systems (such as embedded systems or supervisory systems) using standard communication protocols like PROFIBUS or others [69].

II.12. The programmable controller

A Programmable Logic Controller (PLC) is an electronic device specifically designed for controlling and monitoring industrial and service processes in real time. It operates by executing a set of instructions stored in its memory as a program, making it comparable to information processing machines.

What sets the PLC apart from conventional computers used in commercial settings are three main features:

- It connects directly to industrial sensors and actuators through its input/output modules.
- It is built to withstand harsh industrial environments, including temperature fluctuations, vibrations, power interruptions, and electrical interference.
- It is programmed using languages tailored for automation, which simplifies both development and deployment.

In our project, we use the SIMATIC S7-1200 CPU1214C DC/DC/RLY from Siemens, a compact and modular controller suitable for small to medium-scale applications. This PLC includes integrated digital and analog I/Os and supports communication protocols like PROFINET, enabling seamless integration into industrial networks. Its versatility, ease of configuration, and robustness make it ideal for our automation system requirements [70].



Fig.II.11. Automate SIEMENS s7-1200 [71]

II.13. Advantages of Programmable Automation

- **Scalability :**

Programmable automation offers high flexibility for development and expansion, making it ideal for upgrading or rebuilding electrical panels without needing to replace the entire system. New modules can be added, or programming can be modified easily as industrial needs evolve.

- **Multiple Functions :**

PLCs provide a comprehensive range of functions, including:

- **Process Control:** Starting, stopping, and regulating operations.

- **Interaction:** Communication with users or operators through visual interfaces or control screens.

- **Communication:** Connecting with other devices or systems such as computers and SCADA systems.

- **Safety:** Ensuring safe operation and preventing dangerous faults or errors.

- **Variety of Sizes and Applications: Programmable** automation comes in a wide range of sizes and capacities from nano, micro, and mid-range systems to large-scale PLCs that manage

complex industrial processes. This diversity allows their use in both simple and advanced applications.

- **Speed:** PLC systems feature very short cycle times, often within a few milliseconds, enabling fast response to inputs and precise real-time processing crucial for modern production systems.
- **Modular Structure:** Many PLC systems are based on a modular rack structure, allowing for easy addition or removal of units (such as I/O cards or communication modules) without replacing the entire system. This simplifie customization and maintenance.
- **Control Architecture:** PLC systems support different control architectures:
  - **Centralized:** All operations are executed from a single central unit.
  - **Decentralized:** Control is distributed across multiple units at different locations using industrial networks such as PROFIBUS or Ethernet/IP ideal for large or multi-site facilities.
- **Ease of Maintenance:** PLC systems are designed for easy maintenance and repair through:
  - Easily replaceable modular units.
  - Standardized programming and connection interfaces.
  - Quick fault diagnosis using software tools [72].

II.14. Components of Programmable Automation Systems

Programmable automation systems are built on an integrated architecture that ensures precise and efficient control of industrial processes. This structure relies on a set of modules that perform specific functions and work in harmony to achieve the required tasks. The main components of this structure are :

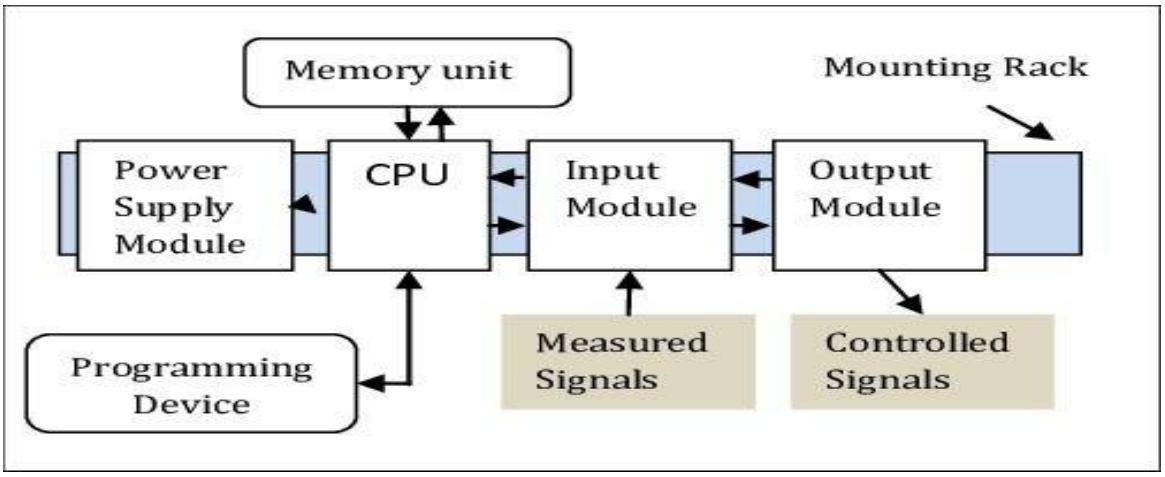


Fig.II.12. Components of Programmable Automation Systems [73]

II.14.1. Central Processing Unit (CPU)

The CPU is the heart of the programmable automation system, executing the logic program stored in memory and controlling the flow of processes within the system. This unit includes a microprocessor and RAM for storing temporary data, as well as EEPROM or Flash memory for saving the program and parameters even after a power failure. The CPU also controls the exchange between input and output units and manages the overall timing of the system.

II.14.1.1 Important Components of the CPU

The S7-1200 CPU is ready to use with its built in 24V power supply and integrated digital inputs and outputs, without the need for additional components.

For communication with the programming device, the CPU is equipped with an integrated TCP/IP port.

Through an Ethernet network, the CPU can communicate with HMI control devices and other CPUs[74].

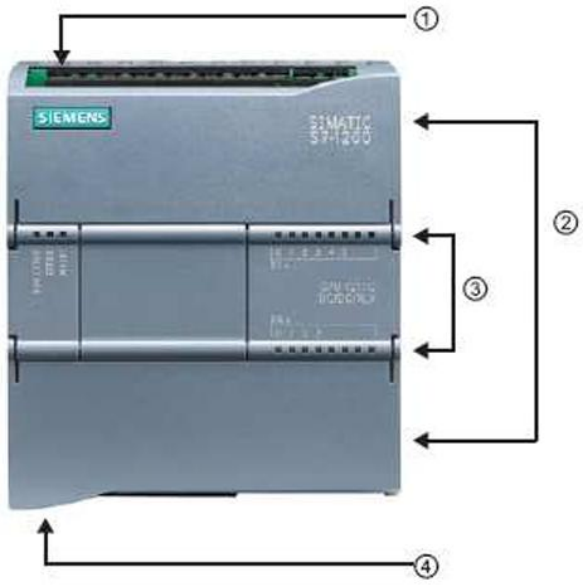


Fig.II.13. Important Components of the CPU [75]

(1) 24V Power Supply

(2) Removable terminal blocks for user wiring (behind plastic covers)

(3) LEDs for integrated I/O and CPU operating mode indication

(4) TCP/IP Connection (located beneath the CPU)

The SIMATIC MC memory card stores the program, data, system data, files, and projects. It is used for the following tasks :

- Transferring programs to different CPUs
- Updating the firmware for CPUs, SM signal modules, and CM communication modules.



Fig.II.14. The SIMATIC MC memory card [76]

II.14.2.Power Supply (PS)

The power supply provides the necessary electrical power to operate all components of the automation system. It is typically supplied with alternating current (220V or 24V) and converts it into appropriate direct current voltages, such as ±5V or ±24V. This unit is crucial for ensuring electrical stability and protecting electronic components from damage caused by power fluctuations [77].



Fig.II.15. The power supply [78]

II.14.3. Input Modules

Input modules receive signals from sensors and switches in the industrial environment. They are divided into two types:

- **Digital:** Handles binary signals (0 or 1).

- **Analog:** Handles variable signals such as voltage or current (0–10V, 4–20mA).

These modules serve as the interface between the physical environment and the programmed system.

II.14.4. Output Modules

Output modules send commands from the CPU to execution elements such as motors, valves, and light indicators. Like input modules, the signals can be digital or analog depending on the type of load connected. They play a critical role in executing the commands issued by the program [79].

II.14.5. Integrated Input/Output Modules

In some systems, integrated I/O modules combine both input and output in a single unit, particularly in small applications. These units help save space, reduce costs, and simplify the wiring and integration of different components.



Fig.II.16. Integrated Input/Output Modules [80]

II.14.6. Special Function Modules

Special function modules are used to perform specific tasks that require high processing speed or precision. Examples of these tasks include counting, positioning control, or regulating physical processes such as temperature and pressure. These modules help reduce the burden on the CPU and provide more efficient and accurate performance [81].

II.14.7. Communication Modules

Communication modules enable the programmed automation system to connect with other systems within or outside the factory. These modules support multiple protocols such as Ethernet, PROFIBUS, and RS-485, facilitating communication between different control devices or integration with supervisory systems (SCADA). They are essential in modern manufacturing environments where communication is a key element [82].



Fig.II.17. Communication RF120C [83]

II.14.8. Simulation Modules

Simulation modules provide an environment to test programs before the system is actually running. These modules simulate input signals using switches and display the status of output signals using indicators like LEDs. They are primarily used for testing, training, and troubleshooting before implementation.

II.14.9. Couplers

When the system needs to be expanded by adding more units, couplers are used to connect multiple units or racks. This allows for an increase in the number of inputs and outputs without affecting system performance, providing greater flexibility for configuration and expansion of the automation system [84].

II.15. Programming Languages for Programmable Logic Controllers

Programmable Logic Controllers (PLCs) can be programmed using different languages, each suited for specific needs and varying levels of complexity. The goal is to make PLC usage accessible even to engineers with limited programming skills. Over time, standards have been established to unify the languages used, ensuring compatibility and consistency between different systems. The IEC 61131-3 standard defines five main languages for programming PLCs. Here's a detailed presentation of these languages:

II.15.1. Ladder Diagram (LD)

Ladder Diagram (LD) is a graphical language that represents Boolean equations in the form of diagrams resembling electrical circuits with contacts and relays. This language allows for manipulating Boolean data, primarily dealing with "on/off" states (0 or 1). In an LD diagram :

- **Contacts (Inputs) :** Represent input conditions.
- **Relays (Outputs):** Represent actions or commands to be executed based on the inputs.

The diagram is bounded by two power rails on the left and right, ensuring a clear and easy-to-understand structure. This language is particularly popular in industry because it is intuitive and closely resembles traditional electrical schematics.

II.15.2. Instruction List (IL)

Instruction List (IL) is a low-level textual language, similar to assembly language. It is particularly suited for simple, small-scale applications. The program consists of a series of instructions, where each instruction operates on a specific register (or result).

- **Instruction Structure:** Each instruction line starts with an operator, followed by operands, and may include modifiers.
- **Comments:** Comments are added after the instruction, improving the program's understanding.
- **Instruction Execution:** Each instruction directly affects the memory of the register, and the results are stored in the same register.

This language is more detailed and requires careful memory management, but it allows for significant optimization in simple applications.

II.15.3. Function Block Diagram (FBD)

Function Block Diagram (FBD) is a graphical language that allows creating complex equations using standard functional blocks, offering a more modular representation of systems.

- **Functional Blocks:** Each block represents a function or operator (such as calculation, level control, etc.).
- **Labels and Conditional Jumps:** Labels are used to control the execution of the program, and conditional jumps allow directing the execution to specific parts of the program.
- **Return:** Indicates the end of a function or block and determines whether the diagram should continue or stop.

FBD is often used for complex systems where interactions between different functions must be clearly visualized.

II.15.4. Structured Text (ST)

Structured Text (ST) is a high-level textual language suited for more complex automation applications. It allows describing advanced procedures and logic that would be difficult to model with graphical languages like LD or FBD.

- **Structure:** A ST program consists of a series of structured instructions in text form.

- **Usage:** It is particularly used for complex actions and conditions related to transitions in control systems.
- **Readability and Comments:** ST allows great flexibility in defining variables and constants, and comments can be inserted to clarify the code.

This language is preferred when managing more elaborate algorithms or systems requiring advanced logic.

II.15.5. Sequential Function Chart (SFC) or GRAFCET

Sequential Function Chart (SFC), also known as GRAFCET, is a graphical language used to describe sequential processes, i.e., processes that occur in a specific order:

- **Steps and Transitions:** The program is structured into steps representing stable system states, and transitions that determine when one step should be followed by another based on Boolean conditions.
- **Applications:** SFC is ideal for describing linear industrial processes, such as production lines or multi step operations.
- **Execution:** Actions within the steps are programmed using other languages such as ST, LD, IL, or FBD.

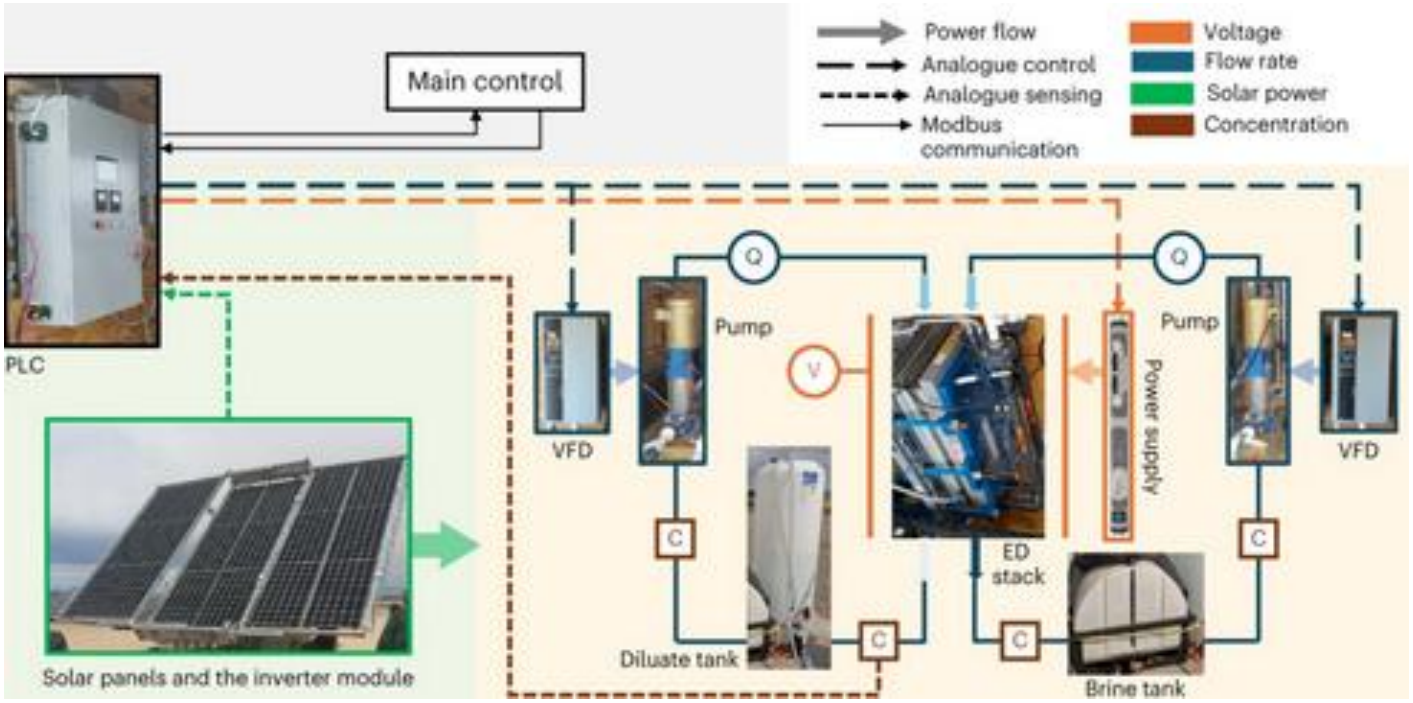
SFC is particularly useful for managing processes where the order of operations is critical [85].

II.16. Conclusion

The most basic and sophisticated ideas in industrial automation were covered at the end of this chapter, with an emphasis on the critical role that PLCs (programmable logic controllers) play in improving the dependability and efficiency of industrial systems. It has been demonstrated that implementing these controllers greatly improves reactivity to changes in complicated work settings, lowers operating expenses, and reduces human error. Along with the programming languages required to configure them, the general structure of automated systems and the parts of PLCs were also presented. This lays the groundwork for the following chapter, which will concentrate on putting this theoretical knowledge to use in a real-world system for managing a water desalination plant with the aid of cutting-edge instruments like TIA Portal

Chapter III

Design and Control of a Solar Powered Seawater Desalination System Using PLC based TIA Portal



III.1. Introduction

This chapter discusses the practical component of the thesis project, which entails designing and implementing an automated control system for a seawater desalination plant based on reverse osmosis (RO) technology and primarily powered by solar energy. It builds on the theoretical concepts discussed in the previous chapter. The Siemens S7-1200 PLC serves as the system's foundation, and the TIA Portal environment served as an integrated platform for communication setup, control logic programming, and hardware configuration [86] .

In order to operate several plant components, including pumps, sensors, and actuation valves, this chapter explains how to create the project within TIA Portal, configure the hardware, set up variable tables, and write the ladder diagram. The chapter also includes the development of a Clean-in-Place (CIP) mechanism, assesses the energy consumption of the system in both stationary and mobile operation modes, and shows electrical and logical schematics [87].

III.2. The TIA Portal (Totally Integrated Automation

by Siemens addresses current industrial challenges by offering a comprehensive and integrated solution for automating machines and plants. In an environment where global competition is becoming increasingly intense, it is crucial to optimize every phase of a plant's lifecycle, from design to commissioning and maintenance, while controlling costs, reducing timelines, and ensuring quality. The TIA Portal achieves this perfect balance by providing a complete system architecture that integrates all aspects of automation. It is designed to be compatible with international standards and third party systems, ensuring high flexibility.

The integration of various functions and tools into a single platform makes it easier to develop and manage automation projects, while also reducing costs and implementation time. Additionally, with its user-friendly interface and simulation tools, it helps optimize processes, thereby improving the productivity and reliability of installations. Thus, the TIA Portal is a robust and optimal response to the modern requirements of industrial automation [88].

III.3. TIA Portal Software Description

Siemens' TIA Portal (Totally Integrated Automation Portal) is a comprehensive software platform designed to provide an integrated environment for implementing industrial automation solutions. It combines various tools, such as Simatic Step 7 for PLC programming and WinCC for process management, supervision, and control, into a single platform. This integration simplifies the management of automation projects and optimizes every stage of an installation's life cycle, from initial design through to commissioning and maintenance. By offering a unified interface, the TIA Portal

streamlines the development process, enabling faster project completion. It also enhances efficiency, reduces costs, and ensures the implementation of higher quality automation solutions. The platform's diagnostic and simulation tools further improve productivity by allowing for thorough testing and troubleshooting before deployment, ensuring reliable and effective systems in industrial environments[89].



Fig.III.1. PLC Programming and Configuration Interface with Siemens Controller with Tia Portal [90]

III.3.1. Views of the Portal and the Project

The workspace is separated into two primary view kinds when TIA Portal is launched:

-Portal View: Designed for easy and fast navigation, this view is task-oriented. It is perfect for novices or simple procedures since it enables users to complete basic activities quickly.

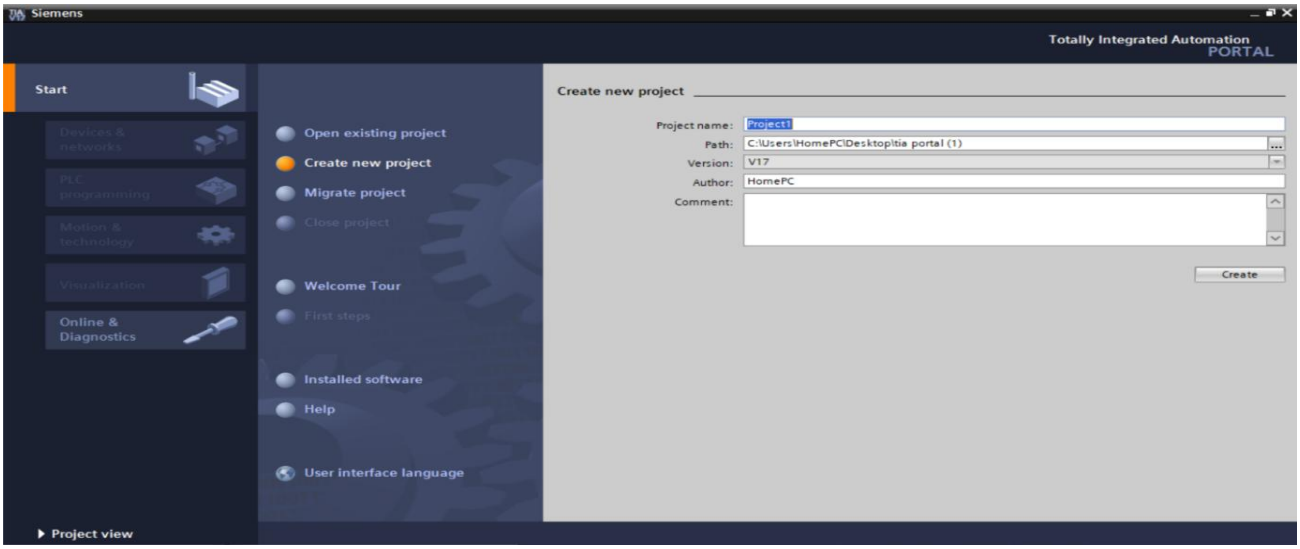


Fig.III.2. Portal View

-Project View: All of the project's components are shown in a tree structure. The required editors wi0ll launch automatically based on the assignment. A more thorough and complete environment for advanced project development is provided by the ability to access and display data, settings, and editors all within a single, cohesive interface.

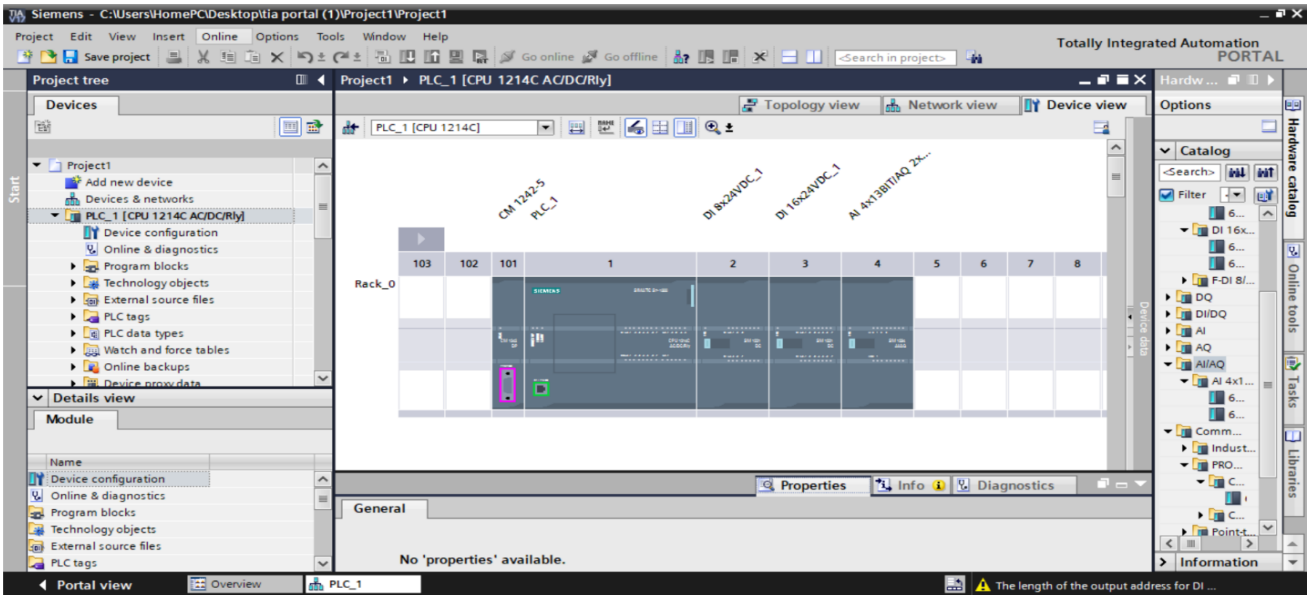


Fig.III.3. Project View

III.3.1.1. View of the Portal

You can manage a particular category of tasks (activities) with each portal. A list of possible actions for the specified task is shown in the window.

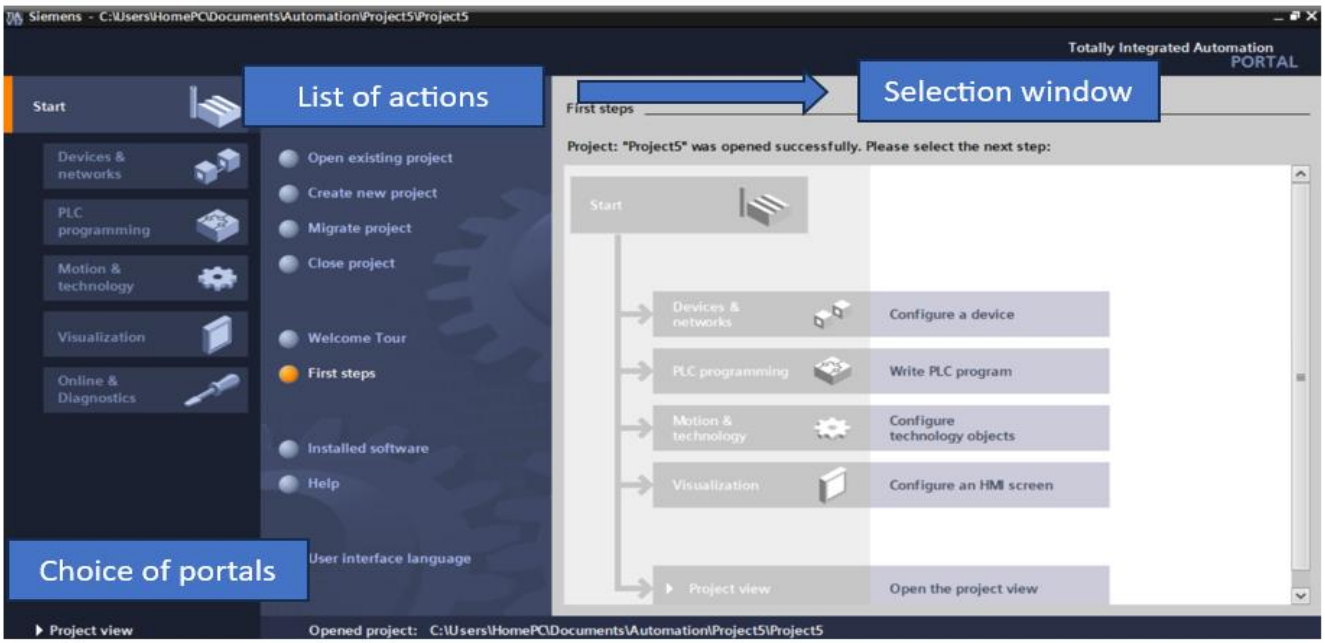


Fig.III.4. View of the Portal

III.3.1.2. View of the Project

All of the parts and information needed to put the intended automation solution into practice are included in the "Project" element.

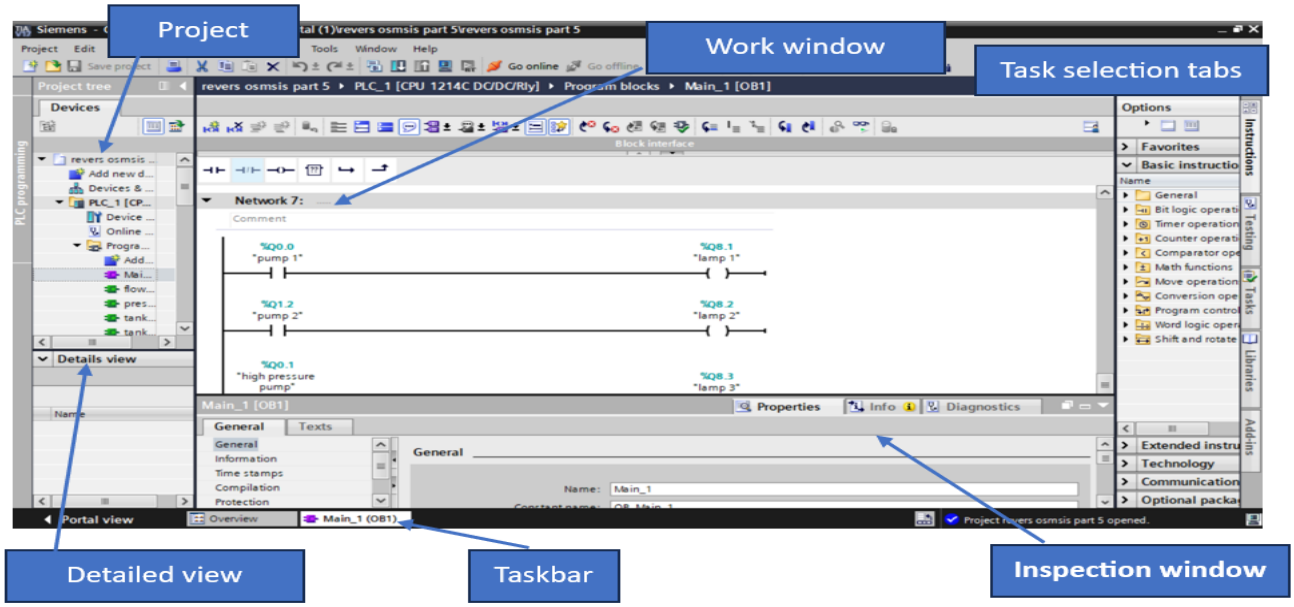


Fig.III.5. View of the Project

- **Work window**

The work area is the main space within the TIA Portal where users can view and manage various elements of a project. These elements may include hardware components (such as input/output modules), program blocks, variable tables, or HMI interfaces. All these components are displayed in an organized manner, allowing the user to interact with them directly and efficiently complete tasks.

- **Inspector Window**

The inspector window provides detailed, additional information about the selected object or the task currently in progress. When a component is selected, its full properties appear, such as its type, address, and related parameters. It also displays error messages and warnings, like issues encountered during program block compilation, which helps in identifying and resolving problems quickly.

- **Task Selection Tabs**

The task selection tabs in the TIA Portal interface present different options based on the object selected in the project. For example, when a hardware configuration is selected, the relevant component library appears; when a program block is selected, the programming instructions are shown. This smart interaction allows quick access to the appropriate tools based on the current context.

➢ **Detailed view**

TIA Portal offers a highly customizable interface. Users can hide or minimize unused windows to reduce visual clutter and stay focused on current tasks. Moreover, windows can be resized, rearranged, or even undocked from their default positions, providing freedom to organize the workspace according to personal preferences and working styles [91].

III.4. Creating a Project and Configuring a Workstation

III.4.1. Creating a Project

To create a project in the Portal View of TIA Portal, select the action **" Create new Project"** You can then give the project a name, choose a directory where it will be saved, add a description or comment, and specify the author of the project. Once all the required information is entered, simply click the "**Create**" button. This will set up the project, and you can begin configuring your hardware and developing the automation program [92].

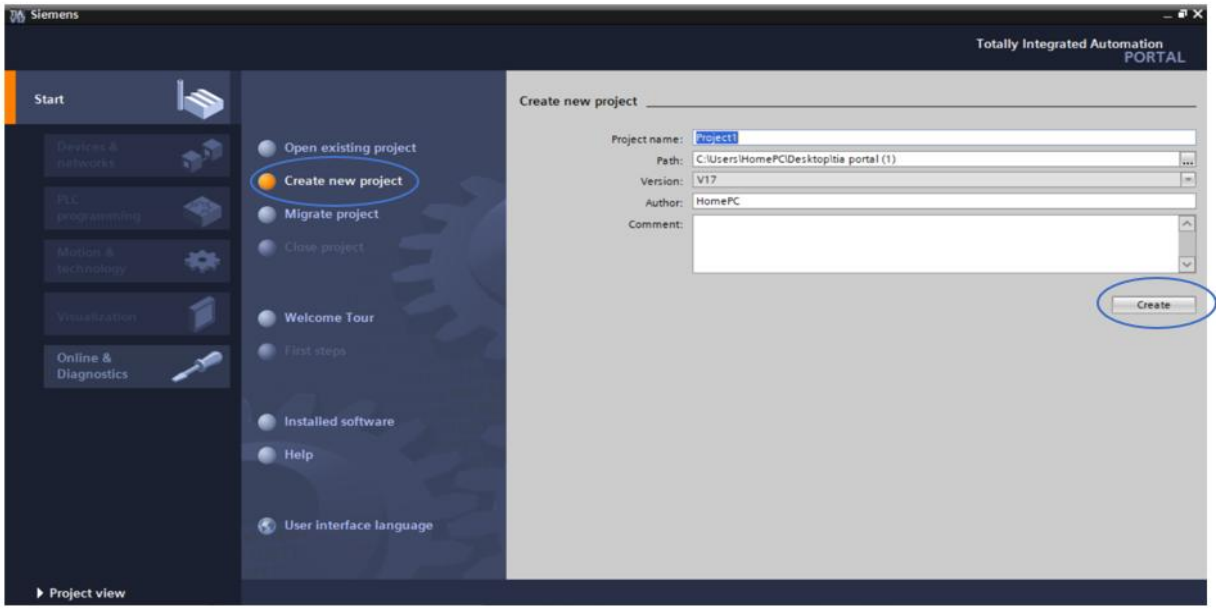


Fig.III.6. Creating a Project

III.4.2. Configuration and Setup of the Hardware:

After creating your project, the next step is to configure the workstation.
The first task is to define the hardware to be used. To do this, go to the project view and click on "Add Device" in the project navigator.

A list of available devices will appear (PLC, HMI, PC system). Begin by selecting the CPU, then proceed to add any additional modules (such as power supply, digital or analog I/O, AS-i communication module, etc.).

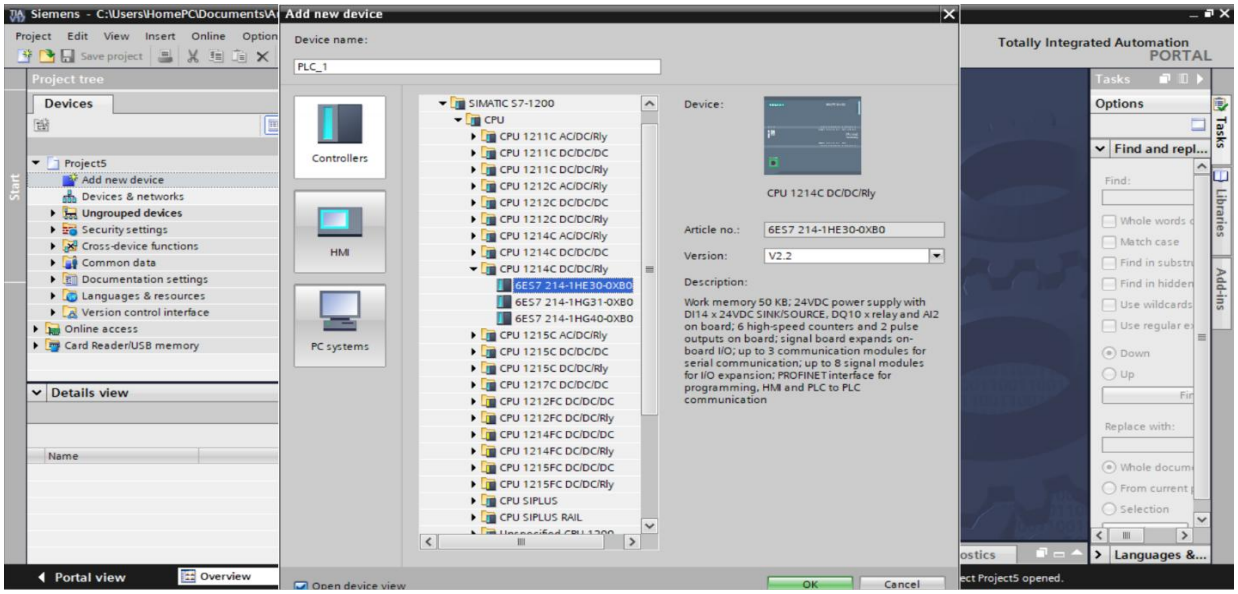


Fig.III.7. choosing the plc

The additional modules for the PLC can be added through the catalog. If you wish to add a screen or another PLC, you must return to the "Add Device" option in the project navigator.

When selecting an item to insert into the project, a description of the item will appear in the information tab[93].

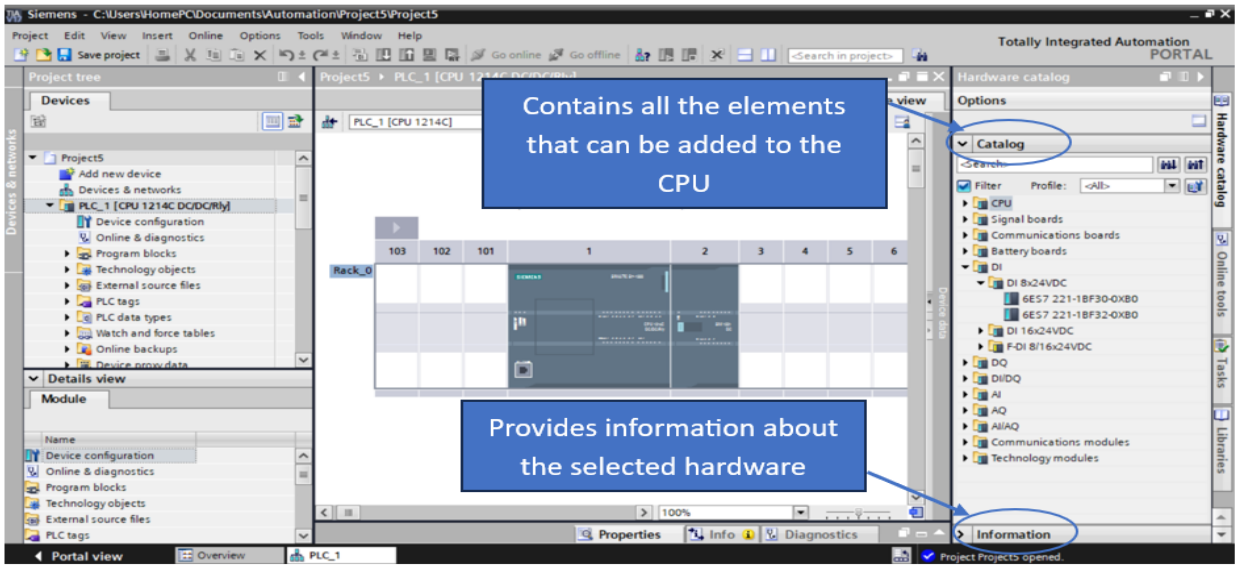


Fig.III.8. Hardware Configuration and Setup

III.5. I/O Addressing

To view the addressing of the inputs and outputs in the hardware configuration, navigate to "Device and Network" in the project navigator. In the work window, ensure you are in the "Device View" tab and select the device you wish to configure.

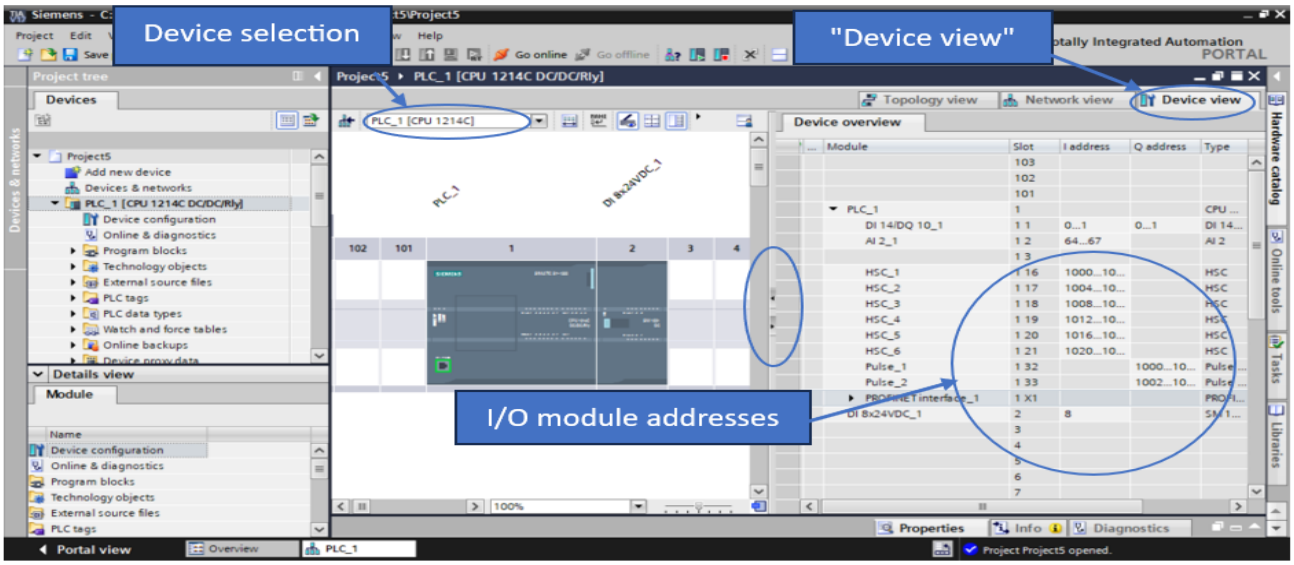


Fig.III.9. Input and Output Addressing

You can select the CPU, and then, by using the two small arrows (as shown in the figure), the "Device Overview" tab will be displayed. You can hide certain windows and reorganize others as needed. The addresses for the inputs and outputs will appear, and you can modify them by entering new values in the corresponding fields [94].

III.6. Ethernet Address of the CPU

Within the CPU properties, it is also possible to define its Ethernet address. A double click on the station's Ethernet connector opens the inspector window, allowing you to configure its communication settings.

To establish a connection between the CPU and the programming console, both devices must be assigned IP addresses within the same network. Typically, the address format used for the PLC is: 192.168.0.CPU_number [95].

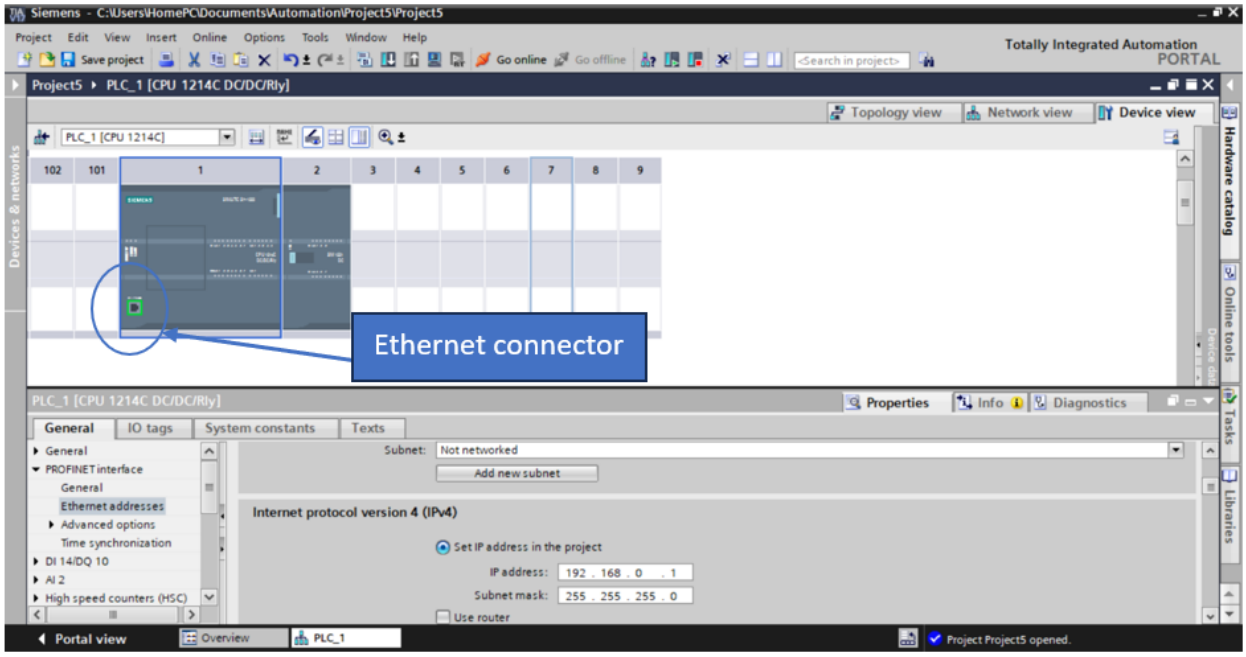


Fig.III.10. Ethernet Address of the CPU

III.7. Compilation and Download of the Hardware Configuration

Once the hardware configuration is completed, it must be compiled and downloaded to the PLC. To do this, select the PLC in the project, then click on the **"Compile"** icon in the toolbar.

Using this method will compile both the hardware and software configurations together.

Alternatively, you can compile only the hardware configuration by right-clicking on the PLC in the project window and selecting **"Compile → Hardware Configuration"**[96].

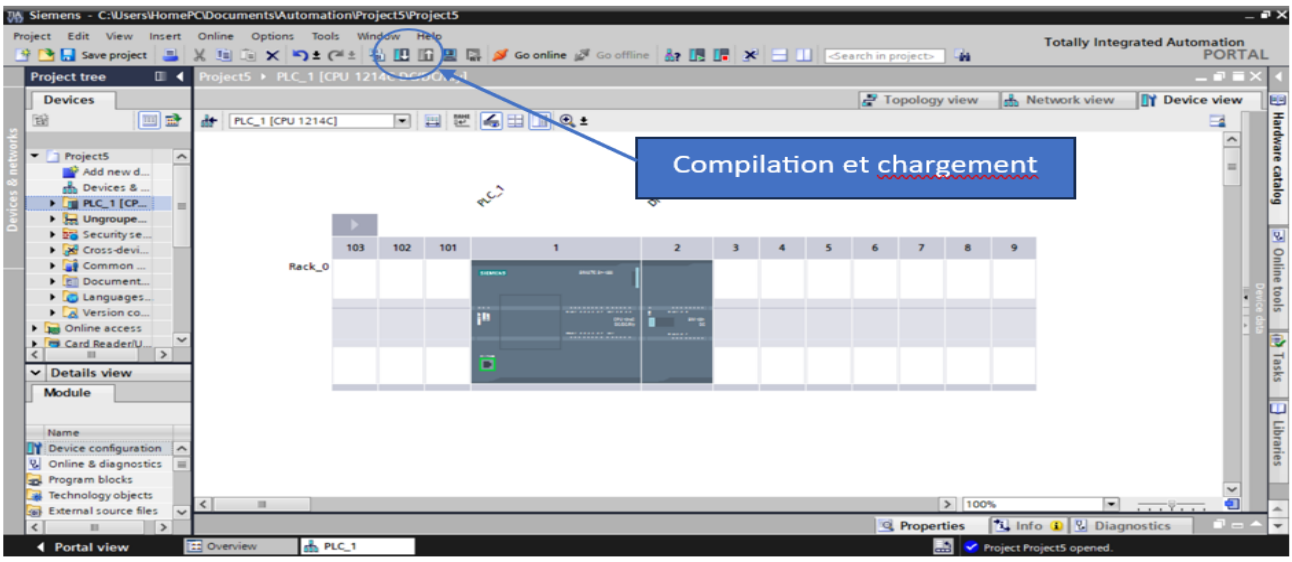


Fig.III.11. Compilation and Download of the Program to the PLC

III.7.1. PC/CPU Connection

For an initial connection or when assigning a specific IP address to the CPU,
it is recommended to use the MPI communication mode and connect the PC to the CPU via a PC Adapter. This method simplifies the setup process and ensures a smooth initial configuration.

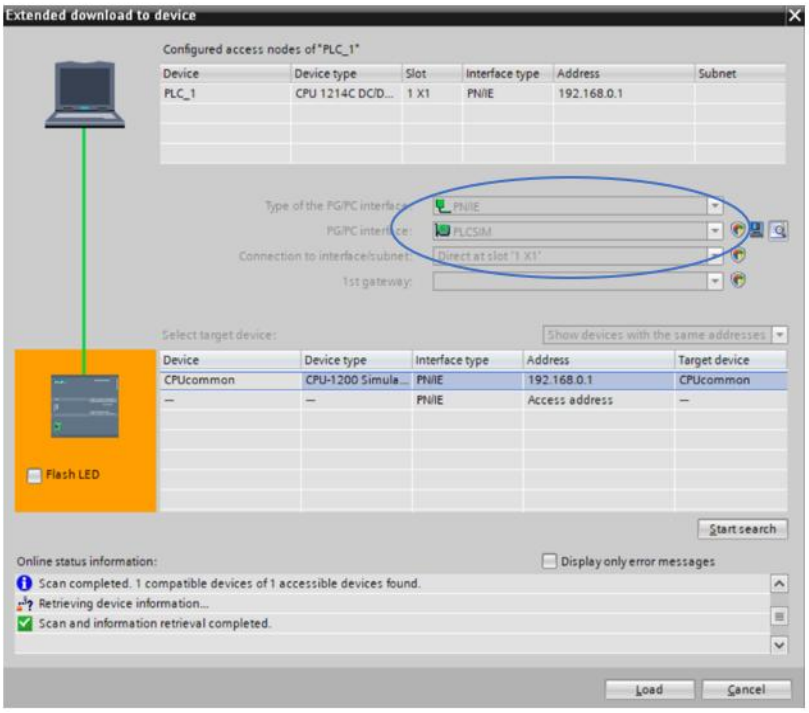


Fig.III.12. PC/CPU Connection

III.7.2. Connection Confirmation and Program Download

When the software detects a connected device, it will appear in the list at the bottom of the connection window.
You can use the "Flashing LED" button to make an LED on the front panel of the device blink, helping you confirm that you are connected to the correct device.

Once the configuration is complete, you can download the setup and program to the device. During this process, warnings or confirmation messages may appear, requiring your approval to proceed. If any errors are detected, they will be displayed in the download window, and the program cannot be loaded until all errors are resolved [97].

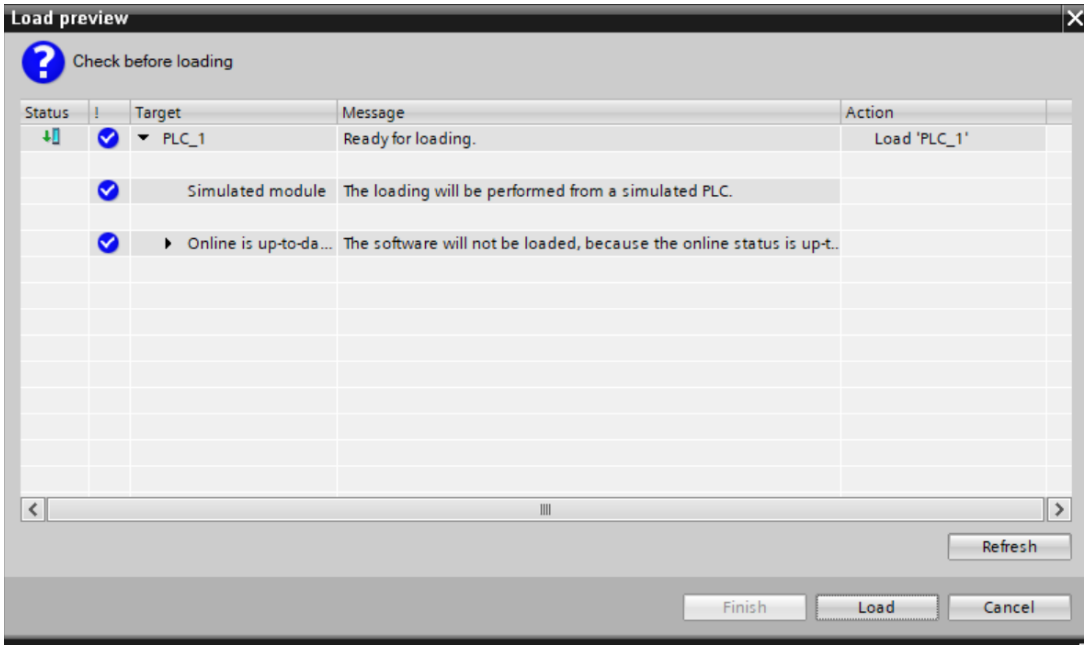


Fig.III.13. Overview of the Download Process

III.8. Programmable Logic Controller Variables

In the TIA Portal environment, all global variables (such as inputs, outputs, and memory bits) have both a symbolic address and an absolute address:

- The absolute address represents the operand identifier (like I,Q, M, etc.) along with its specific address and bit number.
- The symbolic address is the name assigned to the variable by the user, for example: Start_Button. This makes the program easier to read and understand.

The link between symbolic and absolute addresses is established in the PLC variable table. During programming, the user can choose to display the symbolic address, the absolute address, or both simultaneously depending on their needs[98].

III.8.1. Programmable Logic Controller Variable Table

The PLC variable table is where all variables and constants used in the program are declared.

When defining a new PLC variable, the following elements must be specified:

- **Name**: This is the symbolic address of the variable, making it easier to identify during programming.
- **Data type**: For example, BOOL, INT, etc., depending on the nature of the variable.

- **Absolute address**: Such as Q0.3, which refers to the actual memory location where the variable is stored.

Additionally, a **comment** can be added to describe the purpose of the variable.
This comment will appear automatically in every network where the variable is used, making the program easier to understand and maintain. for example:

Tabel.III.1. PLC Variable Table

	Name	Data Type	ADDRESS
1	SN1_sup10	BOOL	%M80.0
2	tag_11	INT	%IW752
3	C1_BP	WORD	%MW10
4	tag_2	REAL	%MD11
5	tag_6	BOOL	%M100.0

III.8.2. Error Indication in the Programmable Logic Controller Variable Table

When working with the variable table in the TIA Portal environment, syntax or input errors may occasionally occur such as entering an incorrect variable name, assigning the wrong address, or using a data type that doesn't match the specified address. To help identify these issues, TIA Portal highlights the problematic cells in red or orange. A red highlight typically indicates a critical error that must be corrected before the project can be compiled or downloaded to the PLC. Examples include duplicated variable names or invalid addresses. On the other hand, an orange highlight usually signals a warning or a less severe issue, such as a missing comment or a potential mismatch that won't necessarily prevent compilation but still requires attention.

When you click on a highlighted cell, an informative error message appears, explaining the nature of the problem. This interactive feedback allows the user to correct the mistake easily and efficiently.It's important to note that you can still save a variable table that contains errors, but it cannot be compiled or transferred to the PLC until all the issues have been resolved. This error indication system greatly enhances the programming experience by ensuring both reliability and accuracy in PLC application development [99].

Data type	Address	Retain	Acces...	Writa...	Visibl...
Bool	%I0.0	☐	☑	☑	☑
Bool	%I0.1	☐	☑	☑	☑
Bool	%I0.2	☐	☑	☑	☑
Bool	%I0.3	☐	☑	☑	☑
Bool	%I0.4	☐	☑	☑	☑
Bool	%I0.1	☐	☑	☑	☑
Bool	%I0.6	☐	☑	☑	☑
Bool	%I0.7	☐	☑	☑	☑
Int	%Q0.0	☐	☑	☑	☑
Bool	%Q0.1	☐	☑	☑	☑
Bool	%Q0.2	☐	☑	☑	☑

Fig.III.14. Error Indication in the Variable Table

III.8.3. Renaming and Reassigning Variables

In the TIA Portal programming environment, users are offered great flexibility when it comes to editing and managing the variables used in a program. Among the most useful features are the Rename and Rewire options, which can be accessed by right-clicking on the desired variable within the programming window.

- Selecting "Rename" allows you to modify the symbolic name of the variable, as well as its associated comment. This is particularly helpful for enhancing the clarity and readability of the program, especially in large-scale projects with many variables.
- The "Rewire" option goes a step further by allowing users to change multiple characteristics of the variable. These include the section it belongs to, its absolute address, the data type (e.g., BOOL, INT), the variable table where it is listed, and the associated comment[100].

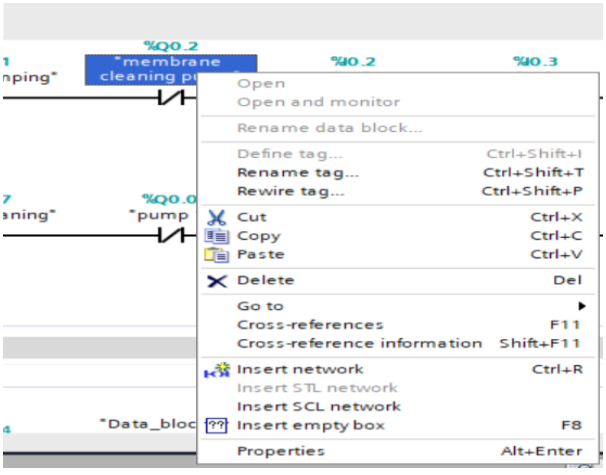


Fig.III.15. Renaming / Reassigning Variables

III.9. Binary Operations

Binary operations are actions performed on variables of the "BOOL" (Boolean) type, meaning they can only hold two possible values: TRUE or FALSE. These operations are fundamental in automation programming and are commonly used to control logical decisions within a process.

Among the most frequently used binary operations are:

- Logical functions such as AND, OR, and Exclusive OR (XOR).
- RS flip-flops (Set-Reset latches), used for memory storage within logic.
- Edge detection functions, which identify rising or falling signal changes.

Several programming languages are available to implement these operations in the TIA Portal environment, including:

- LADDER diagram (LAD), which visually resembles electrical relay logic.
- Function block diagrams (LOG).
- Instruction list language (LIST), which is text-based and resembles assembly code.

III.10. Logical Programming Concepts in Control Systems

III.10.1. Logical Functions AND, OR, XOR

- AND Function: The logical result is "1" when all inputs are in the "1" state. In LADDER language, this is represented by placing the contacts in series.
- OR Function: The logical result is "1" when at least one of the inputs is in the "1" state. In LADDER language, this is represented by placing the contacts in parallel.
- XOR Function: The logical result is "1" when only one of the two inputs is in the "1" state (in the case of two inputs). In LADDER language, the instruction is programmed as shown in the figure below.

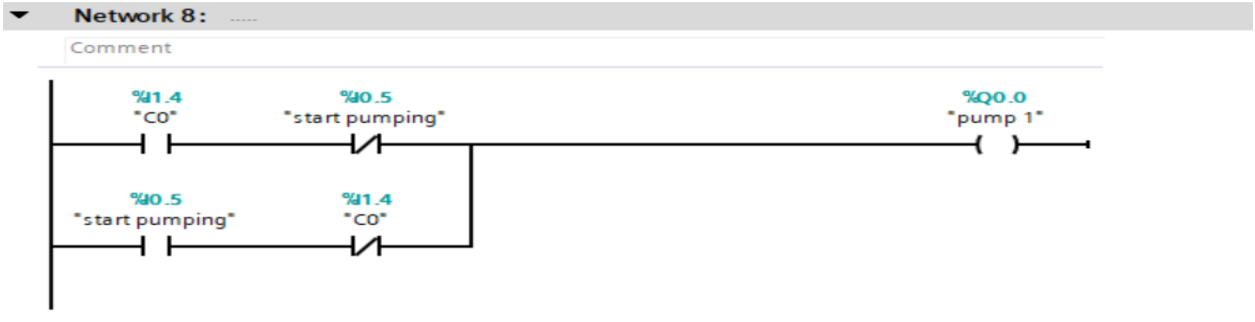


Fig.III.16. AND Function, OR Function, XOR Function

III.10.2. Interrogation at 1 and at 0

In LADDER programming, the symbols for interrogation at 1 and at 0 are widely used. These are essential elements for creating logical operations, starting timers, counters, and more.

⇒ **Interrogation at 1**, also known as a Normally Open contact (NO), returns a logic value of TRUE (1) when the associated operand is in the ON or TRUE state. It allows current (logical flow) to pass only if the condition is met.

⇒ **Interrogation at 0**, or Normally Closed contact (NC), returns TRUE (1) when the operand is in the OFF or FALSE state. It allows logical flow to continue only when the condition is not met.

The outcome of these interrogations will vary depending on the type of sensor or signal being tested. For example, a button, a switch, or a sensor might behave differently when connected to NO or NC contacts.

III.10.3. Assignment / Set to 1 and Set to 0

---( )--- ⇒ Assignment transmits the logical result to the specified operand. This result remains available after the assignment and can be used in other operations or assigned to another operand.

---(S)--- ⇒ Set to 1 → If the logical result is "1", the specified operand is set to "1" (SET). If the result is "0", the operand remains unchanged.

---(R)--- ⇒ Set to 0 → If the logical result is "1", the specified operand is set to "0" (RESET). If the result is "0", the operand remains unchanged.

The SET and RESET instructions can be combined using SR and RS flip-flops[101].

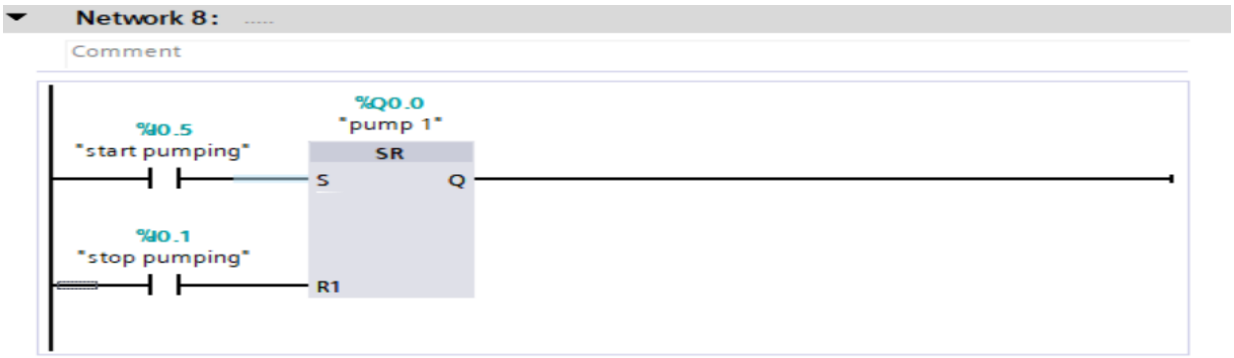


Fig.III.17. Set and Reset with SR and RS Flip-Flops

III.10.4. Timer TON

TON Function (Timer ON Delay): The TON function is used to delay the execution of a process for a specified time. The logical result is "1" when the timer has completed its delay period. In LADDER language, this is represented by using a timer block with a preset time.

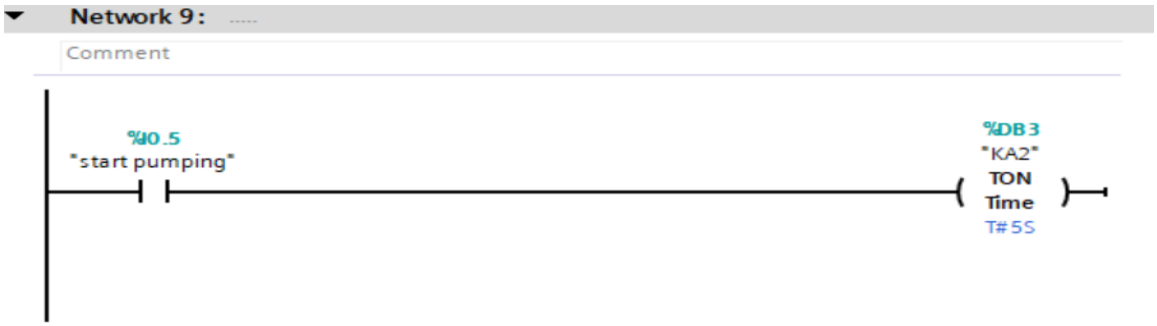


Fig.III.18. TON Function

III.10.5. SCALE-X Function

SCALE-X Function: The SCALE-X function is used to scale an input value based on a given range. It maps the input to a corresponding output range, producing a result based on the scaling factors. In LADDER language, this is represented by a scaling block that adjusts the input value accordingly.

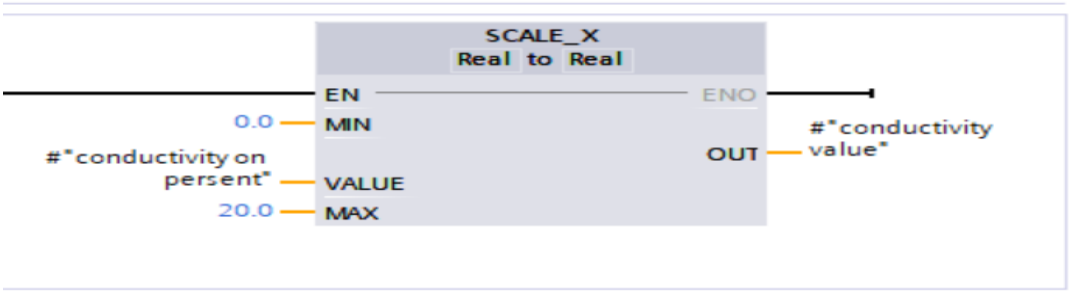


Fig.III.19. SCALE-X Function

III.10.6. Comparator less / greater

- COMPARATOR LESS Function: The LESS comparator function checks if one value is less than another. The logical result is "1" when the first value is less than the second. In LADDER language, this is represented by a comparator block set to the "less than" condition.
- COMPARATOR GREATER Function: The GREATER comparator function checks if one value is greater than another. The logical result is "1" when the first value is greater than the second. In LADDER language, this is represented by a comparator block set to the "greater than" condition[101].

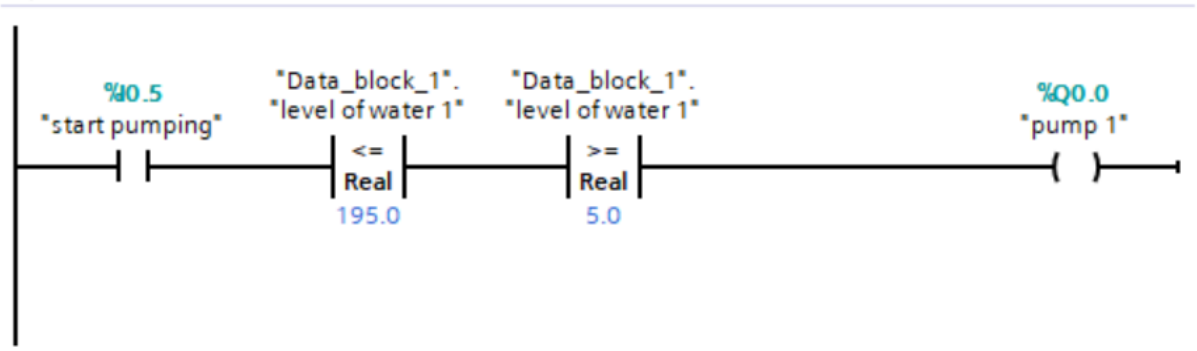


Fig.III.20. Comparator less / greater

III.11. The Problem Statement

Reverse osmosis (RO) technology is considered one of the most well-known and effective methods due to its high capacity for removing salts and contaminants. In this context, solar energy is a viable option for powering these systems. However, integrating solar energy with a precise desalination system requires strict control conditions to ensure efficient and stable operation. Therefore, the main topic of this chapter is : How can a seawater desalination system using reverse osmosis technology be managed and operated effectively and reliably through an integrated automatic control system based on a PLC using the TIA Portal platform? For that the system components will be explain in this chapter by giving the technical specifications and robust control plan which can the safety and stable operation of the desalination system, based on PLC control and HMI supervision ,while considering the use of solar energy as the primary power source.

III.11.1. Description of the controlled System

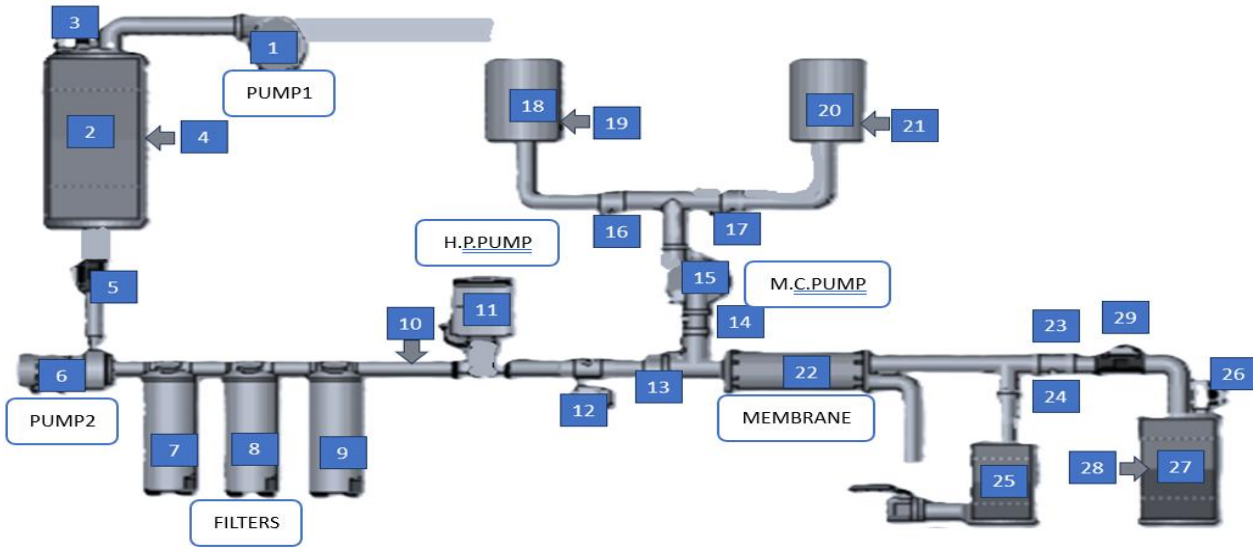


Fig. III.21. Main Components of The System.

Tabel.III.2. Tabel Of RO System Components

Number	Name of component	I/O Type
1	filling Pump	output
2	Tank 1	N/A (Not Applicable)
3	ultrasonic sensor 1	input
4	The raw water quality sensor 1	input
5	Water flow sensor 1	input
6	Pump 2	output
7	Coarse Filter (Sand or Screen Filter)	N/A (Not Applicable)
8	Activated Carbon Filter	N/A (Not Applicable)
9	Fine Filter	N/A (Not Applicable)
10	Water sensor	input
11	High pressure pump	output
12	Pressure sensor	input
13	Non return valve	N/A (Not Applicable)
14	Non return valve	N/A (Not Applicable)
15	Membrane cleaning pump	output
16	electromagnetic valve 3	output
17	electromagnetic valve 4	output
18	Cleaning solution tank (tank 3)	N/A (Not Applicable)
19	Low level sensor 1	input
20	Water tank (tank 4)	N/A (Not Applicable)
21	Low level sensor 2	input
22	membrane	N/A (Not Applicable)
23	electromagnetic valve 2	output
24	electromagnetic valve 3	output
25	Polluted water tank (tank 5)	output
26	ultrasonic sensor 2	input
27	The pure water tank (tank 2)	N/A (Not Applicable)
28	The pure water quality sensor 2	input
29	Water flow sensor 2	input

III.11.1.1. System Description

The Reverse Osmosis (RO) system illustrated in the diagram operates by treating water through several integrated stages to ensure the production of clean, impurity-free water. Below is a step-by-step explanation of each stage according to the components shown:

- **Water Inlet Stage**

The first tank filling pump is used to pump raw water into the system, providing the water required for treatment. Prior to going through the filtering processes, the water is kept in the first tank. While raw water quality and flow rate sensors keep an eye on whether the water is suitable for treatment, an ultrasonic level sensor checks the tank's water level to guarantee a sufficient supply.

- **Preliminary Filtration Stage**

A dedicated pump pushes the water through a series of filters to remove large and small impurities. It starts with a coarse or sand filter that removes suspended solids. The water then passes through an activated carbon filter, which eliminates chemicals, odors, and organic pollutants. Finally, the water flows through a fine filter that captures remaining small particles, preparing it for advanced treatment.

- **Advanced Treatment Stage**

In this step, the water is forced through the reverse osmosis membrane by a high-pressure pump, which extracts fine contaminants and dissolved salts from the water. To guarantee correct operation and avoid problems, a pressure sensor keeps an eye on the system's pressure. To provide effective pollutant removal and precise process control, electrically operated valves control the flow of water between system components.

- **Cleaning and Maintenance Stage**

To maintain membrane performance and efficiency, a special cleaning pump is used to periodically clean the membrane. The cleaning solution is stored in a dedicated tank, and electrically actuated valves direct water and the cleaning solution during the cleaning process. This helps remove fouling and debris, extending the membrane’s lifespan.

- **Clean and Waste Water Management**

After treatment, the brine is released straight outside, and the clean water is kept in special tanks for later use. A brine solution tank holds the concentrated waste generated by the RO process. To guarantee that pure water, polluted water, and waste byproducts are kept apart, electric valves regulate the water flow between these tanks.

- **Sensors and Automation Level**

The system is based on a collection of sensors that track flow rates, water quality, and tank levels at different locations. These include water quality sensors to make sure the treated water satisfies

regulations, low-level sensors to notify operators of low water levels, and ultrasonic sensors for precise level measurement. Through regular maintenance and ongoing monitoring, this guarantees safe and effective system operation**.**

III.11.1.2. Reverse Osmosis System Specification

When the start button is selected , Pump 1 operates to fill Tank *T1* with water. Once the tank is full, Pump 1 stops. Before Pump 2 is activated, Solenoid Valves 1 is engaged, allowing water to flow into the filtration units, which consist of three stages: a sand or mesh filter, an activated carbon filter, and a fine filter. When Pump 2 begins operating, it continues running until the sensor detects the presence of water after the filtration stage. At that point, the high-pressure pump is automatically activated to push water through the semi-permeable membrane for the reverse osmosis process. The resulting purified water is directed into *T2*, while the brine (salty water) is discharged.

Throughout the process, water quality sensors measure the quality of water (conductivity, turbidity, temperature and ph) in both Tanks *T1* and *T2*, while ultrasonic sensors monitor the water levels in both tanks to ensure the system operates smoothly.

III.11.1.3. Cleaning-in-Place (CIP) Mode

When the cleaning button is selected, the cleaning pump operates along with electromagnetic valves 2 and 3, pumping cleaning solution from Tank *T3* into the semi-permeable membrane.

Once the low-level sensor 1 detects that the cleaning solution in Tank *T3* is depleted, Valve 3 closes, and Valve 4 opens to pump water from Tank *T4* to flush the membrane and remove any remaining cleaning solution.

When low level sensor 2 detects that the water in Tank *T4* has run out, Valves 4 and 2 close, and the cleaning pump stops. The used cleaning water is then directed to Tank *T5*.

III.12. Problem solving methodology

This chapter will adopt an analytical and engineering based methodology to address the issue by designing an intelligent and efficient control system of a solar powered water desalination unit using reverse osmosis technology. A comprehensive description of the proposed system components will be provided, including both mobile and stationary versions, and identification of all key technical components such as pumps, filters, sensors, and control devices.

Next, a thorough analysis of daily energy consumption will be conducted, preceded by the calculation of the electrical power required to operate the system. This data will be used to determine

the number of solar panels and batteries needed to ensure stable and efficient system performance under various conditions, taking into account the type of system used (stationary or mobile).

Once the energy aspect has been addressed, an electrical control diagram will be created to illustrate how power is distributed and how each system component operates, considering automatic control, logical sequencing, and safety aspects. A control program will be developed within the TIA Portal platform using Ladder Logic. The program will then be implemented and tested through simulation using PLCSIM to ensure the system's efficiency and responsiveness to different operating conditions.

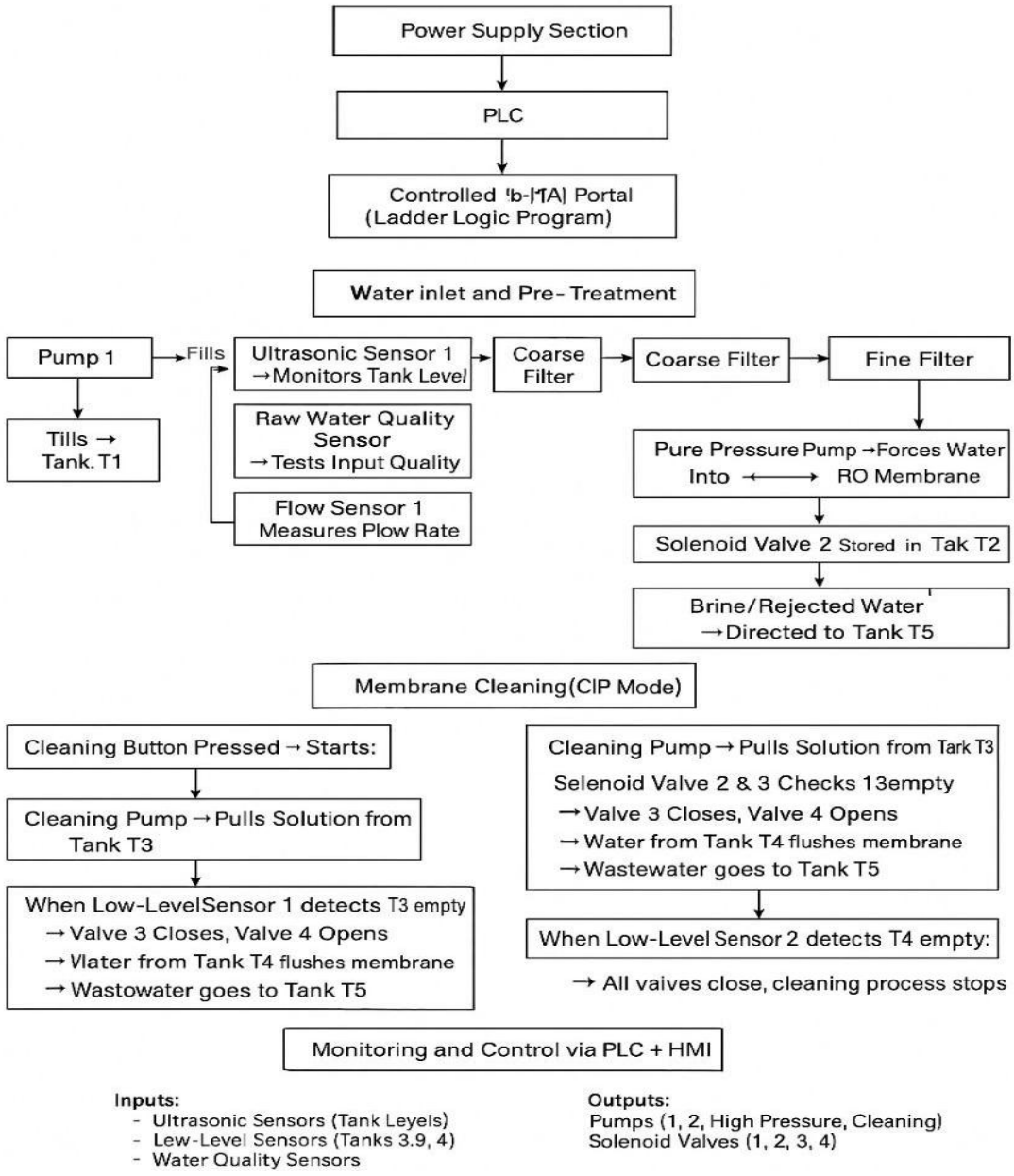


Fig. III.22. Functional Diagram of a Solar-Powered Reverse Osmosis Desalination System with PLC Control.

III.13. Energy Consumption Analysis

III.13.1. In The Case of a Fixed Reverse Osmosis System

III.13.1.1 Electrical Power Requirement Calculation for The RO System

- Density (ρ) ≈ 1000 kg/m³ (for water)
- Gravitational acceleration (g) = 9.81 m/s²
- The relationship between pressure and height :

  Head (m)=Pressure (bar)×10.2 [63]

❖ **Pump 1 :**

- **Flow rate :** 10 m³/h
- **Head :** 15 m
- **Efficiency :** 65%

the Hydraulic Power for a Pump: $\text{Phydraulic(kW)} = \frac{\text{Q(m3/h)}\times\text{H(m)}\times\rho\text{(kg/m3)}\times\text{g(m/s2)}}{3600\times1000}$ [64]

Where :

- Q = Flow rate in cubic meters per hour (m³/h)
- H = Total head (pressure height) in meters (m)
- ρ= Fluid density in kilograms per cubic meter (kg/m³) (For water, ρ≈1000kg/m3)
- g = Gravitational acceleration, approximately 9.81 m/s^2
- 3600 = Seconds in an hour (to convert m^3/h to m^3/s)
- 1000 = To convert Watts to kilowatts (1 kW = 1000 W)

To simplify water: $\text{Phydraulic(kW)} = \frac{\text{Q(m3/h)}\times\text{H(m)}\times9.81}{3600}$

$$\text{Phydraulic(kW)} = \frac{10\times15\times9.81}{3600} = 0.408KW$$

Efficiency correction: $\text{Pactual(kW)} = \frac{0.408}{0.65} = 0.627KW$

❖ **Pump (2) :**

- **Efficiency :**0.65%
- **Flow :** 2 m³/h

- **Pressure :** 4 bar

$$\text{Head (m)=Pressure (bar)}\times 10.2 = 4\times 10.2 = 40.8 \text{ m}$$

$$\text{Phydraulic(kW)} = \frac{2 \times 40.8 \times 9.81}{3600} = 0.222KW$$

$$\text{Efficiency correction: Pactual(kW)} = \frac{0.222}{0.65} = 0.342KW$$

❖ **High Pressure Pump (RO Pump) :**

- **Flow :** 2 m³/h
- **Pressure :** 65 bar
- **Efficiency :** 50%

$$\text{Head (m)=Pressure (bar)}\times 10.2 = 65\times 10.2 = 663 \text{ m}$$

$$\text{Phydraulic(kW)} = \frac{2 \times 663 \times 9.81}{3600} = 3.613KW$$

$$\text{Efficiency correction: Pactual(kW)} = \frac{3.613}{0.5} = 7.227KW$$

*** Total Power Required**

$$\textbf{Ptotal} = 0.627 + 0.342 + 7.227 = 8.196\text{KW}$$

***** Daily Energy Consumption (8 operating hours) :

W= Total Power× Operating hours per day

$$\textbf{wtotal} = \text{Energy per day} = 8.196 \times 8 = 65.568 \text{ kWh/day}$$

III.13.1.2. Battery Sizing Calculation

- **Battery type :** AGM/Gel (12V,200Ah)
- **Total system voltage :** 24V
- **DOD** = 50% = 0.5

$$\text{Battery capacity (Ah)} = \frac{\text{Daily energy (Wh)}}{\text{System voltage (V)} \times \text{DOD}}$$

Where:

- **Ah** = Ampere-hour

- **Wh** = Watt-hour
- **V** = Volts (system voltage)
- **DOD** = Depth of Discharge (usually expressed as a percentage, but used as a decimal in calculations)[65].

$$\text{Battery capacity (Ah)} = \frac{65568}{24 \times 0.5} = 5464\text{Ah}$$

Connect two 12V batteries in series to form 24V [66].

Thus, to calculate the total number of batteries:

$$\text{Number of groups} = \frac{5464}{200} = 27{,}32 \approx 28$$

Each group requires 2 batteries (connected in series)[67] .

* the total number of batteries is :

$$\textbf{Number of batteries} = 28 \times 2 = 56 \text{ batteries}$$

56 batteries of 12V 200Ah

III.13.1.3. Solar Panel Sizing Calculation

- **Panel Power Rating :** 400 W
- **Average Solar Irradiance in Algeria:** 5.5 kWh/m²/day
- **Correction Factor (for losses):** 0.75

Daily production per panel $\approx 400 \times 5.5 \times 0.75 = 1650 \text{ Wh/day} = 1.65 \text{ kWh/day}$ [68].

Calculating the number of required panels **:**

$$\textbf{Number of panels} = \frac{65.568}{1.65} = \mathbf{39.73}$$

Number of panels → **40** solar panels of 400W each.

III.13.2. In The Case of a Mobile Reverse Osmosis System :

III.13.2.1. Electrical Power Requirement Calculation for the RO System :

❖ **Pump (1)**

- **Flow rate :** 2 m³/h
- **Head :** 15 m
- **Efficiency :** 65%

$$\text{Phydraulic(kW)} = \frac{2 \times 15 \times 9.81}{3600} = 0.081KW$$

$$\text{Efficiency correction: Pactual(kW)} = \frac{0.081}{0.65} = 0.125KW$$

❖ **Pump (2)**

- **Efficiency :**0.65%
- **Flow :** 0.25 m³/h
- **Pressure :** 4 bar

$$\text{Head (m)=Pressure (bar)}\times 10.2 = 4\times 10.2 = 40.8 \text{ m}$$

$$\text{Phydraulic(kW)} = \frac{0.25 \times 40.8 \times 9.81}{3600} = 0.027KW$$

$$\text{Efficiency correction: Pactual(kW)} = \frac{0.027}{0.65} = 0.042KW$$

❖ **High Pressure Pump (RO Pump)**

- **Flow :** 0.25 m³/h
- **Pressure :** 65 bar
- **Efficiency :** 50%

$$\text{Head (m)=Pressure (bar)}\times 10.2 = 65\times 10.2 = 663 \text{ m}$$

$$\text{Phydraulic(kW)} = \frac{0.25 \times 663 \times 9.81}{3600} = 0.451\ KW$$

$$\text{Efficiency correction: Pactual(kW)} = \frac{0.451}{0.5} = 0.902\ KW$$

* Total Power Required

$$\textbf{Ptotal} = 0.125 + 0.042 + 0.902 = 1.069\text{kW}$$

* Daily Energy Consumption (8 operating hours) :

W= Total Power× Operating hours per day

$$\textbf{wtotal} = \text{Energy per day} = 1.069 \times 8 = 8.552\ \text{kWh/day}$$

III.13.2.2. Battery Sizing Calculation

- **Battery type :** AGM/Gel (12V,200Ah)
- **Total system voltage :** 24V
- **DOD** = 50% = 0.5

$$\text{Battery capacity (Ah)} = \frac{8552}{24 \times 0.5} = 712.66\ \text{Ah}$$

Connect two 12V batteries in series to form 24V.

Thus, to calculate the total number of batteries :

$$\text{Number of groups} = \frac{712.66}{200} = 3.56 \approx 4$$

Each group requires 2 batteries (connected in series).

* The total number of batteries is :

$$\textbf{Number of batteries} = 4 \times 2 = \textbf{8}\ \text{batteries}$$

6 batteries of 12V 200Ah

III.13.2.3. Solar Panel Sizing Calculation

- **Panel Power Rating :** 400 W
- **Average Solar Irradiance in Algeria :** 5.5 kWh/m²/day
- **Correction Factor (for losses) :** 0.75

$$\text{Daily production per panel} \approx 400 \times 5.5 \times 0.75 = 1650\ \text{Wh/day} = 1.65\ \text{kWh/day}$$

Calculating the number of required panels :

$$\textbf{Number of panels} = \frac{8.552}{1.65} = 5.18$$

* Number of panels → **6** solar panels of 400W each.

III.14. Electrical and Ladder Diagrams of the Reverse Osmosis System

III.14.1. Power diagram

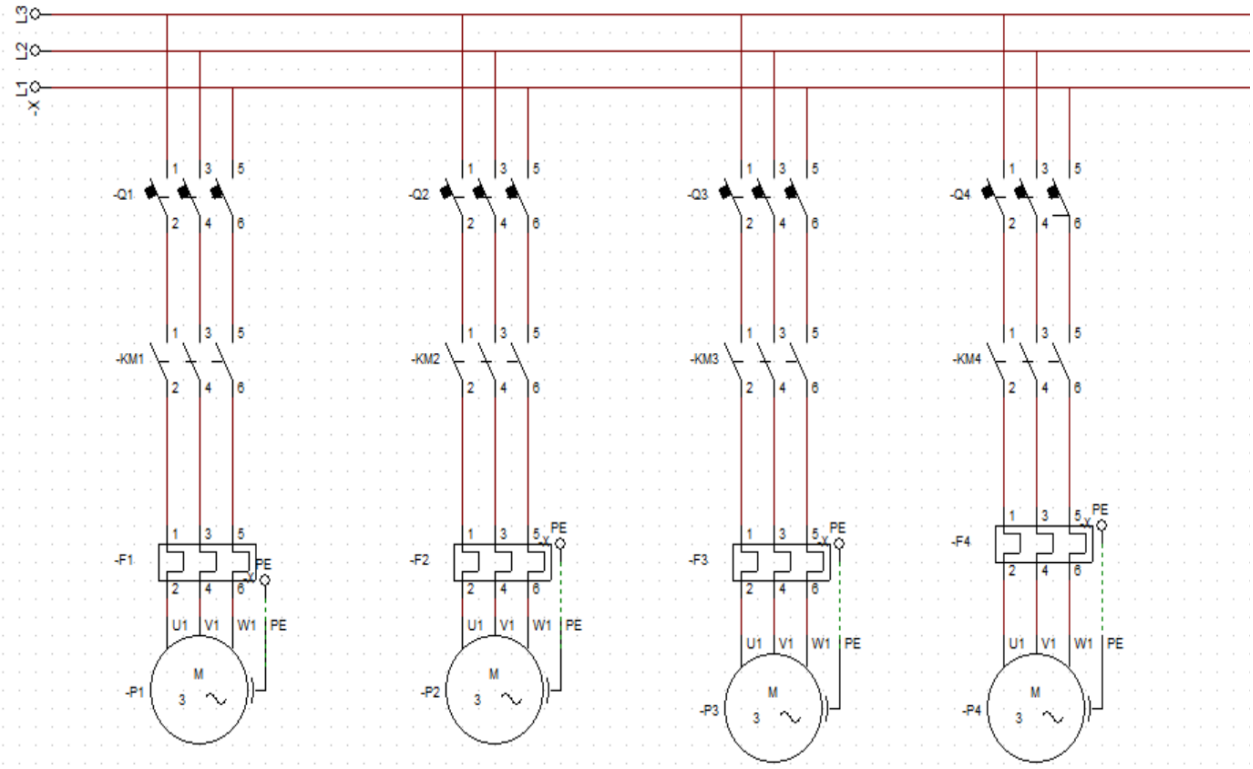


Fig. III.23. Power diagram.

III.14.2. Control diagram

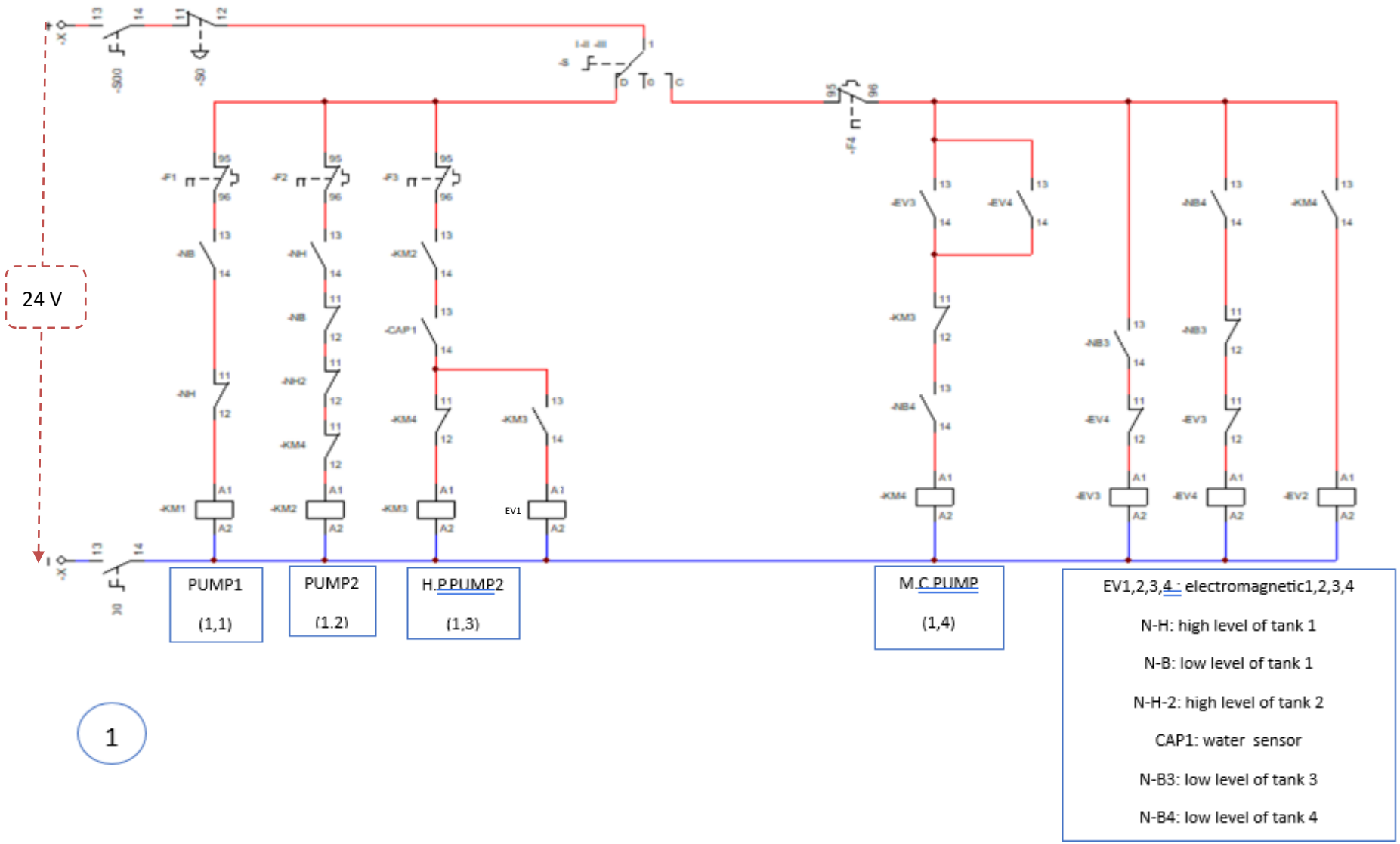


Fig. III.24. Control diagram

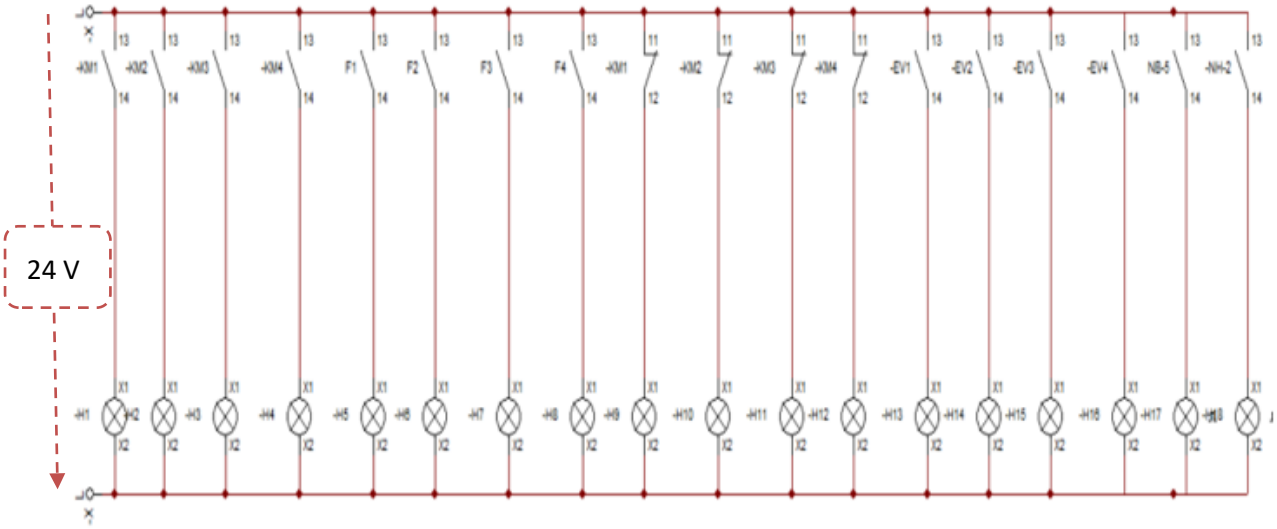


Fig. III.25. Signal diagram.

III.14.3. Ladder Logic Diagram control

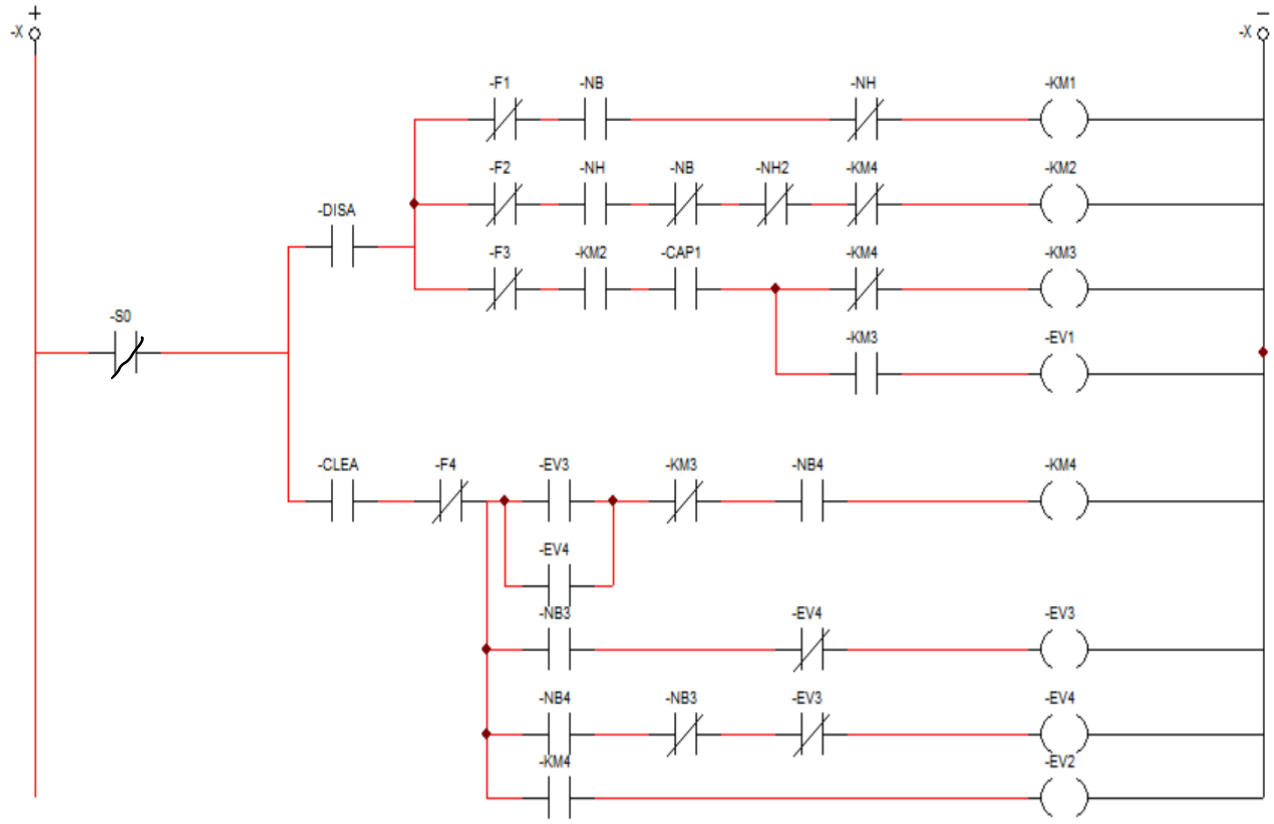


Fig. III.26. Ladder Logic Diagram.

*** Electrical Diagram :** The electrical diagram shows the basic arrangement of connections between the different parts of the reverse osmosis system, including solenoid valves and pumps. According to the electrical point numbering, it contains exact wiring information for operational parts such as *PUMP1, PUMP2, M.C.PUMP,* and *H.P.PUMP* that are connected to the control panels via contacts or relays. In order to ensure that the system components operate safely and sequentially, the diagram also shows how power is distributed and how system outputs are controlled based on data from sensors. When doing electrical repair or the actual installation procedure, this schematic is the major source of reference.

*** Ladder Diagram :** This graphic shows the programmed control logic that controls how the system operates. It shows the connection between the inputs (such sensor status signals or manual switches) and the outputs (like solenoid valves and pumps being activated). By turning on the outputs in response to preset conditions, the diagram's logical flow guarantees effective system operation. The Programmable Logic Controller (PLC) is programmed using this figure, which provides a clear illustration of how the system functions from the standpoint of industrial automation.

III.15. Ladder Logic Diagram in tia portal

III.15.1. Programmable Logic Controller Variables table

ro system TEST 1 ▸ PLC_1 [CPU 1214C DC/DC/Rly] ▸ PLC tags ▸ Tag table_1 [62]

Tag table_1

	Name	Data type	Address	Retain	Acces...	Writa...	Visibl...
1	emergency stop	Bool	%I0.0	☐	☑	☑	☑
2	F1	Bool	%I0.2	☐	☑	☑	☑
3	F2	Bool	%I0.3	☐	☑	☑	☑
4	F3	Bool	%I0.4	☐	☑	☑	☑
5	pump 1	Bool	%Q0.0	☐	☑	☑	☑
6	high pressure pump	Bool	%Q0.1	☐	☑	☑	☑
7	membrane cleaning pump	Bool	%Q0.2	☐	☑	☑	☑
8	sensor of l tank 4 level	Bool	%I1.0	☐	☑	☑	☑
9	sensor of l tank 5 level	Bool	%I1.1	☐	☑	☑	☑
10	elecmag valve 1	Bool	%Q0.3	☐	☑	☑	☑
11	elecmag valve 2	Bool	%Q0.4	☐	☑	☑	☑
12	elecmag valve 3	Bool	%Q0.5	☐	☑	☑	☑
13	elecmag valve 4	Bool	%Q0.6	☐	☑	☑	☑
14	start pumping_sup	Bool	%M1.3	☐	☑	☑	☑
15	elecmag valve 5	Bool	%Q1.1	☐	☑	☑	☑
16	elecmag valve 6	Bool	%Q8.0	☐	☑	☑	☑
17	lamp 1	Bool	%Q8.1	☐	☑	☑	☑
18	lamp 2	Bool	%Q8.2	☐	☑	☑	☑
19	lamp 3	Bool	%Q8.3	☐	☑	☑	☑
20	lamp 4	Bool	%Q8.4	☐	☑	☑	☑
21	lamp 5	Bool	%Q8.5	☐	☑	☑	☑
22	lamp 6	Bool	%Q8.6	☐	☑	☑	☑
23	lamp 7	Bool	%Q8.7	☐	☑	☑	☑
24	lamp 8	Bool	%Q9.0	☐	☑	☑	☑
25	lamp 9	Bool	%Q9.1	☐	☑	☑	☑

26		pressure level before membrane	Int	%IW112				
27		level of water(1)	Int	%IW114				
28		conductivity(1)	Int	%IW116				
29		ph(1)	Int	%IW118				
30		turbidity(1)	Int	%IW120				
31		temperature(1)	Int	%IW122				
32		conductivity_2	Int	%IW124				
33		ph_2	Int	%IW126				
34		turbidity_2	Int	%IW128				
35		temperature_2	Int	%IW130				
36		level of water_2	Int	%IW132				
37		pump 2	Bool	%Q1.2				
38		F4	Bool	%I1.6				
39		DESASLINATION	Bool	%I1.7				
40		CLEAN MEMBRANE	Bool	%I2.0				
41		flow of water_1	Int	%IW134				
42		flow of water_2	Int	%IW136				
43		lamp10	Bool	%Q9.2				
44		lamp11	Bool	%Q9.3				
45		start cleaning_sup(1)	Bool	%M1.1				
46		pressure level before membran.	DWord	%MD200				
47		level of water_1	DWord	%MD204				
48		conductivity_1	DWord	%MD208				
49		ph_1	DWord	%MD212				
50		turbidity_1	DWord	%MD216				
51		temperature_1	DWord	%MD220				
52		conductivity-2	DWord	%MD224				
53		ph-2	DWord	%MD228				
54		turbidity-2	DWord	%MD232				
55		temperature-2	DWord	%MD236				
56		level of water-2	DWord	%MD240				
57		flow of water-1	DWord	%MD244				
58		flow of water-2	DWord	%MD248				
59		water sensor	Bool	%Q9.4				
60		lamp 12	Bool	%Q9.5				
61		lamp 13	Bool	%Q9.6				
62		lamp 14	Bool	%Q9.7				

Fig. III.27. PLC Variables table.

Tabel.III.3. Tabel of the inputs and outputs

Components	Designation	mnemonic
S_{00}	Input	General ON /OFF Switch
S_0	Input	Emergency Stop
S	Input	Start Switch
F_1	Input	Circuit Breaker For Pump 1
F_2	Input	Circuit Breaker For Pump 2
F_3	Input	Circuit Breaker For High Pressure Pump
F_4	Input	Circuit Breaker For Cleaning Pump
NB	Input	Low Level of Tank 1
NH	Input	High Level of Tank 1
NH_2	Input	High Level of Tank 2
CAP_1	Input	Water Sensor
KM_1	Output	Contactor Pump 1
KM_2	Output	Contactor Pump 2
KM_3	Output	Contactor Pressure Pump
KM_4	Output	Contactor Cleaning Pump
EV_1	Output	Electromagnetic Valve 1
EV_2	Output	Electromagnetic Valve 2
EV_3	Output	Electromagnetic Valve 3

EV_4	Output	Electromagnetic Valve 4
NB_3	Output	Low Level of Tank 3
NB_4	Output	Low Level of Tank 4
$Lamp_1$	Output	Pump 1 Operation Indicator Light
$Lamp_2$	Output	Pump 2 Operation Indicator Light
$Lamp_3$	Output	Pressure Pump Operation Indicator Light
$Lamp_4$	Output	Cleaning Pump Operation Indicator Light
$Lamp_5$	Output	Pump 1 Stop Indicator Light
$Lamp_6$	Output	Pump 2 Stop Indicator Light
$Lamp_7$	Output	Pressure Pump Stop Indicator Light
$Lamp_8$	Output	Pump 1 Fault Indicator Light
$Lamp_9$	Output	Desalination Complete Indicator Light
$Lamp_{10}$	Output	Cleaning Complete Indicator Light
$Lamp_{11}$	Output	Cleaning Pump Stop Indicator Light
$Lamp_{12}$	Output	Pump 2 Fault Indicator Light
$Lamp_{13}$	Output	Pressure Pump Fault Indicator Light
$Lamp_{14}$	Output	Cleaning Pump Fault Indicator Light
Conductivity	Input	Conductivity Sensor
ph	Input	Potential of Hydrogen Sensor
turbidity	Input	Turbidity Sensor
Temperature	Input	Temperature Sensor
Flow of water	Input	Flow Sensor

III.15.2. Programmed Ladder Diagram for Reverse Osmosis System Control

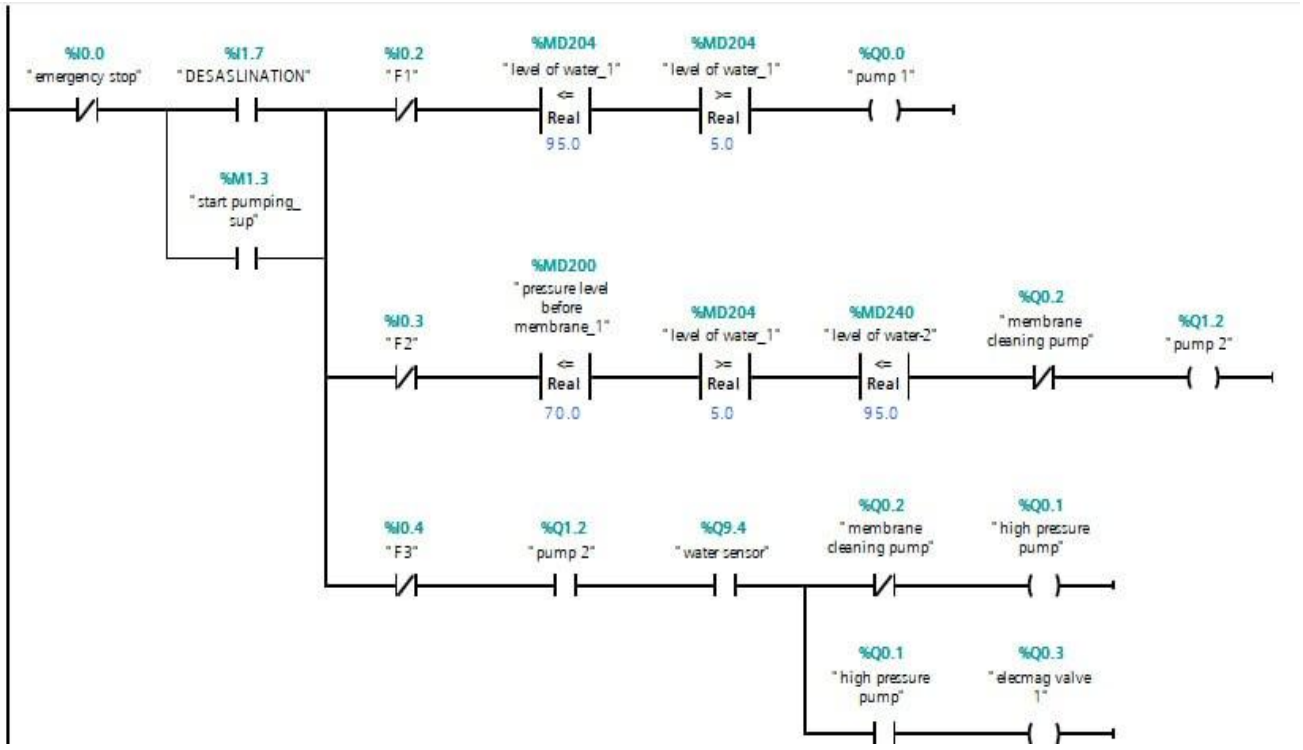


Fig. III.28. Desalination system.

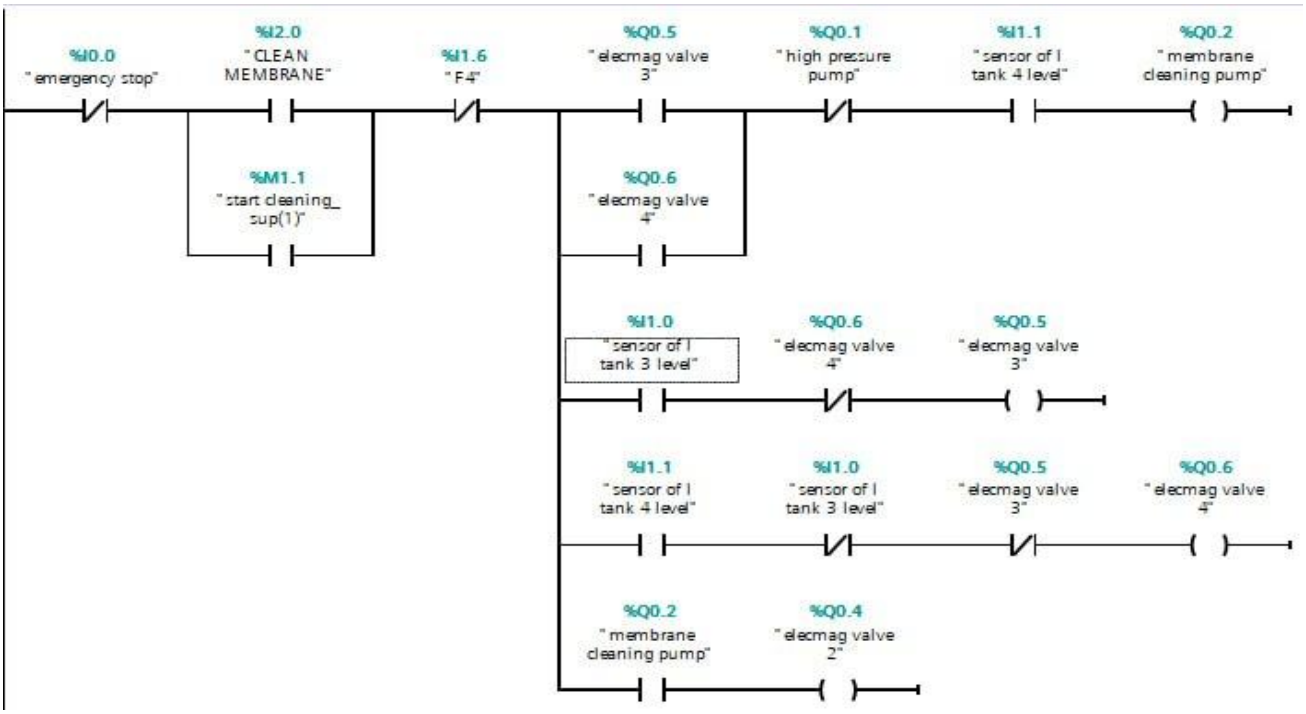


Fig. III.29. Membrane cleaning system .



Fig. III.30. Pump operation signals.

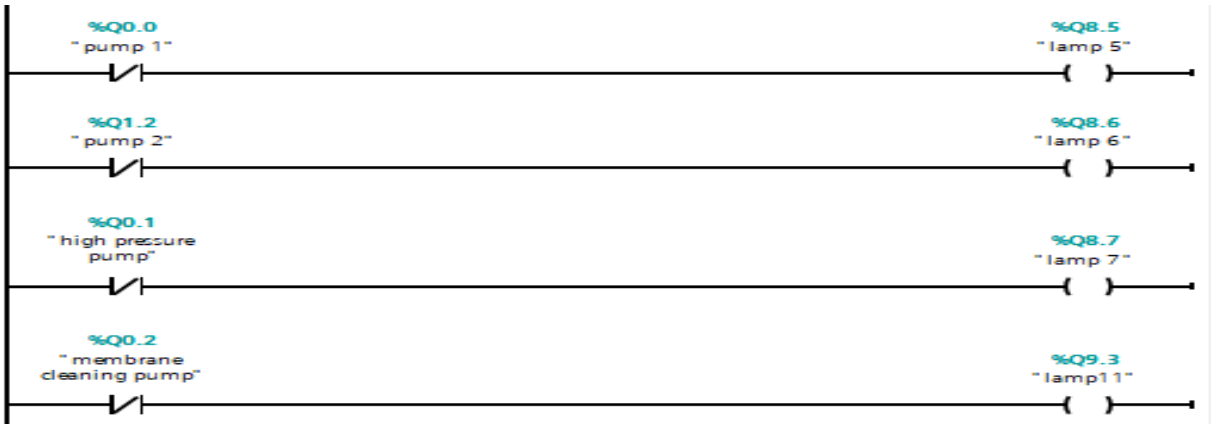


Fig. III.31. Pump stop signals.

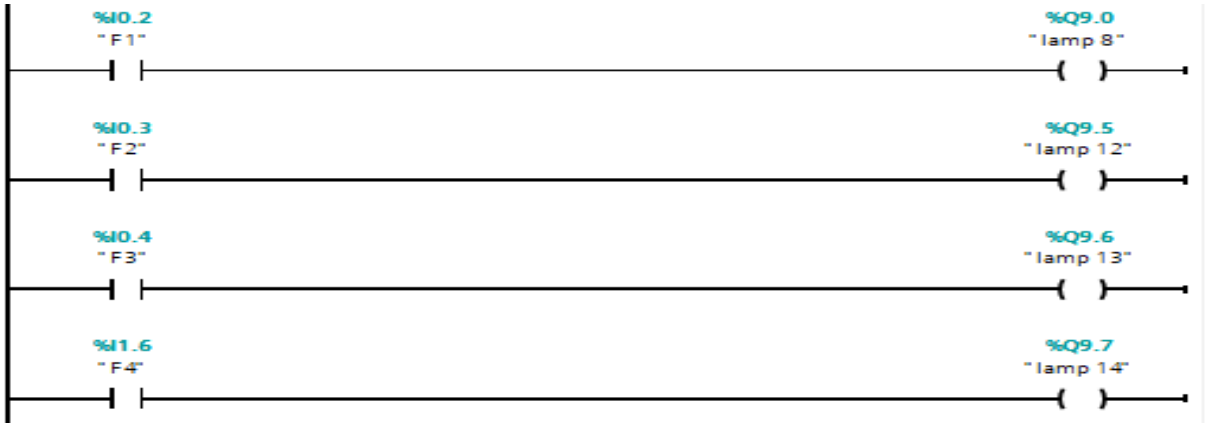


Fig. III.32. Pump fault signals.

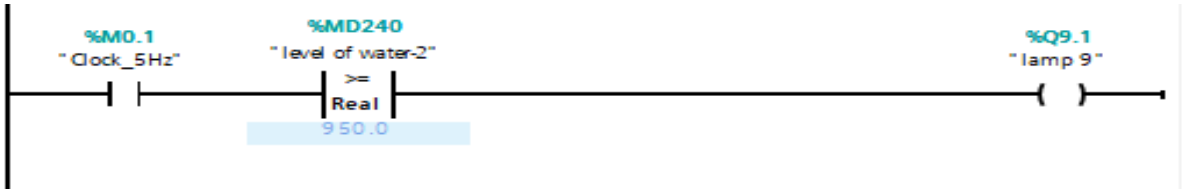


Fig. III.33. Desalination completed signal.



Fig. III.34. Membrane cleaning done signal.

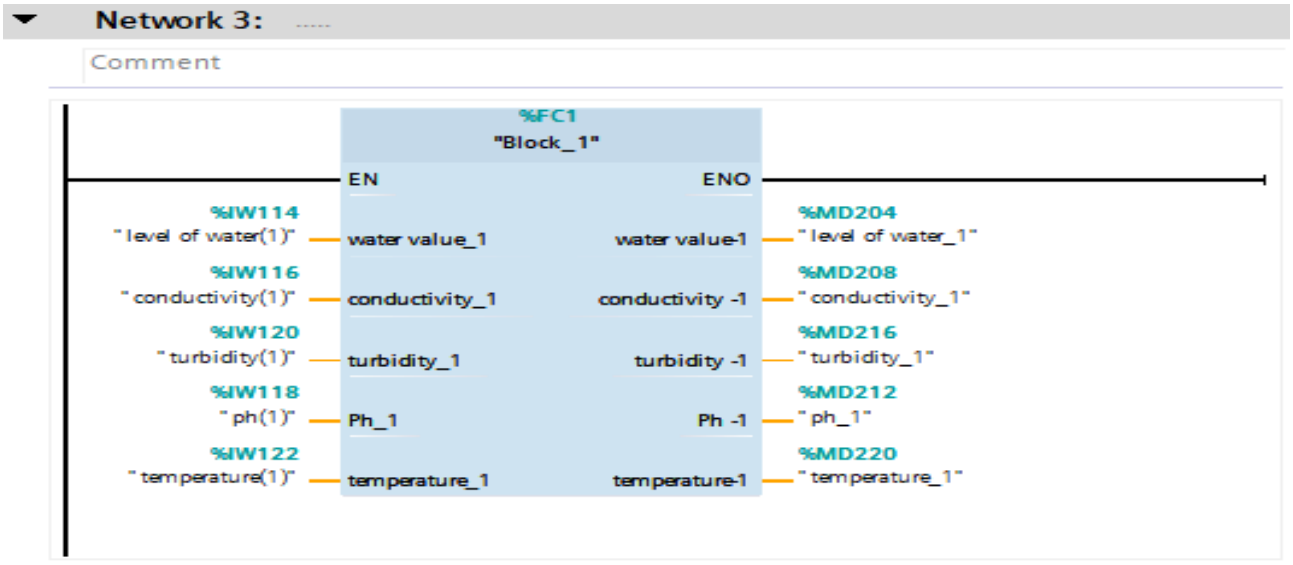


Fig. III.35. tank 1 sensor inputs and processing block.

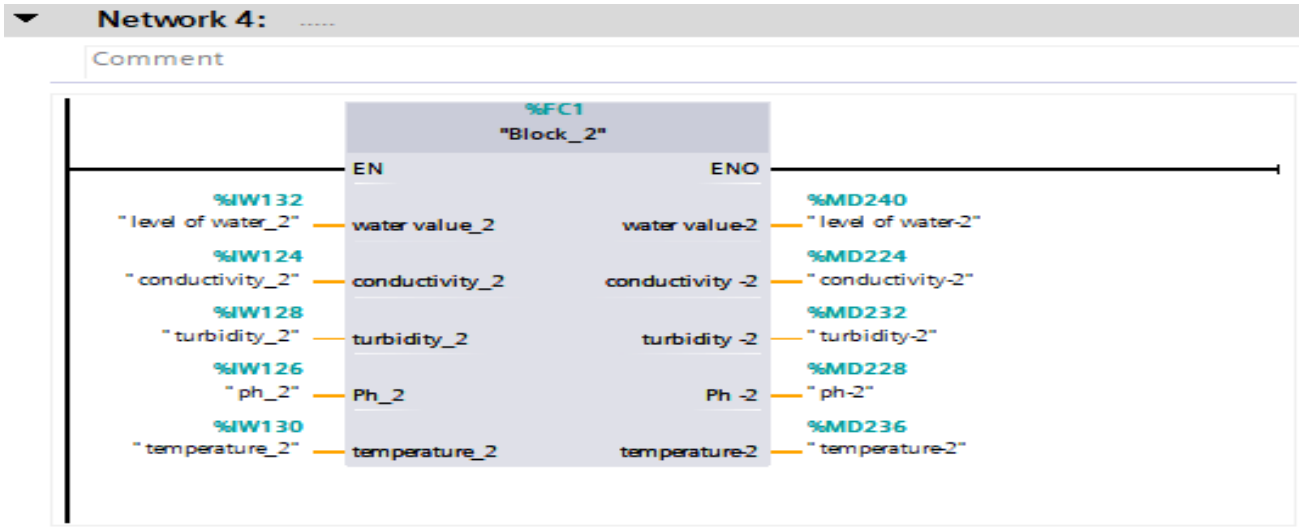


Fig. III.36. tank 2 sensor inputs and data processing block.

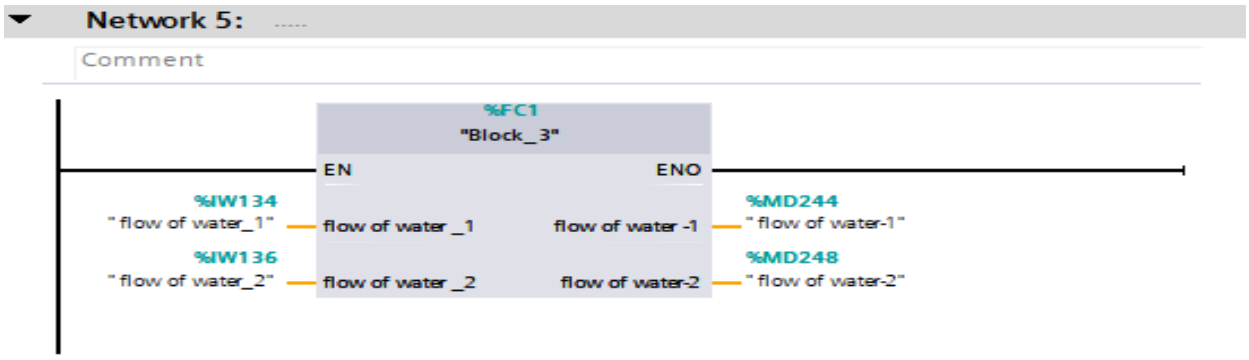


Fig. III.37. flow sensor and data processing block.

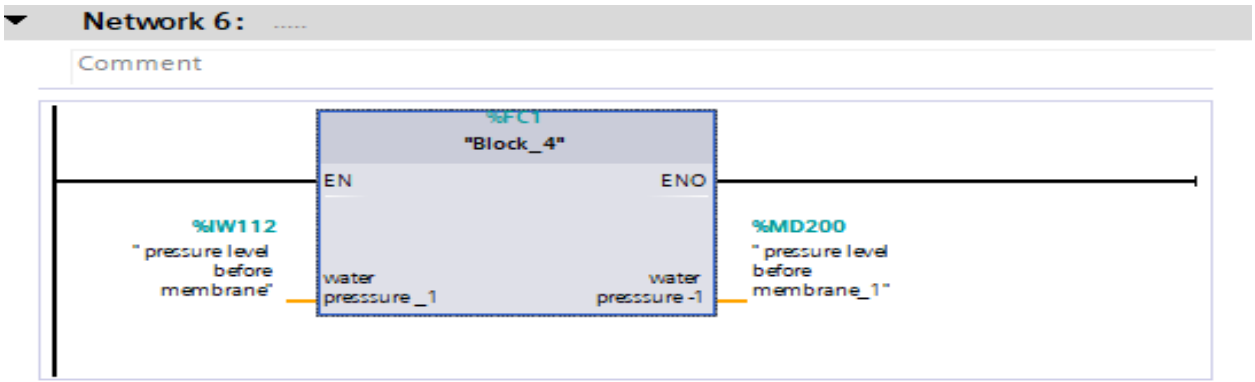


Fig. III.38. pressure sensor and data processing block.

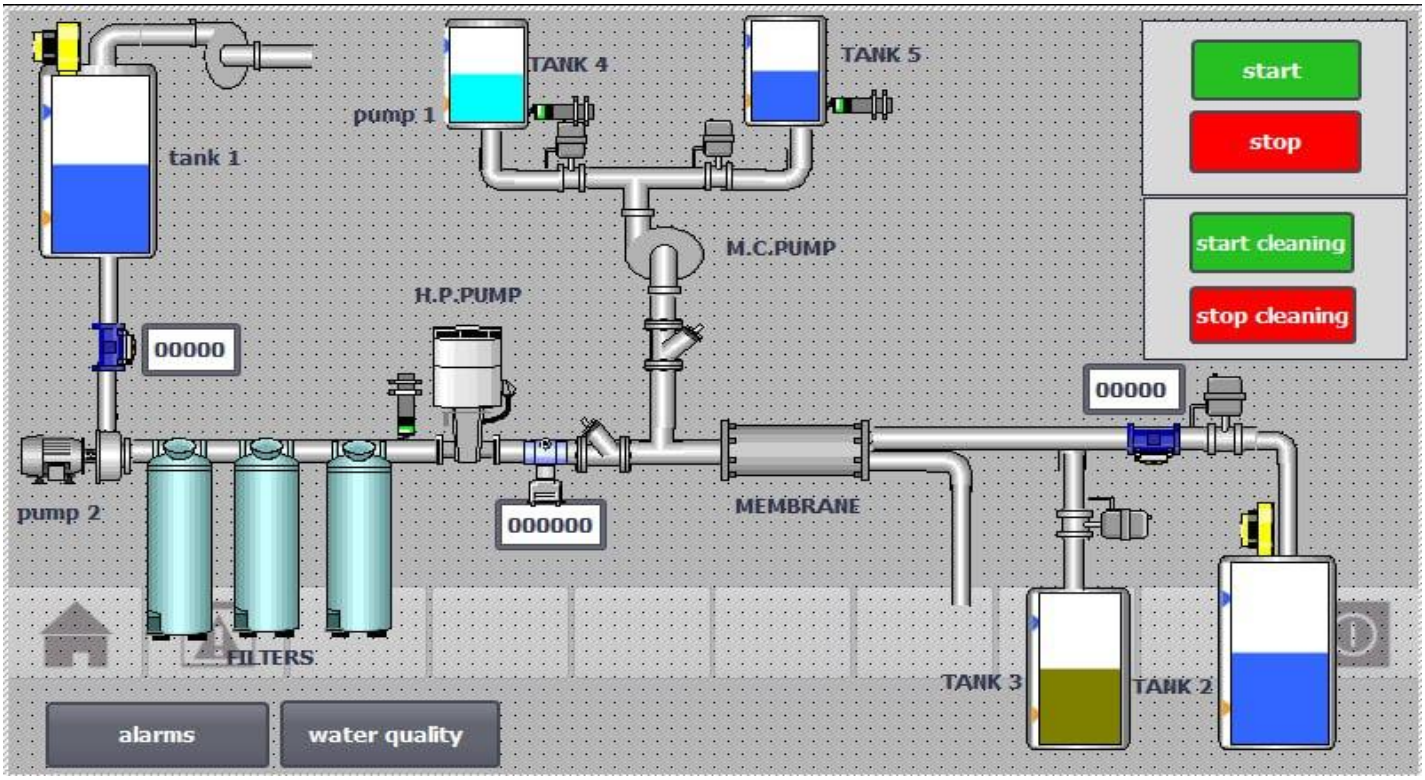
III.16. Conclusion

By utilizing the Siemens S7-1200 controller and the TIA Portal environment to design and construct an integrated control system for a saltwater desalination plant based on reverse osmosis technology, this chapter emphasizes the project's practical element. From hardware setup and variable configuration to programming the control logic in Ladder Diagram language, all project phases were completed. Additionally, energy usage was analyzed and various working modes, including self-cleaning, were taken into consideration.

The findings demonstrated that the TIA Portal offered a centralized and effective setting for integrating all system elements, allowing for accurate and adaptable plant control. This application is a perfect illustration of how crucial it is to include industrial automation into water and energy projects in order to produce intelligent and sustainable solutions.

Chapter IV

Supervision of a Reverse Osmosis Desalination System Using WinCC integrated in TIA Portal



IV.1. Introduction

Supervision is an advanced form of human-machine interaction that allows real-time monitoring of an automated system's status, ensuring optimal operation and maximum transparency. This transparency is provided by the Human-Machine Interface (HMI), which connects the operator to the process, such as a water treatment plant.

This chapter focuses on the supervision and simulation of the water treatment system using PLCSIM, a tool for testing the developed programs. The TIA Portal software offers several testing features, including visualization and supervision, supported by WINCC. Implementing an HMI will enhance process control and enable quick diagnosis in case of failures [108].

IV.2. Supervision

Industrial supervision involves monitoring the operational status of a process to ensure it operates at its optimal performance. The goal is to provide real-time visualization of the evolving parameters of the process, using pre-configured interfaces and the appropriate software. This software acts as an entity capable of providing useful information to the operator, helping them make informed decisions aligned with their objectives, such as process control, production rates, product quality, and the safety of both people and assets. The primary function of the software is to collect data (acquisition and storage), process it, and present it to the operator for supervision. In industrial computing, process supervision serves as an advanced control panel, allowing the monitoring and control of process tasks.

Typically, supervision software runs on a computer connected via an industrial local area network to one or more electronic devices, such as Programmable Logic Controllers (PLCs) or direct control computers (digital control systems). The supervision software consists of a set of screens or pages, with the operator interface presented as a schematic diagram. The application can be single user (monopost) or multi user (multipost). In the case of multi-user supervision, the architecture may be redundant (for redundancy), client server based (one station manages communication for others), or a combination of both. This system plays a critical role in managing alarms and events triggered by threshold breaches, drawing the operator's attention to important issues. It also records the history of faults, operation times, alarms, and predefined parameters [109].

IV.3. WinCC under TIA Portal

WinCC (TIA Portal) is an engineering software used for configuring Simatic panels, Simatic industrial PCs, and standard PCs through the visualization software. Integrated within TIA Portal, WinCC is part of a new integrated engineering concept that provides a unified environment for programming and configuring control solutions, visualization, and drive systems. It is designed for all HMI applications, ranging from simple control solutions with basic panels to SCADA applications for multi-station systems based on PCs [110].

IV.4. HMI Variables

The variables used in supervision systems can be classified into two main types: external variables and internal variables.

- **External variables:** play a crucial role in communication between the various components of an automated system. They allow data exchange between the operator panel and other elements of the system, such as programmable logic controllers (PLCs). These variables are essential for synchronizing information between different devices and ensure smooth and real-time interaction with the automated process. They are typically used to send and receive critical information about the system's status or to adjust certain process parameters based on control needs.

- **Internal variables**: on the other hand, are specific to the operator panel and have no direct connection with the PLC. These variables are stored in the operator panel's internal memory and are used for local tasks such as calculations, temporary data storage, or managing the system's internal states. They are not intended for communication between the operator panel and other system components but are mainly used to facilitate internal supervision operations, allowing data processing functions to be carried out without needing interaction with the PLC.

Thus, each type of variable has a distinct yet complementary role, contributing to the overall performance of the supervision system and ensuring smooth and efficient system operation [111]
.

IV.5. Creation of Supervision

To ensure optimal control of the process, it is essential for the operator to have full transparency, which enables them to effectively supervise and control the installation. This transparency is made possible through the Human-Machine Interface (HMI), an essential tool that ensures the automation system operates the water treatment process correctly.

Once connected to the network, the supervision panel offers several key functions, including:

- Visualization of the status of actuators (pumps, valves) and sensors (pressure, level, temperature).
- Displaying alarms.
- Interacting with the pumps and valves to adjust their operation.
- Detecting faults within the system.
- Remote monitoring of the process.
- Diagnosing and handling alarms to ensure a quick response to any issues [112].

IV.5.1. Programmable Logic Controller Insertion

This step involves inserting the Programmable Logic Controller (PLC) into the project environment as part of the system configuration process

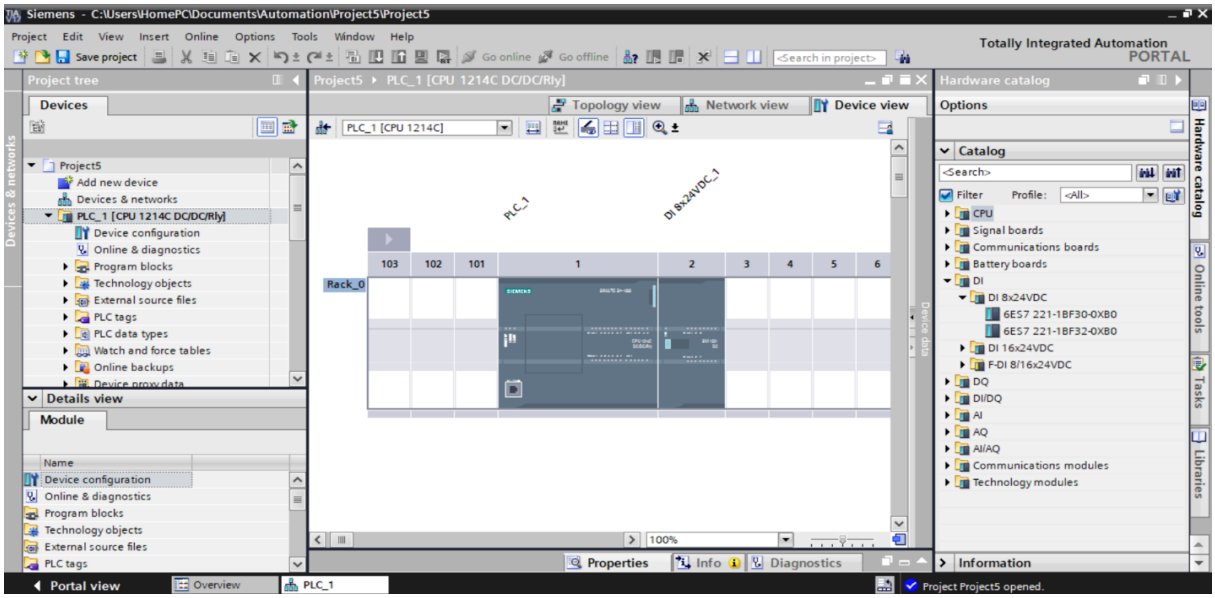


Fig. IV.1. Inserting or Adding the Selected PLC–S7-1214-DC-DC-RLY

IV.5.2. Selection of the Operator Panel or HMI for Visualization (Supervision)

This step involves choosing the appropriate operator panel or HMI device to be used for process visualization and supervision.

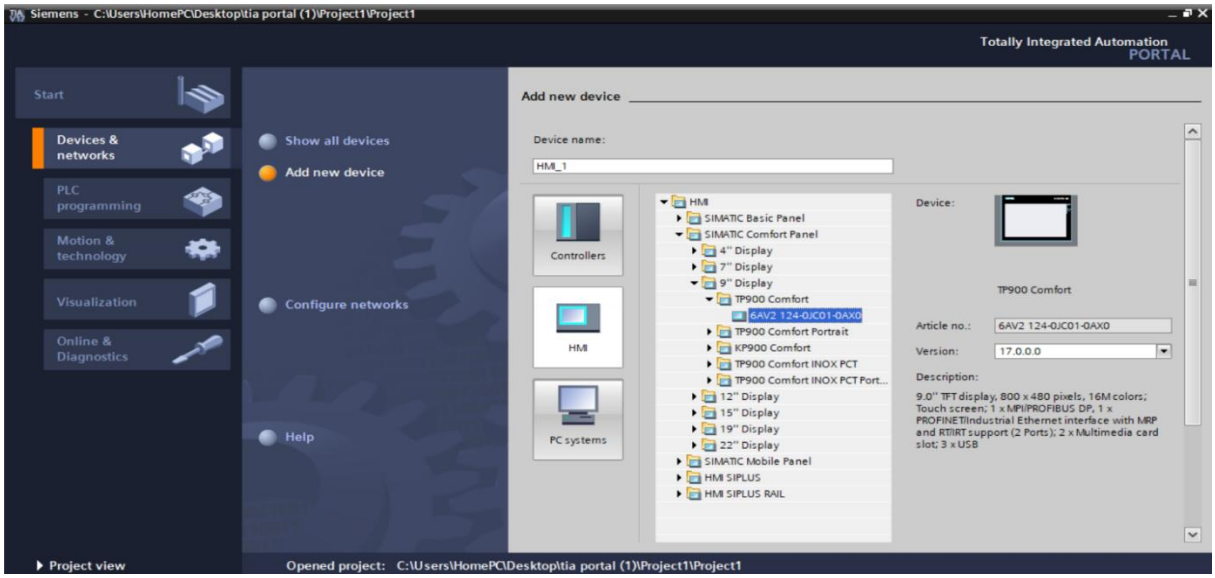


Fig. IV.2. Selection of the Visualization Panel

IV.5.3. Presentation of the Used Control Panel

The TP900 Comfort control panel is an advanced device that offers many features contributing to improved performance and efficiency in control systems. Some of its key features include :

- **High-Quality Touchscreen**: Provides an easy-to-use interface with a high-resolution touchscreen, allowing comfortable and fast interaction with the system.
- **High Performance**: It offers powerful performance that helps manage operations efficiently, making it suitable for various industrial systems.
- **Wide Integration Capability**: Supports a wide range of applications in control and measurement, making it suitable for various industrial systems and facilities.
- **Archiving Capability**: It stores alarms and production data periodically, contributing to performance monitoring and continuous analysis.
- **Automatic Report Generation**: Enables the automatic generation of system and production reports when team shifts change, facilitating process tracking and better organization.
- **Switching Between Manual and Automatic Modes**: Allows easy switching between manual and automatic modes, providing flexibility in process control.
- **Operations Management with Multiple Access Rights**: Allows customization of access to different system functions based on user roles, enhancing security.

- **Flexible Data Display**: Offers a flexible presentation of operational states, current values of production processes, and alarms, as well as displaying any issues that may arise in the system.
- **Multilingual Support**: Provides the option to switch between French and English, making it suitable for use in multilingual environments.
- **Ease of System Shutdown**: Allows the user to shut down the production system quickly and easily when necessary.

The TP900 Comfort control panel is an ideal choice for providing a comfortable and efficient monitoring and control experience in industrial environments [113].

IV.5.3.1. Features of SIMATIC HMI TP900 Comfort

- **Touchscreen**: Equipped with a responsive touchscreen for easy interaction.
- **Tactile Control**: Provides precise tactile control for intuitive operation.
- **TFT Display**: 9" TFT display with high resolution for clear visuals.
- **16 Million Colors**: Capable of displaying rich, vibrant colors for detailed and clear visual information.
- **PROFINET Interface**: Supports the PROFINET communication protocol for seamless connectivity.
- **MPI/PROFIBUS-DP Interface** : Compatible with MPI/PROFIBUS-DP interfaces for flexible communication options.
- **Configuration Memory**: 12 MByte memory for storing configuration settings.
- **Windows CE 6.0**: Runs on Windows CE 6.0, with support for Microsoft updates and security patches.
- **Configurable with WinCC Comfort V11**: Easily configurable using WinCC Comfort V11 software for enhanced setup and management [114].

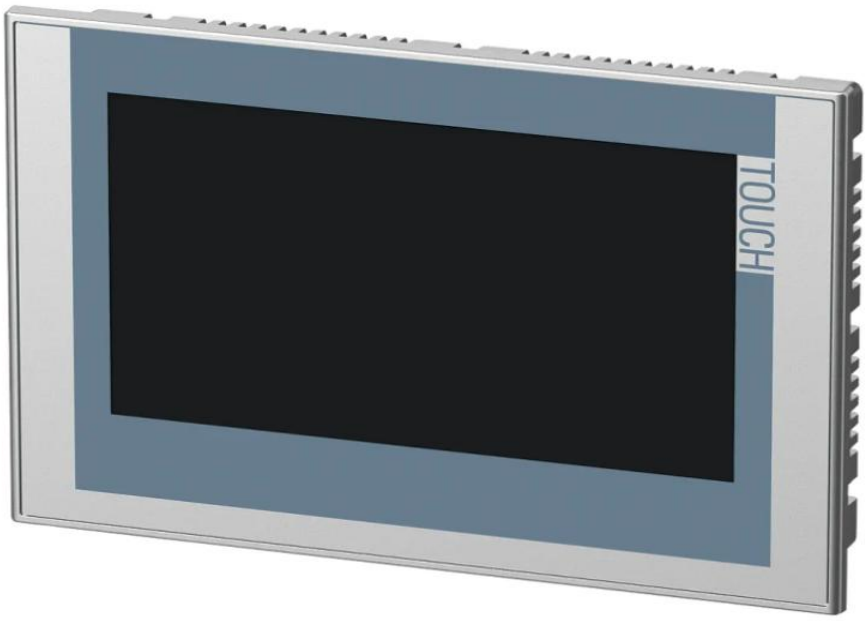


Fig. IV.3. Choosing the Visualization Panel [115]

IV.5.3.2 HMI Configuration

The following figures illustrate the steps involved in configuring a Human-Machine Interface (HMI).

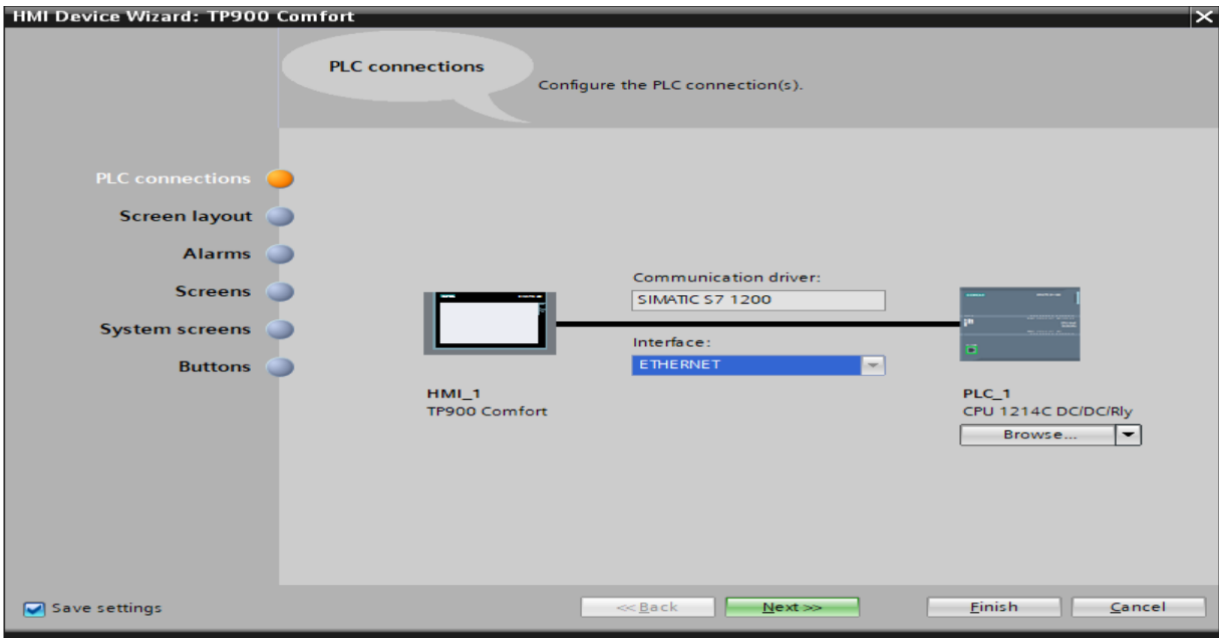


Fig. IV.4. HMI/PLC Connection

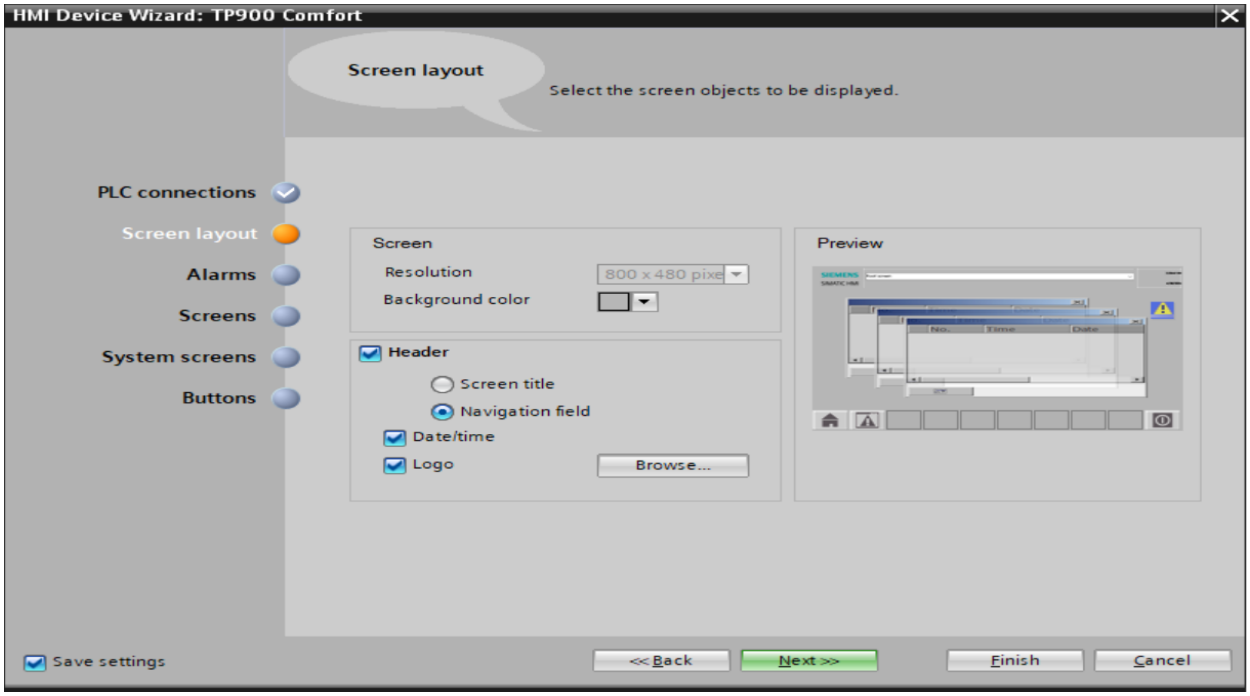


Fig. IV.5. select the screen objects

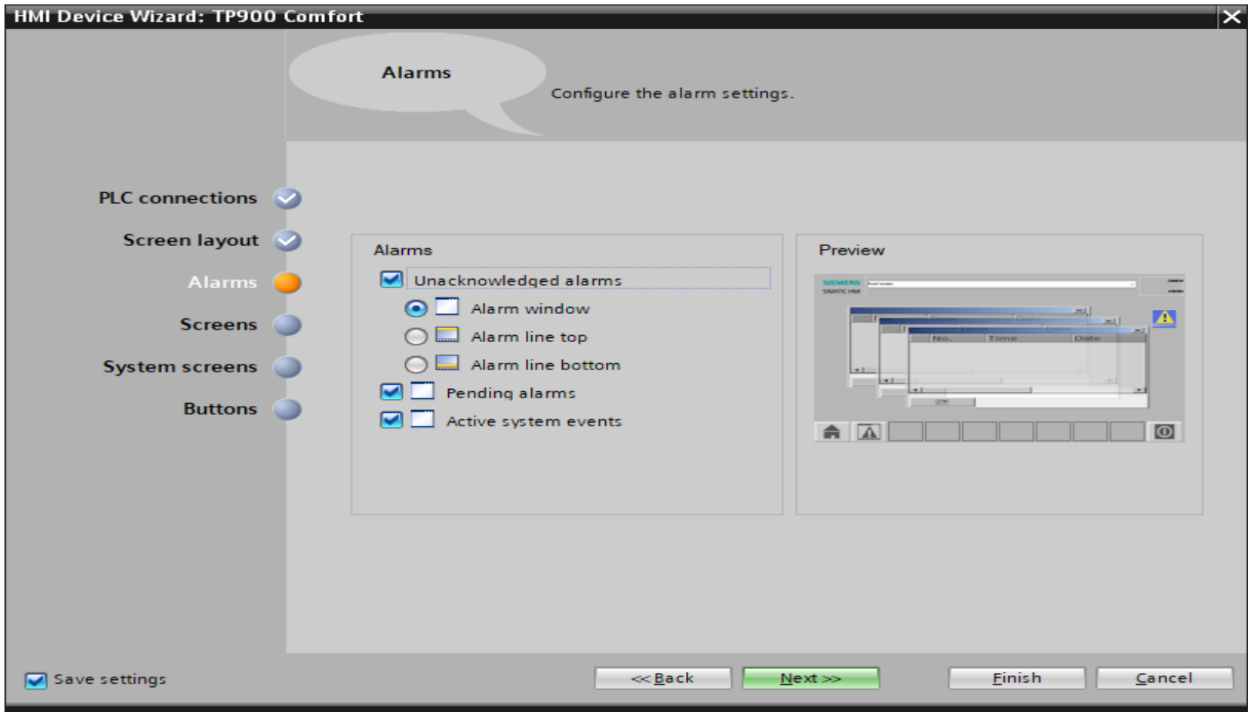


Fig. IV.6. configure the alarm settings

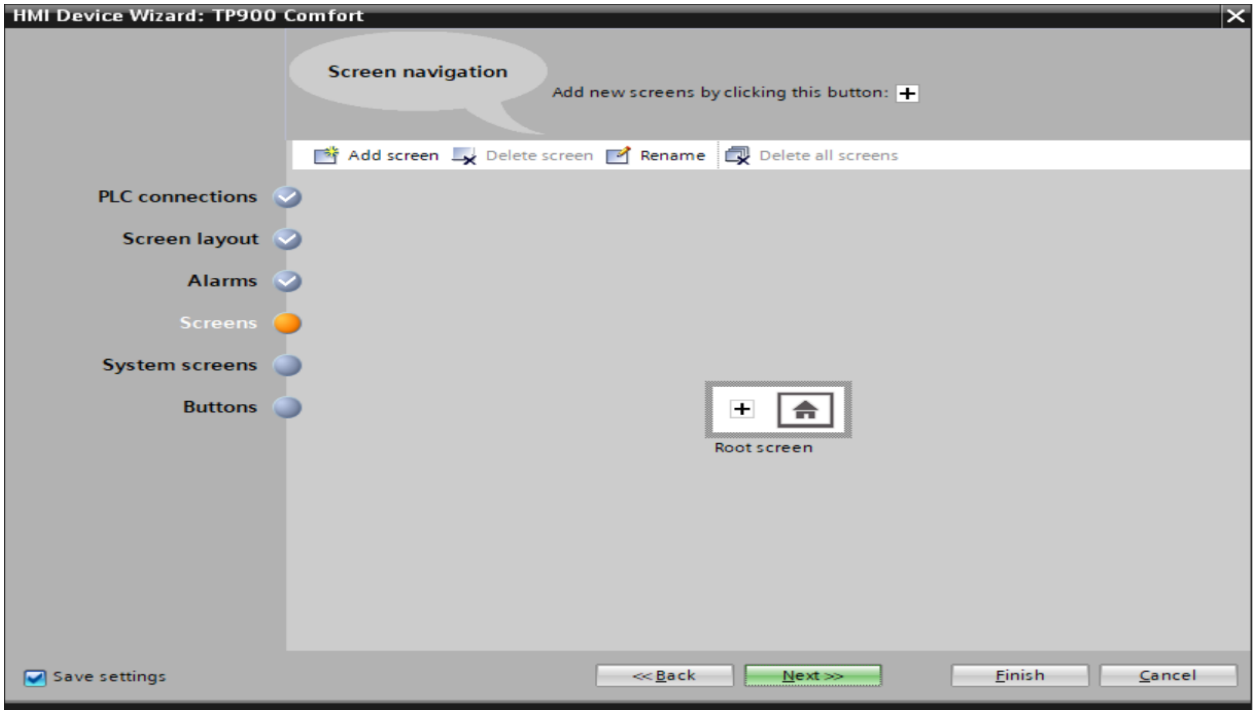


Fig. IV.7. add new screens

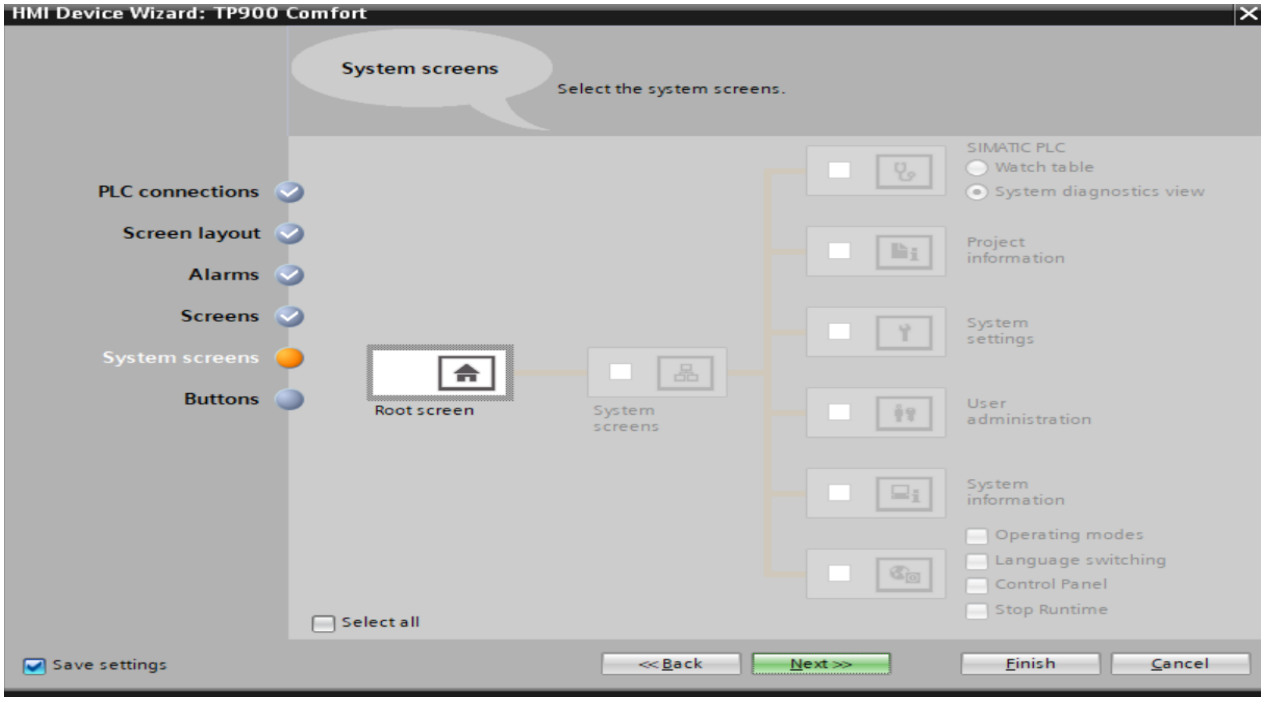


Fig. IV.8. select the system screens

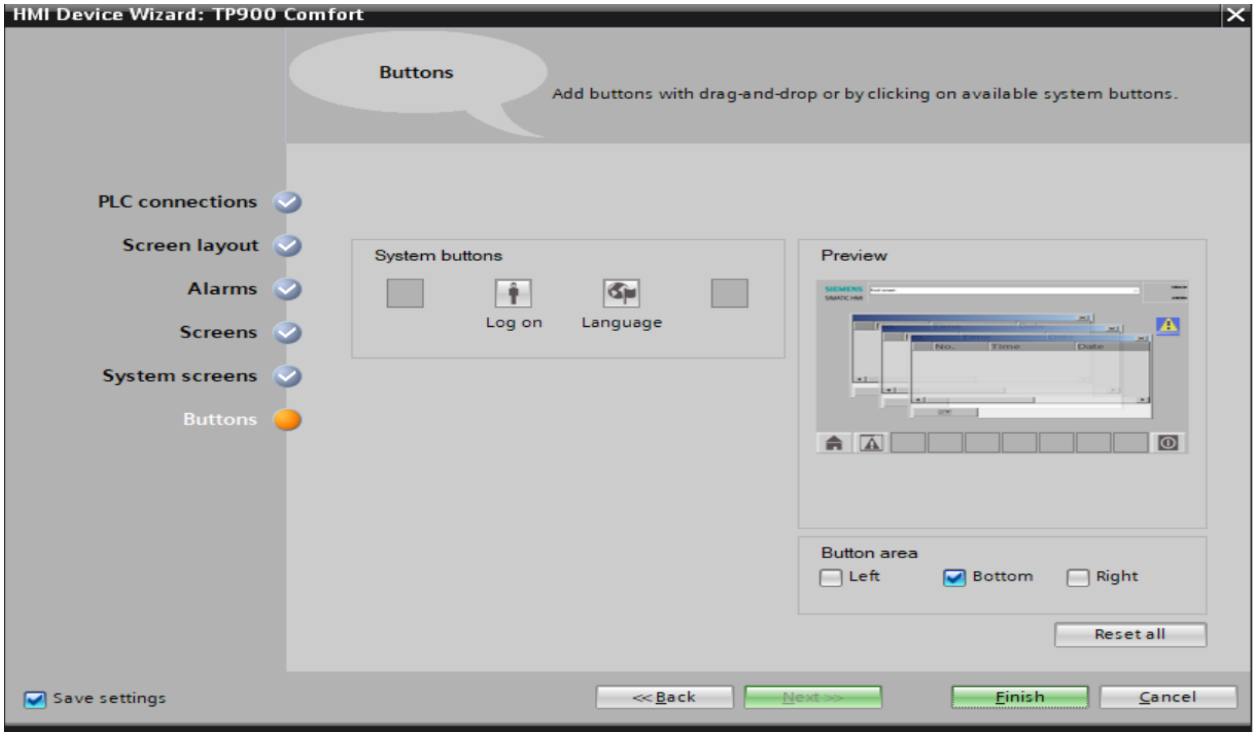


Fig. IV.9. add buttons

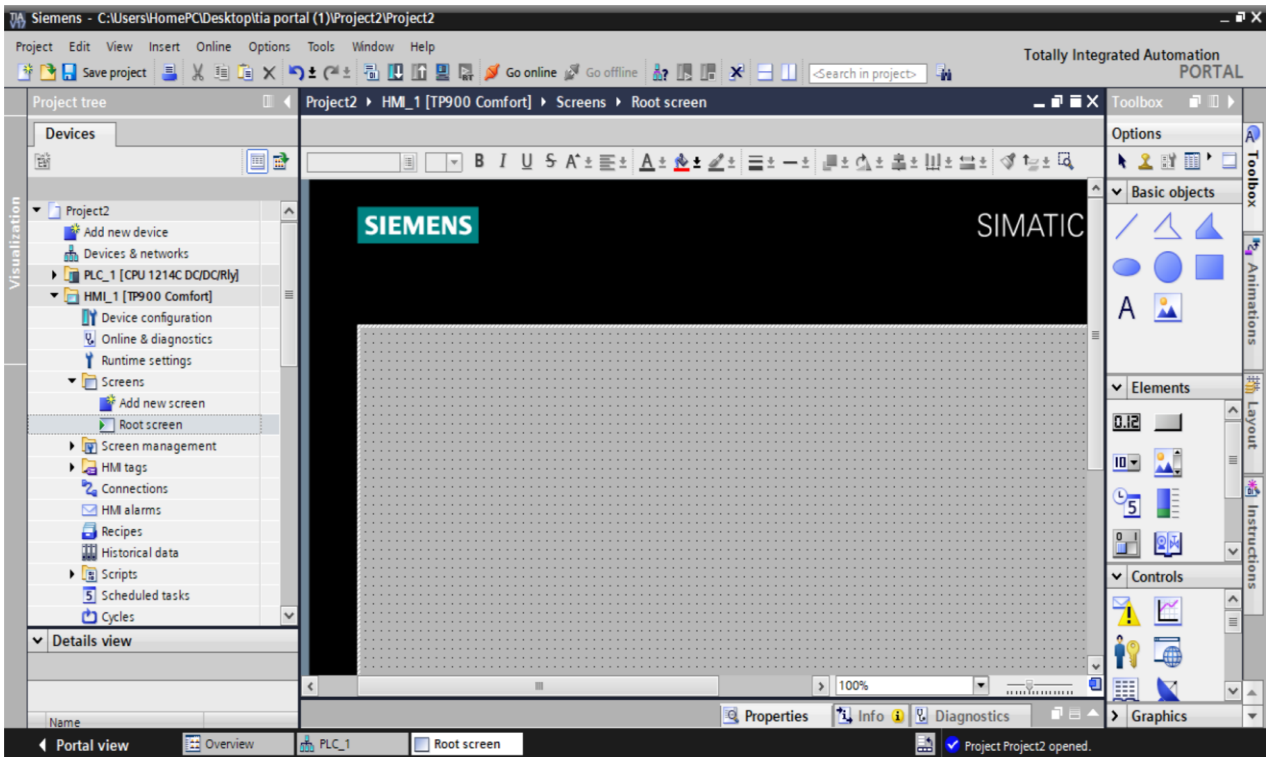
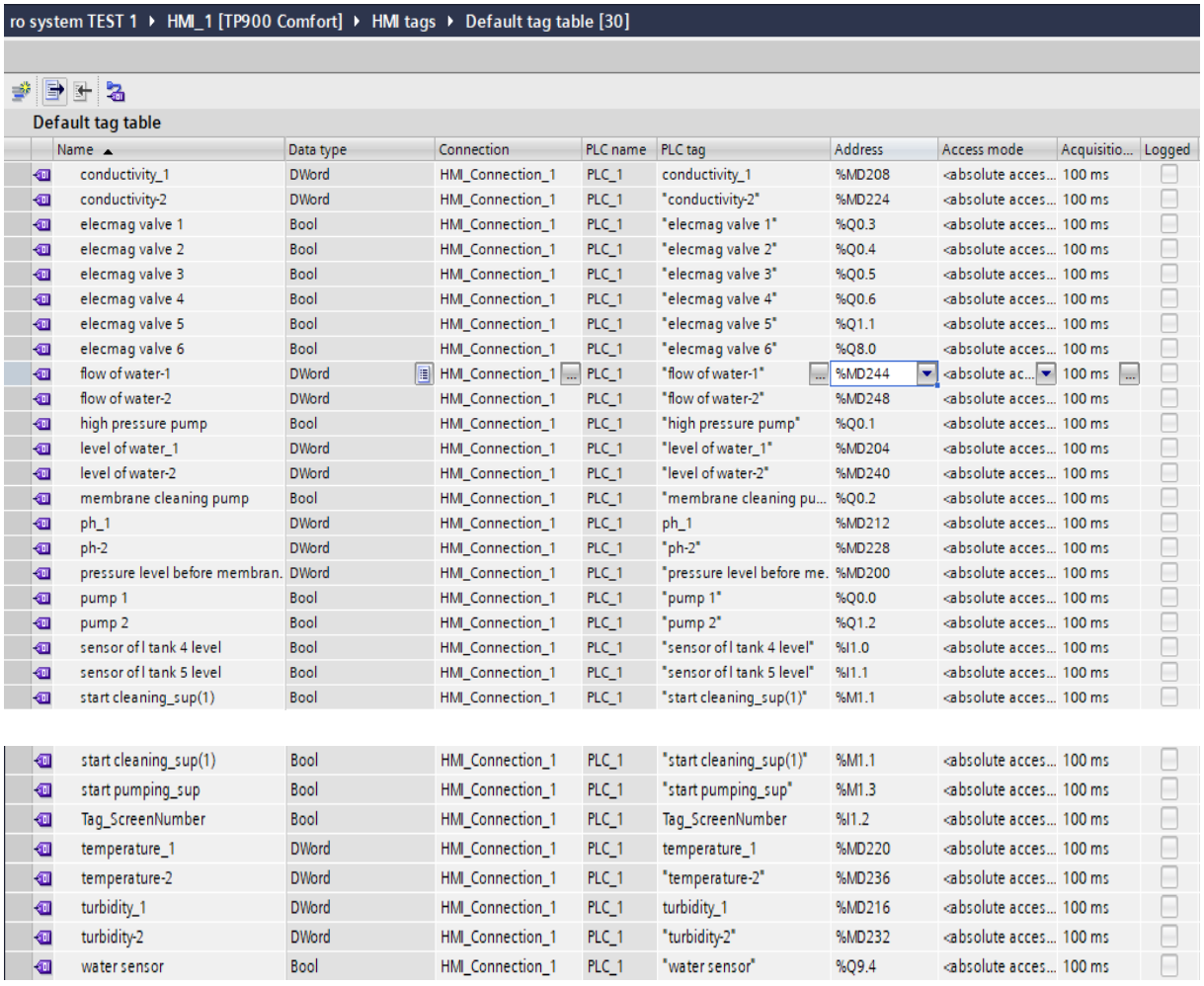


Fig. IV.10. Root View of the Project

IV.6. HMI Variables

In all programs, it is essential to define a list of variables that will be used during programming. For this purpose, a dedicated variable table is created. Using clear and meaningful variable names greatly improves the readability and ease of use of the program. This type of addressing is referred to as "relative addressing «. After specifying the variable name, the data type is defined, followed by its address in memory. The input and output variable tables are defined based on the requirements outlined in the project specifications [116].



ro system TEST 1 ▸ HMI_1 [TP900 Comfort] ▸ HMI tags ▸ Default tag table [30]

Default tag table

Name	Data type	Connection	PLC name	PLC tag	Address	Access mode	Acquisitio...	Logged
conductivity_1	DWord	HMI_Connection_1	PLC_1	conductivity_1	%MD208	<absolute acces...	100 ms	
conductivity-2	DWord	HMI_Connection_1	PLC_1	"conductivity-2"	%MD224	<absolute acces...	100 ms	
elecmag valve 1	Bool	HMI_Connection_1	PLC_1	"elecmag valve 1"	%Q0.3	<absolute acces...	100 ms	
elecmag valve 2	Bool	HMI_Connection_1	PLC_1	"elecmag valve 2"	%Q0.4	<absolute acces...	100 ms	
elecmag valve 3	Bool	HMI_Connection_1	PLC_1	"elecmag valve 3"	%Q0.5	<absolute acces...	100 ms	
elecmag valve 4	Bool	HMI_Connection_1	PLC_1	"elecmag valve 4"	%Q0.6	<absolute acces...	100 ms	
elecmag valve 5	Bool	HMI_Connection_1	PLC_1	"elecmag valve 5"	%Q1.1	<absolute acces...	100 ms	
elecmag valve 6	Bool	HMI_Connection_1	PLC_1	"elecmag valve 6"	%Q8.0	<absolute acces...	100 ms	
flow of water-1	DWord	HMI_Connection_1	PLC_1	"flow of water-1"	%MD244	<absolute ac...	100 ms	
flow of water-2	DWord	HMI_Connection_1	PLC_1	"flow of water-2"	%MD248	<absolute acces...	100 ms	
high pressure pump	Bool	HMI_Connection_1	PLC_1	"high pressure pump"	%Q0.1	<absolute acces...	100 ms	
level of water_1	DWord	HMI_Connection_1	PLC_1	"level of water_1"	%MD204	<absolute acces...	100 ms	
level of water-2	DWord	HMI_Connection_1	PLC_1	"level of water-2"	%MD240	<absolute acces...	100 ms	
membrane cleaning pump	Bool	HMI_Connection_1	PLC_1	"membrane cleaning pu...	%Q0.2	<absolute acces...	100 ms	
ph_1	DWord	HMI_Connection_1	PLC_1	ph_1	%MD212	<absolute acces...	100 ms	
ph-2	DWord	HMI_Connection_1	PLC_1	"ph-2"	%MD228	<absolute acces...	100 ms	
pressure level before membran...	DWord	HMI_Connection_1	PLC_1	"pressure level before me...	%MD200	<absolute acces...	100 ms	
pump 1	Bool	HMI_Connection_1	PLC_1	"pump 1"	%Q0.0	<absolute acces...	100 ms	
pump 2	Bool	HMI_Connection_1	PLC_1	"pump 2"	%Q1.2	<absolute acces...	100 ms	
sensor of l tank 4 level	Bool	HMI_Connection_1	PLC_1	"sensor of l tank 4 level"	%I1.0	<absolute acces...	100 ms	
sensor of l tank 5 level	Bool	HMI_Connection_1	PLC_1	"sensor of l tank 5 level"	%I1.1	<absolute acces...	100 ms	
start cleaning_sup(1)	Bool	HMI_Connection_1	PLC_1	"start cleaning_sup(1)"	%M1.1	<absolute acces...	100 ms	
start cleaning_sup(1)	Bool	HMI_Connection_1	PLC_1	"start cleaning_sup(1)"	%M1.1	<absolute acces...	100 ms	
start pumping_sup	Bool	HMI_Connection_1	PLC_1	"start pumping_sup"	%M1.3	<absolute acces...	100 ms	
Tag_ScreenNumber	Bool	HMI_Connection_1	PLC_1	Tag_ScreenNumber	%I1.2	<absolute acces...	100 ms	
temperature_1	DWord	HMI_Connection_1	PLC_1	temperature_1	%MD220	<absolute acces...	100 ms	
temperature-2	DWord	HMI_Connection_1	PLC_1	"temperature-2"	%MD236	<absolute acces...	100 ms	
turbidity_1	DWord	HMI_Connection_1	PLC_1	turbidity_1	%MD216	<absolute acces...	100 ms	
turbidity-2	DWord	HMI_Connection_1	PLC_1	"turbidity-2"	%MD232	<absolute acces...	100 ms	
water sensor	Bool	HMI_Connection_1	PLC_1	"water sensor"	%Q9.4	<absolute acces...	100 ms	

Fig. IV.11. HMI tag table

IV.7. SCADA Programming for RO Desalination System Using TIA Portal

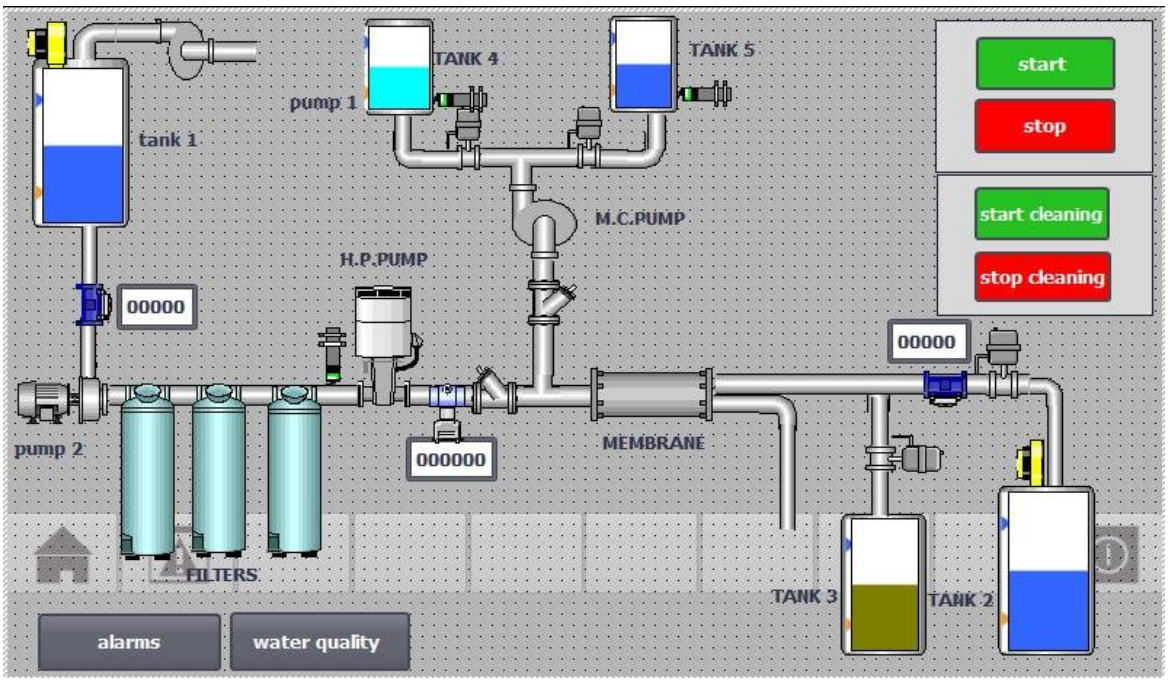


Fig. IV.12. SCADA Programming for RO Desalination System

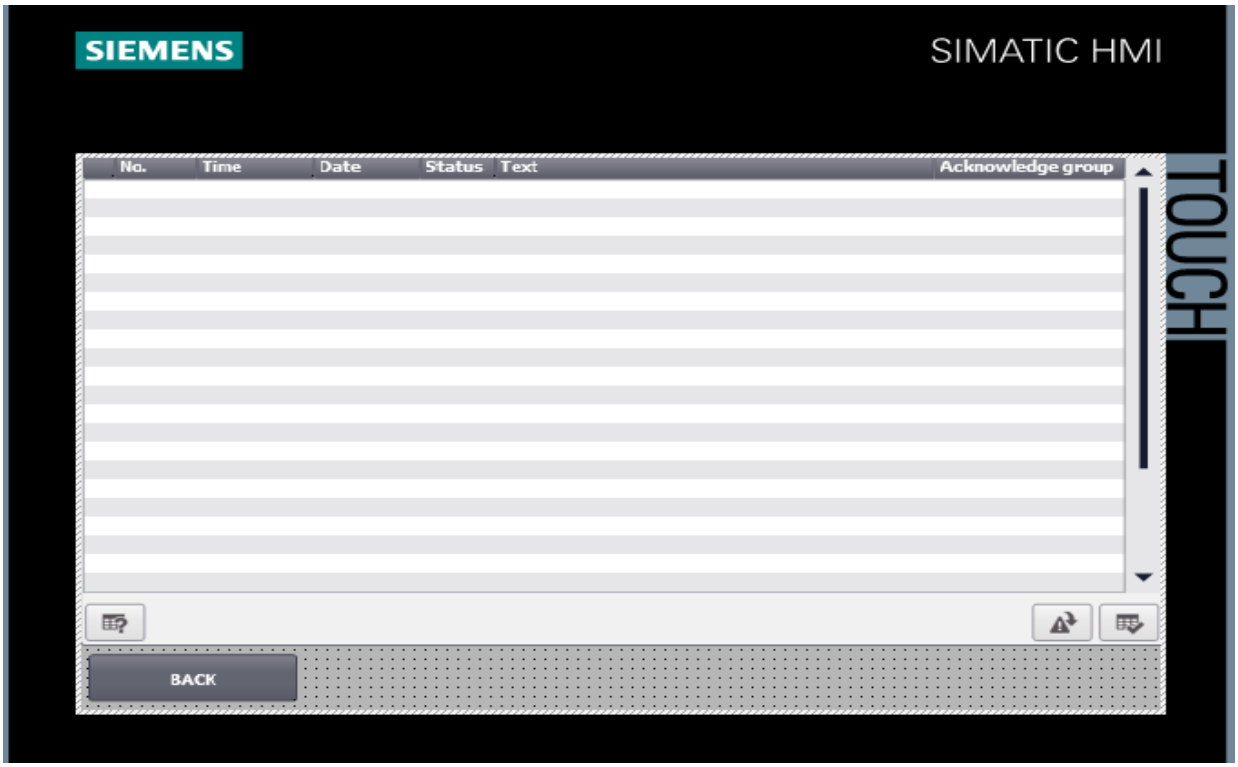


Fig. IV.13. Alarme screen

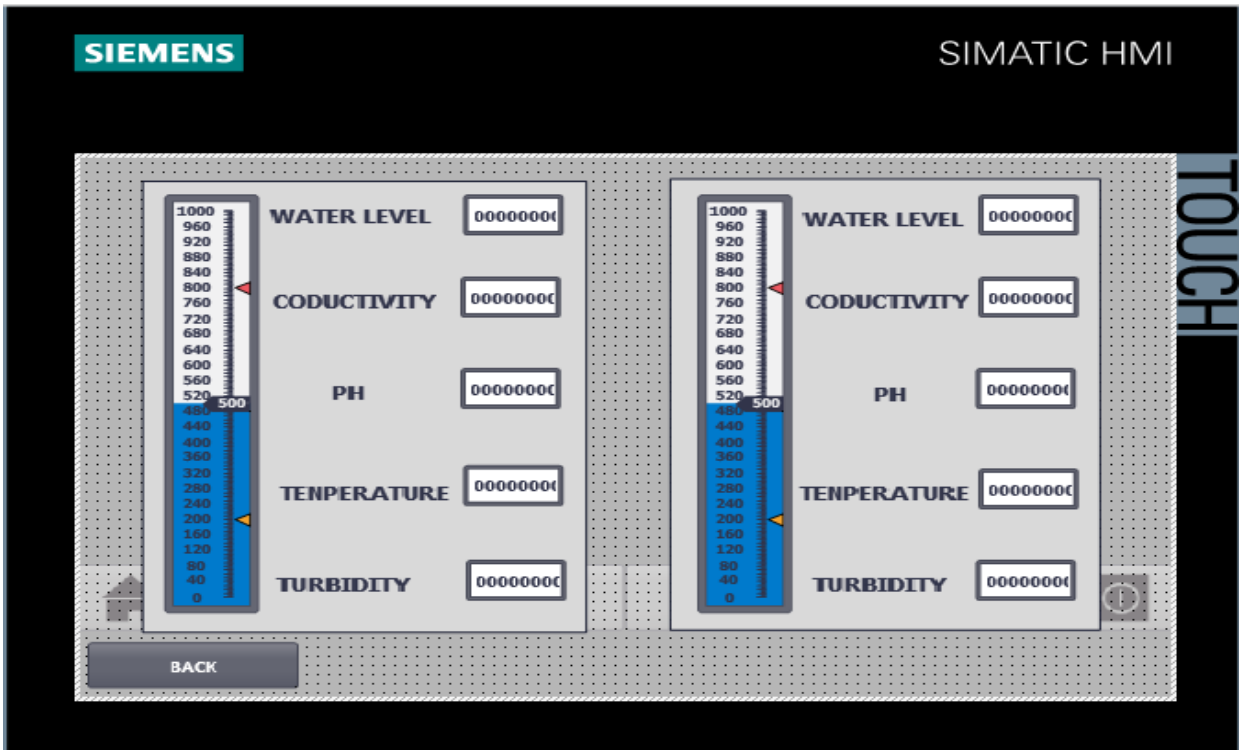


Fig. IV.14. quality water screen

IV.8. Conclusion

In this chapter, we developed the supervision interface for the reverse osmosis system, which enables real-time monitoring of the process. We found that the WinCC software within the TIA Portal V17 platform is a powerful and versatile tool, offering a wide range of features that make it ideal for integrated automation solutions. It ensures a continuous and reliable flow of information throughout the system. The modular structure of WinCC allows for seamless integration of necessary applications. It combines a modern Windows-based architecture with the simplicity of graphical design tools, and includes all the essential components for process visualization and control. The operator can easily design a clear and dynamic interface that reflects the actual state of the installation, using animated effects, color codes, and custom messages to enhance system transparency and understanding.

Additionally, the use of (PLCSIM) enabled us to thoroughly test the developed programs. TIA Portal offers multiple simulation and testing options, such as real-time visualization and supervision, all supported by WinCC. This makes it an ideal environment for validating and optimizing the control logic of the reverse osmosis system before its real world implementat.

General Conclusion

Water desalination technologies are among the most effective scientific methods to address the growing problems related to the scarcity of fresh water, particularly in areas suffering from drought or limited water resources. In this context, reverse osmosis (RO) technology has established its leading position due to its exceptional ability to remove salts and minerals, making water suitable for both human and industrial use. However, the practical success of RO technology relies not only on its physical and chemical efficiency but also heavily on the precision of the control systems managing its operations.

In this regard, programmable logic controllers (PLC) contribute significantly to the precise control and continuous optimization of desalination unit performance. According to studies, the integration of PLC systems in RO systems enhances operational reliability by monitoring operational variables and activating automatic adjustment mechanisms based on pre-defined criteria. This leads to a reduction in human error and an increase in water and energy consumption efficiency.

Automated control systems also enable proactive preventive maintenance, accurate fault detection, and real-time monitoring of operational data, directly contributing to reduced downtime and improved operational sustainability for desalination plants. Furthermore, the compatibility of these systems with other advanced technologies, such as Supervisory Control and Data Acquisition (SCADA) systems, paves the way for smarter and more flexible desalination solutions to tackle future challenges.

Thus, it can be said that the level of integration and control provided by automated digital systems is a critical factor for the future success of water desalination technologies, alongside innovations in treatment methods themselves. It is recommended to continue developing specialized industrial software for desalination plants and supporting applied research that integrates automation and renewable energy, as this plays a significant role in enhancing resource efficiency and reducing environmental impact.

Based on the above, integrating reverse osmosis desalination systems with PLC based control frameworks represents a comprehensive and promising technological model for improving water security and developing vital infrastructure for resource management, within a broad vision founded on the principles of sustainability, efficiency, and innovation.

Perspectives

Industrial automation provides plenty of benefits for the user. It comes in several types to fit the needs of various requirements of manufacturing industries. Therefore, automation products are important because they reduce production costs while improving product quality, resulting in higher profits. At Schneider Electric, we help our clients achieve reduced costs, increased productivity, and improved equipment supervision through Industrial automation.

The future of the industrial automation industry looks promising. With advancements in technologies like AI, robotics, and IIoT, the industry is expected to witness further growth and innovation. Automation will continue to revolutionize various sectors, including manufacturing, healthcare, transportation, and agriculture. As businesses strive for increased efficiency and competitiveness, industrial automation will play a crucial role in shaping the future.

The industrial automation industry is experiencing significant growth and transformation. With the integration of AI, adoption of collaborative robots, and advancements in IIoT, the industry is poised for further development. However, challenges such as high initial investment and cybersecurity threats need to be addressed. Overall, industrial automation is driving sustainable development and revolutionizing various sectors, making it a crucial industry for the future.

Despite its numerous benefits, the industrial automation industry also faces certain challenges. One of the major challenges is the high initial investment required for implementing automation systems. Additionally, there is a need for skilled professionals who can design, operate, and maintain these complex systems. Cybersecurity is another concern; as industrial automation systems are vulnerable to cyber threats.

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