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MÉMOIRE

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Thème

Développement d'un DCS pour une Station de Dessalement sous PCS7 v9.1

Development of a DCS for a Desalination Station with PCS7 V9.1

Présenté et soutenu publiquement par :

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Abstract:

This project focuses on the theoretical aspects of water desalination and how to select the appropriate process for study. Additionally, it explores the practical application of process-oriented plant automation in DCS, using an actual desalination concept provided by Siemens as an example, further we initialize the realization of this project starting off by the description of the specifications sheet, then identifying and modelling specific process and the logic behind the program that runs the process then establish a simulation of plant all that under Siemens's software PCS7 v9.1.

Key-words: *Desalination, PCS7, DCS, development, CFC Programming, WinCC*

Résumé :

Ce projet se concentre sur les aspects théoriques du dessalement de l'eau et sur la manière de sélectionner le processus approprié pour l'étude. De plus, il explore l'application pratique de l'automatisation des usines axée sur les processus dans un système de contrôle distribué (DCS), en utilisant un concept réel de dessalement fourni par Siemens comme exemple. De plus, nous initialisons la réalisation de ce projet en commençant par la description du cahier de charge, puis en identifiant et en modélisant des processus spécifiques et la logique du programme qui les exécute. Ensuite, nous établissons une simulation de l'usine, le tout sous le logiciel PCS7 v9.1 de Siemens.

Mots clés *: Déssalement, PCS7,DCS, Developement,CFC programmation,WinCC*

.

الملخص:

يركز هذا المشروع على الجوانب النظرية لتحلية المياه وكيفية اختيار العملية المناسبة للدراسة.

بالإضافة إلى ذلك ، يستكشف التطبيق العملي لأتمتة المصانع القائمة على العمليات في نظام تحكم موزع (DCS) ، باستخدام نموذج تحلية المياه مقدم من شركة siemens كمثال.

بالإضافة إلى ذلك ، نبدأ في تحقيق هذا المشروع من خلال البدء بوصف المواصفات ، ثم تحديد ونمذجة العمليات المحددة ومنطق البرنامج الذي ينفذها.

بعد ذلك ، قمنا بإنشاء محاكاة للمصنع ، كل ذلك بموجب برنامج PCS7 v9.1 من شركة.Siemens

كلمات مفتاحية:تحلية المياه, نظام التحكم الموزع,تطوير, برمجة.,WinCC

بِسْمِ اللهِ الرَّحْمَنِ الرَّحِيمِ

رَبِّ أَوْزِعْنِي أَنْ أَشْكُرَ نِعْمَتَكَ الَّتِي أَنْعَمْتَ عَلَيَّ وَعَلَىٰ وَالِدَيَّ وَأَنْ أَعْمَلَ صَالِحًا
تَرْضَاهُ وَأَدْخِلْنِي بِرَحْمَتِكَ فِي عِبَادِكَ الصَّالِحِينَ

I have the great pleasure of dedicating this modest work, as a gesture of gratitude:

To her who gaves me birth in pain and joy, my symbol of love :

My very dear mother the light of my life.

To whom I hold dear and greatly appreciate his continued support throughout from my studies

,my support in life:

My reason for living my father "Vava"

To my siblings Kenza and Omar Abdelaziz

To all my family Nawel,Saadia,Rachid ,Fares, and all my aunts and

uncles, my Grand-parents and my cousins

To my dear friends Djihene, Djihene, Nesrine, Rajaa

To Bouhanna Zakaria

At the end I dedicate this thesis to my partner Bouhanna Oussama

HOUBELLI SARRA

بسْمِ اللهِ الرَّحْمَنِ الرَّحِيمِ

رَبِّ أَوْزِعْنِي أَنْ أَشْكُرَ نِعْمَتَكَ الَّتِي أَنْعَمْتَ عَلَيَّ وَعَلَىٰ وَالِدَيَّ وَأَنْ أَعْمَلَ صَالِحًا تَرْضَاهُ وَأَدْخِلْنِي بِرَحْمَتِكَ فِي عِبَادِكَ الصَّالِحِينَ

I have the great pleasure of dedicating this modest work, as a gesture of gratitude:

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To my dear Grandmother, my aunt and my cousin Bilal

To all the individuals whom I genuinely care for them and who reciprocate that love towards me

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BOUHANNA OUSSAMA

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Acronyms

AC	Alternating current
APL	Advanced Process Library
AS	Automation System
ASI	Actuator Sensor Interface
CAN	Controller Area Network
CFC	Continuous Function Chart
CM	Control Module
CMT	Control Module Type
COM	Component Object Model
CPU	Central Processing Unit
CSP	Concentrating Solar Power
D COM	Distributed Component Object Model
DC	Direct Current
DCS	Distributed Control System
DP	Profibus
EDR	Electrodialysis Reversal
ERP	Enterprise Resource Planning
ES	Engineering Station
FBD	Function Block Diagram
Fig	Figure
GSD	General Station Description
HMI	Human Machine Interface
HPP	High Pressure Pump
HW	HardWare
I/O	Input/ Output
IE	Industrial Ethernet
INT	Integer
Intlk	Interlock
IoT	Internet of Things
IP	Internet Protocol address
LSI	Langeliers Saturation Index
LT	Level Transmitter
MBP	Manchester Bus Powered
MED	Multi Effect Distillation
MES	Manufacturing Execution System
MPI	Multi-Point Interface
MRP	Media Redundancy Protocol
MSF	Multi-stage flash
MSF BR	multi-stage flash Brine recycle
MVC	Mechanical Vapor Compression

OLE	Object Linking and Embedding
OLM	Optical Link Module
OPC	Open Platform Communications
OS	Operating Station
P & ID	Piping and instrumentation diagram
PCS7	Process Control System 7
Permit	Permission
PLC	Programmable Logic Controller
PLC SIM	Programmable Logic Controller Simulator
PN	Profinet
Protect	Protection
Pv	Process Value
PV	Photovoltaic
RE	Renewable Energy
RO	Reverse Osmosis
RT	Runtime
SCADA	Supervisory Control and Data Acquisition
SFC	Sequential Function Charts
Sw	SoftWare
SW	SeaWater
SWRO	SeaWater Reverse Osmosis
T	Temperature
TCP/IP	Transmission Control Protocol/Internet Protocol
VFD	Variable Frequency Drives
WH	Warning High
WinCC	Windows Control Center

General Introduction

Water is the number one resource, and desalination is a key technology to produce sufficient and affordable drinking water. While the market is growing steadily, it is at the same time subject to enormous cost pressures. To achieve optimum plant performance and return on investment, the industry needs to streamline the design, construction, commissioning, and operation of desalination plants.

The automation of water treatment plants has now become a necessity. It improves operation conditions, plant performance, assist supervision and reduces the risk of human error as well as improve the operational safety.

Standardizing automation engineering presents a significant challenge due to the diversity of process actions, procedures, devices, and complex plant configuration requirements. This requires careful selection and sizing of products tailored to the specific application. Our task stands to choose the appropriate hardware and software that offers reliable plant-wide automation solution in the water industry sector.

This thesis is organized into four chapters as follows:

The first chapter begins with a brief introduction to seawater desalination and its necessity. It then delves into a discussion of the existing processes and technologies utilized in desalination. Additionally, renewable-driven power techniques implemented in the process are explored. The chapter concludes with a comparison of the processes, determining the technology to be applied for the remainder of the thesis.

The second chapter discuss the theory and evolution of distributed control systems (DCS) were discussed. Furthermore, a comprehensive overview of DCS architecture, its components, communication methods across its full structures, and the typical field devices employed in desalination plants was provided.

The third chapter focalise on Siemens' DCS PCS7, the description of this system encompasses both its software and hardware aspects. The specification sheet of post-treatment in a desalination plant concept, provided by Siemens, was analysed to extract valuable information and identify automation system features suitable for program development.

In the final chapter, the procedures to implement a DCS application with PCS7 are described. The techniques employed to develop the program, including the use of supervisory view pictures, are explained. Additionally, the discussion covers the operation rules required to establish a reliable and secure system. In the last part, the application is executed on PLCSIM with WinCC Runtime to observe the process behavior and present simulation results.In the final chapter, we describe the procedures to implement a DCS application with PCS7. We explain the techniques used to develop our program, including the use of supervisory view pictures. Additionally, we discuss the operation rules necessary to create a reliable and secure system. In the last part, we run the application on PLCSIM with WinCC Runtime and observe the behavior of the process, providing our simulation results.

Chapter 1: Desalination Engineering Overview

This chapter starts by giving a short introduction to why seawater desalination is important. It then talks about the different methods and technologies used in desalination. It also looks at how renewable energy can be used to power the process. The chapter ends by comparing the different processes and deciding which technology will be used for the rest of the thesis.

1.1 INTRODUCTION

Approximately 97.5 percent of the water on our planet is located in the oceans and therefore is classified as seawater. 2.5% is freshwater on the world, roughly 70% is found as polar ice and snow, and 30% is found as groundwater, river and lake water, and air moisture. The amount of water on Earth is enormous, but only a small portion of it (8.4 million mi3 of its 333 million m^3) has low salt and can be used after ordinary water treatment. Desalination offers a way to access the ocean, which is the world's main source of freshwater [1].

Recognizing the importance of water for sustainable development, the United Nations declared 2005-2015 the “Water for Life” decade. This year water crises ranked as third on the world’s top ten risks, according to a report from the World Economic Forum based on concern, likelihood, impact and interconnections [2]. Indeed, water is crucial for social and economic development. Yet evidence points to the fact that the current use of water is unsustainable [3]. Growing demand for water resources due to population growth and evolving consumption patterns has increased water scarcity, amplifying the pressure on the natural resource and the ecosystem. The global population is expected to reach 9.3 billion by 2050 [4]. This growth will increase the urban areas of the planet and the need for drinking water, health and sanitation, as well as energy, food and other goods and services that require water for their production and delivery. Agricultural water consumption, which is a significant cause of water scarcity, is expected to increase 20% by 2050 [4].

1.2 DEFINITION

Desalination is the process of removing salt and other minerals from seawater or brackish water to make it suitable for human consumption, irrigation, or industrial use. This process involves various technologies that remove salt and other minerals from the water to produce fresh water. Desalination is becoming an increasingly important solution to address water scarcity issues in regions with limited freshwater resources [5].

1.3 DESALINATION TECHNOLOGIES

A desalination process essentially separates saline water into two parts - one that has a low concentration of salt (treated water or product water), and the other with a much higher concentration than the original feed water, usually referred to as brine concentrate or simply as ‘concentrate’.

Seawater and brackish water are commonly subjected to desalination using two primary water treatment technologies: thermal evaporation (distillation) and reverse osmosis (RO) membrane separation [1].

Both technologies need energy to operate and produce fresh water. Within those two broad types, there are sub-categories (processes) using different techniques. The major desalination processes are identified in Table .

Table 1-1. Desalination Technologies and processes

Thermal Technology	Membrane Technology
Multi-Stage Flash Distillation (MSF)	Electrodialysis (ED)
Multi-Effect Distillation (MED)	Electrodialysis Reversal (EDR)
Vapor Compression Distillation	Reverse Osmosis (RO)

1.4 THERMAL DESALINATION

All thermal desalination technologies apply distillation (i.e., are based on heating the source water) to produce water vapor, which is then condensed into a low-salinity water. Since the energy for water evaporation is practically not dependent on the source water salinity concentration, thermal evaporation is very suitable for desalination of high-salinity waters and brine. This is one of the reasons that thermal desalination has been widely adopted by Middle Eastern countries such as Saudi Arabia, Oman, Qatar, the United Arab Emirates, Bahrain, and Kuwait, which use some of the most saline water bodies on the planet for water supply (namely, the Red Sea, Persian Gulf, Gulf of Oman, and Indian Ocean). At present, approximately 75 percent of the world’s thermal desalination plants are located in the Arabian Peninsula [1].

All thermal desalination plants have five key streams: source water (seawater, brackish water, or brine) used for desalination; steam needed for evaporation of the source water; cooling water to condense the freshwater vapor generated from the source water’s evaporation; low salinity distilled water (distillate); and concentrate (brine), which contains the salts and other impurities separated from the source water.

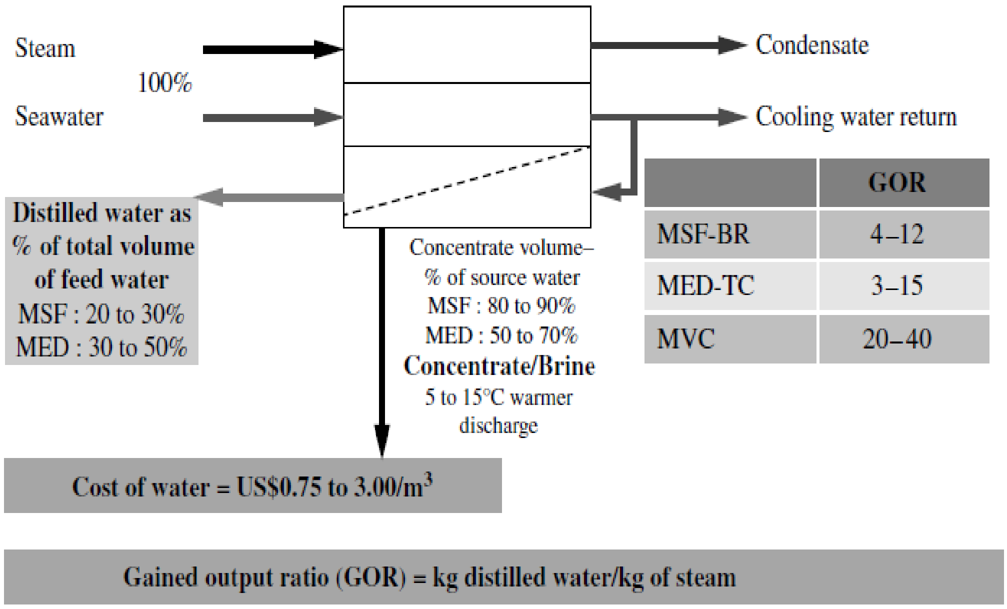

Figure 1-1. General schematic of thermal evaporation technologies [1]

1.4.1 Multistage Flash Distillation

In the multistage flash distillation (MSF) evaporator vessels (also referred to as flash stages or effects), the high-salinity source water is heated to a temperature of 90 to 115°C in a vessel (the heating section in Fig) to create water vapor. The pressure in the first stage is maintained slightly below the saturation vapor pressure of the water. So, when the high-pressure vapor created in the heating section enters into the first stage, its pressure is reduced to a level at which the vapor "flashes" into steam. Steam (waste heat) for the heating section is provided by the power plant co-located with the desalination plant. Each flash stage (effect) has a condenser to turn the steam into distillate. The condensers are equipped with heat exchanger tubes, which are cooled by the source water that is fed to the condensers [1].

Entrainment separators (mist eliminators or demister pads) remove the high-salinity mist from the low-salinity rising steam. This steam condenses into pure water (distillate) on the heat exchanger tubes and is collected in distillate trays, from where it is conveyed to a product water tank. Distillate flows from stage to stage and is collected at the last stage. The concentrate (brine) is generated in each stage and after collection at the last stage some of it typically is recycled to the source water stream in order to reduce the total volume of source water that must be collected by the intake for desalination. The recirculated brine flowing through the interior of the condenser tubes also removes the latent heat of condensation. As a result, the recirculated brine is also preheated close to maximum operating temperature, thereby recovering the energy of the condensing vapor and reducing the overall heating needs of the source water. This "brine recycle" feature has been adopted in practically all the most recent MSF facility designs and allows significant improvement of the overall cost competitiveness of MSF installations. Each flash stage typically produces approximately 1 percent of the total volume of the desalination plant's condensate. Since a typical MSF unit has 19 to 28 effects, the total MSF plant recovery (i.e., the volume of distillate expressed as a percentage of the total volume of processed source water) is typically 19 to 28 percent. For comparison, RO seawater desalination plants have a recovery of 40 to 45 percent. The latest MSF technology has 45-stage units—i.e., can operate at 45 percent recovery. This feature allows it to compete with RO systems in terms of recovery [1].

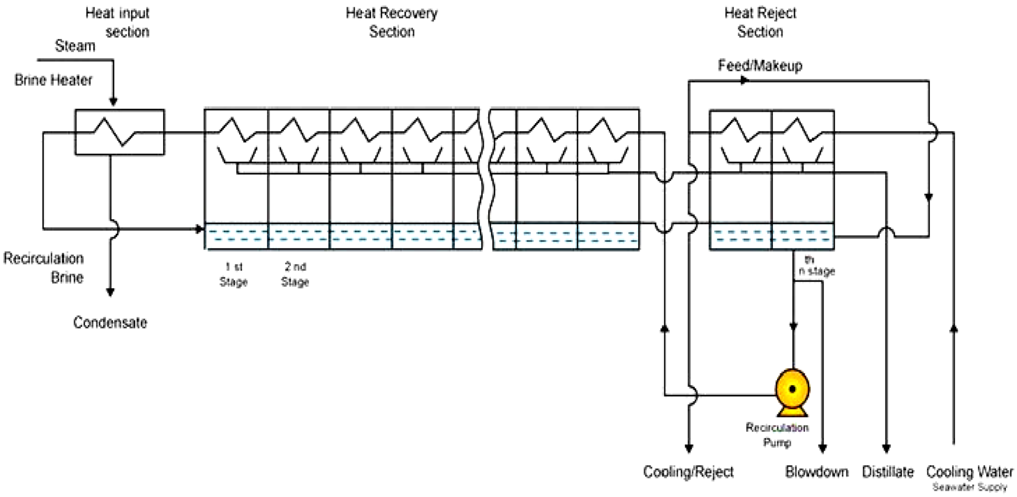

Figure 1-2. A simplified process flow diagram of the MSF evaporator with brine [6]

1.4.2 Multiple-Effect Distillation

In multiple-effect distillation (MED) systems, saline source water is typically not heated; cold source water is sprayed via nozzles or perforated plates over bundles of heat exchanger tubes. This feed water sprayed on the tube bundles boils, and the generated vapor passes through mist eliminators, which collect brine droplets from the vapor. The feed water that turned into vapor in the first stage (effect) is introduced into the heat exchanger tubes of the next effect. Because the next effect is maintained at slightly lower pressure, although the vapor is slightly cooler, it still condenses into freshwater at this lower temperature. This process of reducing the ambient pressure in each successive stage allows the feed water to undergo multiple successive boiling without the introduction of new heat. Steam flowing through the exchanger tubes is condensed into pure water (Fig.) and collected from each effect. Heating steam (or vapor) introduced in the heat exchanger tubes of the first effect is provided from an outside source by a steam ejector.

The MED system shown in Figure 1-3 is also equipped with a brine recycle system, which allows the introduction of warmer-than-ambient water in the first effects of the system, thereby reducing both the volume of feed water that must be collected by the plant intake system and the overall energy needs of the system. The main difference between the MED and MSF processes is that while vapor is created in an MSF system through flashing, evaporation of feed water in MED is achieved through heat transfer from the steam in the condenser tubes into the source water sprayed onto these tubes. This heat transfer at the same time results in condensation of the vapor to freshwater [1].

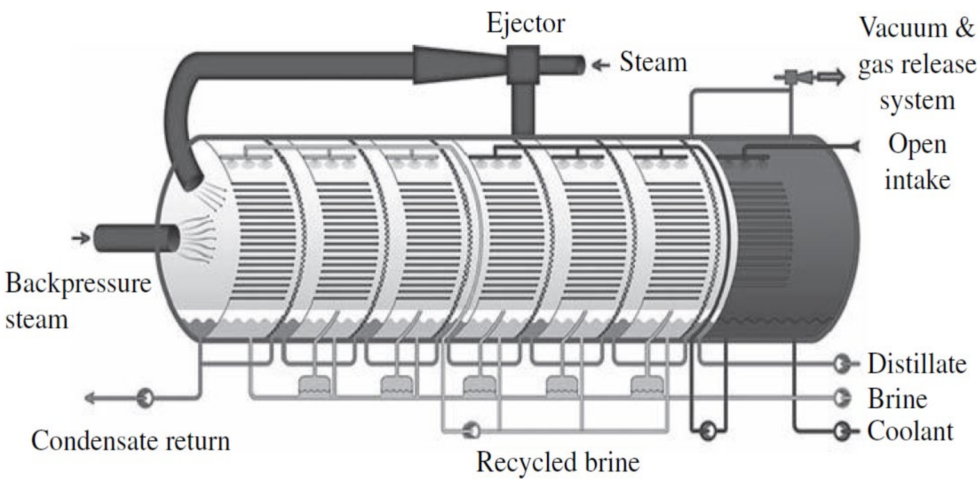

Figure 1-3. Schematic of an MED system [1]

1.4.3 Vapor Compression

Thermal evaporation is a well-known method for coating a thin layer in which the source material evaporates in a vacuum due to high temperature heating, which facilitates the vapor particles moving and directly reaching a substrate where these vapours again change to a solid state. In this method, a charge holding boat or resistive coil is used in the form of a powder or solid bar. In order to get the high melting points necessary for metals, the resistive boat/coil is exposed to a large direct current (DC), where the high vacuum (below 10^{-4} Pa) supports the evaporation of the metal and further carrying it to the substrate. This technique is especially applicable for material with low melting points.

1.5 MEMBRANE DESALINATION

Membrane desalination is a well-established process that involves the use of semipermeable membranes to separate minerals from the source water. Two predominant types of technologies utilized for membrane desalination include electrodialysis (ED) and reverse osmosis (RO). The ED process involves the application of direct current to separate salts from the source water, while in RO, pressure-driven transport through a semipermeable membrane is utilized to separate the product water or permeate from the salts present in the source water.

1.5.1 Electrodialysis

In electrodialysis (ED)–based desalination systems, the separation of minerals and product water is achieved through the application of direct electric current to the source water. This current drives the mineral ions and other ions with strong electric charge that are contained in the source water through ion-selective membranes to a pair of electrodes of opposite charges (Figure 1-4) [1].

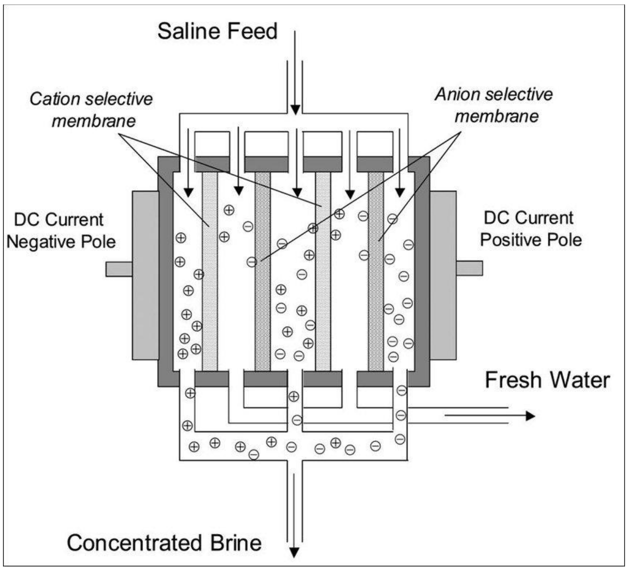

Figure 1-4. Schematic of the electrodialysis process [7]

Electrodialysis (ED) is a process that involves accumulating ions on the surface of electrodes which can cause fouling over time and require frequent cleaning. Electrodialysis reversal (EDR) is a practical solution to this problem, where the polarity of oppositely charged electrodes is reversed periodically (typically two to four times per hour) to avoid frequent cleaning [8].

1.5.2 Reverse Osmosis

Reverse osmosis (RO) is a process where water containing inorganic salts (minerals), suspended solids, soluble and insoluble organics, aquatic microorganisms, and dissolved gases (collectively called source water constituents or contaminants) is forced under pressure through a semipermeable membrane. Semipermeable refers to a membrane that selectively allows water to pass through it at much higher rate than the transfer rate of any constituents contained in the water. Depending on their size and electric charge, most water constituents are retained (rejected) on the feed side of the RO membrane while the purified water (permeate) passes through the membrane [1].

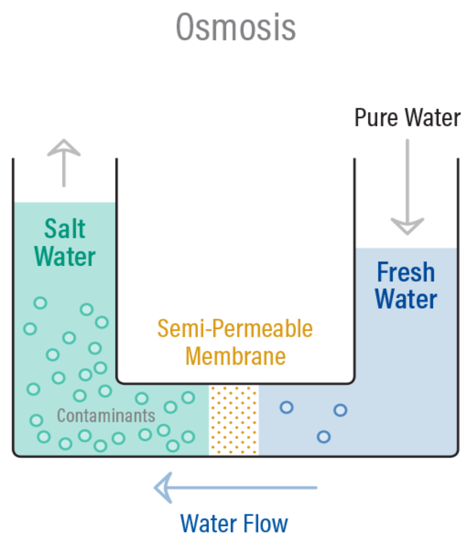

Figure 1-5. working principle of reverse osmosis membrane [9]

In a U tube, separated in two compartments by a semi-permeable membrane (Figure 1-5) one compartment is filled with fresh water and the other one with seawater. Through the semipermeable membrane water flows from the compartment containing fresh water to the compartment filled with seawater. The static liquid pressure in the freshwater compartment is lowered and that of the seawater compartment is increased. This process continues till an equilibrium situation is reached where equal amount of water flows on both sides through the membrane. At equilibrium the liquid level in the seawater compartment is higher than the level in the freshwater compartment, creating a hydrostatic pressure difference over the membrane. This pressure difference is called the osmotic pressure and it depends on the temperature and the concentration of the seawater. If the pressure of the seawater compartment is increased to a pressure higher than this osmotic pressure a water transport in the reversed direction, from the seawater compartment to the freshwater compartment, takes place. This phenomenon is called reverse osmosis and is applied to produce fresh water from saline water. The flow velocity is proportional to the difference of the applied pressure and the osmotic pressure. If this pressure difference is increased, the water flow through the membrane also increases while the salt flow remains practically constant resulting in lower salt concentration in the product water. The salt concentration of the product water depends on the salt concentration of the brine and the salt permeability of the membrane [10].

RO membranes can reject particulate and dissolved solids of practically any size. However, they do not reject well gases, because of their small molecular size. While RO membranes can retain both particulate and dissolved solids, they are designed to primarily reject soluble compounds (mineral ions). The structure and configuration of RO membranes is such that they cannot store and remove from their surface large amounts of suspended solids. If left in the source water, the solid particulates would accumulate and quickly plug (foul) the surface of the RO membranes, not allowing the membranes to maintain a continuous steady-state desalination process. Therefore, the suspended solids (particulates) contained in source water used for desalination have to be removed before they reach the RO membranes [1]. In Figure 1-6, the basic process flow diagram of the SWRO is shown.

The SWRO process consists basically of five components, namely [11]:

- The seawater pretreatment;
- The high pressure pumps;
- The membrane separation process;
- The energy recovery device;
- The post treatment of the product water.

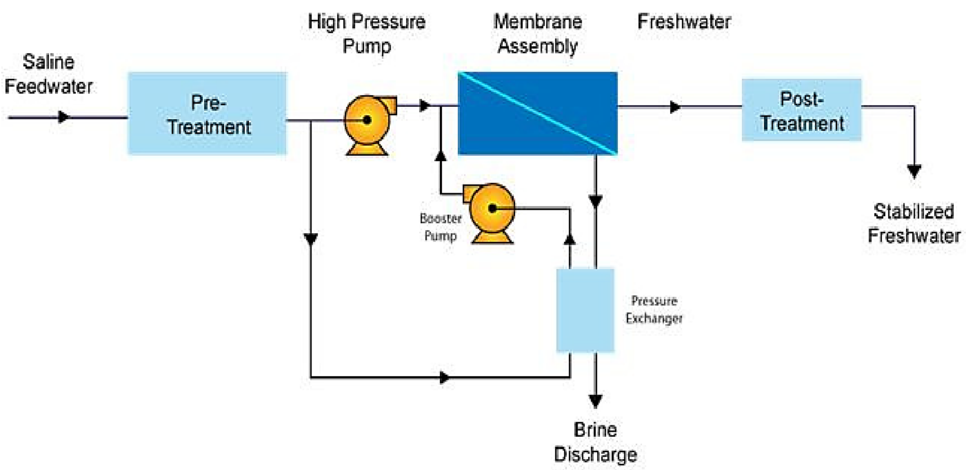

Figure 1-6. The basic process flow diagram of the SWRO [6]

1.6 RENEWABLE ENERGY POWERED DESALINATION

Desalination is crucial for global potable water supplies, especially in remote areas. To reduce environmental impact and cost, renewable energy sources like solar, wind, and geothermal can be used, as they are cost-effective and environmentally friendly [12].

Currently, renewable-powered desalination capacity represents less than 1% of the world's desalination capacity [13]. Most of the existing renewable-powered desalination plants are based on RO technology (62%), followed by MSF and MED. The dominant renewable energy source for water desalination is solar photovoltaic (PV), used in 43% of the existing RE desalination plants, followed by solar thermal and wind energy. Figure 1-7 depicts the ratio of the renewable energy resources currently used for desalination.

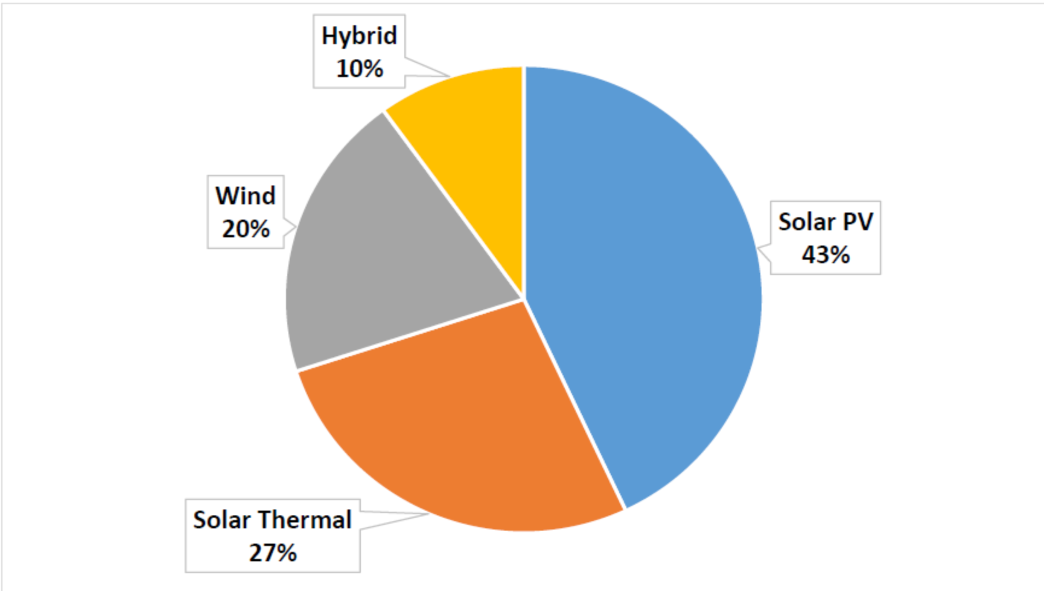

Figure 1-7. Renewable energy sources currently utilized for desalination [14]

Table 1-2. Different combinations of RE with desalination units

RO Resource	Desalination Process				
	MSF	MED	VC	RO	ED
Solar thermal	■	■			
Solar PV				■	■
Wind			■	■	■
Geothermal	■	■	■	■	■

The combination energy source/desalination technology is crucial to match energy and water demand economically and with the lowest environmental impact possible. The feasibility of a RE plant will depend on a variety of factors such as location, the salinity of feed water, available RE sources, plant capacity or availability of grid electricity [12]. The possible combinations can observe in.Table .

1.6.1 Solar Thermal Desalination

Seawater desalination using solar heat as a renewable energy source is promising. The process can be indirect or direct, with concentrating solar power (CSP) plants being particularly attractive. CSP plants harness solar radiation for electricity production and can be used with membrane or thermal desalination units. They are suitable for medium- to large-scale seawater desalination, especially in desert regions with high solar radiation. The choice between CSP-MED and CSP-RO processes depends on feed-water quality, with CSP-MED being more energy-efficient for highly saline seawater in the Arabian Gulf.[15]. Figure 1-8 summarises the different methods for solar thermal desalination.

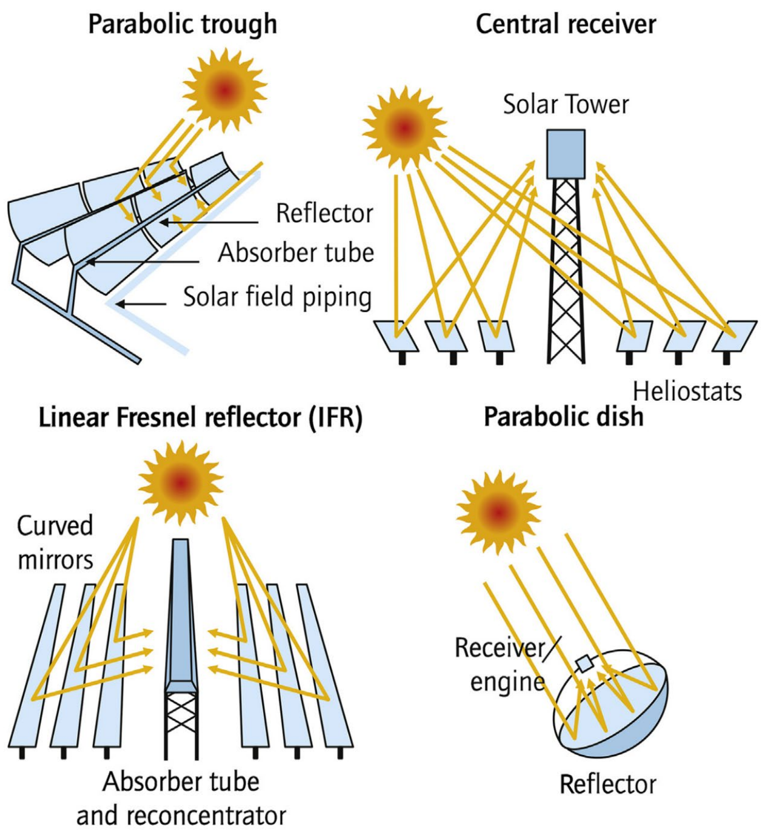

Figure 1-8. Technologies for concentrating solar radiation [16]

1.6.2 Photovoltaic desalination

Solar photovoltaic (PV) systems (Figure 1-9) convert sunlight into direct current electricity by utilizing semi-conductor materials that display the photovoltaic effect, PV cells. The PV cells form PV modules, which produce direct current that can be stored in batteries or directly fed to an inverter, which converts the direct current in alternating current. PV cells can be made from diverse technologies, being monocrystalline silicon and polycrystalline silicon the most common choice.

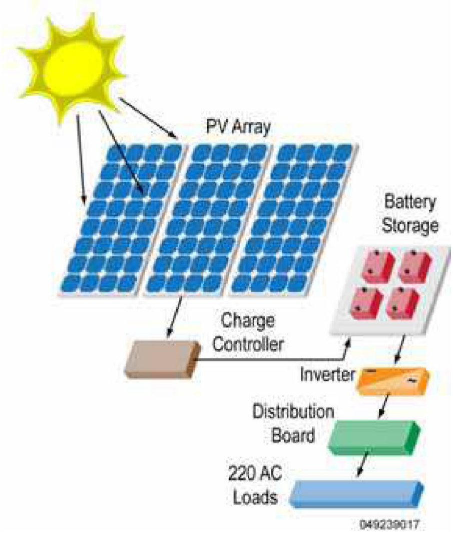

Figure 1-9. Diagram of a typical photovoltaic system [17]

Solar PV systems can be connected directly to RO or ED desalination processes as both require electrical energy for the pumping system. The system can include a set of batteries for energy storage, in order to stabilize the energy input of the RO unit, and a charge controller that regulates the charge of the batteries, avoiding deep discharges and overcharge. The set of batteries avoids variations in pressure and flow, enabling the membrane system to produce a known amount of water at the desired quality [18].

PV-RO is considered one of the strongest options for renewable energy powered desalination, particularly for remote areas, as both PV and RO are highly modular and scalable [19]. This modularity also assists in cost reduction being achieved via economies of scale. Furthermore, this modularity allows for small-scale systems that can be realized by coupling the DC output of PV modules directly to DC pumps and electronics, increasing overall system efficiency by 5 to 10% due to the avoidance of losses in DC-AC power conversion and AC-DC rectification [18].

1.6.3 Geothermal-Powered Desalination

Geothermal energy can be used for heat and electricity generation, making it an option to couple with any major desalination system that requires thermal or electrical energy. Geothermal energy sources are qualified in terms of measured temperature: low (<100 ºC), medium (100-150ºC) and high temperature (>150ºC). Thus, it is usable for a wide range of temperatures, from room temperature to over 150ºC. The energy is usually extracted with ground heat exchangers and heat can be directly used for thermal desalination or indirectly by producing electricity, although the first option is preferred [12]. However, the exploitation of geothermal energy very much depends on the specific local conditions, with upfront investment costs that are usually high [15].

1.6.4 Hybrid-Powered Desalination

Hybrid renewable energy sources is the concept of combining more than one renewable energy resource. In order to deal with the intermittency of renewable energy sources such as solar and wind, the utilization of both becomes ideal since in certain locations their energy production profile does not coincide.

A recent study by Koutroulis, E and D Kolokotsa [20] about PV/Wind energy production, concluded that utilizing such hybrid solutions result in lower overall cost compared to desalination systems powered by either only PV or Wind exclusively.

An even more recent study by Hossam-Eldin, A, AM El-Nashar [21] analysed the techno-economic optimization of hybrid renewable energy systems for RO desalination. It concluded that the choice of technologies depends on a variety of factors such as availability of energy resources, specific design constraints or available components specifications and prices. For this reason, an iterative approach is most likely to be applied, one that assesses all the available energy combinations and their economic viability for a given location. It also concluded that in order to reduce the total cost of energy productions it is crucial to minimize the amount of excess energy produced. Lastly, it concluded that utilizing hybrid energy production is more appropriate for medium scale RO than for small scale RO for countries with similar conditions to Egypt.

1.7 CONCLUSION

This chapter has outlined the current technologies used for the desalination process, as well as the renewable energy sources that could be integrated into desalination.

To summarize the discussion of this chapter we'd give a comparative study between the most common desalination technologies which are the RO and MSF to decide the most favourable process technology in our country. Multi-Stage Flash (MSF) is a commonly preferred method for large-scale dual-purpose seawater desalination plants due to its high efficiency and low energy consumption. However, for single-purpose plants with moderate capacity, Reverse Osmosis (RO) has become a competitive alternative. The choice of desalination process is heavily influenced by factors such as power generation, desalting capacity, and fuel costs. However, SWRO desalination usually is more cost competitive than thermal desalination technologies, therefore for the next chapter we'll discuss the automation using DCS and its essential elements to implement it in a RO desalination station.

Chapter 2: Modern Distributed Control System

In this chapter, the theory and evolution of distributed control systems (DCS) are discussed. Additionally, a thorough overview of DCS architecture, its components, communication methods throughout the system, and the usual field devices used in desalination plants is provided.

2.1 INTRODUCTION TO INDUSTRIAL AUTOMATION

Industrial automation refers to the use of technology and control systems to operate and control industrial processes and machinery, with minimal human intervention. The main aim of industrial automation is to increase productivity, improve quality, and reduce costs by automating repetitive, time-consuming, and dangerous tasks.

Industrial automation relies on a combination of hardware and software systems, including sensors, actuators, controllers, and computer software. These systems work together to monitor, control, and optimize the performance of industrial machinery and processes.

The use of automation in industry is expected to continue to grow, with new technologies such as artificial intelligence, machine learning, and the Internet of Things (IoT) enabling even greater levels of automation and connectivity.

2.1.1 History of Automation

Automation, in the sense of using machines or equipment, dates to the 11th century when miners used waterwheels to drain out water from underground tunnels and shafts. The modern form of automation took shape during the Industrial Revolution in the 1800s when automated processes and tools were used to increase factory productivity. Use of electricity in the1920s led to faster production process at the factory changing the factory floor dynamics. The application of feedback controllers by the industry during the 1930s and 40s was a significant step towards modern automation in manufacturing.

By 1980s the world saw new levels of automation with many sectors from manufacturing and retail to pharmaceutical and consumer goods embracing some or the other form of technology to further productivity [22].

2.1.2 Automation Equipment hierarchy (automation pyramid)

The automation pyramid is a hierarchical model that describes the different levels of industrial automation systems, from the physical process level to the enterprise level. The pyramid is divided into five levels, each with its own set of functions, technologies, and protocols. The five levels of automation can be summarised by the pyramid shown in Figure 2-1:

Level 1: Process Level - This level includes the physical processes or machines that are being controlled and monitored. It includes sensors, actuators, and other physical components that are responsible for collecting data and performing actions.

Level 2: Control Level - This level is responsible for controlling the physical process and ensuring that it operates according to the desired specifications. It includes Programmable Logic Controllers (PLCs) and Distributed Control Systems (DCS), which are responsible for monitoring the process, making decisions, and sending commands to the physical components.

Level 3: Supervisory Level - This level is responsible for supervising the control level and providing a higher level of control and management. It includes Human Machine Interfaces (HMIs) and SCADA (Supervisory Control and Data Acquisition) systems that provide a graphical interface for operators to monitor and control the process.

Level 4: Manufacturing Execution System (MES) Level - This level is responsible for managing the production process and optimizing it for efficiency and productivity. It includes software systems that integrate with the control level to track production data, manage workflows, and provide real-time visibility into the production process.

Level 5: Enterprise Level - This level is responsible for managing the entire enterprise, including the production process, supply chain, and business operations. It includes Enterprise Resource Planning (ERP) systems that integrate with the MES level to provide a comprehensive view of the enterprise and support decision-making processes.

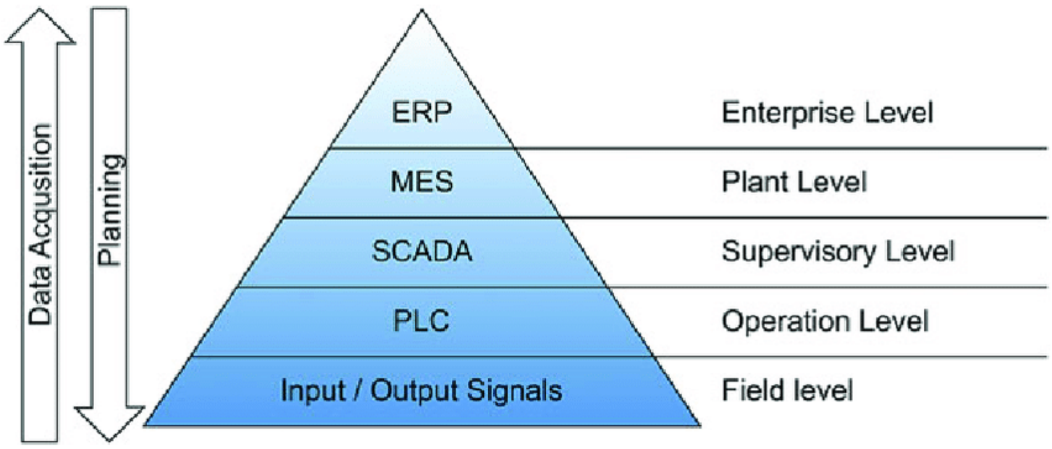

Figure 2-1. Automation pyramid [23]

2.1.3 Process oriented automation

Process-oriented automation is a type of industrial automation that focuses on automating specific processes or tasks within a larger industrial system. The goal of process-oriented automation is to improve the efficiency and reliability of the process by automating repetitive, time-consuming, and error-prone tasks.

Process-oriented automation involves the use of specialized hardware and software systems, such as sensors, programmable logic controllers (PLCs), and human-machine interfaces (HMIs), that are designed to monitor and control specific aspects of the process.

With the advent of traditional PLCs, individual controllers became powerful. They could execute more number of control algorithms and more complex programs. They could also control a larger set of control steps. It became easy to move the intelligence involved in controls to lower levels and improve the signal processing in transmitters. Powerful microcontrollers also enabled the design of faster networks. Together the concept of DCSs could be turned into a reality.

2.2 DISTRIBUTED CONTROL SYSTEMS

A DCS is defined as a system comprising of functionally and physically separate automatic process controllers, process monitoring and data logging equipment all of which are interconnected through a fast, digital network. This ensures sharing of relevant information for optimum control of the plant. In large-scale manufacturing or process plants, there are hundreds of control loops to be monitored and controlled. For such large processes, the commercial DCS is normally the control system of choice.Figure 2-2 shows the most common architecture of the distributed control systems in the world today.

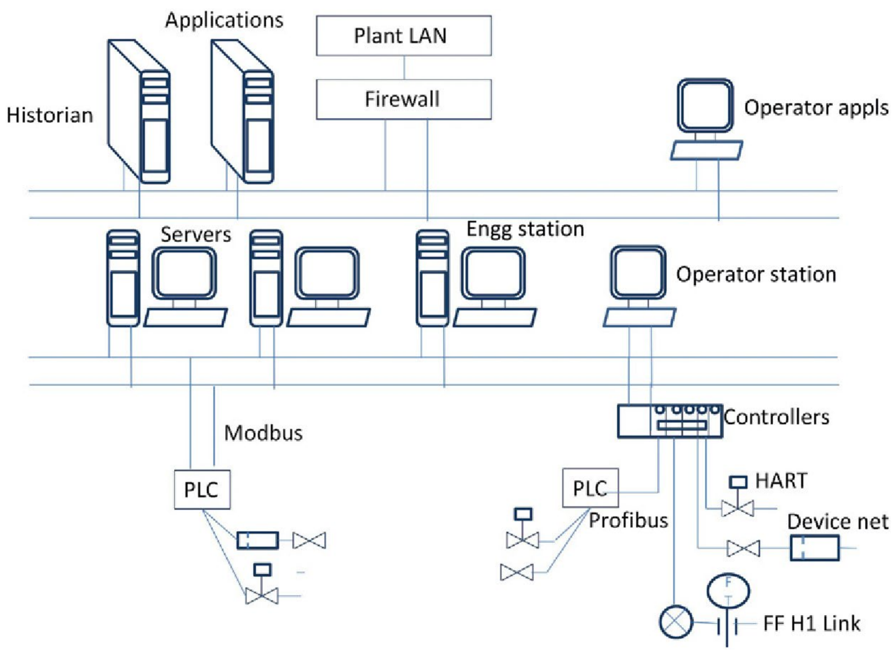

Figure 2-2. Architecture of a simple DCS [24]

- The DCS is process oriented; it looks at the controlled process (the chemical process plant) as the center of focus, and it presents data to operators as part of its job. A DCS operator station is normally intimately connected with its I/O (through local wiring, fieldbus, networks, etc.). When the DCS operator wants to see information, he usually makes a request directly to the field I/O and gets a response. Field events can directly interrupt the system and advise the operator. The DCS is always connected to its data source; so, it does not need to maintain a database of 'current values'. Redundancy is usually handled by parallel processing.

- SCADA is mainly focused on data-gathering and the control center and operators are the main focus. The remote equipment collects data and may also control complex processes. SCADA must continue operating even when field communications fail. Providing high-quality data to operators is essential. Special event processing mechanisms are used to handle conditions between data acquisition periods. Redundancy is typically distributed [25].

2.2.1 DCS COMPONENTS AND GENERAL ARCHITECTURE

Siemens provides a wide array of components and architectures for Distributed Control Systems (DCS) used in industrial automation and process control. The specific implementations may differ based on the application and needs.

Hardware description

PCS7 is a popular Distributed Control System (DCS) offered by Siemens. It provides comprehensive control and automation solutions for various industries. Here is a general overview of PCS7 components and architecture.

1. Process Field Devices: These are sensors, actuators, and instruments that measure and control the physical process parameters, such as temperature, pressure, level, and flow. Field devices interface with the process and provide data to the DCS.
2. Input/Output (I/O) Modules: These modules act as the interface between field devices and the PCS7 system. They convert analog or digital signals from the field devices into a format that can be processed by the DCS. PCS7 supports various I/O modules to accommodate different types of signals.
3. Controllers: PCS7 employs S7 400 as Central Programmable Logic Controller, it has a modular design that allows for easy configuration and expansion. This controller executes control logic, performs calculations, and manage the overall system operation, it supports both centralized and distributed control approaches, allowing for flexibility in system design.

4. Operator Stations: The operator stations provide a user interface for operators to monitor the process, make control adjustments, and view alarms and events. PCS7 offers graphical displays, trending, and diagnostic tools for efficient operation and decision-making. Operator stations can be located in the control room or accessed remotely.

5. Communication Network: A robust communication network is vital for data exchange between different components of PCS7. Siemens utilizes industrial communication protocols such as PROFINET, PROFIBUS, or Ethernet/IP to ensure reliable real-time communication between field devices, controllers, and operator stations.

6. Engineering Station: The engineering station is where the PCS7 system is configured, programmed, and maintained. The SIMATIC PCS 7 includes engineering tools for system configuration, application programming, and diagnostics. It allows users to define control strategies, configure alarms, and generate reports.

7. Redundancy and Fault Tolerance: PCS7 architecture supports redundancy at various levels to ensure system availability and fault tolerance. This includes redundant controllers, communication networks, power supplies, and redundant servers. Redundancy helps minimize downtime and enhances system reliability.

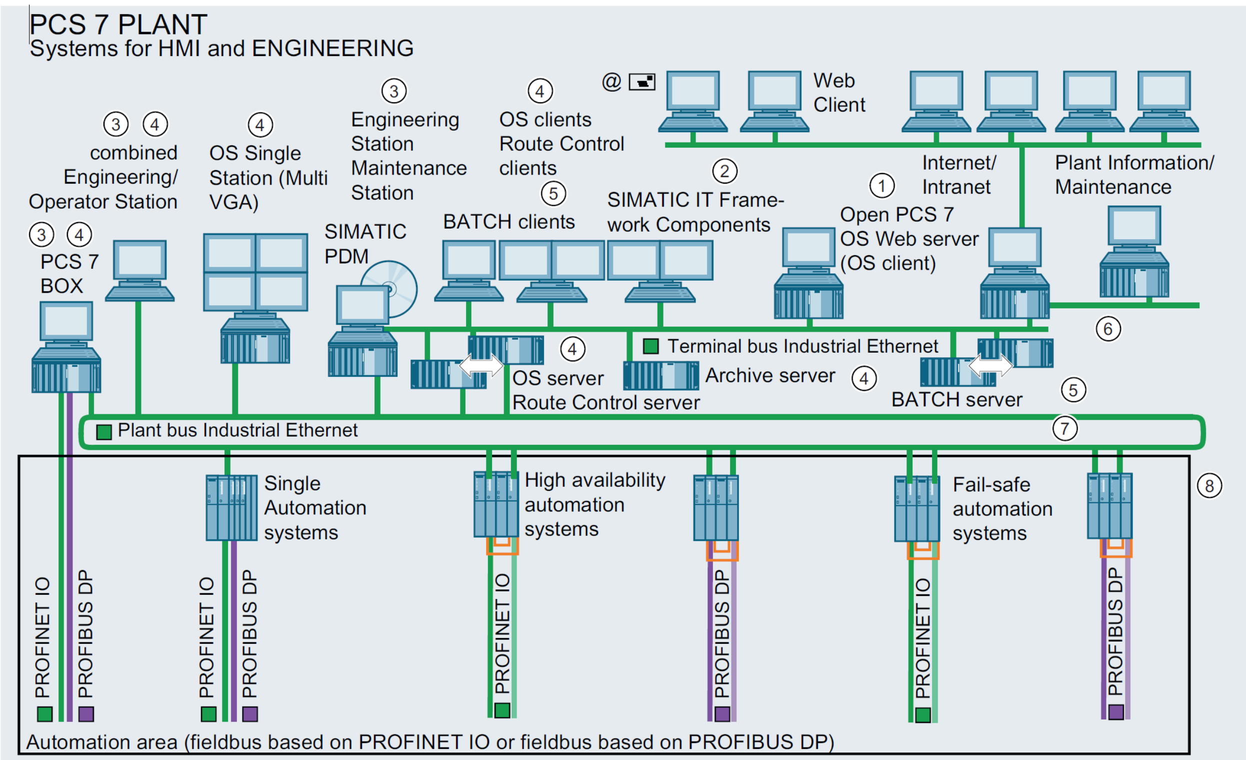

Figure 2-3. General case system on a PCS 7 plant [26]

Software description

The provided Siemens' description sheet states the components utilized in the control level of the PCS7 automation system, which are listed below:

- Engineering Station

Windows 10 IoT Enterprise • PCS 7 SW AS/OS ENGINEERING, • SW Maintenance Station RT & Engineering, Advanced ES (optional) • SIMATIC PDM • SIMATIC Industry Library • SIMATIC WinCC Comfort (for engineering of SIMATIC panels)•

- PCS 7 Server 1 & 2

Windows Server 2012 • PCS 7 Server Redundancy

- PCS 7 Clients 1 & 2

Windows 10 IoT Enterprise • PCS 7 OS, Client

- Process Historian:

Windows Server 2016 • PCS 7, software, Process Historian Basic Package V9.0

- Anomaly Detection Sensor

Claroty OS • Continuous Threat Detection Software

2.3 COMMUNICATION IN DCS

DCS (Distributed Control System) is a control system used to manage and monitor industrial processes. Communication is a critical aspect of DCS, as it enables different components of the system to exchange data and information in real-time. There are different types of communication used in DCS, including:

Fieldbus Communication: Fieldbus is a digital communication system used to connect field devices such as sensors, actuators, and controllers to the DCS. It enables two-way communication between devices and the central control system, allowing for real-time monitoring and control of industrial processes.

Ethernet Communication: Ethernet is a widely used communication protocol in DCS. It provides high-speed data transfer, reliability, and scalability. Ethernet communication is used for connecting different control systems, subsystems, and computers to the DCS.

Wireless Communication: Wireless communication is becoming more common in DCS. It enables communication between remote devices and the central control system without the need for physical wires. This type of communication is suitable for applications where running wires is not feasible, such as in large factories or outdoor installations.

Serial Communication: Serial communication is a simple and reliable communication method used in DCS. It involves the transmission of data one bit at a time over a single wire. Serial communication is commonly used to connect local devices such as programmable logic controllers (PLCs) and human-machine interfaces (HMIs) to the DCS.

The communication medium plays a major role in the entire distributed control system. It interconnects the engineering station, operating station, process station and smart devices with one another. It carries the information from one station to another. The common communication protocols used in DCS include Ethernet, Profibus, Foundation Field Bus, DeviceNet, Modbus, etc.

It is not mandatory to use one protocol for entire DCS, some levels can use one network whereas some levels use different network. For instance, consider that field devices, distributed I/Os and process station are interconnected with Profibus while the communication among engineering station, HMI and process station is carried through Ethernet [27].

2.3.1 Networks, Nodes, and Topologies

A Network is an interconnected group of computers and/or controllers, and devices that interact with computers and controllers. A Node is a computer or other device in a network. Networks are interconnected by different types of conversion devices, cables, and sometimes, by radio transceivers.

There are 3 basic common topologies, or arrangements for networks, are discussed below:

- Bus ;
- Star ;
- Ring ;
- Hybrid.

The Bus topology is the simplest. Figure 2-4 shows a simple bus network. Note the presence of resistors at the ends of the bus. Each node is exposed to data traffic on the bus, but it will only respond if data is directed to it. Otherwise, the data is ignored. A bus topology has the disadvantage that failure of the bus cable will stop communications. End resistors with identical resistances are used to improve signal quality on the bus.

A Point-to-Point connection is the simplest example of the bus topology. Point-to-point connections are used, for example, to connect a PC and a single printer (Figure 2-4).

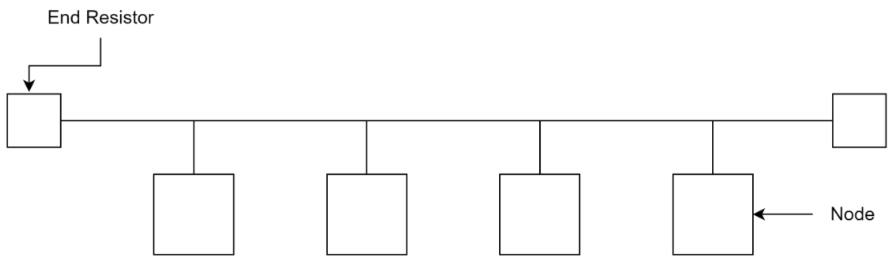

Figure 2-4. Bus Topology

In a Star topology (Figure 2-5), individual nodes are connected to a central node. Very often the central node is a Switch. Switches allow temporary pathways to be made so any node on the network can communicate with any other node. In a star topology, an individual node can be disconnected without affecting communications on the rest of the network. It's more reliable than a bus topology. All data traffic stops if the central node fails. However, switches are built for high reliability, and often, Uninterruptible Power Supplies are connected to provide temporary backup power in event of loss of line power. Sometimes redundant switches are used for improved reliability. In that case, each node has two ports, with separate cables attached to each distributed node.

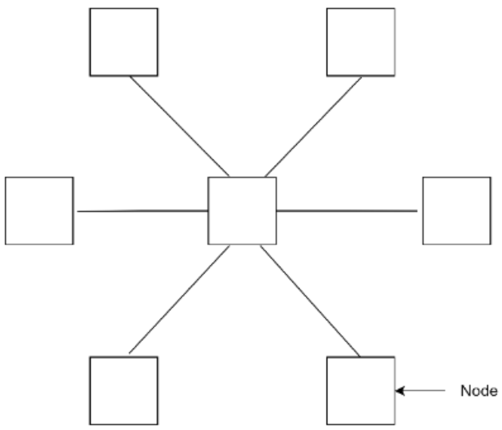

Figure 2-5 Star Topology

Figures illustrates the Ring topology. The ring doesn't need to have a master device, but usually it does. Each node can both send and transmit data. Data sent from one node to another is forwarded around the ring from the originating node to the destination node to which it is addressed. If a segment fails, data can be sent in the reverse direction. A double ring provides enhanced reliability.

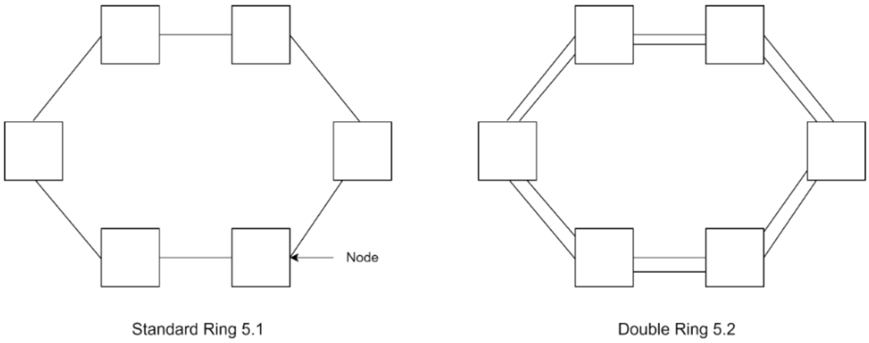

Figure 2-6 Ring Topologies

Many different types of devices besides computers, controllers and switches can be part of a network – such as printers, scanners, barcode readers, TV cameras, etc. Ultimately, networks are interconnected in many ways, some networks consist of combinations of one or more of the three basic networks. It is also the case with a hybrid topology consisting of combinations of one or more of the three basic networks, as shown in Figure 2-7. In a properly set-up network, data can get from one node to another if a path for data transmission exists [28].

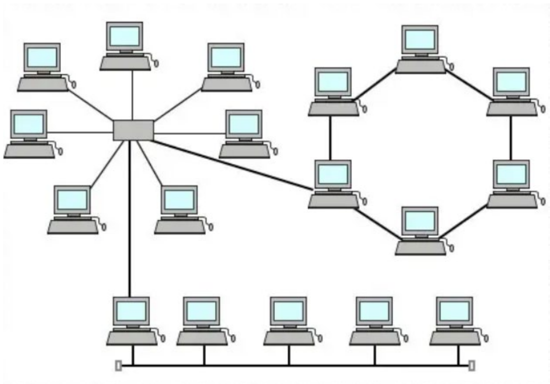

Figure 2-7 Hybrid Topology [28]

2.3.2 Fieldbus Protocols

Within the scope of Field Level, the communication network on fieldbus is defined by protocols for global compatibility. Popular communication protocols used in DCS include those for instruments, controllers, and environmental zones.

4-20 mA Signal

The 4-20 mA signal is an analog signal protocol used for transmitting control variable data from a sensor to a control station and for sending control signals from the control station to a remote actuator. I to P and P to I converters are used to operate pneumatic devices using this signal over longer distances. A simple 250-ohm resistor can be used to convert the signal to a 1-5 V range. The 4-20 mA signal is suitable for industrial environments and has a high signal-to-noise ratio, making it accurate at low levels. It is lossless even over long distances. However, only one parameter can be transmitted in a single 4-20 mA so there is only one transmitter connected in a loop, and multiple current loops can create unwanted ground loops. This is summarized in ***Figure 2-8***

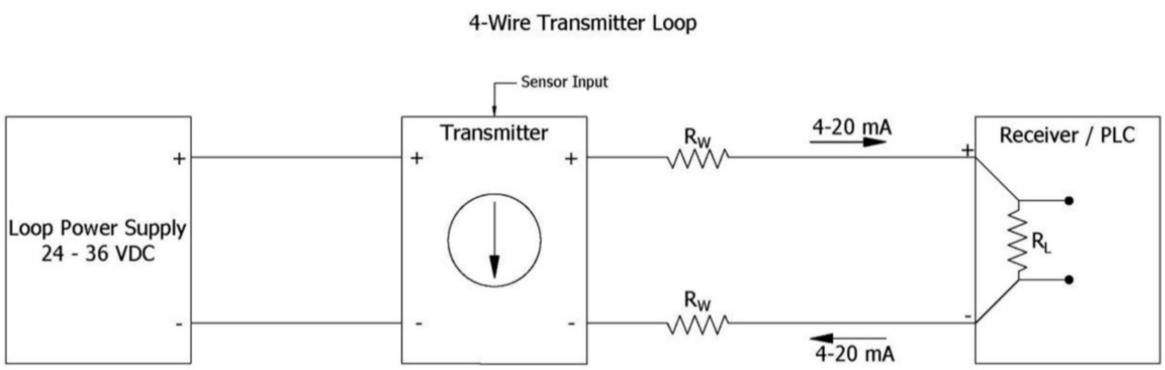

Figure 2-8. Typical 4-20 mA current loop [29]

HART Protocol

HART is a hybrid protocol that is a combination of both analog and digital signals. It is bidirectional, half-duplex, and overcomes the drawbacks of 4-20 mA line being compatible with existing 4-20 mA wiring. HART is a master-slave communication protocol where each slave(field) device communication is initiated by a master(PLC/DCS) device. HART makes additional digital information like device diagnostics, configuration, calibration, troubleshooting to be communicated along with the normal process variables to/from a smart field device using the FSK principle. As depicted in Figure 2-9, the FSK signal is phase continuous, it doesn’t produce interference with the 4-20 mA signal. HART technology is cost-effective, easy to use, robust, highly accurate, and risk-reducing [30].

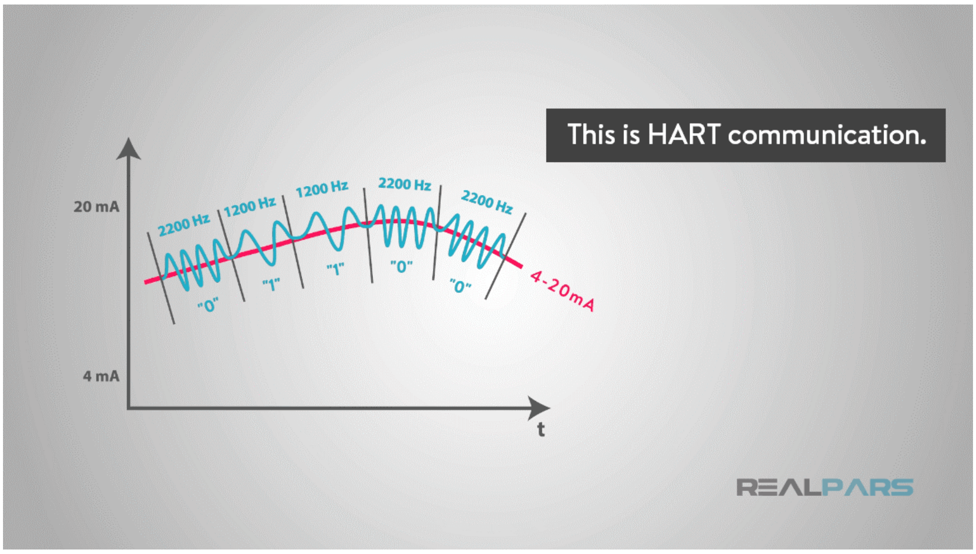

Figure 2-9. Signal transmission in HART

Profibus

The Profibus (Process Fieldbus) is used for the networking of complex devices with its multi-master protocol. Profibus helps extend the user range from field level to process control level. It is designed to address the needs of discrete manufacturing and building automation. Profibus has two variants, the most common Profibus DP and less used (application-specific) Profibus PA. Profibus DP is used to operate sensors and actuators via a centralized controller in factory automation applications. Profibus PA is a master/slave protocol and is used to monitor measuring equipment via a process control system in process automation applications. Profibus PA is designed to operate in hazardous areas.

Foundation Fieldbus

Fieldbus is a standard for a local area network of industrial automation smart field devices based on the OSI model. Fieldbus is a bi-directional communication protocol that allows many input and output variables to be transmitted on the same medium. Thus, sensors can transmit measured signal values as well as other diagnostic information. Also, the features like process monitoring can be carried out leading to increased fault tolerance. Other variants of Fieldbus include ASI interface, Ethernet IP, Profinet, CANopen, Modbus, Devicenet, etc. Fieldbus is a replacement of analog and digital point-to-point communication with superior, high speed, and reliable digital communication networks for a harsh industrial environment. Foundation Fieldbus is easily installable, maintainable, and supports plug-and-play features [30].

Summary of DCS communication protocols

The aforementioned DCS communication protocols can be summarized in Table 2-1.

Table 2-1. Summary and comparison of DCS-based protocols in process control systems [30]

Protocol	Data Rate	Range	Application
Ethernet	100mbps, 1 and 10 gbps	100 m	Connecting fieldbuses to existing business networks or the internet
Foundation Fieldbus	H1: 31.5 kbps, HSE: 100 mbps, 1 gbps	1900 m max	Connect sensors, actuators in process control
HART	1200 bps, 3600 bps	< 3000 m	Analog digital sensor and actuator connection in process control
Modbus	9.6 and 19.2 kbps	< 300 m	Monitor and control with PLCs
Profibus	9.6 and 31.23 kbps to 12 mbps	1200 m	Monitor and control in process automation

2.4 OPC INTERFACE

OLE for process control (OPC) for object linking and embedding, is an open industrial standard for process control and information system interconnectivity designed based on Microsoft's ActiveX (OLE), Component Object Model (COM), and Distributed COM (DCOM) technology. Data access and exchange by using MS COM/DCOM defines common set of interfaces, methods, and properties for use in industrial automation applications and follows client/server architecture. It is often interfaced through gateway across multiple systems or through customized techniques that a DCS vendor provides.

, OPC follows server/client architecture. Server is a slave device – it responds to requests from a master OPC server and understands how to communicate with the vendor device. Client is a master device – it requests data from a slave. OPC client understands how to communicate to the vendor host server and client. DCOM is the vital design for OPC communication and offers communication across two subsystems and management consoles. It is used for monitoring applications and I/O specific software drivers and low-level sensors typically use a dedicated hardware interface and protocol.refer to Figure 2-10 on how the communication works.

OPC is capable of providing real-time sensor data – temperature, pressure, flow, and control parameters such as open, close, run, stop, and status information along with:

Status of the hardware connection
Status of the local software and subsystem

Each OPC server such as data access is a separate object. The data access server provides a window into existing data. Data is accessed by name (a string), which is generally vendor or hardware specific.

Data for lists of items can be read explicitly (polled) or subscriptions can be created. It is perfect for merging DCS alarms and events, logging network events, replacing sequence of event recorders, loggers, or any other type of device that sends text-based messages. Applications are interested in a subset of the data items (tags) available within the underlying control subsystem. Applications are interested in many different subsets of data items at different times and may have variable requirements for response and resolution. Applications want to be independent of the data structures (or objects) used by the subsystems (i.e., they want symbolic access to the data) [24, 31].

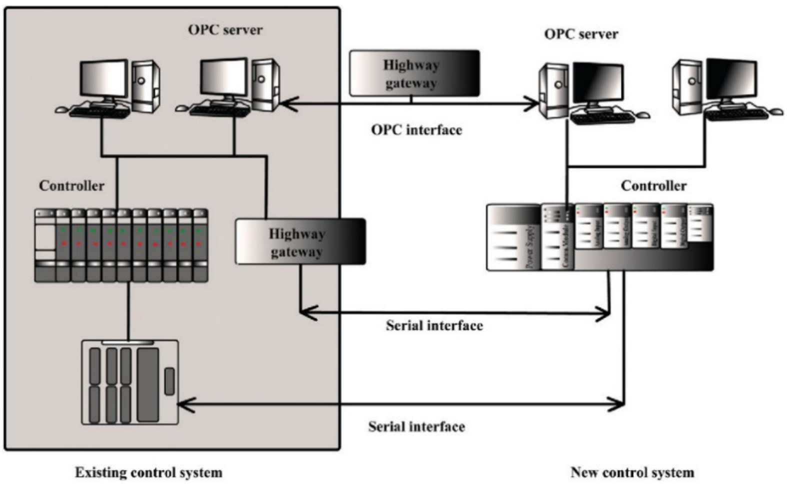

Figure 2-10. Integration of OPC in automation [31]

2.5 CONNECTING THE DISTRIBUTED I/O ON FIELDBUS

Typically, a factory comprises two sections: the control room housing industrial pc and servers and the plant field level area featuring sensors and actuators. These sensors are monitored by a PLC and are spread throughout the factory. However, a challenge arises when the I/O of the PLCs are connected to each sensor and actuator separately. This approach results in a substantial number of cables running between the field area and the control room, making it costly and inefficient. To address this issue, the most effective solution is to utilize an industrial network, like Profibus-DP, to ensure seamless monitoring of all the sensors in the factory.

2.5.1 Profibus DP

As shown in Figure 2-11. The connection between the remote I/O module and the PLC is established using a single RS-485 cable. This approach significantly reduces the number of cables required, making cable management easier and more efficient. Additionally, it is a cost-effective solution compared to the previous method.

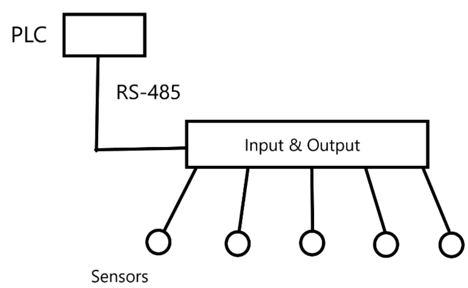

Figure 2-11. Profibus connection between PLC and remote I/Os

Features

- Transfer medium: - Shielded, twisted two-wire cable.

  - Glass or plastic fiber-optic cable.
- Access procedure: token passing with master/slave.
- Length: - Up to 9 km with a two-wire cable.

  - Up to 90 km with glass fiber-optic cable.
- Maximum of 127 nodes.
- Response times down to 1 ms.
- Topology Line, tree, ring, star.

2.5.2 Profinet

Profinet is based on Ethernet and expands Profibus technology for applications requiring high-speed data communication via Ethernet networks. There are some similarities in the engineering concepts and in the use of GSD (General Station Description) files to describe the properties and functions of Profinet devices [32]. Profinet ensures that real-time communication is not disrupted by standard TCP/IP-based communication and that time requirements are met reliably. This flexibility offers a great advantage over other Ethernet real-time systems [33].

Use of Fiber optics & Features

The fiber optics are insensitive to electromagnetic interference but is more expensive than RS-485. The Optical Link Modules (OLM) permits the connection between fiber optics and Profibus DP. The length that gives us fiber optics is up to 2000 m.

- Transfer medium: - Double-shielded coaxial cable.

  - Glass fiber-optic cable.
- Access procedure: TCP/IP.
- Transmission speed 10/100 Mbit/s.
- Length: - Up to 1.5 km with a two-wire cable.

  - Up to 4.5 km with glass fiber-optic cable, 200 km using switches.
- Over 1000 nodes.
- Topology Line, tree, ring, star

Profibus PA

Profibus process automation (PA) – shown in Figure 2-12– is used in process manufacturing applications. The physical layer of Profibus PA is Manchester encoded bus powered (MBP), and the physical layer for Profibus DP is RS-485. Even though a different physical layer is employed, Profibus PA is the same protocol as Profibus DP.

Process automation environments, while typically requiring slower procedures, might also be characterized by explosive or hazardous environments. In such applications, Profibus PA is a suitable solution. Profibus PA can be deployed in hazardous environments since its physical layer: MBP, is intrinsically safe.

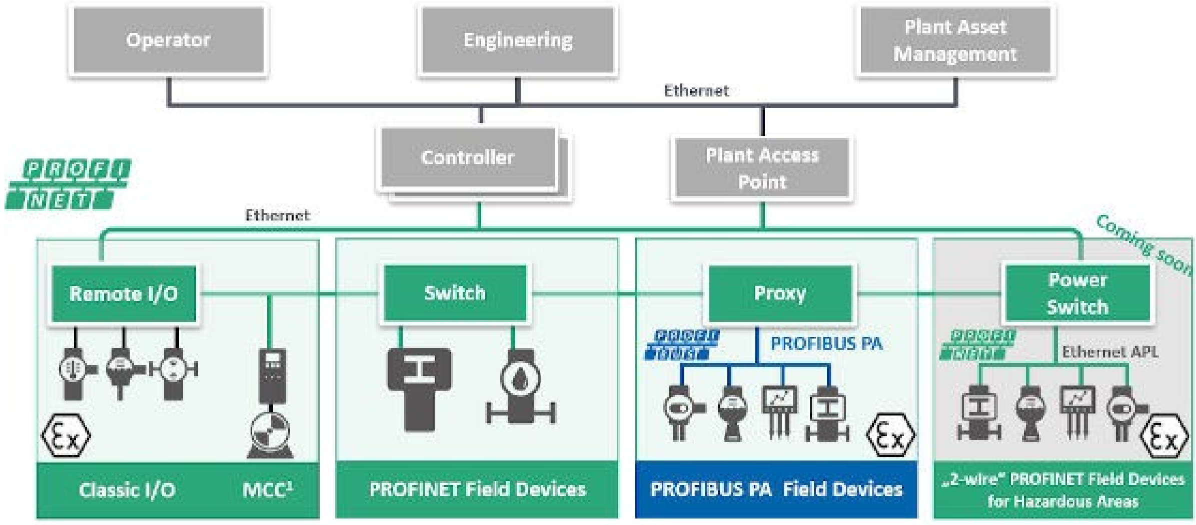

Figure 2-12. Evolution of field I/O for instruments and actuators [34]

2.6 FIELD DEVICES USED IN INDUSTRY

2.6.1 Industrial Instrumentation

Instrumentation is the science of automated measurement and control [35], the fundamental objective of instrumentation in a process plant or environment is to collect data from different process parameters and to subsequently monitor the obtained values. Transmitters are one of the foundations in measurement instrumentation used in process control system. They are what originally convert physical parameters from equipment and processes into digital information that machines and people can use. [36].

Once we measure the quantity we are interested in, we usually transmit a signal representing this quantity to an PLC/DCS systems where either manual or automated interventions take place. Both the measurement device and the final control device connect to some physical system which we call the process (Figure 2-13).

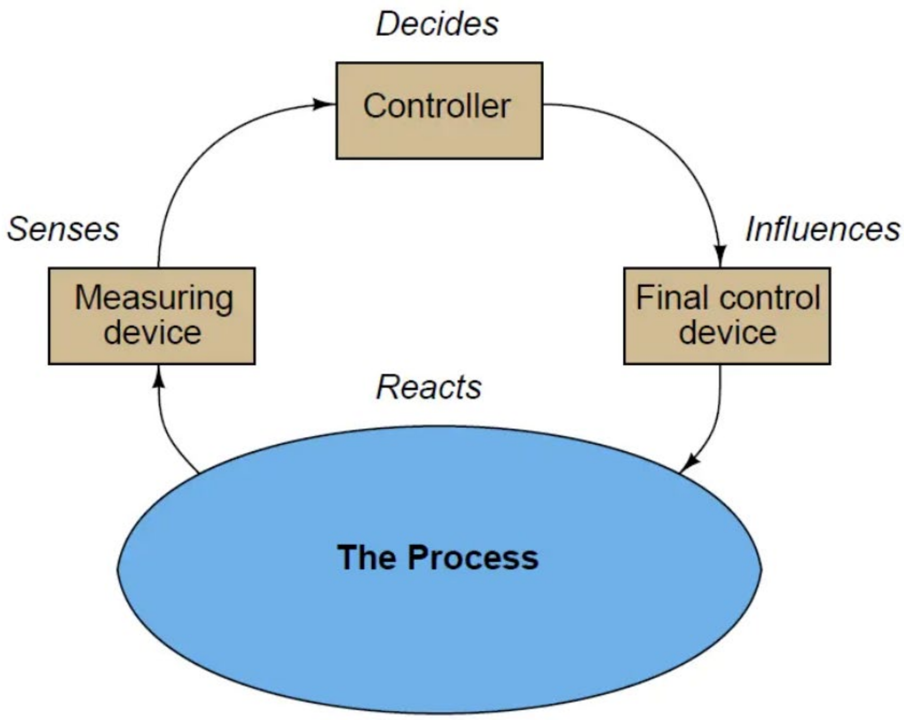

Figure 2-13 block diagram of sensors/actuators communication through the process [35]

The core sensors and transmitters used in process controls instrumentation for water desalination industry are:

- Level sensors: Measure levels of water, other liquids, and solids in various holding tanks

Figure 2-14 POINTEC CLS200 capacitance Level Switch /SITRAINS Probe LU Ultrasonic level transmitter

- Pressure sensors: Measure pressures in piping and pressure vessels

Figure 2-15 SITRANS P410 digital pressure transmitter

- Temperature sensors: Measure water temperature, equipment temperatures, and other temperatures

Figure 2-16 SIEMENS SITRANS TS500 Temperature Sensor

- Flow meters: Measure the flow rates of water and additives through piping

Figure 2-17 SITRANS FM MAG Flow transmitter

Additionally, there are various type of sensors used in water chemical treatment process such as: Ph, Conductivity, Turbidity, Redox and Chlorine sensors [37].

2.6.2 Valves

A valve is a device that regulates the flow of gases, liquids or loose materials through an aperture, such as a pipe, by opening, closing or obstructing a port or passageway [38]. There are many types of valves, each designed to meet specific needs and applications. Some common types of valves include:

- Globe valve:

These are used to regulate flow and are commonly found in water supply and HVAC systems.

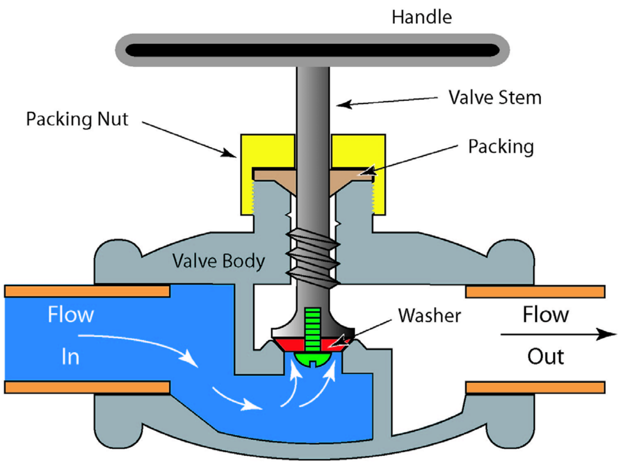

Figure 2-18 • Globe valve

- Gate valves:

These are used to either fully open or fully close the flow of fluid, and are commonly used in gas and oil pipelines.

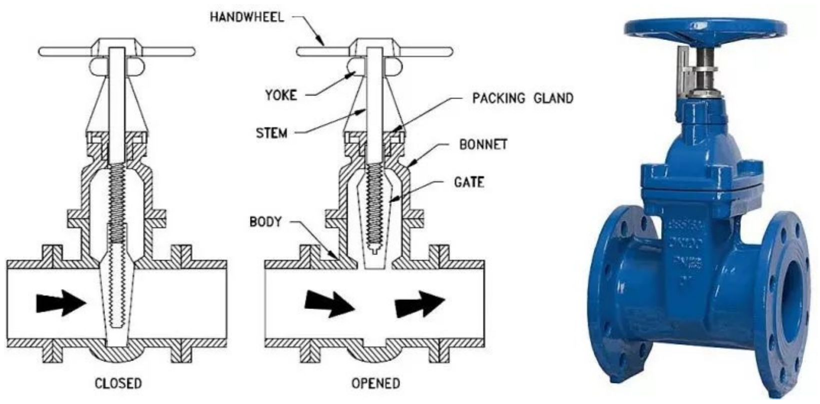

Figure 2-19 • Gate valve

- Ball valves:

These valves have a spherical closure unit that allows for quick and easy shut-off of the flow of fluid. They are commonly used in industrial processes.

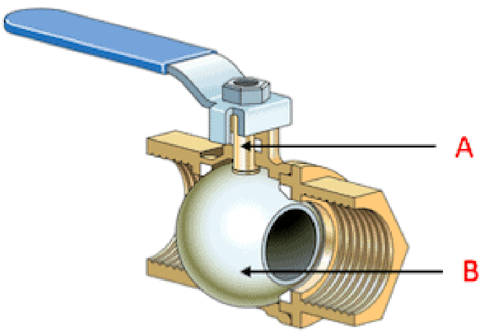

Figure 2-20 • Ball valve

- Butterfly valves:

These are quarter-turn valves that are used to regulate flow. They are commonly found in water treatment plants and power plants.

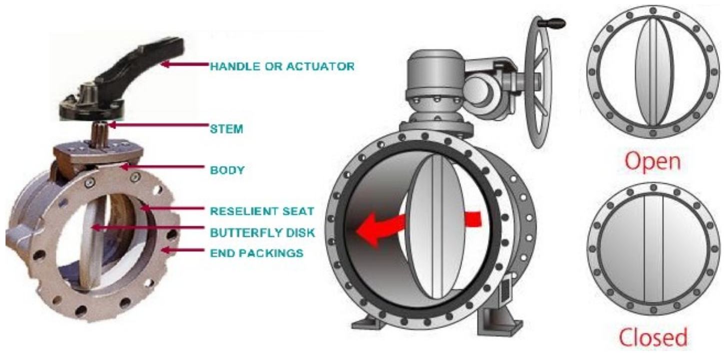

Figure 2-21 • Butterfly valves

- Check valves:

These valves are used to prevent backflow in a system and are commonly used in wastewater treatment systems.

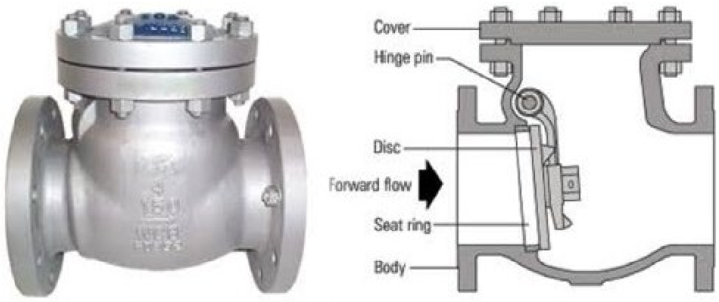

Figure 2-22 • Check valves

- Pressure relief valves:

These valves are used to prevent overpressure in a system, and are commonly found in oil and gas pipelines and pressure vessels.

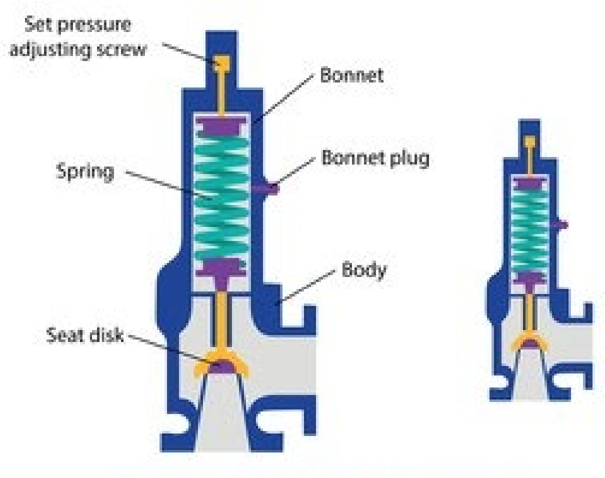

Figure 2-23•   Pressure relief valves

2.6.3 Motors

Motors are devices that convert electrical or mechanical energy into rotational motion. They are commonly used in a variety of applications, including industrial machinery, household appliances, automobiles, and robotics. In water industries, Motors are widely used to drive various types of pumps along with motorized driven valves.

Direct current (DC) motors

DC motors are the simplest and most common. They are often used in electric tools, industrial equipment, electric vehicles, and robots. DC motors are easy to control and can be reversed by simply changing the polarity of the electrical supply.

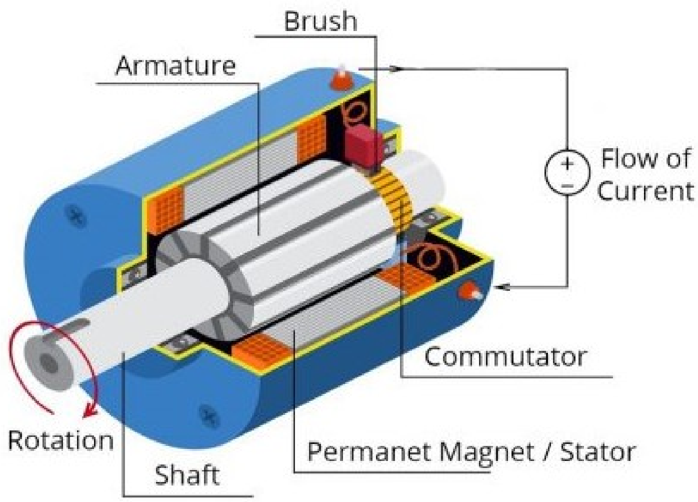

Figure 2-24 Direct current (DC) motors

[39]

Alternating current (AC) motors

AC motors are often used in industrial machinery, fans, pumps, and air conditioners. They are more efficient than DC motors but are more complex and difficult to control.

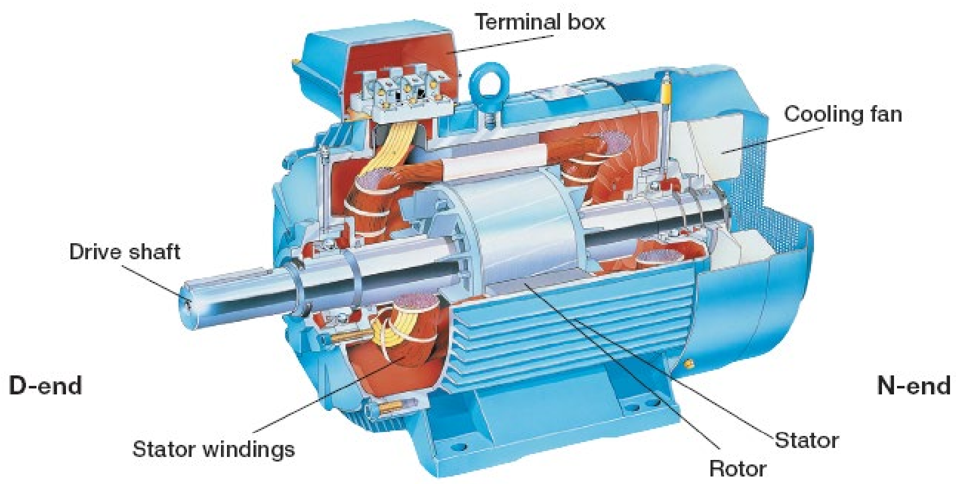

Figure 2-25Alternating current (AC) motor[40]

Synchronous motors

Synchronous motors are alternating current (AC) electric motors that have a rotating magnetic field. They are often used in industrial equipment, fans, compressors, and pumps.

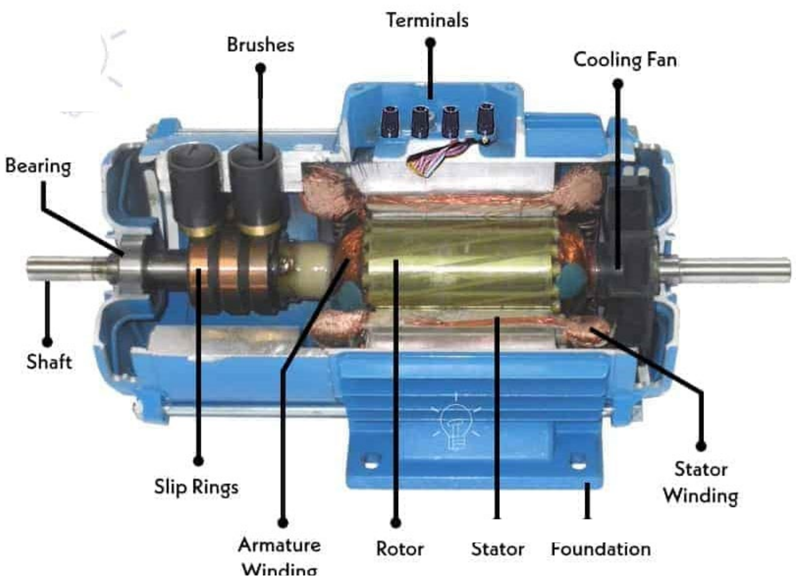

Figure 2-26 synchronous motor [41]

Asynchronous motors

Asynchronous motors, also known as induction motors, are alternating current (AC) electric motors that have a rotor that rotates at a slightly lower speed than the rotating magnetic field. They are often used in pumps, fans, compressors, and industrial equipment.

Stepper motors

Stepper motors are electric motors that rotate in precise steps. They are often used in 3D printers, scanners, CNC machines, and robots.

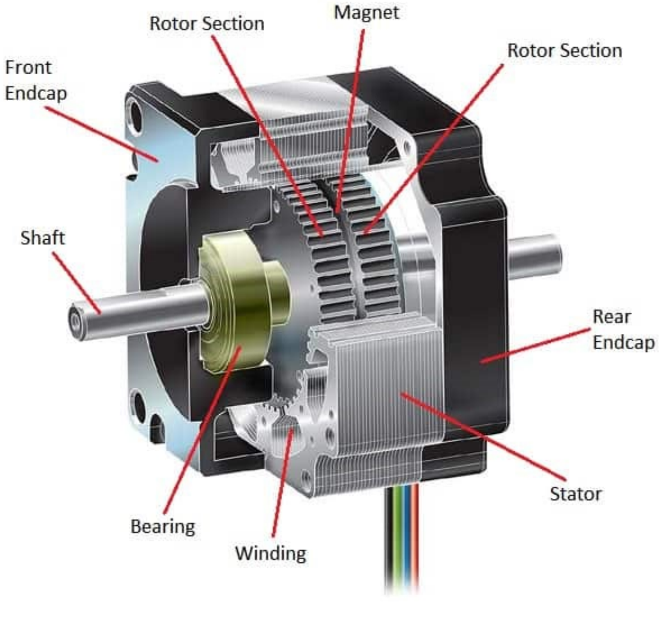

Figure 2-27Stepper motor [42]

2.6.4 Motor Management System

A motor management system is a set of tools and solutions that help protect, control, maintain, and manage the impact on the electrical network and parallel loads of electric motors 1

. These systems provide full motor monitoring, control, and protection when used with short circuit protection and a contactor.

. Here are some key features of motor management systems:

Motor monitoring: Motor management systems can monitor the performance of electric motors, including factors such as temperature, current, and voltage, to ensure they are operating efficiently and safely`

Motor control: These systems can control the operation of electric motors, including starting, stopping, and adjusting speed

Motor protection: Motor management systems can protect electric motors from damage due to factors such as overloading, overheating, and short circuits

Centralized information management: Best-of-breed CMMS packages provide centralized information management on a company's motor assets in a variety of technologies – electrical, mechanical, and others

Motor management systems are often used in critical processes where motor failure could have serious consequences

. They can be used in a variety of industries, including manufacturing, oil and gas, and water treatment

. Some examples of motor management systems include the TeSys T Motor Management System from Schneider Electric and Siemens flexible and modular motor management system

SIMOCODE

SIMOCODE pro (SIRIUS Motor Management and Control Devices) is a motor management and equipment control system with a Profinet interface. It is flexible, modular and supports all the necessary functions of a motor feeder [43].

. Here are some key features of SIMOCODE:

Motor protection: SIMOCODE provides comprehensive protective functions for electric motors, including overload protection, short-circuit protection, and phase failure protection.

Motor monitoring: SIMOCODE can monitor the performance of electric motors, including factors such as temperature, current, and voltage, to ensure they are operating efficiently and safely.

Motor control: SIMOCODE can control the operation of electric motors, including starting, stopping.

.

Figure 2-28SIMOCODE[43]

Variable Frequency Drive

A Variable Frequency Drive (VFD) is a type of motor controller that drives an electric motor by varying the frequency and voltage supplied to the electric motor

Here are some key features of VFDs:

Motor control: VFDs can control the speed of AC induction motors by varying the frequency and voltage of the electricity powering the motor.

Energy savings: VFDs can reduce energy consumption by controlling the ramp-up and ramp-down of the motor during start or stop, respectively.

Intelligent motor control: Today's VFDs integrate networking and diagnostic capabilities to better control performance and increase productivity.

Types of VFDs: There are many diverse types of VFDs available since they are widely used in industry. Both single-phase VFDs and three-phase VFDs have evolved to suit a wide variety of applications. VFDs are also known as adjustable-frequency drives, adjustable-speed drives, variable-speed drives, AC drives, micro drives, inverter drives, or drives, they are used in a variety of applications, including HVAC systems, pumps, fans, and conveyors [44].

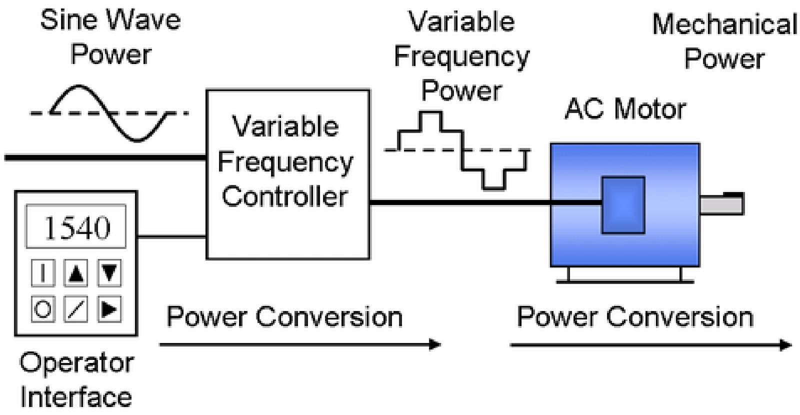

Figure 2-29Variable Frequency Drive (VFD)[44]

2.7 CONCLUSION

Distributed control systems (DCS) have become integral to modern industrial processes as they offer efficient and effective control of complex systems, making them an ideal solution for the water industry. With a solid understanding of DCS fundamentals, implementing the system should be straightforward for desalination plants. This involves breaking down the general DCS architecture into multi-layer levels, understanding each essential component, and comprehending the network communication protocols used to link the field level with the control system. By doing so, the desalination plant can leverage the advantages of DCS to improve its processes and achieve optimal functioning.

the next chapter will discuss in details our studied DCS concept for the desalination station.

Chapter 3: DCS Implementation for a Desalination Plant

In the third chapter, the focus is on Siemens' DCS PCS7. The description of this system covers both its software and hardware components. The specification sheet of post-treatment in a desalination plant concept, which was provided by Siemens, is analyzed to extract important information and identify automation system features that are suitable for program development.

3.1 INTRODUCTION

In this chapter of the thesis, PCS7 will be introduced as the program that enables the project to be carried out and covers its key components. To identify the ideal configuration and control strategies for the DCS under PCS7, we will explain the water flow of the general process and then focus on the studied post-treatment process. We will consider a functioning strategy and further analyze it to develop a logical functional description of the unit, this is done by analysing the specifications sheet of desalination station provided by Siemens. Through this analysis, a thorough understanding of the post-treatment process will be gained, and the main elements that will be worked on with PCS7 will be identified.

3.2 PCS7 DESCRIPTION

PCS 7 is an integrated, full-feature scalable DCS control system based on the latest technology from Siemens. PCS7 builds upon the Siemens SIMATIC hardware platform and integrates seamlessly into the totally integrated automation software platform [45].

PCS7 can be consider as a hybrid control system: characteristics of both DCS and PLC, it has the power of a DCS and the flexibility of PLC. The CPU at the heart of the system is an S7-400 advanced controller. In the PCS7 structure, this processor is referred to as the AS-400, for automation system controller.

3.2.1 S7-400 PLC Description

The S7-400 is the most high-end PLC that SIEMENS has designed until now. It is fast, robust, and strong in communication, has been proven as a controller in the upper-performance range of factory automation and can be found in plants for process automation as well. Similar to the S7-300, for engineering, the established STEP 7, STEP 7 Professional in the TIA Portal or in the mighty, process-oriented PCS7 can be used for its programming. It can be networked with Multipoint interface (MPI), PROFIBUS and Industrial Ethernet Profinet.[46]. The Figure 3-1 show a standard S7-400 module.

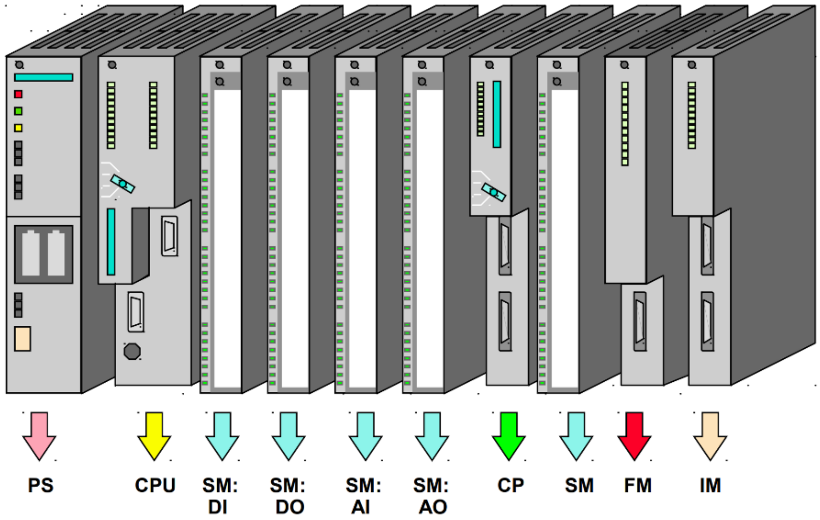

Figure 3-1 S7-400 Modules [47]

The SIMATIC S7-400 is available in several versions:[48]

- S7-400: The power PLC for the mid to high-end performance ranges with modular, fanless design.
- S7-400H: Fault-tolerant automation system with redundant design for fail-safe applications.
- S7-400F/FH: Fail-safe automation system with redundant design that can also have high availability.

3.2.2 SIMATIC Manager

Simatic Manager is a software program developed by Siemens for programming and configuring their Simatic programmable logic controllers (PLCs). Simatic Manager provides a range of tools and functions for PLC programming, such as creating and editing programs, configuring hardware components, monitoring and debugging the PLC's performance, and managing communication with other devices on the network.

Simatic Manager is widely used in industrial automation and control systems, particularly in manufacturing, process control, and building automation applications. It supports a variety of programming languages, including ladder logic, function block diagrams (FBD), and structured text (ST), among others. Additionally, Simatic Manager allows for the integration of various Siemens automation technologies, such as human-machine interfaces (HMIs), motion control, and safety systems, to create a complete automation solution.

The SIMATIC Manager is the basic application for configuring and programming. You can perform the following functions in the SIMATIC Manager:[49]

- Set up Project
- Configure and assign parameters to hardware
- Configure hardware networks
- Program blocks
- Debug and commission the programs

The SIMATIC Manager shown in Figure 3-2 is the central place for the PCS7 project engineering tasks. The SIMATIC Manager provides three views (the Plant view, Component view, and Process object view) to access a project data. Project objects are created, copied, moved, and edited, etc. in the SIMATIC Manager environment.

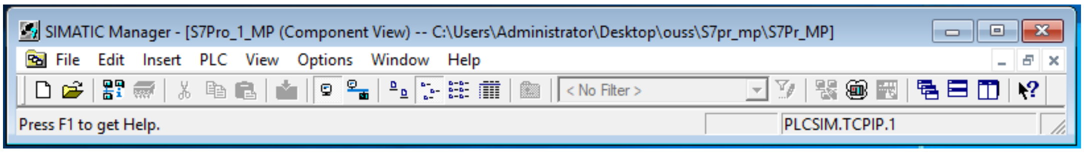

Figure 3-2 SIMATIC Manager main window

Project views and objects

There are 3 views for a project in the SIMATIC Manager.

- Plant View
- Component View
- Process Object View

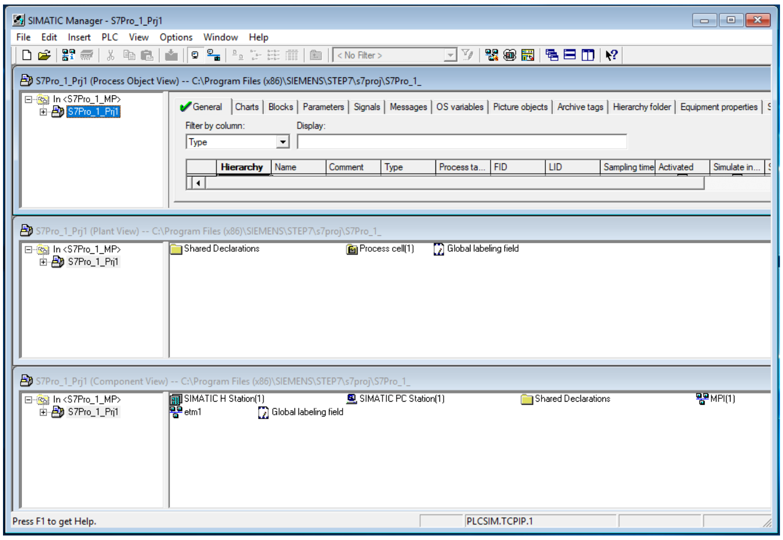

Figure 3-3 Plant view, Component view, and Process object view of a project

Plant View

Plant view shows a project with hierarchical levels, which is a logic representation of real plant hierarchy. A project can have up to 5 levels of plant.

In the Plant view (Figure 3-4), we can insert the following objects: Hierarchy folder, CFC, SFC, Picture, Report and Additional documents.

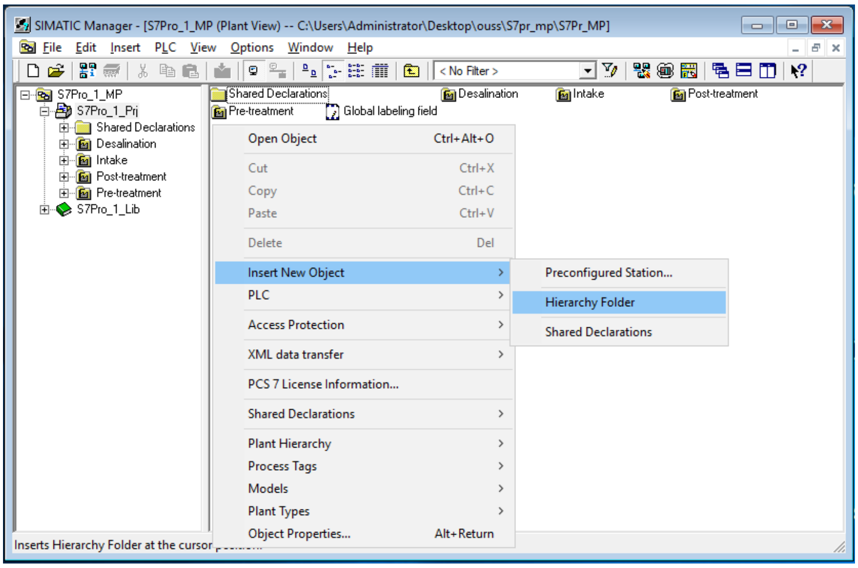

Figure 3-4 SIMATIC objects which are inserted in the Plant view

Component View

Component view contains hardware parts, bus systems, automation stations, and PC stations.

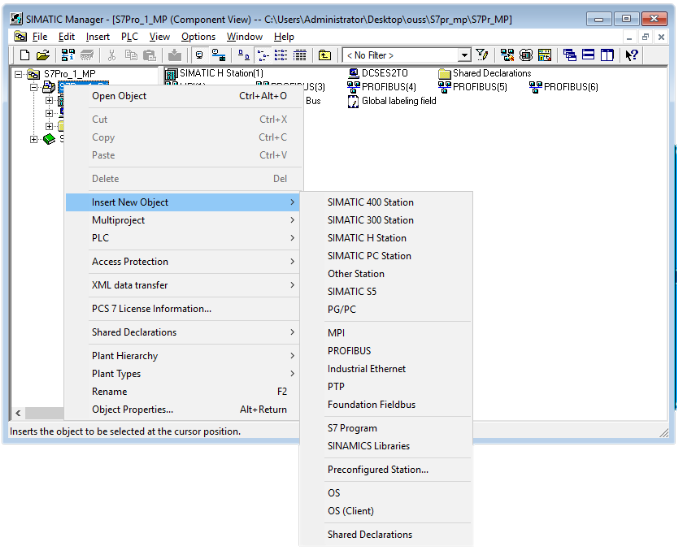

Figure 3-5 SIMATIC objects which are inserted in the Component view

In the Component view, we can insert hardware components

- SIMATIC S7 400 Station
- SIMATIC H Station
- SIMATIC PC Station
- S7 Program OS (Operation server project)
- OS (client project)

Process Object View

Process object view contains all the engineering aspects of a project, e.g. parameters, signals, messages, texts, graphic images, measured value archives. It provides a central place to edit, add, and mend data of a project. In the process object view you can also insert Plant hierarchy, CFC, SFC, pictures, etc. The same as you can do in the plant view. the process object view, is a powerful filtering functions to facile finding a group of data or a specific datum.

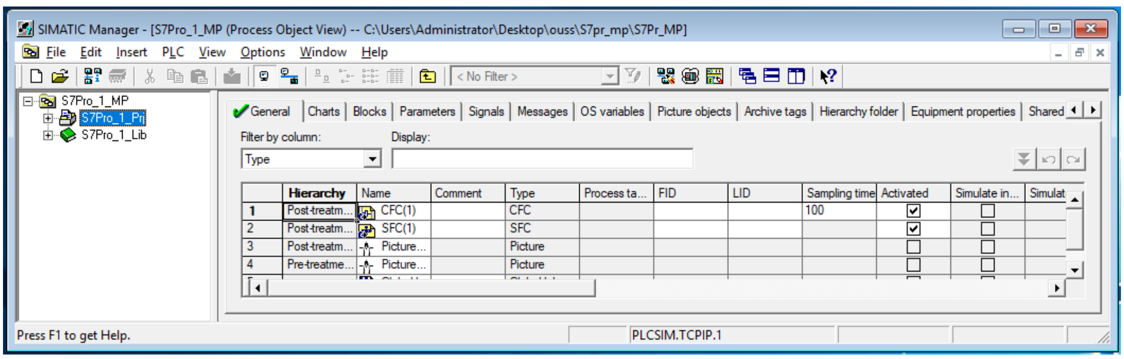

Figure 3-6 Process object view window

Multiprojects

Multiproject is a type of project in the SIMATIC Manager. Within the SIMATIC Manager, projects (single projects), libraries, and multiprojects can be created. A multiproject consists of at least one single project and one library. The library is referred to as the master data library.[50]

3.2.3 Advanced Process Library

The APL is offered as a standard feature of SIMATIC PCS 7. It includes preconfigured and pre-tested function blocks, faceplates and block icons for simplified, graphically based control of all process equipment. APL's comprehensive and flexible range of modules includes options for mathematical operations, control logic, motors, valves, field devices, monitoring, diagnostics and more.[51]

3.2.4 Continuous Function Chart (CFC)

CFC (Continuous Function Chart) is an editor with a graphical user interface, an extension based on the Simatic Manager software package. It is used to create the entire software structure of the CPU and uses pre-configured blocks. The editor lets you insert blocks into function charts, assign block parameters and interconnect blocks. Interconnecting means that values can be transferred from one output to one or more inputs during communication between the blocks or other objects.[26]

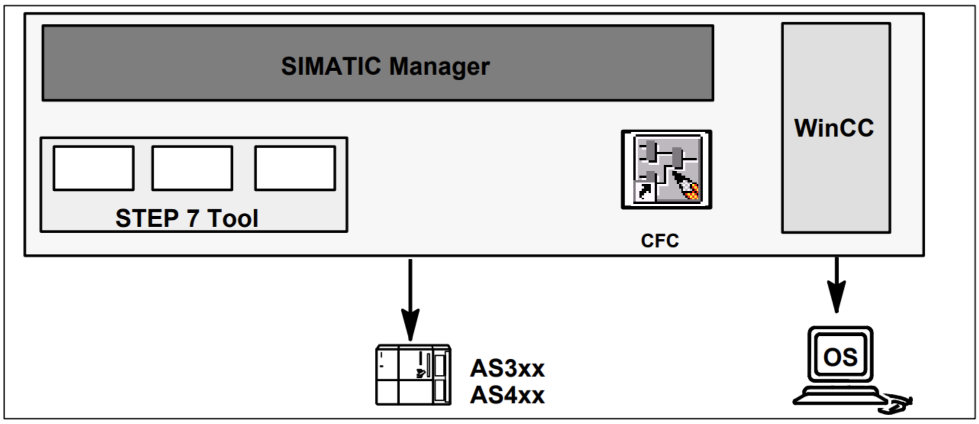

Figure 3-7 CFC in the STEP 7 Environment[26]

Blocks in CFC

In CFC, working with ready-made blocks that have specific functions is common practice. These function blocks are placed in the chart, interconnected, and assigned parameters.

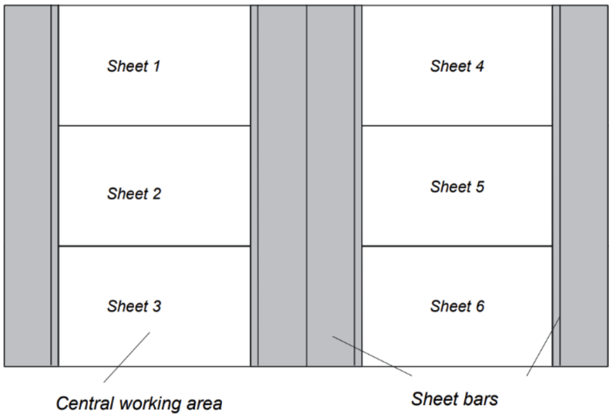

Figure 3-8 CFC Chart in the Overview Display

3.2.5 Blocks parameterization

1. block configuration: Open the PCS7 project in the SIMATIC Manager tool. Naigate to the area where you want to add the APL blocks. It can be a functional unit, a module, or a specific area of the project.
2. Adding the APL block: Right-click on the target object and select "Add APL block" or "Create APL block" from the context menu. This will create a new API block instance in the project.
3. Block parameterization: Double-click on the newly created block to access its properties. In the properties tab, you can configure various parameters such as the block name, input and output variables, communication options, etc. Configure these parameters according to the requirements of the program you are integrating
4. Error handling: Set up error handling in the block to address potential communication or data processing errors. This may include defining status variables, implementing error recovery mechanisms, or logging errors
5. Compiling and download: to check for any errors or warnings to be considered

3.2.6 PLCSIM

S7 PLCSIM is a software tool that simulates the operation of a Siemens S7 PLC (programmable logic controller) on a PC. It allows users to test and debug their PLC programs without connecting to a real PLC device. S7 PLCSIM can be integrated with PCS7 (process control system 7), a distributed control system that manages complex industrial processes. With S7 PLCSIM and PCS7, users can create realistic scenarios and optimize their automation solutions.

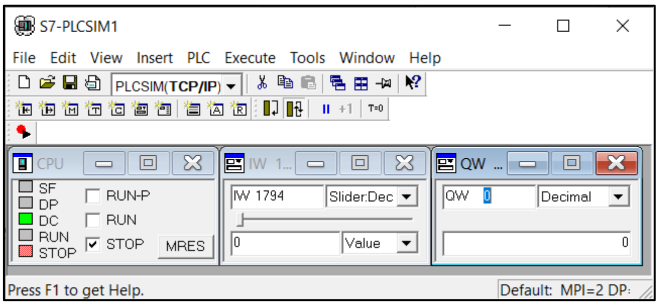

Figure 3-9 PLCSIM window

3.2.7 WinCC

The SIMATIC WinCC V7 SCADA software is an innovative, scalable process visualization system with numerous high-performance functions for monitoring automated processes in all industries [52].

SIMATIC WinCC is a supervisory control and data acquisition (SCADA) and human-machine interface (HMI) system from Siemens. SCADA systems are used to monitor and control physical processes involved in industry and infrastructure on a large scale and over long distances. SIMATIC WinCC can be used in combination with Siemens controllers. WinCC is written for the Microsoft Windows operating system.It uses Microsoft SQL Server for logging and comes with a VBScript and ANSI C application programming interface [53].

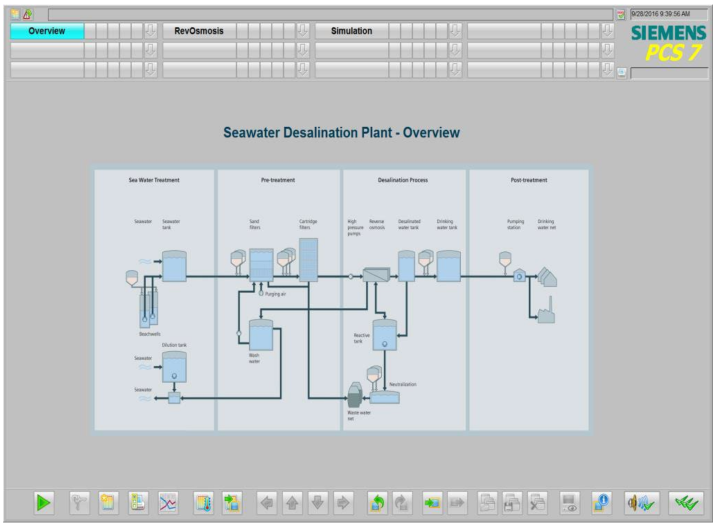

Figure 3-10 Example of WinCC View

3.3 DESCRIPTION OF SPECIFICATION SHEET

3.3.1 Overall process description

The provided concept from siemens (Figure 3-11) describe a typical plant configuration dealing with the frequently used technological implementation of a Sea Water Reverse Osmosis Plant with the capacity of About 14,000 m³/day with a middle to high automation grade.

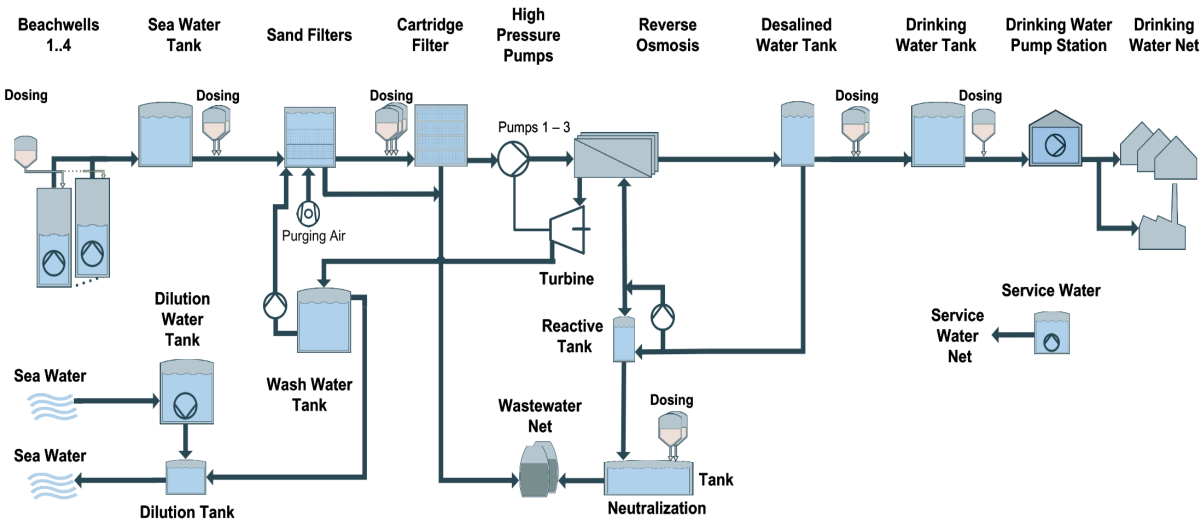

Figure 3-11 Desalination Plant overview [Annex C]

There are 3 main stages in the desalination which contains several sub-processes:

1. Pre-treatment: Water from the sea water tank is cleaned of dirt and sand using mechanical filtration and ultrafiltration. In addition, the ph value is balanced and bacteria are eliminated by adding chemical dosing
2. Desalination Process: In the actual desalination process, the salt water is pressed at hight pressure into a filter system containing a large number of osmosis membranes, the osmotic pressure of the sea water must be overcome (Reverse Osmosis).
3. Post-treatment: Finally, the pH value is regulated again and the potable water is enriched with minerals.

These stages are described regardless the sea water intake phase.

Here's detailed explication of water flow in the desalination plant process:

1. Intake: the seawater is drawn from beach wells and filtered by natural layers of sand, additionally hypochlorite dosage is added in SW to prevent biological growth in the following filter process.
2. The seawater is stored on a tank to prepare it for the next process.

3. Pre-treatment dosing: Adding chemical treatments such as Ferric chlorite and sulfuric acid before entering mechanical filtration process.
4. Mechanical Filtration: involves the use of sand filters to eliminate colloids and other substances causing harm to the membranes. In order to maintain the filters' effectiveness, it is necessary to implement cleaning system removing process residuals. This guarantees the proper functioning and efficiency of the filtration equipment.
5. Second Pre-treatment dosing: the seawater goes through multiple chemical treatment sub-units stated as follows:
   1. Caustic Soda dosing
   2. Dispersant dosing
   3. Sodium Bisulfite dosing
6. Cartridge Filter: Otherwise known as ultra-filtration stage, is designated for the purpose of eliminating any residual organic compounds and solid particulates from the seawater source prior to its introduction into the subsequent desalination stage.
7. Waste Water disposal: the residuals of filtration processes are discarded into waste water net
8. High Pressure Pumps: The pre-treated water is fed into a HPP so salt can be separated from water by reverses osmosis membranes, concentrate pressure is transferred to a Pelton turbine to support pumps pressurizing the reverse osmosis system.
9. Reverse Osmosis: a separation process that utilizes a semi-permeable membrane, produces two distinct output streams - permeate water and brine by-product.
10. Desalinated & Drinking water tank: from this sub-unit he post-treatment stage begin:
    1. Lime Milk dosing (Silo & mixer tank, Saturator)
    2. Carbone dioxide dosing
    3. Post-chlorination dosing
11. Finally, the potable water is ready for distribution.

3.3.2 Post-Treatment Process

Our focus in this thesis is on the post-treatment section, which is the process of conditioning the water that has passed through the reverse osmosis membranes. It includes disinfection, pH adjustment, remineralization, and corrosion inhibition. The purpose of post-treatment is to prevent microbial growth, stabilize the water quality, enhance the taste, and protect downstream equipment and piping.

The potabilization process consists of three-unit operation: carbonation, liming and chlorination. The drinking water then passes to pumping station for distribution. The carbonation and liming, based on the use of carbon dioxide gas and hydrated lime, result in an increase in hardness and alkalinity of the water to a desirable level so that the water becomes well buffered and non-aggressive while maintaining a slightly positive Langelier saturation index (LSI).

The lack of carbonate alkalinity makes the desalinated water unstable and aggressive and prone to wide variations in pH due to the low buffering capacity. The basic principle involved in the remineralization steps is the chemical reaction between carbon dioxide and calcium hydroxide to form water-soluble calcium bicarbonate and simultaneous adjustment of pH. Such treatment method aids in establishing the calcium carbonate equilibrium and forming corrosion inhibiting protective layers of calcium carbonate. The chlorination is conducted by injecting chlorine gas to disinfect the water and to eliminate bacterial growth [54].

Continuous monitoring and quality control measures are essential to ensure that the desalinated water meets regulatory standards and remains safe for consumption. This involves regular testing for various parameters such as pH, conductivity, turbidity, and disinfection byproducts. The Figure 3-12 show the studied post-treatment unit.

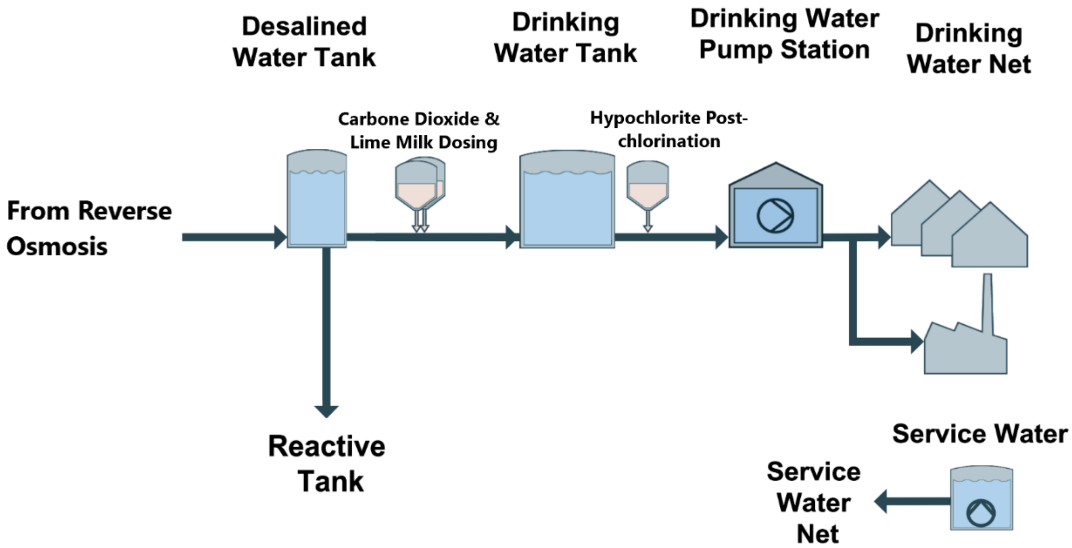

Figure 3-12 Post-treatment system by RO [annex C]

3.3.3 Functional analysis of the Process

The desalinated water from the previous RO process is placed in desalinated water tank.

A portion of this water will be used in three different processes: pressure groups, Reactive tank, and flocculation chamber.

The majority of the water will be transferred through pipes to another reservoir while injecting CO2 through another pipe.

Then, the water will fill the drinking water reservoir with a volume of 3000m^2, with the injection of Lime Milk, which will be monitored by a level transmitter (LT) with a height of 12m, where the minimum level is 0.5m.

The water will be transported through three pumping lines (two operational and one reserve). At the beginning of each line, a motorized valve injects hypochlorite.

Inventory of post-treatment unit

The equipement inventory table is retrieved from the specifications description [annex A]

Table 3-1 Equiment Inventory list

Inventory	Quantity	Equipment & Instrument ID
Motors	6	(3) Fan drinking water **DT1 YIS 12/22/32** (3) Pumps drinking water **DT1 NC 10/20/30**
Valves	6	(3) Valve pressure side **DT1 YIS 12/22/32** (3) Valve hypochlorite dosage **DT1 YS 02-04**
Measures	10	Level desalinated water tank **DW1 LIRA 01** (3) Pressure pumps drinking water **DT1 PISA 05-07** Flow rate product **DT1 FQIR 08** Level drinking water tank **DT1 LIRA 01** Thermostat DW pumps **DT1 TISA 15** Probe controller SC200 **DT1 C 02** Conductivity DT1 AIR 09 pH drinking water DT1 AIR 09

		Probe controller SC200 DT1 C 01 pH drinking water tank DT1 AIR 22

The functioning of pumping lines

Line 1: The hypochlorite will be injected through valve YS04, and then the water will be pumped by DT1-10 towards valve YIS12 to rise the pH Level from 6.5 to 8.5 as limits.

Line 2: YS03 → DT1-20 → YIS22

Line 3: YS02 → DT1-30 → YIS32

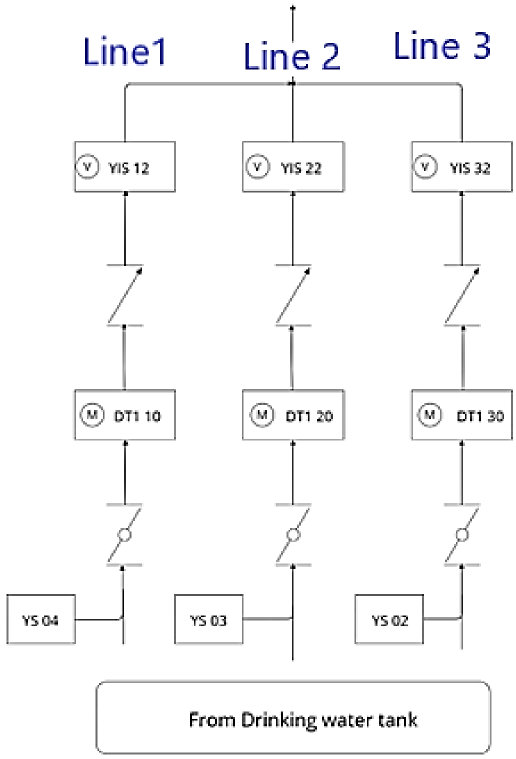

Figure 3-13 Pumping Station in post-treatment

During regular operation, two lines are in service while the third line remains on standby.

In case of detecting any failure, an automatic switch occurs to activate the reserved line.

Sensors:

The motors are equipped with temperature transmitters, with three transmitters for monitoring the winding temperature and two transmitters for monitoring the bearing temperature.

T Windings: 85°

T Bearings: 110°

Additionally, the motors are equipped with pressure sensors for monitoring the pressure levels while in service.

Pressure measurement during pumping should be between 8 and 10 Bar.

For protection reasons the pump has to be working in an ideal inlet pressure to avoid cavitation, so we define another monitoring parameter which is the level of the tank that has threshold of 0.5m to completely shut down the pumping station.

The three parallel pumping lines combine into a common line at the end that leads to the subsequent process.

This pipe contains a conductivity sensor and another one for pH,by using dosing valves YS-X pH level will raise from 6.5 to 8.5 and through this pipe, the water will flow towards the next subprocess.

3.4 AUTOMATION SYSTEM

The automation configuration mainly starts by setting the control level of the plant, the overall dcs structure from siemens seen in previous chapter (Figure 2-3) can be narrowed down to the essential elements used in studied concept shown in Figure 3-14.

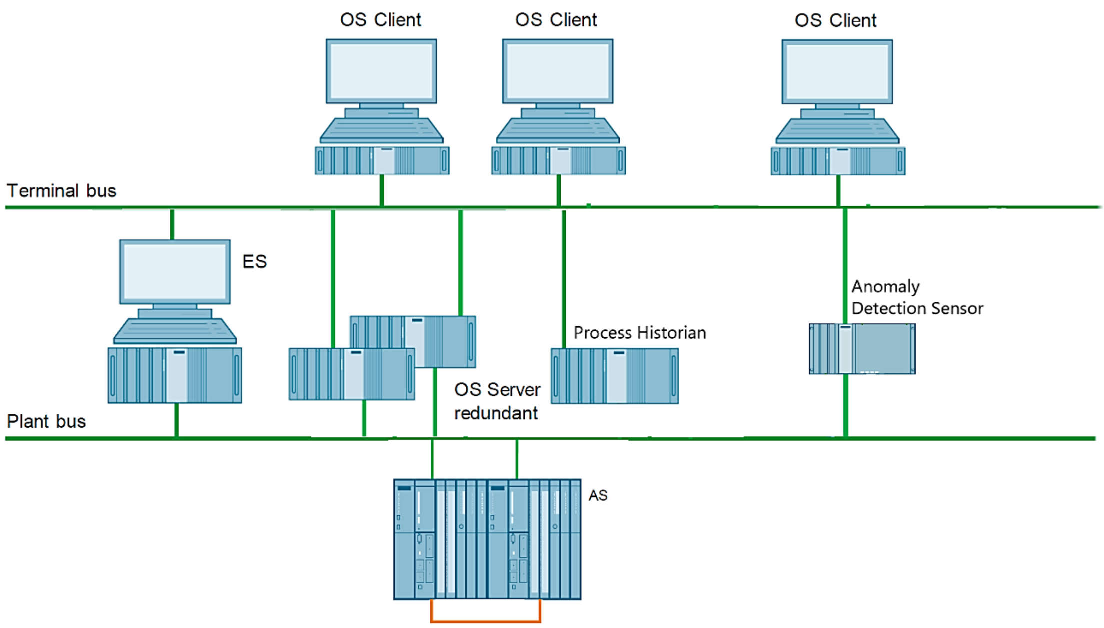

Figure 3-14 Control Level of Automation System [Annex A]

Essentially in this configuration, the system has one pair of redundant OS servers (PCS7 server), one separated ES and three operator station (1 in server room/ 2 in control room), Process historian and Anomaly Detection Sensor, all linked together by means of Scalance switches.

3.4.1 PROFINET as a fieldbus

there are four types of PROFINET redundancy used in PCS7: S1, S2, R1 and R2. These configurations differ in how the PROFINET controllers and devices communicate with each other in case of a failure [55].

- **S1** is the simplest configuration where a single PROFINET controller communicates with a single PROFINET device. If either one fails, the communication is interrupted.
- **S2** is a configuration where a single PROFINET controller communicates with two identical PROFINET devices that support system redundancy. If one device fails, the controller switches to the other device without interruption.
- **R1** is a configuration where two identical PROFINET controllers communicate with a single PROFINET device. If one controller fails, the other controller takes over the communication without interruption
- **R2** is a configuration where two identical PROFINET controllers communicate with two identical PROFINET devices that support system redundancy. If one controller or one device fails, the communication is maintained by the remaining components without interruption

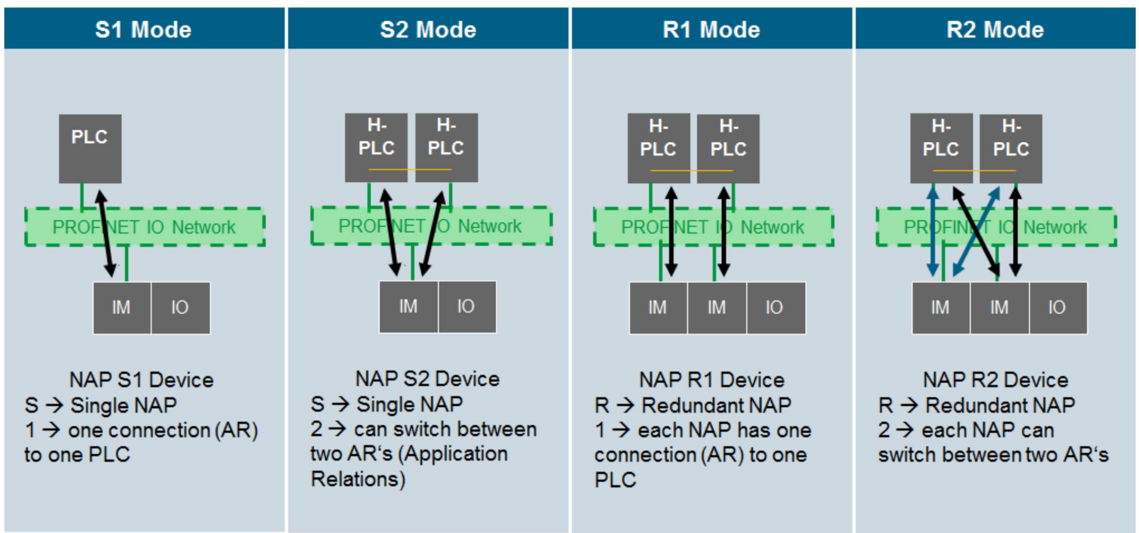

Figure 3-15 Overview of the PROFINET system redundancy configurations [55]

In this configuration (Figure 3-15), R1 redundancy is used in combination with Media Redundancy Protocol MRP starting from OS/ES stations to distributed I/O through central CPU. R1 redundancy refers to having two identical CPUs that run in parallel and synchronize their data and program execution.

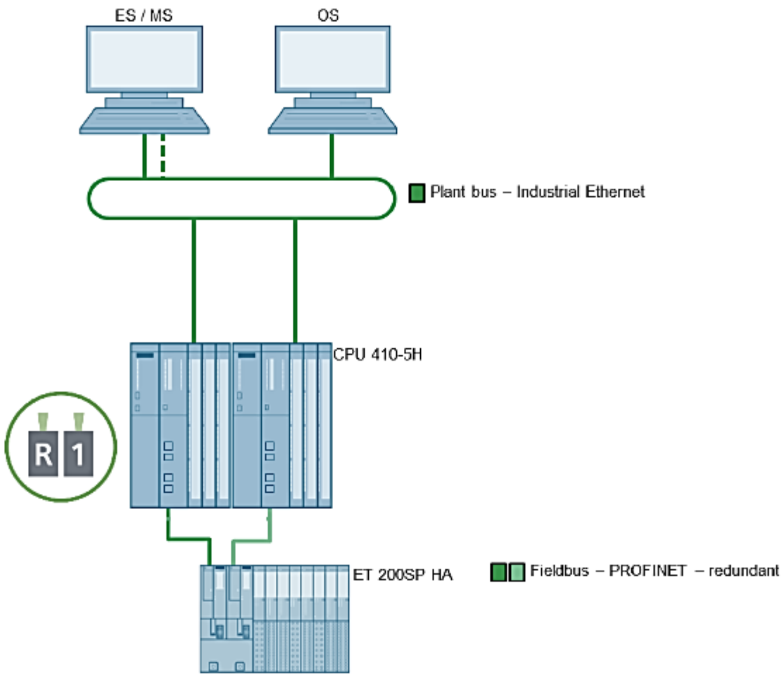

Figure 3-16 Control Level connection to central PLC

Excluding the CPU 1510SP-1PN from the system will result in changes, such as the need to interconnect motor drives and SIMOCODE valves and CFU PA in an MRP ring topology. The overall configuration of the unit is illustrated in the following Figure 3-17

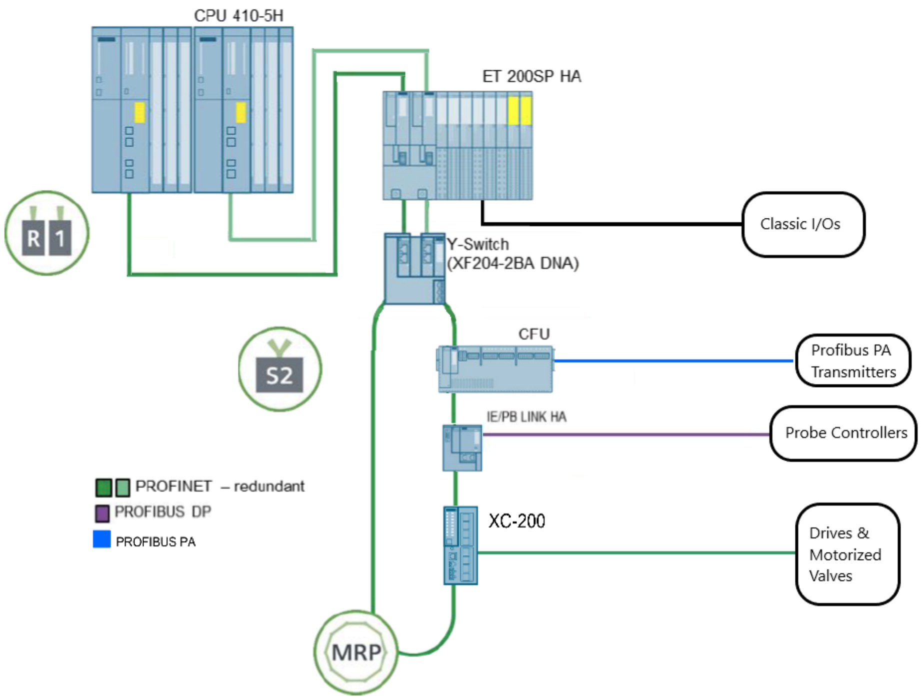

Figure 3-17 Hardware configuration on field level of post-treatment unit

3.4.2 Components description

AS 410 Automation System: it utilizes CPU 410-5H (Figure 3-18) that are specifically designed for process automation. It is one of the few IO controllers that support all PROFINET functions (S1, S2, R1, CiR, and SoE) and, therefore, form the requirements for PROFINET in the PCS 7 environment (as of version V9.0) and the basis for future developments.[56]

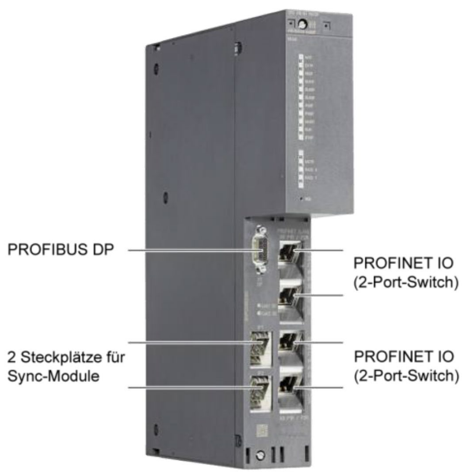

Figure 3-18 CPU 410-5H[56]

The CPU 410 has two PN/Ethernet interfaces with an integrated 2-port switch. Up to 250 IO devices can be connected per PROFINET interface. The CPU 410-5H has 8 KB and the CPU 410E has 1.5 KB for the I/O address range per PN interface [56].

Distributed I/O: The ET 200SP HA (Figure 3-19) is the preferred choice as a distributed I/O in the case of a single PCS 7 system with PROFINET. It enables the integration of standard and fail-safe signal modules. Configuration variants with optional single (one) or redundant (two) interface modules enable connection via single PROFINET configuration S1, system redundancy S2 or redundant PROFINET R1 configuration .

1. BusAdapter
2. Interface module
3. I/O modules
4. Terminal blocks without peripheral module
5. Server module
6. Carrier module for two interface modules
7. Carrier modules with terminal blocks
8.

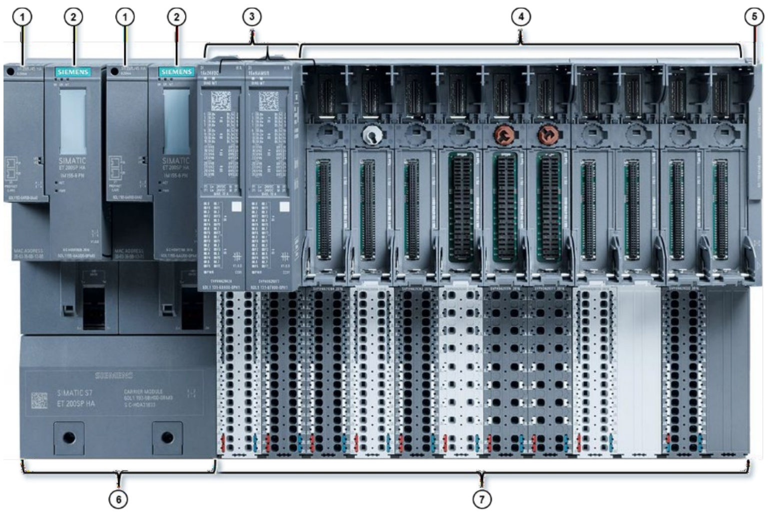

Figure 3-19 ET200SP HA composition[56]

SIMATIC Compact Field Unit: The Compact Field Unit PA (CFU PA) shown in Figure 3-20 is a field distributor for process-oriented, distributed connection of digital I/O signals and PROFIBUS PA field devices to the PROFINET fieldbus [56].

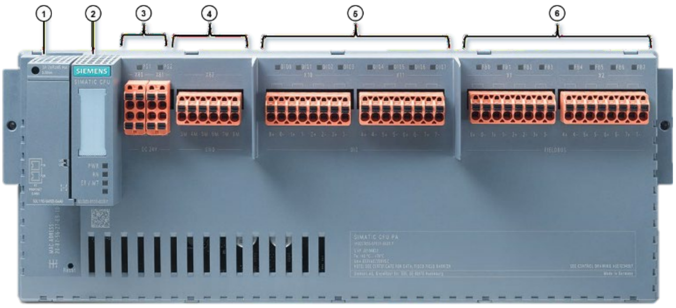

Figure 3-20 Compact Field Unit PA

1. BusAdapter
2. Interface module
3. Power supply
4. Connections for reference potential (mass)
5. Connections for freely configurable digital I/O channels
6. Connections for each PROFIBUS PA field device

SCALANCE Switches: it uses XC-200 and XF204-2BA that are family of Ethernet switches. XC-200 are used to extend network to field devices that uses PROFINET such as G150 Drives and SIMOCODE Pro V for pressure side valves.

XF204-2BA DNA, also called Y switch, enables S2 devices to be connected to R1 networks. The network separation of both R1 networks is maintained [56].

IE/PB link: The IE/PB LINK HA is a Gateway between Industrial Ethernet and PROFIBUS [56] and is used to connect probe analyser to the DCS.

Figure 3-21 IE/PB LINK HA switch[56]

3.5 CONCLUSION

In this chapter, we've seen the essential functions of PCS7 and its utilities, as well as understanding the whole desalination process then focalising on the post-treatment unit to extract a functional description and deriving a list of equipment inventory to implement it on the automated system with a brief view of its components, by settling basic ground we disclose this chapter to the fourth and final chapter where we'll develop the program and realize the simulation of the process.

Chapter 4: Realization and development of DCS in PCS7

In this chapter the procedures for implementing a DCS application with PCS7 are described. The techniques used to develop the program, such as the utilization of supervisory view pictures, are explained. Furthermore, the discussion includes the operational rules needed to establish a dependable and secure system. In the last section, the application is executed on PLCSIM with WinCC Runtime to observe the behavior of the process and present simulation results.

4.1 INTRODUCTION

the development of a distributed control system (DCS) program for the "Desalinated and Drinking Water Tank" process unit under PCS7 v9.1 will be discussed. The chapter describes the technique used to create the program, configure the communication network, and define hardware configuration. It also covers the creation of control logic by interconnecting and customizing blocks. Furthermore, the chapter explains the process of defining operational rules for the unit, including setting interlocks, permissions, and protection conditions for each equipment. Lastly, the chapter demonstrates how to simulate the process using PLCSIM and monitor its behavior in WinCC Runtime.

4.2 APPLICATION DEVELOPMENT PROCEDURES

4.2.1 Multiproteic Creation

First (1), SIMATIC Manager is launched, and the menu command File > 'New Project' Wizard is selected. The PCS 7 Wizard: 'New Project' opens, and the Next button is clicked to proceed. The main CPU of the project is chosen at this point. For the equivalent Central PLC of the desalination station, AS410-2H is selected.

On the next window (3), the number of levels of the plant hierarchy is chosen, and the PCS7 OS box is checked to create OS objects. For this station, level 3 is the ideal choice. The Preview option can be used to see how the Plant hierarchy is organized before creating the new project.

In the last step (3), we give a suitable name to the project and choose a location to save it on our device. Refer to Figure 4-1

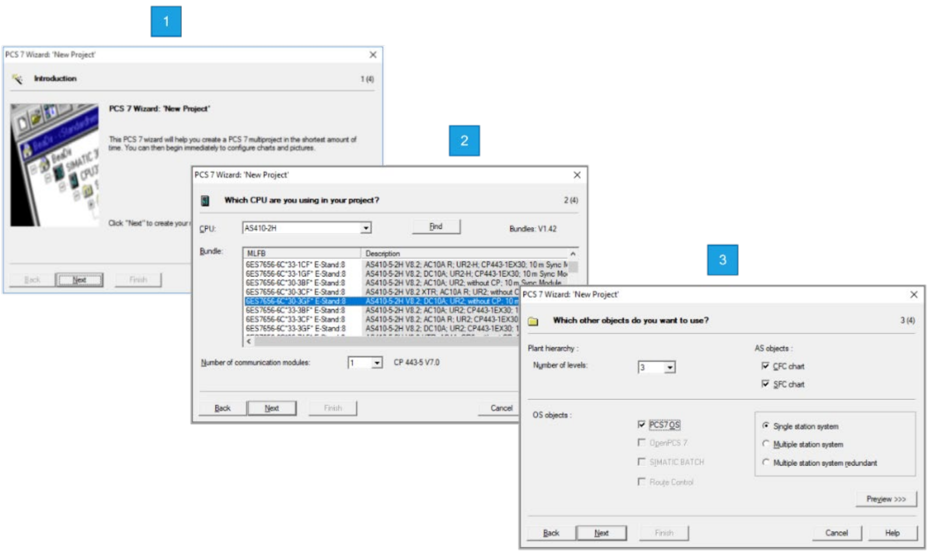

Figure 4-1 PCS7 project creation procedures

4.2.2 Plant hierarchy

To create a new folder in PCS7 plant hierarchy, follow the steps below

1. Open the Plant View.
2. Right-click on any hierarchy folder.
3. Select "Insert New Object" and then "Hierarchy Folder"

This will create a new folder in the plant hierarchy. The structure of the plant is implemented in PCS 7 using a folder structure, and by nesting the hierarchy folders, complex plants can also be mapped

If the hierarchy folders are not shown in the Plant View after retrieving a PCS7 project on a new laptop, users can select "Plant Hierarchy > Update in the multiproject" by right-clicking on any hierarchy folder to open a new window

the previously discussed process is divided into several subsystems through the following hierarchy (Figure 4-2)

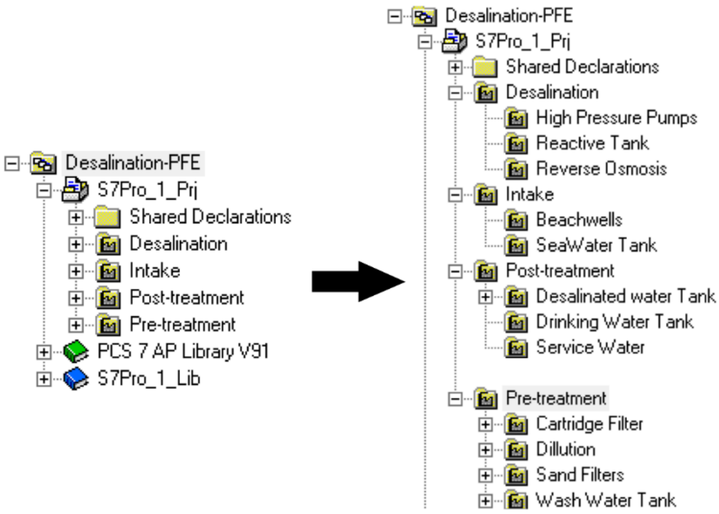

Figure 4-2 Plant hierarchy

4.2.3 Hardware configuration

The overall configuration consists of configuring two types of hardware: the PC station where the OS would launch on, and SIMATIC Station (AS) the responsible hardware to control the process. Refer to Figure 4-3:

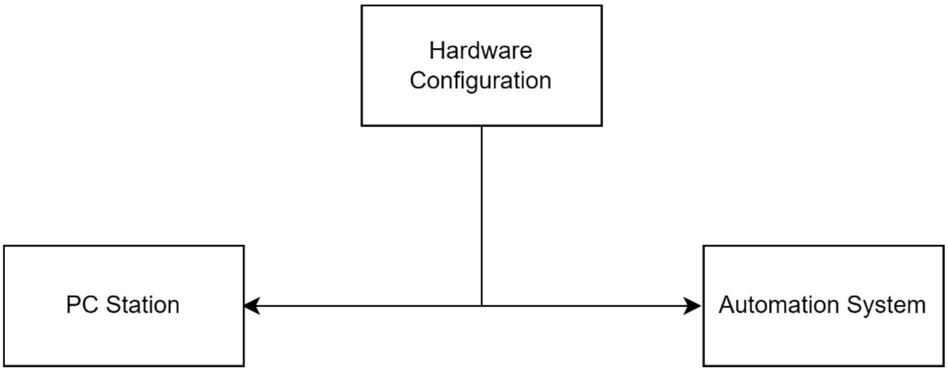

Figure 4-3 HW Config scheme

PC station configuration

This configuration (Figure 4-4) consists of establishing a connection between the OS/ES and the CPU 410-5H. It presents the minimum requirements to create a project and test the functioning of a simulated program in WinCC.

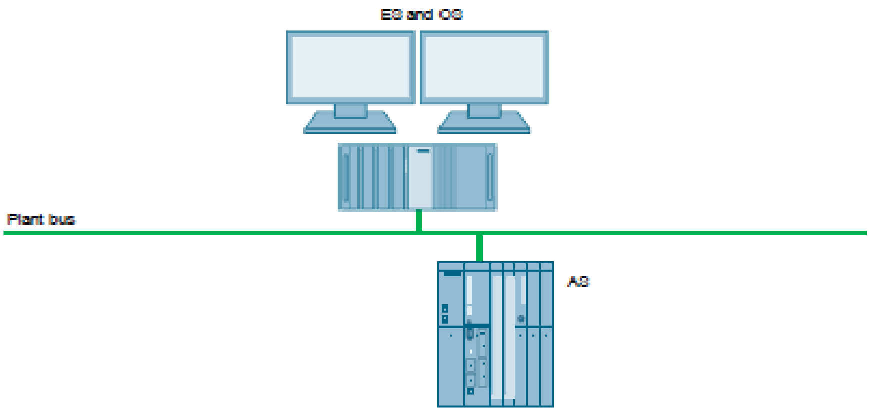

Figure 4-4 Single station structure [57]

The computer or virtual machine must have changed its name to ES, the important thing is that the name in the project is the same as the name of the physical machine. When the design and the machine have the same name, the PC Station icon will have a yellow arrow as shown in Figure 4-5.

Retrieving the IP address from the computer's network adapter to use it later for IP assignment (Figure 4-6).

From Components View → PC Station (Desktop's name) → Configuration Insert Ethernet communication board for OS (General IE). It's in the catalog on Simatic PC Station\CP-Industrial

Ethernet\IE-General SW V9.1. Add in position 1 of the PC Rack (index 1) and Assign address to ES General with IP 192.168.0.50 as well as networking it to Ethernet subnet (Figure 4-7).

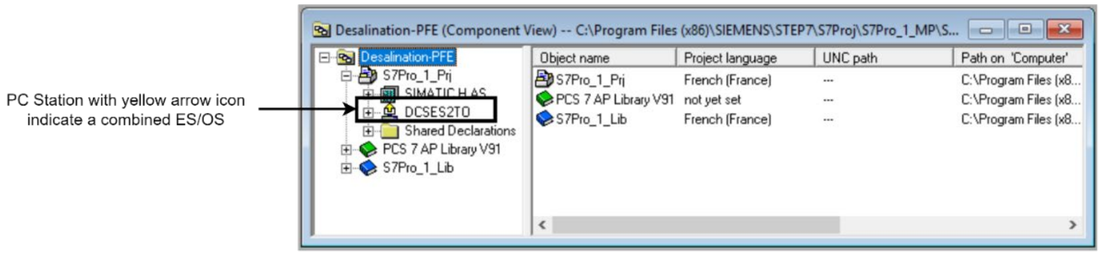

Figure 4-5 Component view

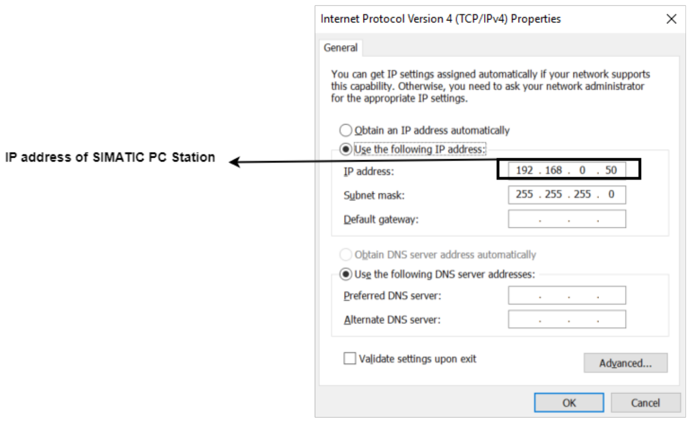

Figure 4-6 Network adapter window

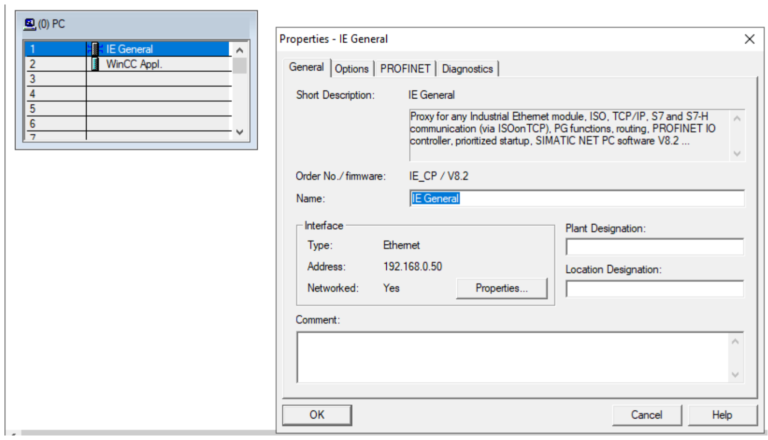

Figure 4-7 PC Station HW Config window

From SIMATIC H AS → Configuration, we set a new IP address for the CPU 410-5H in any of the 2 Profinet interface module, here in this application PN-IO-X8 is used to communicate with PC Station with 192.168.0.1 IP address, the redundant CPU is also configured in a same way in a unique IP address all in one same Ethernet subnet. (Figure 4-8)

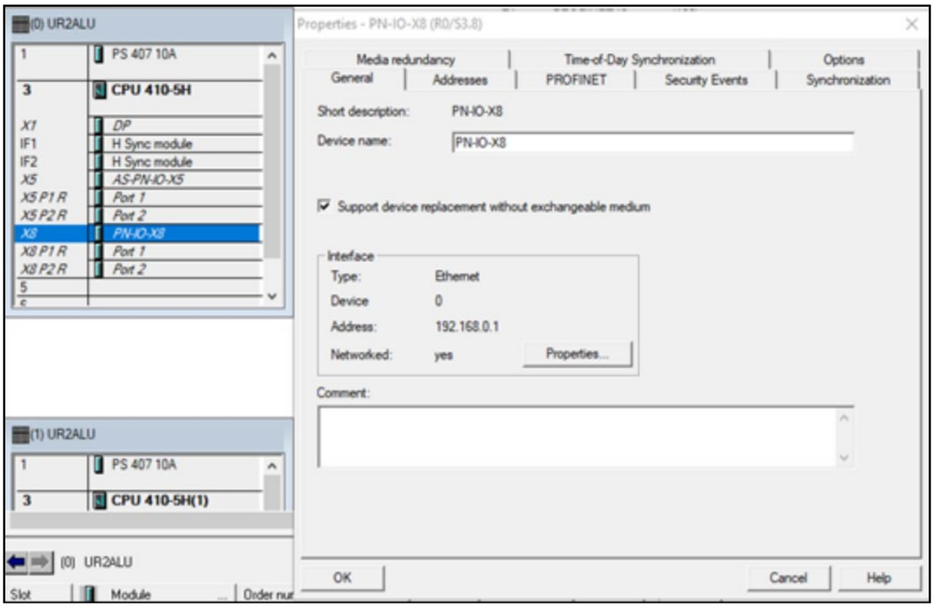

Figure 4-8 HW Config Networking option

This part of the hardware configuration is completed by establishing an AS-OS connection. The networks and connections are configured in the NetPro application. NetPro allows for configuring, parameter assignment, and documenting the network configuration of the plant in a simple and clear manner. To open NetPro, go to the SIMATIC Manager Options menu, select Configure Network, choose CPU 410-5H, select the connection type as S7 Connection, and click OK.

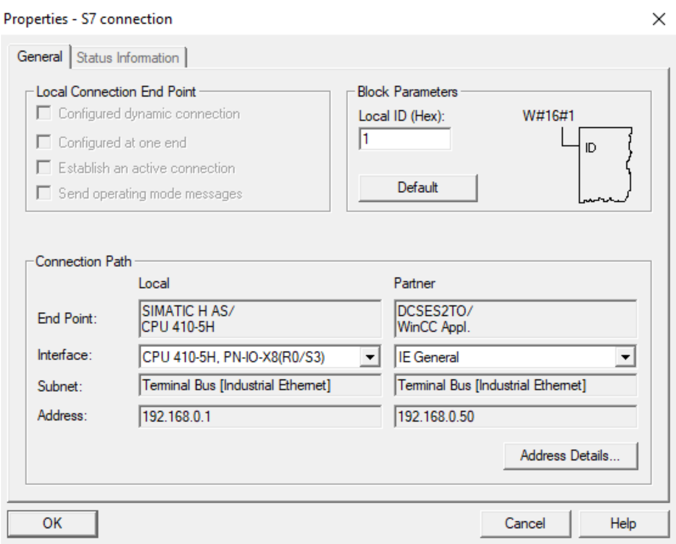

Figure 4-9 NetPro S7 connection window

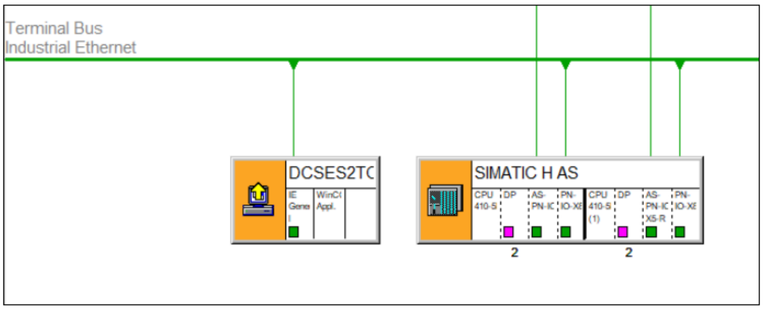

Figure 4-10 Established network connection between PC station and AS

4.2.4 SIMATIC H AS

HW Config is where the hardware configuration of the SIMATIC H AS is made. To open HW Config, double-click on AS > Hardware.

In the right corner appears the Hardware Catalog. To enable Hardware Catalog visibility, select View Catalog. Components must be selected in the Hardware Catalog and dragged to the main HW Config window (Figure 4-11). Then, we assign components to the subnet of Plant Bus by defining IP address of each one including the connection to redundant PROFINET IO system. The overall configuration is shown as follows.

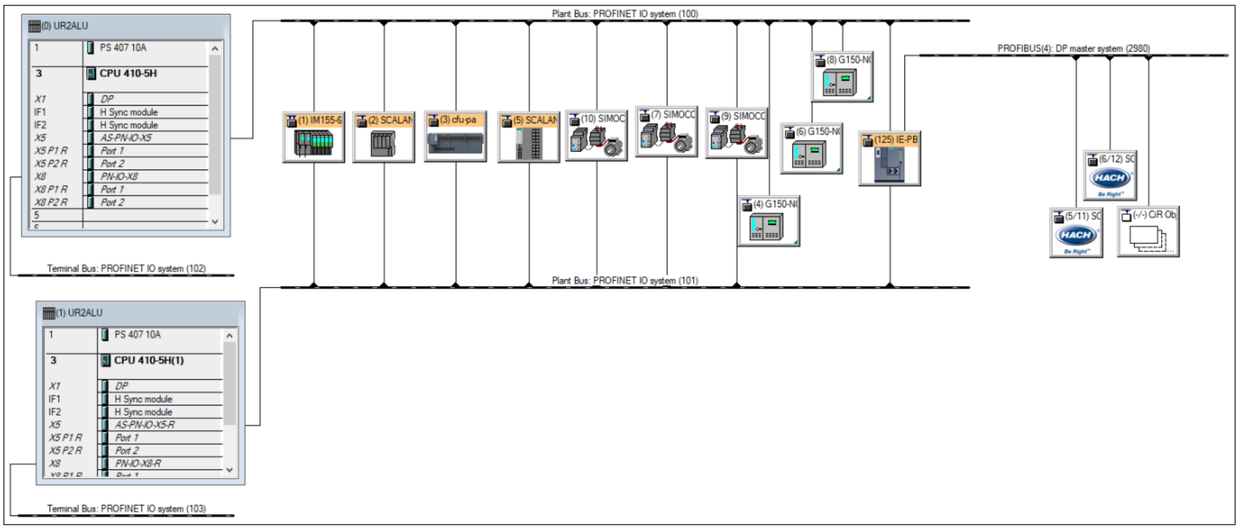

Figure 4-11 Overall configuration of automation station

The topology of the automation system is formed accordingly to specification description seen in the previous chapter. Refer to

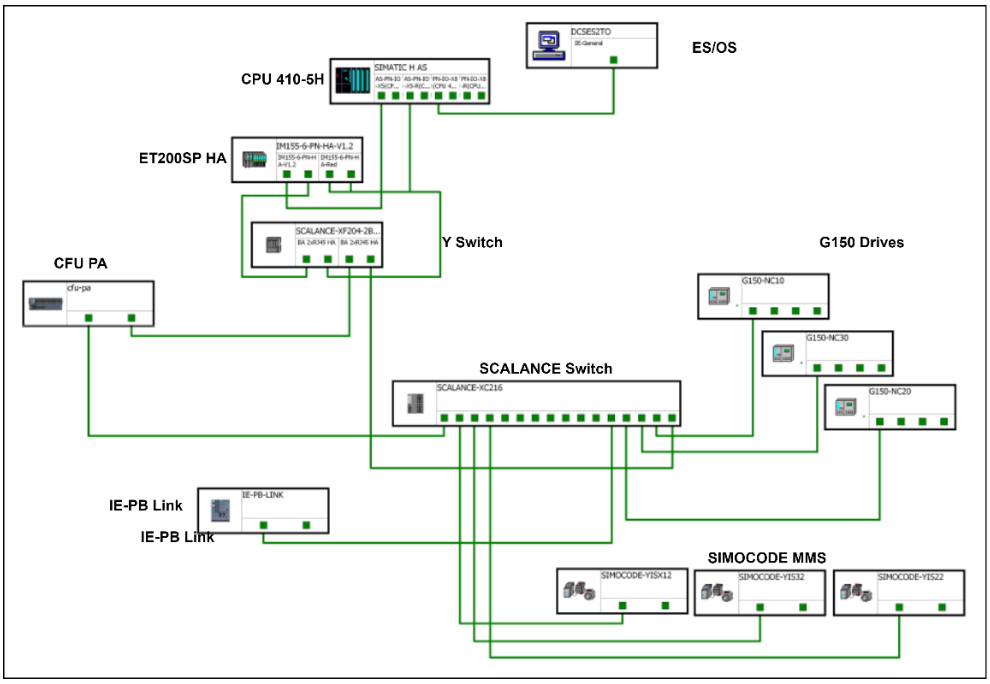

Figure 4-12 Network Topology of AS

All symbols in the project can be entered one by one or imported at once. The number of I/O is determined by the devices in the plant. The following list provides an overview of the number of devices and their corresponding I/O. The I/O assignment procedures can be summarized in the following flowchart (Figure ***4-13***).

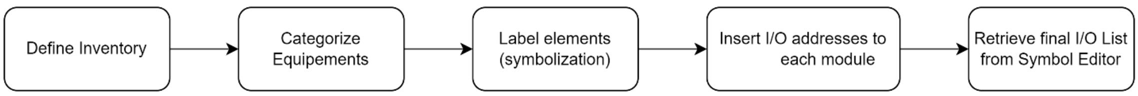

Figure 4-13 ***I/O Assignment Steps for the process***

Digital Input

Symbol	Address	Data Type	Comment
VALVE-YS-02_O	I 1.0	BOOL	Dosing valve YS02 OPENED
VALVE-YS-02_C	I 1.1	BOOL	Dosing valve YS02 CLOSED
VALVE-YS-03_O	I 1.2	BOOL	Dosing valve YS03 OPENED
VALVE-YS-03_C	I 1.3	BOOL	Dosing valve YS03 CLOSED
VALVE-YS-04_O	I 1.4	BOOL	Dosing valve YS04 OPENED
VALVE-YS-04_C	I 1.5	BOOL	Dosing valve YS04 CLOSED

Digital Outputs

DT1-YS-04-C	Q	2.0	BOOL	VALVE HYPOCHLORITE 3 CLOSING
DT1-YS-03-C	Q	1.7	BOOL	VALVE HYPOCHLORITE 2 CLOSING
DT1-YS-02-C	Q	1.6	BOOL	VALVE HYPOCHLORITE 1 CLOSING
DT1-YS-04	Q	1.2	BOOL	VALVE HYPOCHLORITE 3 OPENING
DT1-YS-03	Q	1.1	BOOL	VALVE HYPOCHLORITE 2 OPENING
DT1-YS-02	Q	1.0	BOOL	VALVE HYPOCHLORITE 1 OPENING

Insertion of I/O addresses from HW Config window is done in a manner shown by the chart (Figure 4-14) below

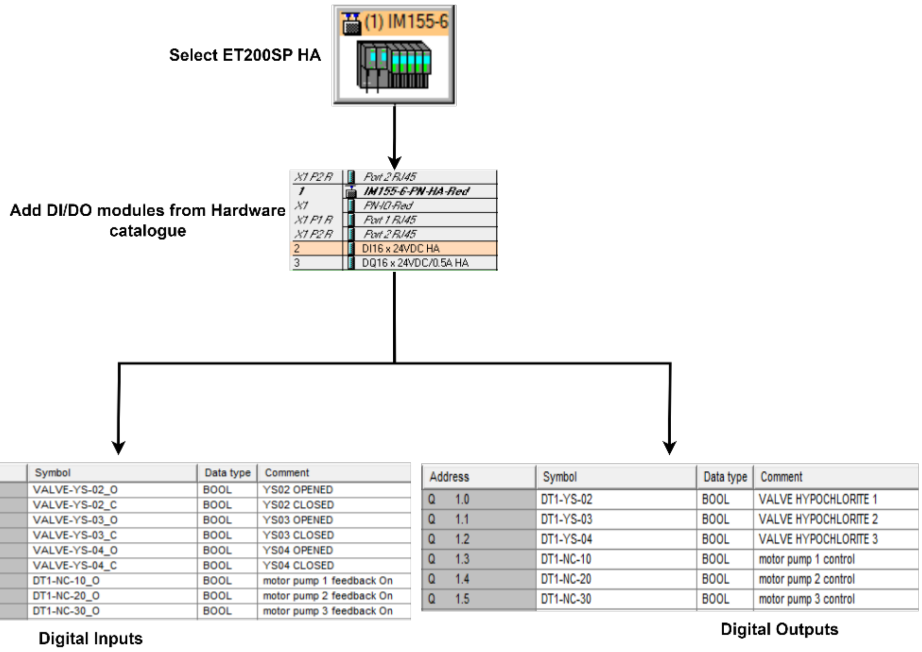

Figure 4-14 Edit symbols chart ET200SP HA

Analog Inputs

DW1-LIRA-01	ID	562	REAL	Level Desalinated Water tank
DT1-PISA-05	ID	567	REAL	pressure pump 1 drinking water
DT1-PISA-06	ID	572	REAL	pressure pump 2 drinking water
DT1-PISA-07	ID	577	REAL	pressure pump 3 drinking water
DT1-FQIR-08	ID	586	REAL	flow rate product DW
DT1-LIRA-01	ID	596	REAL	level drinking water tank
DT1-TISA-15	ID	601	REAL	Thermostat DW pumps
COND-DW	IW	524	WORD	Conductivity drinking water
pH-DW	IW	526	WORD	pH drinking water
pH-DWT	IW	528	WORD	pH drinking water tank

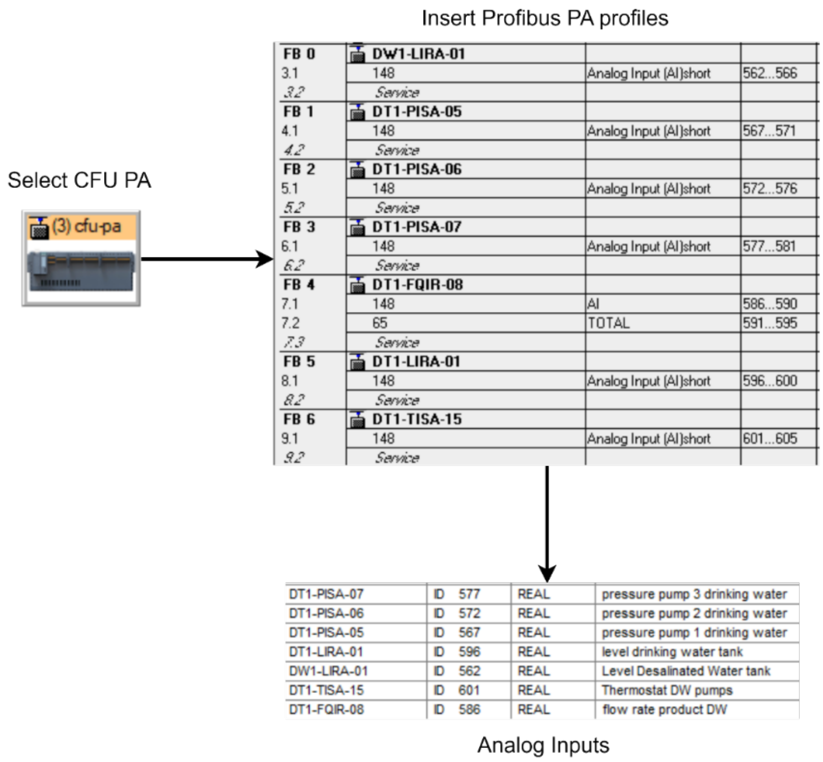

Figure Edit symbols chart CFU PA

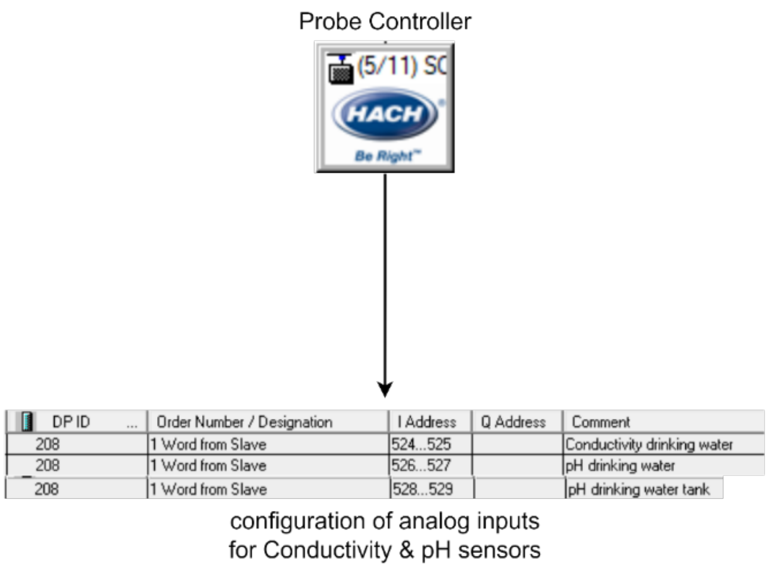

Figure 4-15 Edit symbols chart of probe controllers

Control and status words of SINAMICS G150 Drive are assigned according to Telegram 20, which is a standard telegram for speed control with setpoint and actual value channel as shown in Table 2 [58].

Table 2 Telegram type 20 structure[59]

Word	Output word	Input word
1	Control word	Status word
2	RPM setpoint	Actual RPM value
3		Motor current
4		Torque
5		Power
6		Namur messages or freely configurable analog value

G150 Drives telegram *20 Inputs*

INPUT-WORDS-1 IW 550 WORD send telegram drive pump1

INPUT-WORDS-2 IW 554 WORD send telegram drive pump2

INPUT-WORDS-3 IW 582 WORD send telegram drive pump3

G150 Drives telegram 20 Inputs

OUTPUT-WORDS-1 QW 550 WORD receive telegram drive pump1

OUTPUT-WORDS-2 QW 554 WORD receive telegram drive pump2

OUTPUT-WORDS-3 QW 582 WORD receive telegram drive pump3

4.2.5 Development technique (CMT) and used APL Blocks

Control Module Type

Standardized engineering can be achieved through the consistent use of Control Module Types (CMTs), a clear type-instance concept will be implemented. Here, the CMT is the template, which is instantiated later in the project (CM). By defining optional blocks in the CMT, a large number of different variants of this CMT can be instantiated in the project[60].

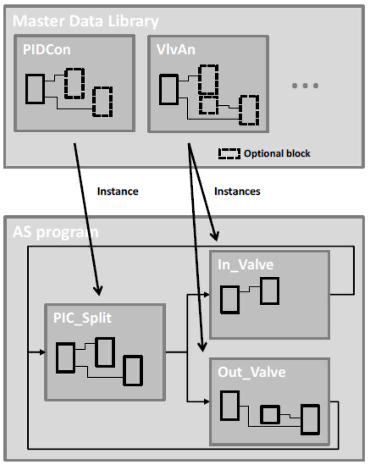

Figure 4-16 Creation of instances from CMT[60]

The creation of typical CFC for model equipment, such as drives, Simocode motorized valves, and measuring instruments used in the studied process unit (desalinated and drinking water tank), enables the optimization of the configuration of signals and parameters for each instance. This approach also leverages the significant benefits of utilizing library CMT instances in engineering, allowing for increased efficiency and flexibility. Any modifications made to a type within the library would be updated across all type instances associated with the AS project, streamlining the process of implementing changes[60]. refer to the following flowchart (Figure 4-17) on the procedures of implementing CMT:

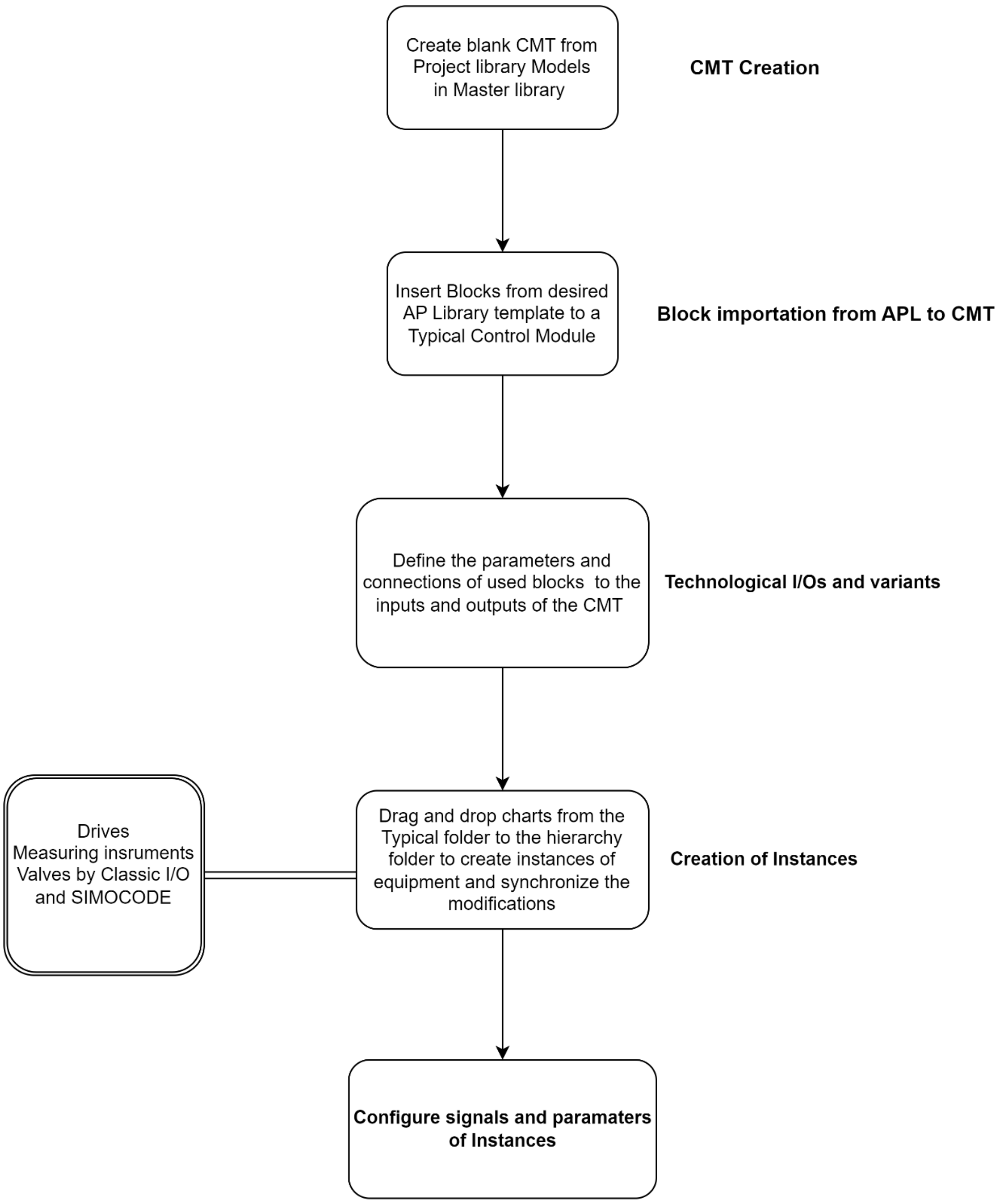

Figure 4-17 Flow chart procedures of using CMT

Used APL templates in the program

Motor valve: This typical model serves as a basis for controlling SIMOCODE motor valve using the VlvMotL block.it is used for controlling motorized gate valves/butterfly valves via binary outputs including position feedback. The drive is monitored for the "Open"/"Closed" position and can be stopped in any intermediate position [61].

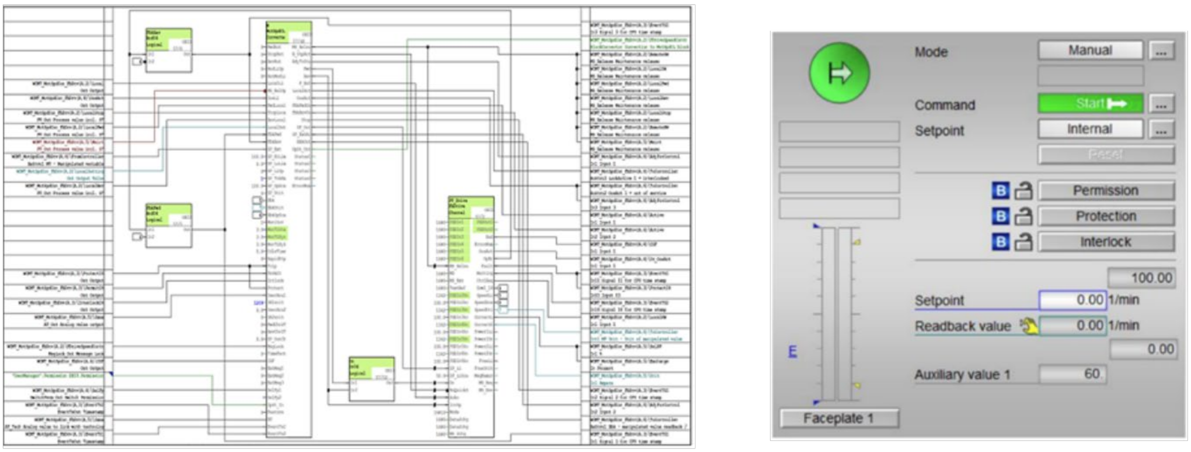

Figure 4-18 ValveMotor CFC and OS faceplate [61]

<u>Drive</u>: Our application uses the 'Drive' template from APL, which includes the blocks 'FbDrive' and 'MotSpdCL'. The CMT of MotSpdCon_FbDrv controls a motor via SINAMICS G150 frequency inverter with infinitely variable speed change and two directions of rotation.[61] However, for a pump application, we need to exclude reverse option.

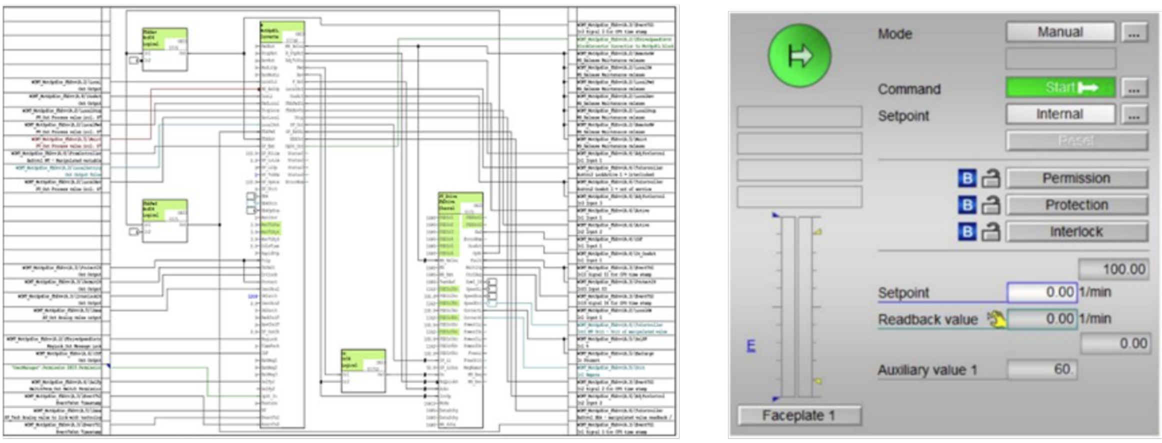

Figure 4-19 CFC of Drive Template and OS faceplate [61]

<u>AnalogMonitoring</u>: MonAnalog is used for monitoring an analog measuring point on up to four limit values. The transmitter is connected with the CMT instance in 2 or 4-wire technology via the input peripherals of the automation system or via fieldbus [61].

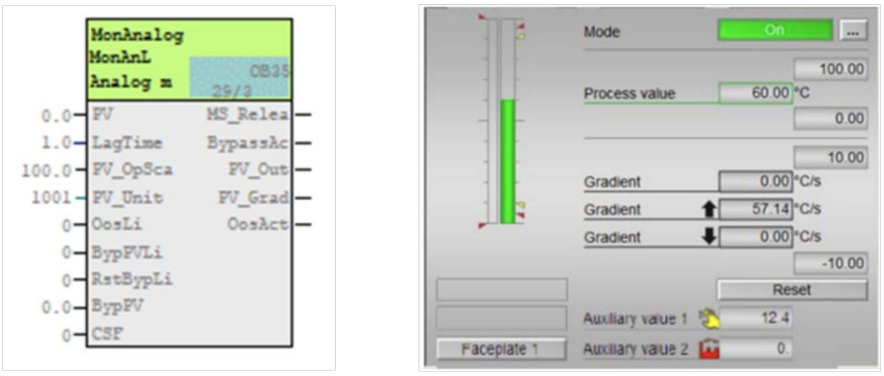

Figure 4-20 MonAnalog block and its OS faceplate [61]

Blocks interconnection

Once we have made the preparations for creating the CFC charts by filling master data library, we can start the programming in CFC.

Before proceeding with the programming of blocks interconnection in CFC, it is necessary to verify the required input/output (I/O) of each equipment module block by performing their parameterization. To do this, follow these steps: right-click on the desired block, select "Object Properties," and navigate to the "I/Os" tab. Here, you can make any necessary changes, such as hiding or showing specific I/O or modifying their values.

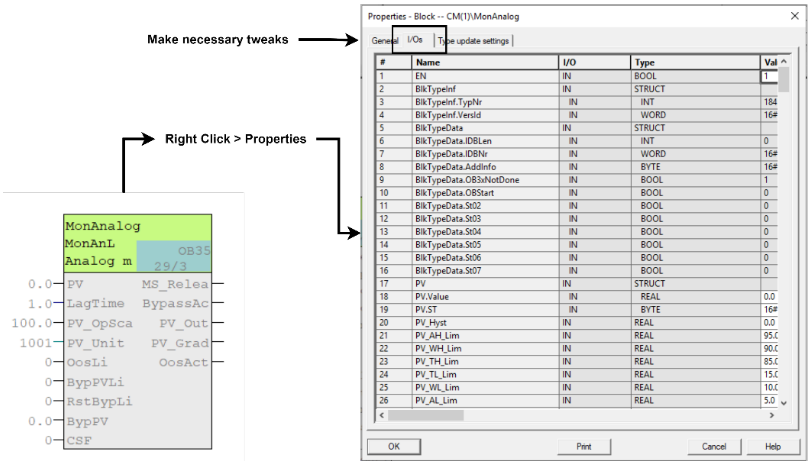

Figure 4-21 Block I/O tweaking

Then, the physical I/Os need to be connected to the program using channel driver blocks. These blocks enable the association of logical variables and signals in the program with the physical inputs and outputs of the controller. The channel driver blocks used for the program are listed below

- **PCS7DiIn**

The block cyclically processes all channel-specific signal functions of a digital input module.

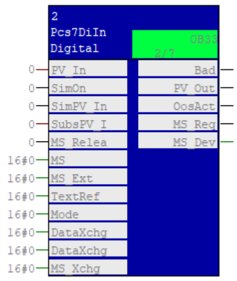

Figure 4-22 Channel Block PCS7DiIn

Table 3 Main inputs and outputs of PCS7Din/Ou[62]

Parameter	Description	type
PV_In	Process value (raw value)	BOOL
SimOn	1 = Simulation on	STRUCT
SimPV_In	Process value used for SimOn = 1	STRUCT
Bad	1 = Process value is not valid	STRUCT
PV_Out	Standard value (physical variable)	STRUCT

- **PCS7DinOu**

The cyclic block processes all channel-specific signal functions of a digital output module. Normally, the process value is written to both redundant channels[51].

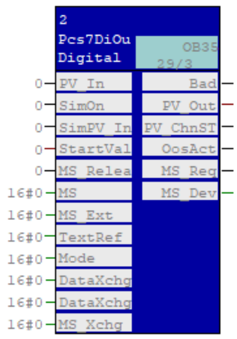

Figure 4-23 Channel Block PCS7DinOu

- **PCS7AnIn**

The block cyclically processes all channel-specific signal functions of an analog input module. It reads a raw analog value from the process image (partition) and converts it to its physical value or calculates a percentage value based on this raw value [51]. refer to Figure 4-24 and Table 4

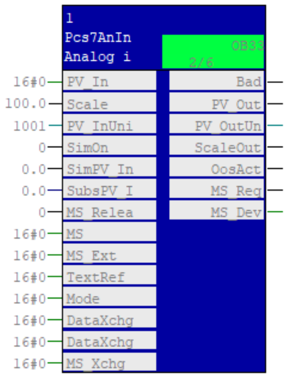

Figure 4-24 Channel Block PCS7AnIn

Table 4 Main inputs and outputs of PCS7AnIn[62]

Parameter	Description	type
PV_In	Process value (raw value)	BOOL
PV_InUnit	Unit of measure for process value	INT
SimOn	1 = Simulation on	STRUCT
SimPV_In	Process value used for SimOn = 1	STRUCT
Bad	1 = Process value is not valid	STRUCT
PV_Out	Standard value (physical variable)	STRUCT
PV_OutUnit	Unit of the process value	INT

Compiling channel drivers will create diagnostic charts that help to realize the troubleshooting by showing the status and errors of the modules and signals.

Sequential Function Chart

A control system sequence performed in stages is called a sequential function chart (SFC). It moves from one stage to another based on certain conditions. It can control functions like CFC charts using and states and process them selectively. The SFC Editor is used to create an SFC. The OS compilation automatically generates SFC block icons.

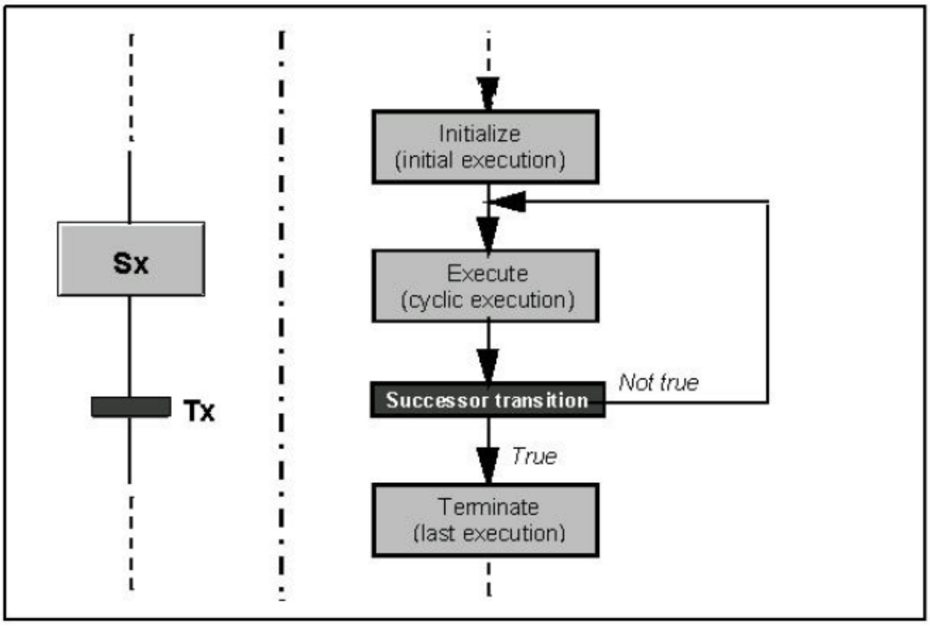

Figure 4-25 Execution of a step and transition[63]

An SFC consists essentially of two basic elements:

• **Transition**: a condition that controls the execution of the subsequent step. It is represented by a small rectangle in the SFC Editor

Tab Properties of a transition:

General - on this tab is named the transition.

Condition – in this tab are inserted the conditions for the sequencer to go to the next step.

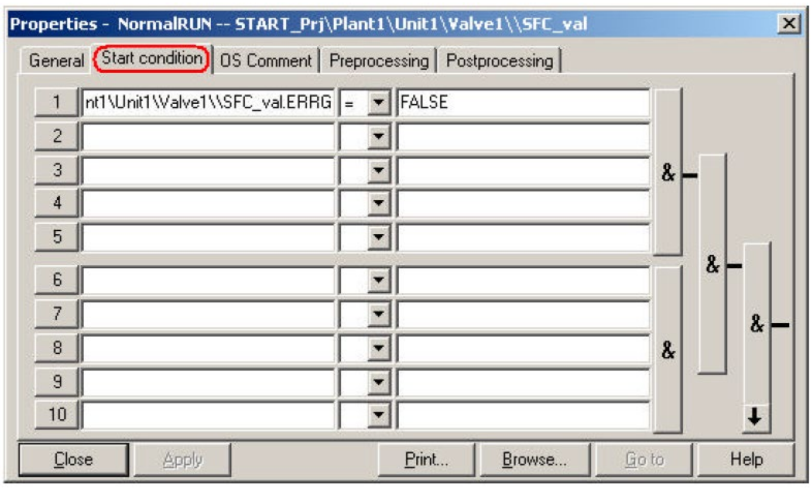

Figure 4-26 Start condition of a sequence path [63]

• **Step**: consists of the actions that will be executed in three phases (Initialization, Execution and Completion). Initialization is performed once when the step is activated. Execution is performed until the condition for the next step is satisfied. The Completion is executed once when the condition for the next step is satisfied and that step is no longer active.

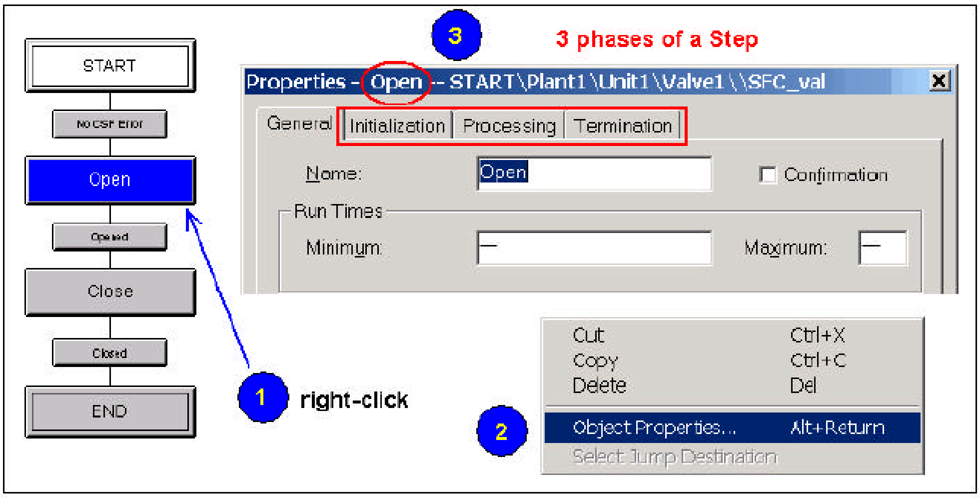

Figure 4-27 Three phases of a step[63]

4.2.6 WinCC OS picture View

After compiling chart objects that have been added to the hierarchical folder of the process, the next step is to navigate to WinCC Explorer > Graphics Designer. This window is used for creating process pictures, including dynamization with process tags. To create a picture view of the process, a suitable picture image named "DDWT.pdf" should be selected, and any necessary modifications can be made.

Static objects

The Graphics Designer (Figure 4-28) offers a variety of toolsets that enable the creation of a process view with static objects, objects such as Bar, I/O Field, Static Text, Line, and Circle can be easily incorporated into the design by dragging and dropping them from the Object Palette. The Siemens HMI Symbol Library offers a diverse assortment of pictures and process icons aiming to attain a comparable perspective to that of a Process and Instrumentation Diagram (P&ID) for the given process.

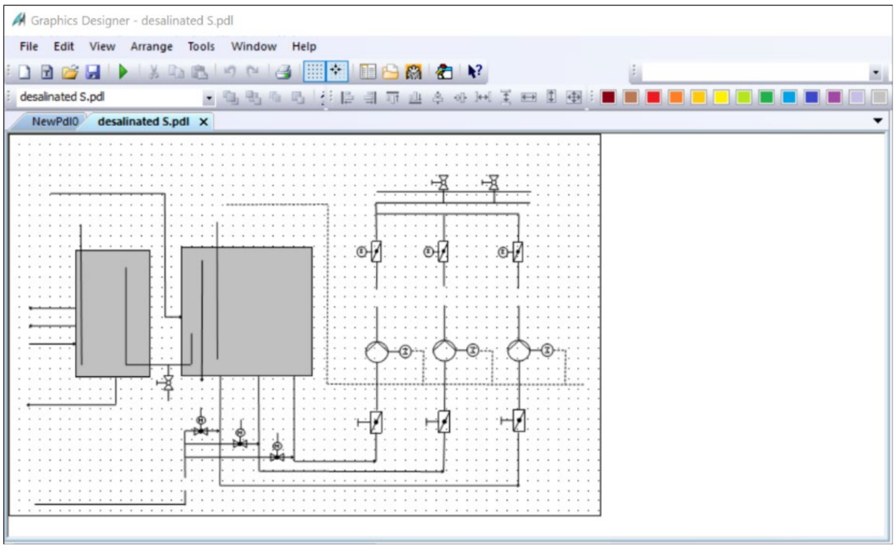

Figure 4-28 Picture View during modification

Dynamic objects

This includes faceplates that has been created displayed in Figure 4-29 after compiling the program and Smart Objects that have dynamic links to process:

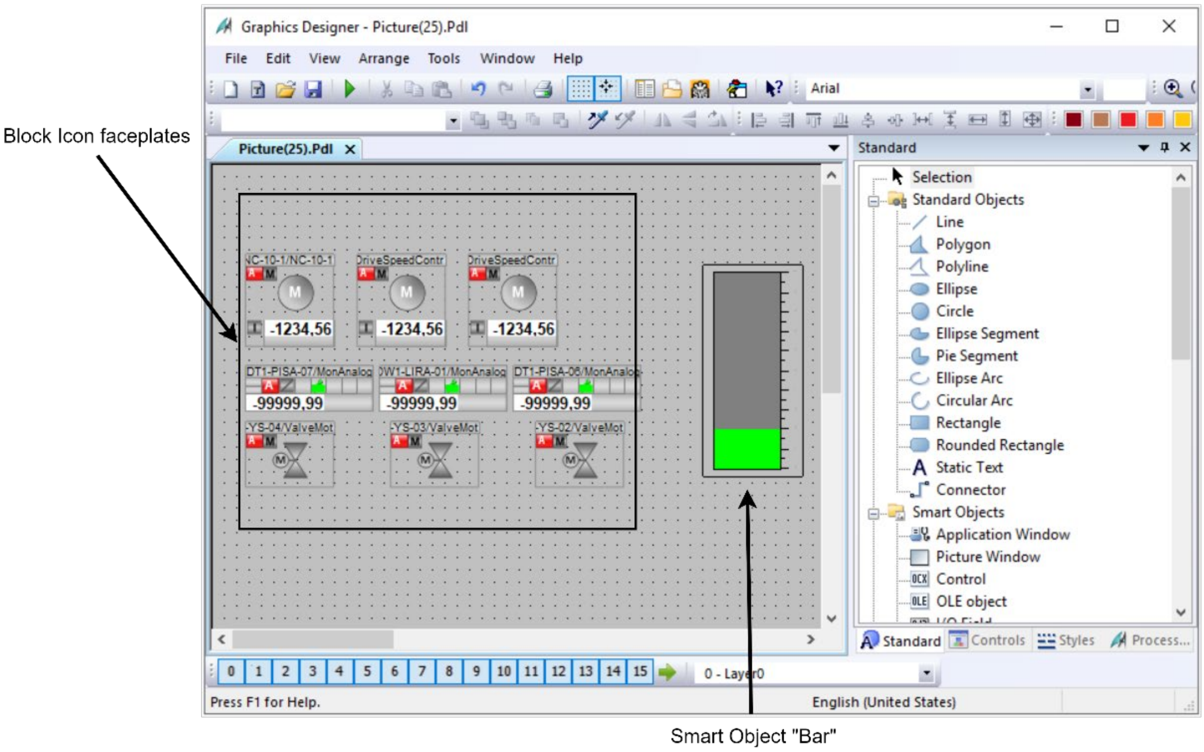

Figure 4-29 Faceplates generation

Picture tree

In accordance with our plant configuration, pictures are inserted in the plant hierarchy to show the process to the operator of the plant. we can enter a picture by hierarchy folder. Inserting pictures into the plant hierarchy results in a picture hierarchy which serves as an important aspect when managing process screens. When compiling the OS, Picture Tree Manager has the hierarchy of the plant hierarchy.

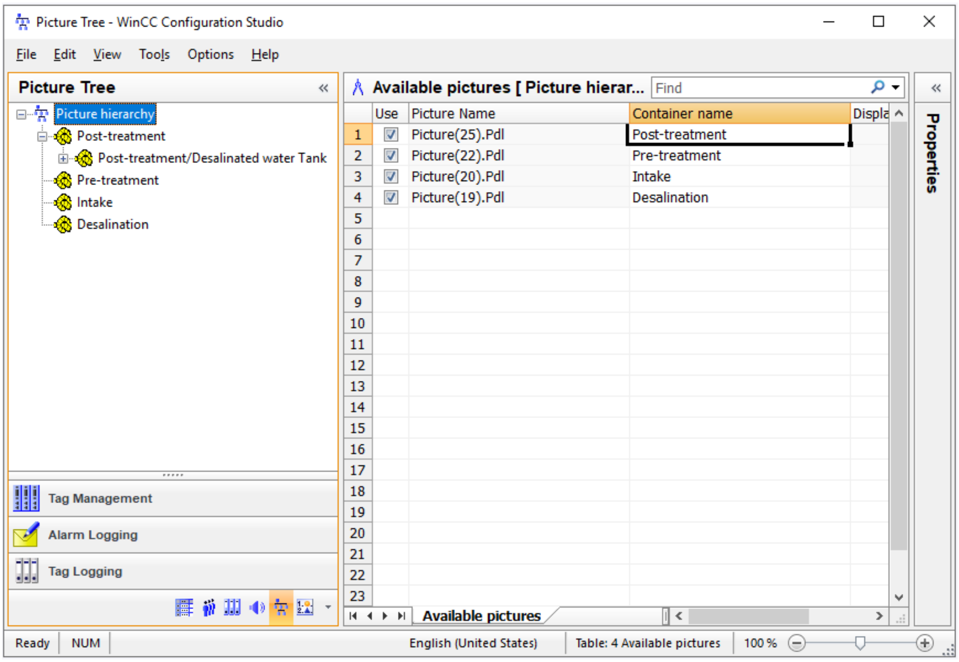

Figure 4-30 Picture Tree window

The final picture view of the process is shown in Figure 4-31:

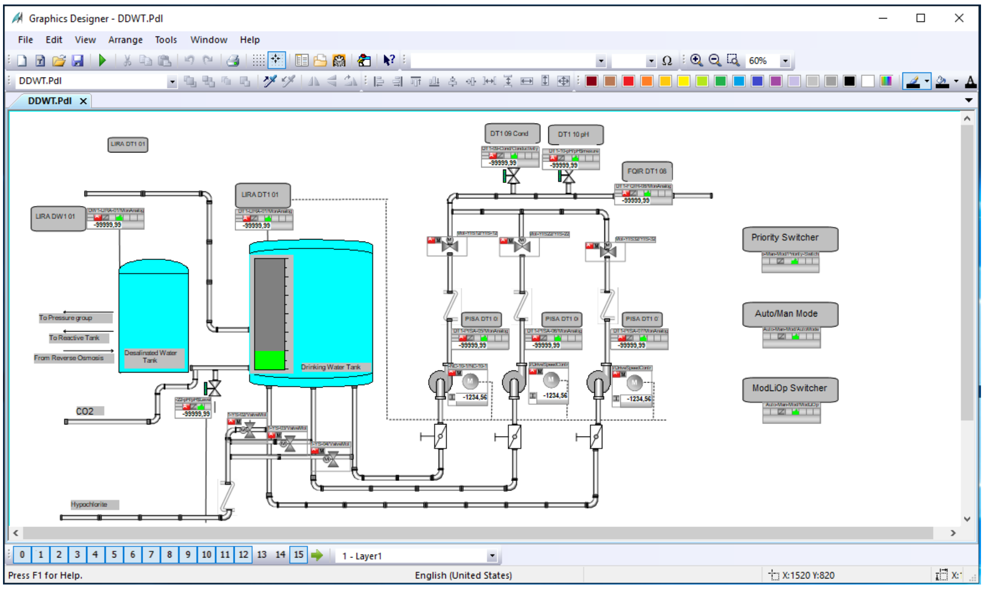

Figure 4-31 Desalinated & Drinking Water tank Picture

4.3 OPERATION RULES

4.3.1 Permissions, Interlocks, Protections

Interlocks, in a general sense, refer to mechanisms or features that prevent certain actions or events from occurring or ensure that specific conditions are met before a process or operation can continue. They are used in a variety of sectors and systems to improve safety, maintain control and prevent undesirable outcomes.

A maximum of three types of interlock can be used depending on the block. Three separate inputs named Permit, Interlock and Protect are available for these functions[64].

they used block "Intlk02" calculate a standardized interlock that can be displayed on the OS. A maximum of 2 input signals can be supplied to the block. They are linked using selectable binary logic. The signal status of the output signal is also determined. You can assign an analog value with the signal status and unit to each input value for display in the faceplate.

The current state is displayed at the output parameter:

Out = 0: Interlock

Out = 1: "Good" state

Activation enable ("Permission")

The activation enable makes it possible to switch the motor in the direction which is enabled. The activation disable is displayed with a padlock in the standard view. The motor cannot switch in the direction which is disabled[64].

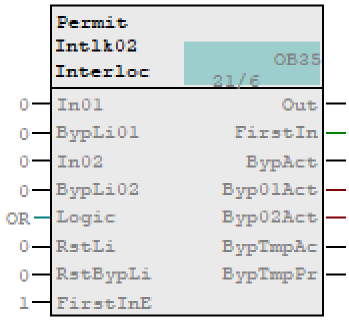

Figure 4-32 Permit block

Examples of Permit

For the permission conditions, an interconnection has been established between the motor and pressure valve of each pumping line separately. When the valve is closed, the motor is locked and cannot be turned on until the valve is opened and the permit condition is met. This ensures that the motor is good to start, taking into account the protection conditions as well.

Table 5 permit of line 1

Interlock(Permit)	Conditions	Logic
DT1 10	- YIS 12 opened feedback signal	OR
YS 04		
YIS 12		

Table 6 permission of line 2

Interlock(Permit)	Conditions	Logic
DT1 20	- YIS 22 opened feedback signal	OR
YS 03		
YIS 22		

Table 7 permission of line 3

Interlock (Permit)	Conditions	Logic
DT1 30 (protect)	- YIS 32 opened feedback signal	OR
YS 02		
YIS 32		

Interlock without reset ("Interlock")

An active interlock condition puts the block to the neutral position (Interlock= 0). After the interlock condition has gone, the currently active control function becomes active again in automatic or local mode. In manual mode, the faceplate can be operated again after the interlock condition has gone.[64]

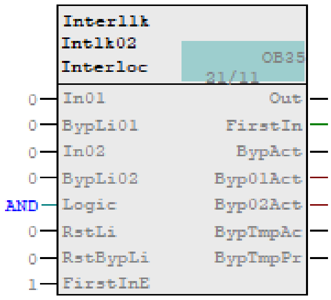

Figure 4-33 Interlock block

Examples of Interlock

Regarding the interlock conditions, each pumping line is equipped with two sets of interlocks located on valves. In the case of dosing valves, they cannot be manipulated unless the pumping motor is turned ON, ensuring that chemical dosing is automatically achieved by measuring the pH level.

Moving on to pressure valves, an interlock condition is established when the motor is running forward, preventing them from being closed by any means. This measure is in place to avoid overloading the water piping lines.

Table 8 interlock of line 1

Interlock	Conditions	Logic
DT1 10		
YS 04	- DT1-10 is ON (retrieved from FdkFwdOut)	OR
YIS 12	- DT1-10 is ON (retrieved from FdkFwdOut	OR

Table 9 interlock of line 2

Interlock	Conditions	Logic
DT1 20		
YS 03	- DT1-20 is ON (retrieved from FdkFwdOut)	OR

YIS 22	- DT1-20 is ON (retrieved from FdkFwdOut)	OR

Table 10 interlock of line 3

Interlock	Conditions	Logic
DT1 30		
YS 02	- DT1-30 is ON (retrieved FdkFwdOut)	OR
YIS 32	- DT1-30 is ON (retrieved FdkFwdOut	OR

Interlock with reset ("Protection")

An active interlock condition puts the block to the neutral position (input Protect = 0). Once the interlock condition is cleared, a reset is necessary. Refer to the Resetting the block in case of interlocks or errors section for more information[64].

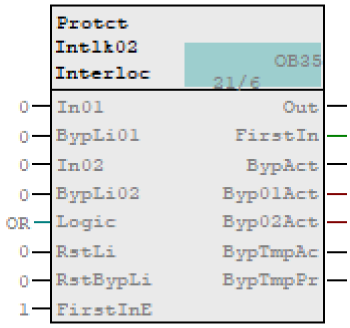

Figure 4-34 Block protect

Examples of Protection

Since the motor pumps are a crucial component, it is highly advised to implement enough protection conditions for any hazardous events, therefore the protection conditions are only applied for the Motors DT1-10/20/30, refer to Table 11.

Table 11 Protection of the 3 lines

LINE	Interlock(protect)	Conditions	Logic
1	DT1 10	-YIS 12 Closed feedback signal -PV LIRA<0.5m -PV PISA<8bar PV T Bearing 110°C PV T Widing 85°C	OR
2	DT1 20	- YIS 22 Closed feedback signal -PV LIRA<0.5m -PV PISA<8bar PV T Bearing 110°C PV T Widing 85°C	OR
3	DT1 30	- YIS 32 Closed feedback signal -PV LIRA<0.5m -PV PISA<8bar PV T Bearing 110°C PV T Widing 85°C	OR

4.3.2 Manual Mode and Auto Mode

The manual and automatic operation control mode are implemented.

- **Manual Mode**

the control settings for the device are made manually by the operator. The operator decides how to change the block's manipulated variable (output signal). The manipulated variable can be analog or binary in accordance with the function block.

- **Automatic Mode**

the control settings for the device are made by the block algorithm via interconnected inputs or inputs controlled by SFC.

The operator block used to switch between auto mode and manual mode is OpDi 01 and digital value is manipulated by interconnection or via the faceplate

The switchover between "manual and automatic mode" takes place as shown in the following schematic (Figure 4-35):

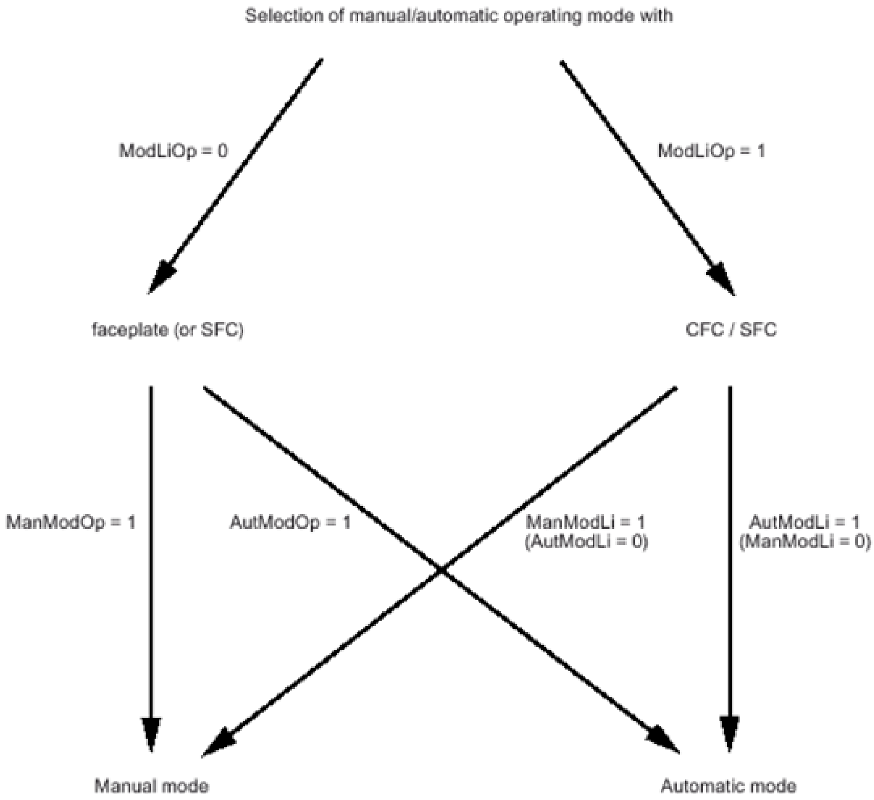

Figure 4-35 manual and automatic mode with ModLiOp diagram

The OpDi01 block is also used as a toggle to switch functioning priority of the pumps. For instance, we have used a combination of Auto/Man LiOp inputs of each actuator block to link the process to the SFC referred in Figure 4-36.

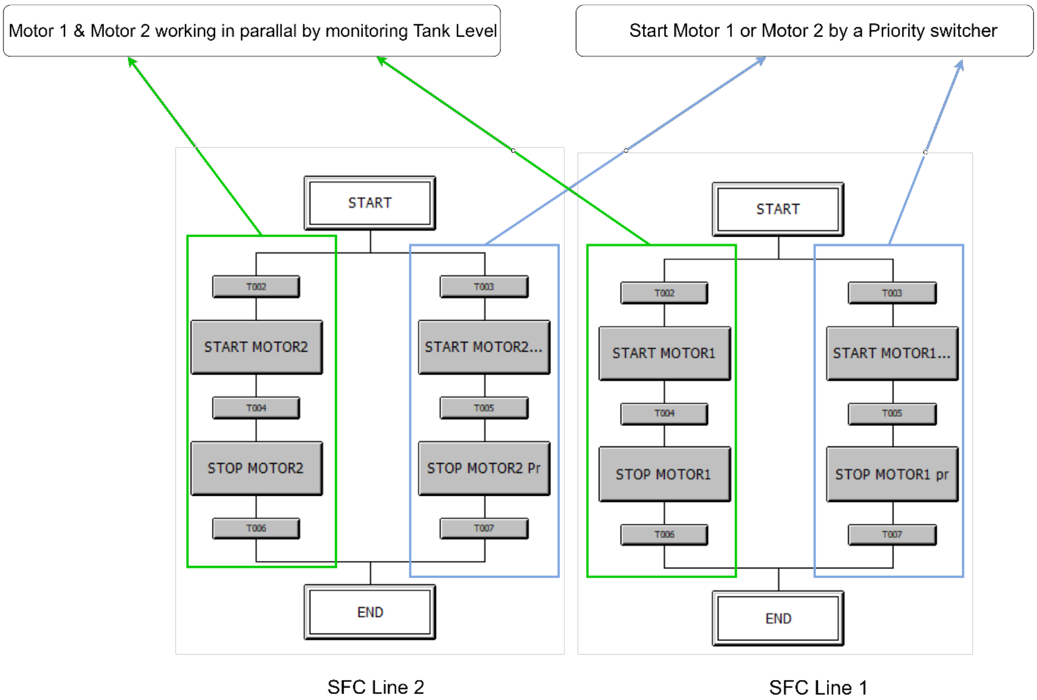

Figure 4-36 SFC of automatic pumping line 1&2

Functioning in automatic mode

Two lines are in service, and the third line is on standby through a priority switch between the first line and the second line. When the priority_switch equals 1, it means that Motor 1 is prioritized, and vice versa.

when the level is greater than 0.5 and less than 10 metres only one pump (of the line chosen by the operator) is on service.

when the level exceeds 10 metres the second pump starts, so both pumps are in operation and the second will stop automatically when the level rises again.

if the level drops below 0.5 metres the pump in operation will stop (shutdown).

in case of a fault on one of the lines, the third pump will be permitted and ready to start manually.

Additionally, dosing valves are always operating in automatic mode relies on the pH level (DT1-10-pH), which works within two threshold values of 6.5 to 8.5 pH.

4.4 SIMULATION WITH PLCSIM AND WINCC RT

After establishing the program for manual and auto control, preparing the picture view, and configuring all interlock types functionalities (permit, interlock, protect), the next step is to set up

PLCSIM and initiate the simulation (Figure 4-37). The simulation can then be monitored using WinCC Runtime.

In WinCC Explorer, the play icon is clicked to start WinCC Runtime demonstrated in Figure 4-37

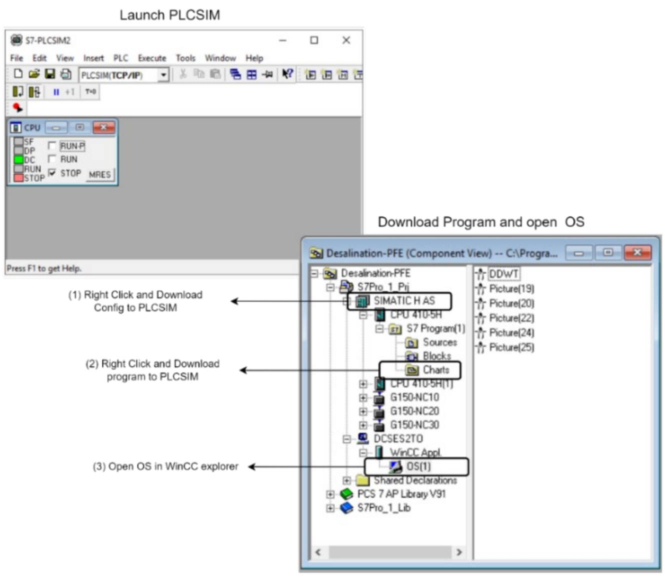

Figure 4-37 Simulation preparations

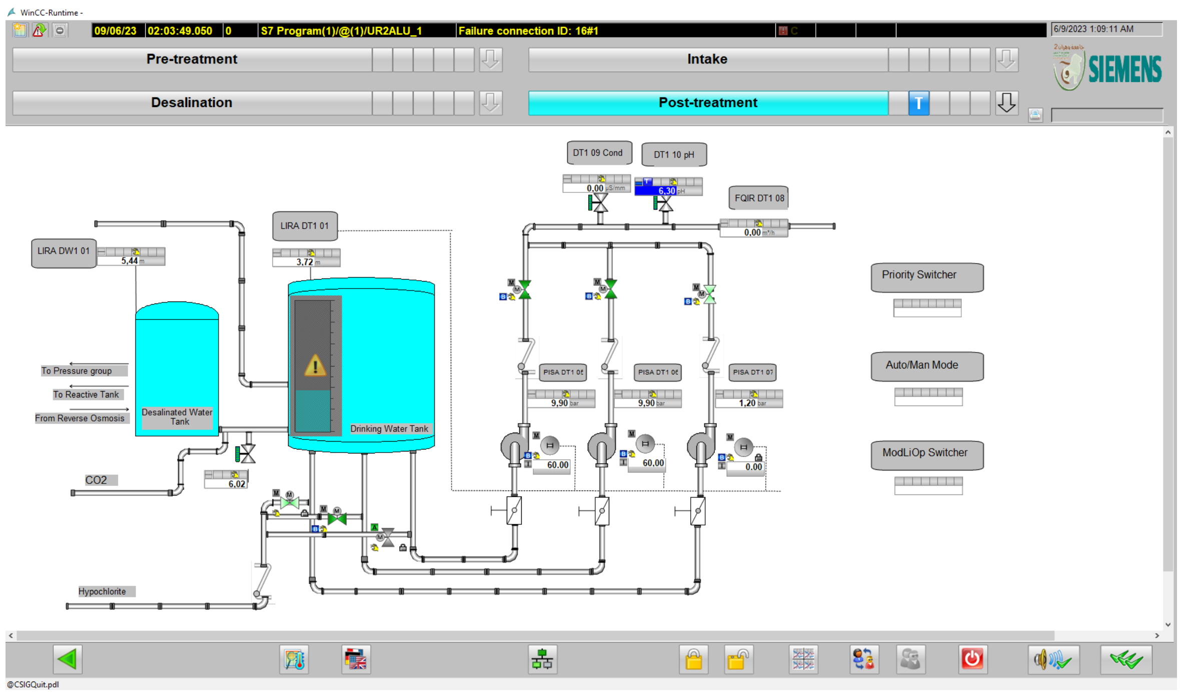

Figure 4-38 Runtime screen of the process

Before executing the startup sequence, it is important to verify whether the operational conditions are met. This verification process includes checking the protection of motors against cavitation and overheating, as well as ensuring that the pipes are not overloaded or underloaded by monitoring the pressure and flow rate.

Regarding motor protection, there are a total of 8 input signals on the protection faceplate. These signals comprise 5 inputs for temperature and tank level, which trigger an Alarm High, and one input for the pressure and flow transmitter. Additionally, a permit rule has been implemented to prevent the motor from starting if the pressure valve is closed. refer to Figure 4-39.

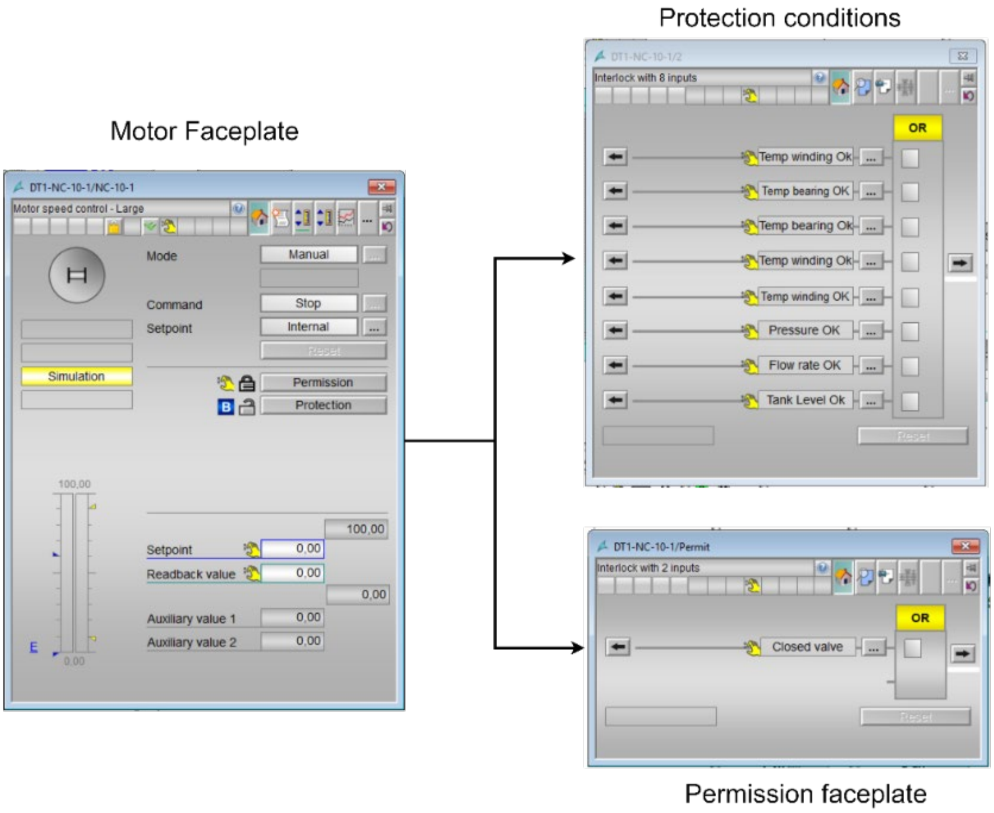

Figure 4-39 Protection interlock for Motor

4.4.1 Manual Mode run sequence

To start the operation on manual mode we just have to check the protection and permit condition of the pump, refer to the diagram below:

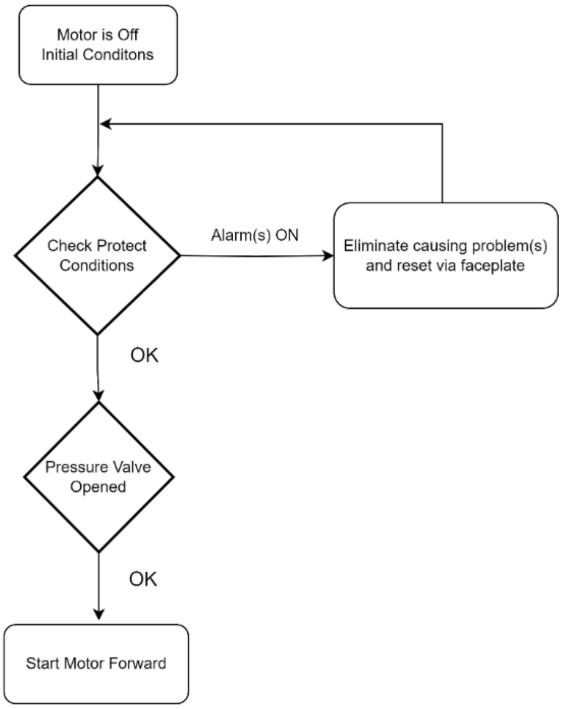

Figure 4-40 Manual Mode execution Flowchart

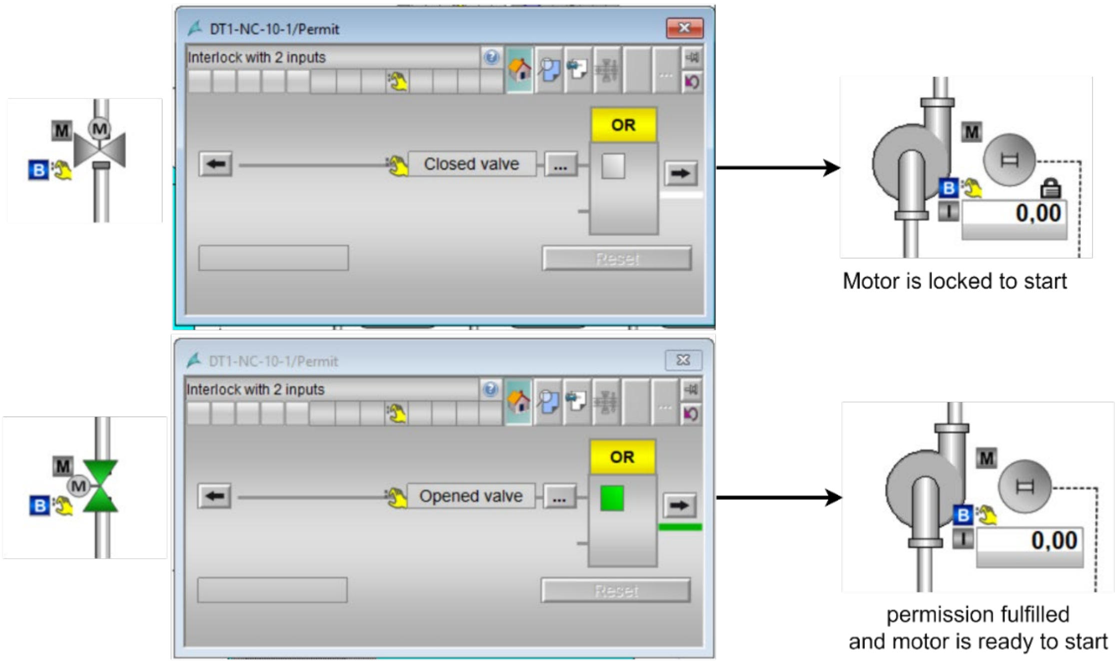

Figure 4-41 Motor permission

When the interlock is gone, we notice the lock icon has disappeared, after opening the pressure valve, the motor is ready to operate via faceplate (Command > forward > OK).

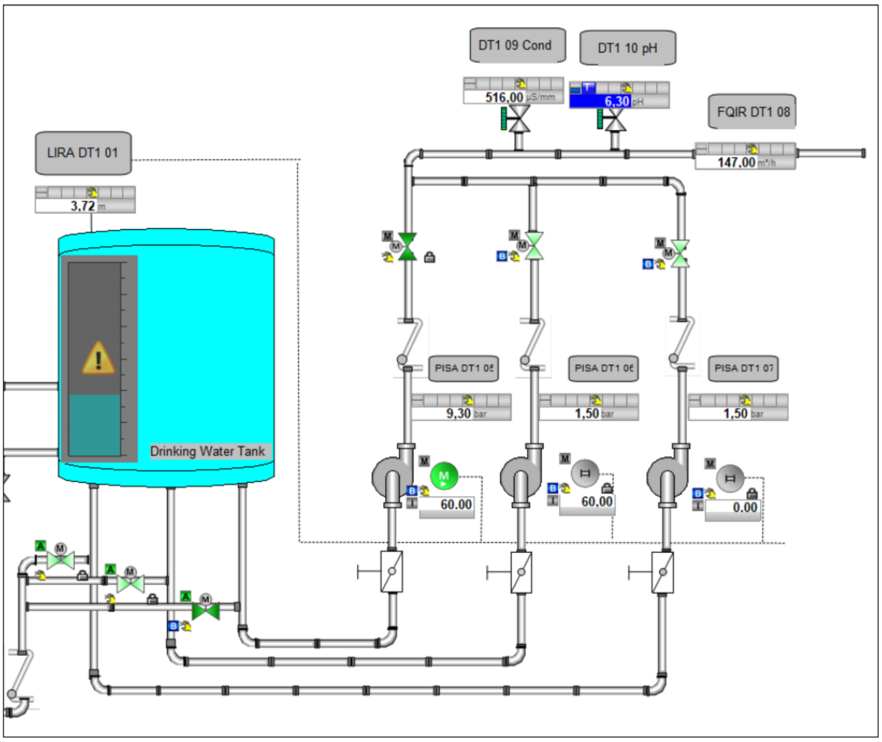

Figure 4-42 Line 1 execution Manual Mode

4.4.2 Automatic Mode run sequence

the sequence execution in Auto mode is outlined in the flowchart of Figure 4-43

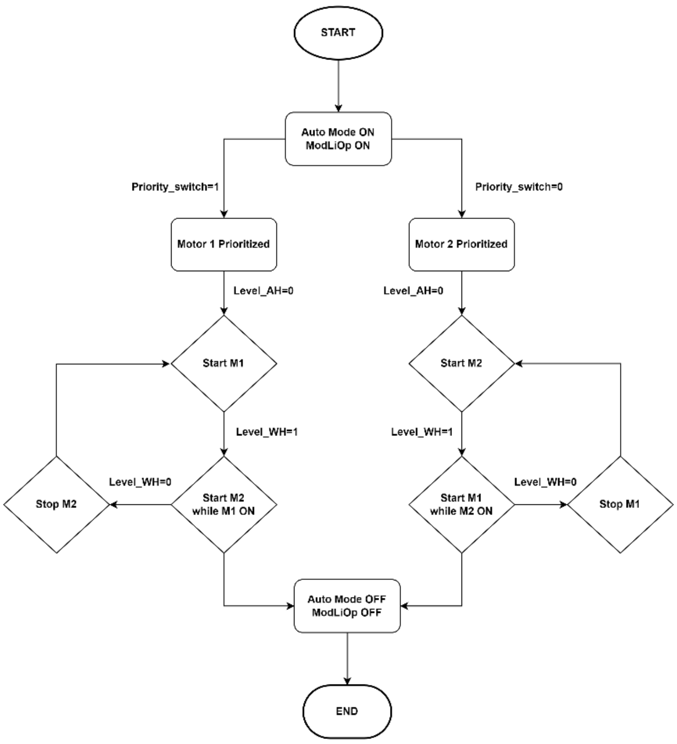

Figure 4-43 Auto Mode Run sequence

To enable fully automatic control of the process we have to set Auto Mode ON, ModLiOp ON and Priority_switcher On, as shown in Figure 4-44

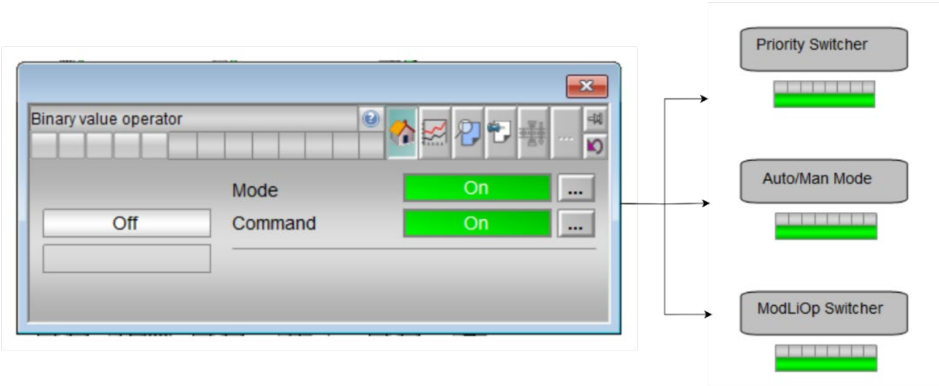

Figure 4-44 OpDI01 faceplate implementation

With SFC MultiChart Control, we can control and monitor multiple SFCs at the same time, giving us the ability to manipulate several SFCs simultaneously. See Figure 4-45 & Figure 4-46:

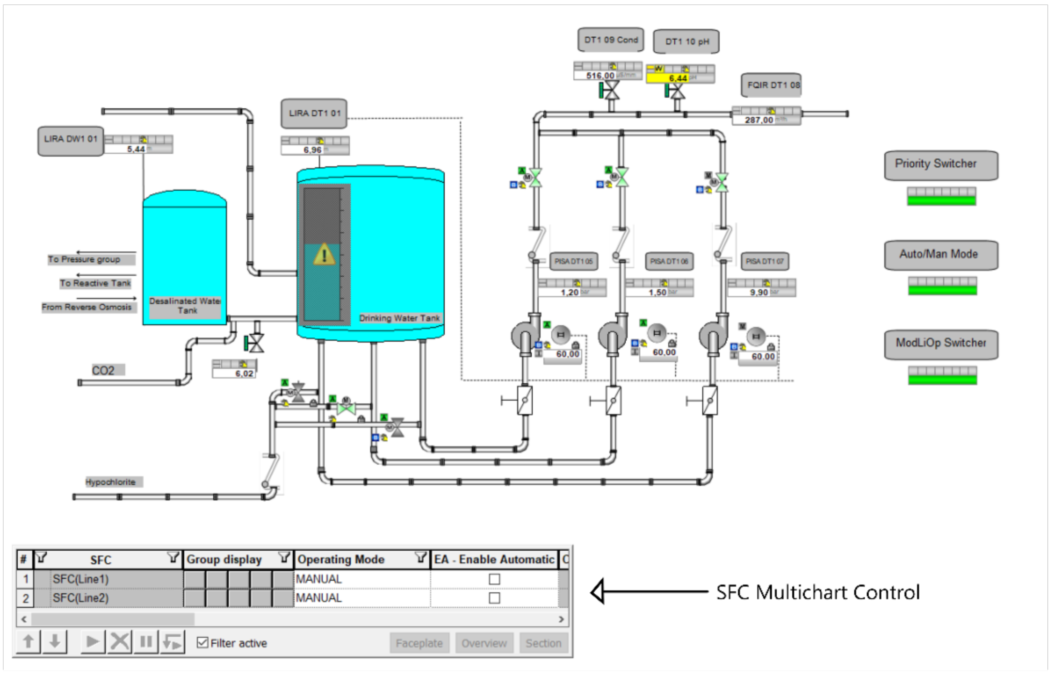

Figure 4-45 Process picture with Multichart function

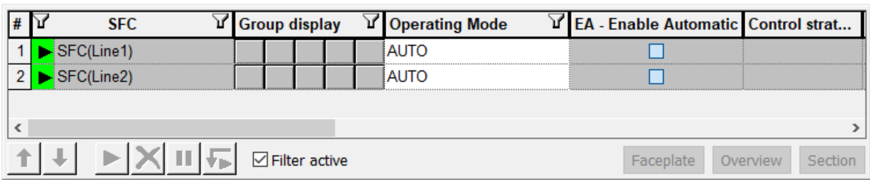

Figure 4-46 SFC Multichart in Auto mode

When the tank level is below 10m (WH_limit=0), the system operates with a single pump. If the level exceeds 10m, a high-level warning event (WH_limit=1) is triggered, initiating the second pump and displaying a Warning message in yellow. Acknowledging the alarm command when the level drops below 10m removes the alarm signal, and the pumping station reverts to running with a single pump. Refer to Figure 4-48.

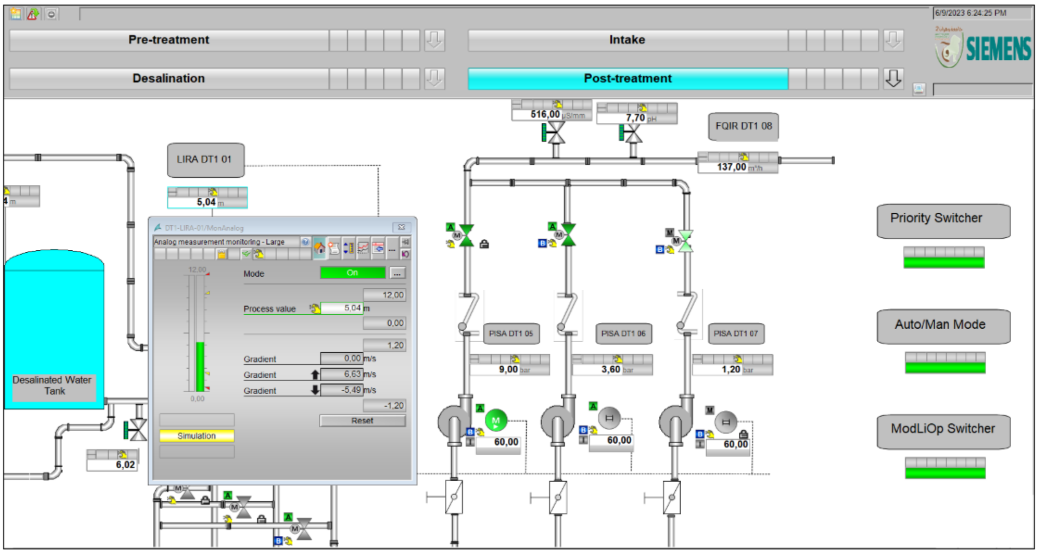

Figure 4-47 Line 1 running Auto mode

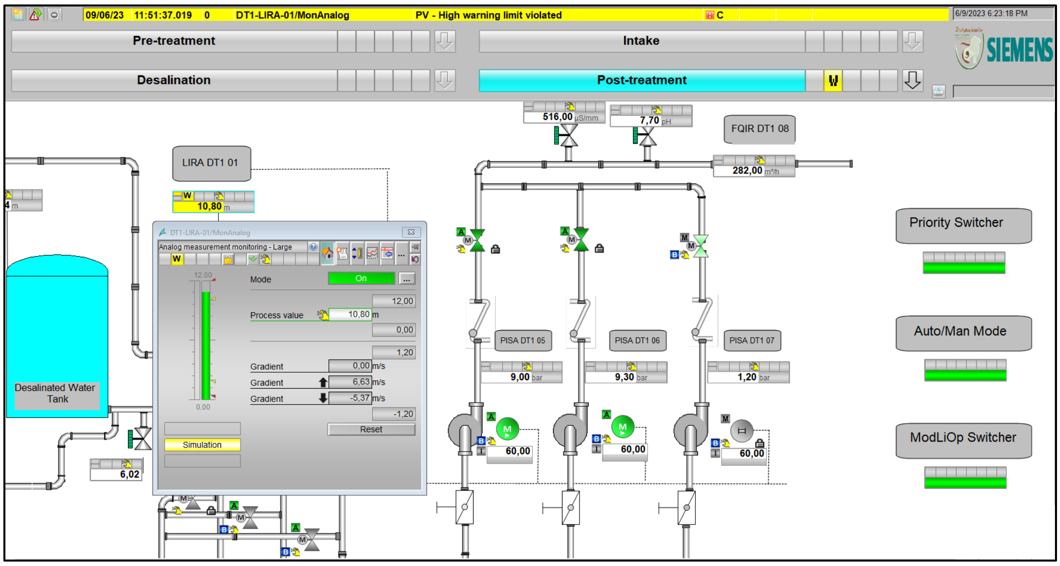

Figure 4-48 Line 1&2 on run with active warning message

In case of a Protection Alarm, the pumping system will shut down entirely, and the equipment will not be operational again until the motors are reset from their respective faceplates. For example, we have utilized the Low tank level alarm to trigger this shutdown.

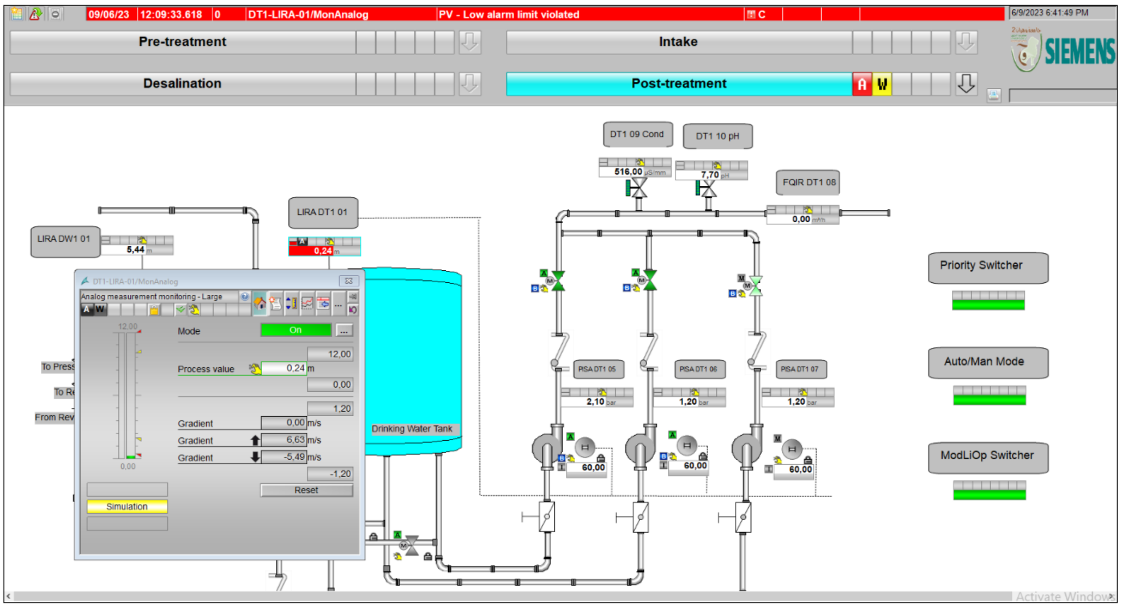

Figure 4-49 process picture with a shut-down alarm

4.4.3 Alarm system

PCS 7 messaging system informs the plant operator about events occurring in the process and in the control system, as well the alarms and messages logging functionality to store it on historian server.

For instance, system alarms are displayed in black banner with yellow text which indicate system alarm message caused by failure or error in some control system components (AS, OS etc.) and detected and signalled by SIMATIC PCS 7. Wire break messages from connected I/O modules are in this class. Process Control Messages are generated by driver blocks and do not need to be configured. (Figure 4-50).

	Date	Time	Priorit	Source	Event	Status
1	10/06/23	11:04:50.188	0	DCSES2TO	Terminal adapter 00:0C:29:C1:60:A6 disconnected	C
2	10/06/23	14:34:45.089	0	S7 Program(1)/@(15)/DT1-TISA-15_1	Device 0/0/0: Maintenance alarm	C
3	10/06/23	14:34:45.089	0	S7 Program(1)/@(15)/DT1-LIRA-01_1	Device 0/0/0: Maintenance alarm	C
4	10/06/23	14:34:45.089	0	S7 Program(1)/@(15)/DT1-FQIR-08_1	Device 0/0/0: Maintenance alarm	C
5	10/06/23	14:34:45.089	0	S7 Program(1)/@(15)/DT1-PISA-07_1	Device 0/0/0: Maintenance alarm	C
6	10/06/23	14:34:45.089	0	S7 Program(1)/@(15)/DT1-PISA-06_1	Device 0/0/0: Maintenance alarm	C
7	10/06/23	14:34:45.178	0	S7 Program(1)/@(15)/DT1-PISA-05_1	Device 0/0/0: Maintenance alarm	C
8	10/06/23	14:34:45.178	0	S7 Program(1)/@(15)/Level_Desalina	Device 0/0/0: Maintenance alarm	C
9	10/06/23	14:35:45.191	0	S7 Program(1)/@(1)/UR2ALU_1	Failure connection ID: 16#1	C
10	~~10/06/23~~	~~14:49:31.897~~	0	S7 Program(1)/@(4)/G150xCU320x2xI	Device ??/??: Failure	C
11	~~10/06/23~~	~~14:49:31.897~~	0	S7 Program(1)/@(4)/G150xCU320x2xI	Device ??/??: Failure	C
12	~~10/06/23~~	~~14:49:31.897~~	0	S7 Program(1)/@(4)/cfu-pa_1	Station ??/??: Maintenance alarm	C
13	~~10/06/23~~	~~14:49:31.897~~	0	S7 Program(1)/@(4)/IM155-6-PN-HA-_	Station ??/??: Failure	C
14	~~10/06/23~~	~~14:49:31.897~~	0	S7 Program(1)/@(4)/IE-PB-LINK_1	Device ??/??: Failure	C
15	~~10/06/23~~	~~14:49:31.897~~	0	S7 Program(1)/@(17)/G150xCU320x2x	Device ??/??: Maintenance alarm	C
16						
17						
18						

Figure 4-50 Alarm logging with active system message

The incoming alarm list can be dismissed by clicking on "Acknowledge messages."

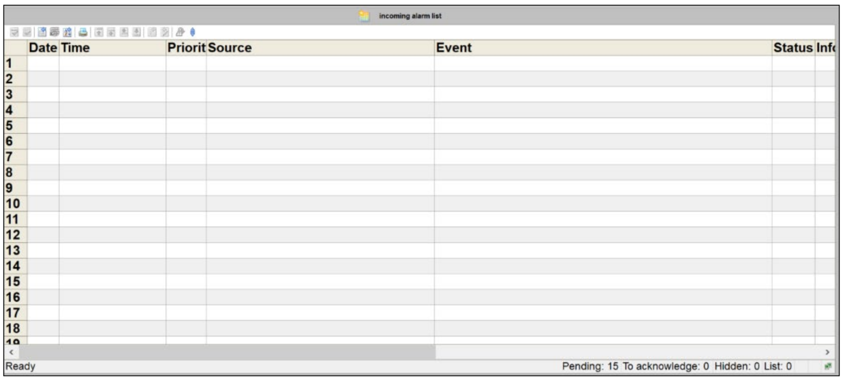

Figure 4-51 Blank incoming alarm list

When any configured process variable violates the PV limit, an "alarm" or "warning" message is generated depending on the previously parameterized blocks (Figure 4-52). In this case, if the tank level surpasses 10m, a "PV warning High" message is generated in yellow. When it comes to critical values, Alarm messages are used. For example, if the motor temperature rises above 85°C (winding temperature), it will generate an alarm message stating "Temperature Alarm High limit violated"(Figure 4-53) in red and trip off the motor, as it is stated as one of the protective conditions.

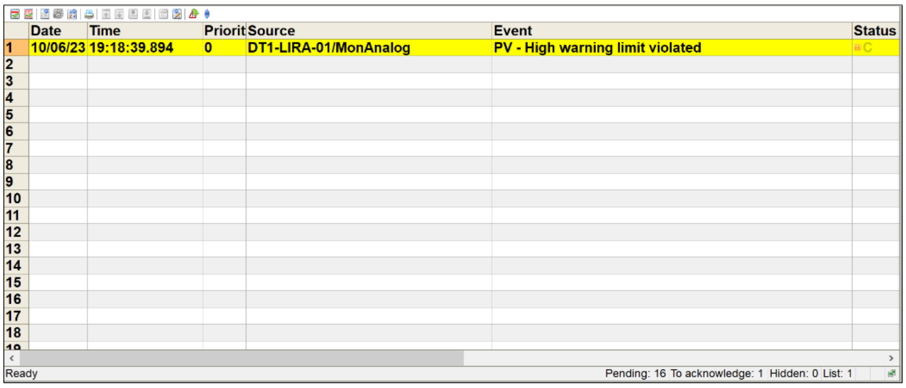

Figure 4-52 incoming message screen with an active warning message

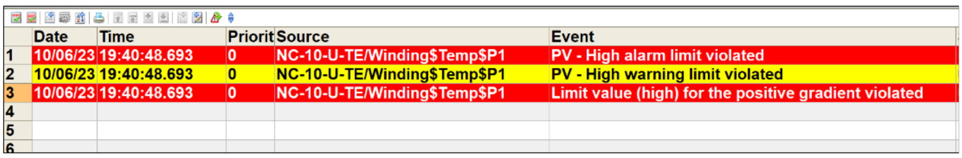

Figure 4-53 Alarm message for AH Temperature

4.5 CONCLUSION

Throughout this chapter, we explored the key aspects involved in the realization and development of the DCS for the desalination station. We discussed the importance of a well-designed and structured architecture, which enables the integration of diverse components such as sensors, actuators, and control algorithms. The visualization of the process is by using PLC Simulation and WinCC RunTime.

One of the significant benefits of the DCS in PCS7 is the ability to optimize the desalination process. Through advanced algorithms and control strategies, the system can continuously monitor and adjust critical parameters such as feedwater flow rates, pressure levels, temperature, and chemical dosing. This optimization leads to enhanced energy efficiency, reduced operating costs, and improved overall performance of the desalination station.

The development of the DCS for the desalination station in PCS7 also offers enhanced safety and reliability. With built-in alarm management, fault detection, and emergency shutdown capabilities, the system ensures prompt response to critical situations, minimizing the risk of equipment damage and ensuring the safety of personnel.

General Conclusion

In a desalination process, the optimization of critical parameters such as pressure, flow measurements, tank level, motor temperature, and chemical dosing has been achieved through the implementation of control logic based on functional analysis. Safety and reliability have also been essential considerations in the development of the DCS, which includes the implementation of alarms and warning messages. These features enable emergency shutdown and ensure a prompt response to critical situations, reducing the risk of equipment damage and ensuring the safety of personnel involved in the desalination process. Additionally, the built-in alarm logging function and diagnostic messages aid in troubleshooting faults with reasoning.

This thesis has made a significant contribution to the advancement of desalination technologies by demonstrating the effectiveness of PCS 7 in developing a tailored DCS specifically for desalination stations. The provided set of tools facilitates engineering processes.

In conclusion, the development of the DCS for the post-treatment unit of the desalination plant under PCS7 was intriguing challenge that introduced us to a new engineering perspective in industrial automation. We acquired proficiency in a new programming language called "continuous function chart," which is essential in any process industry. Combining it with the sequential function chart allowed us to create a coherent control system and gain a comprehensive understanding of the process and equipment functioning logic.

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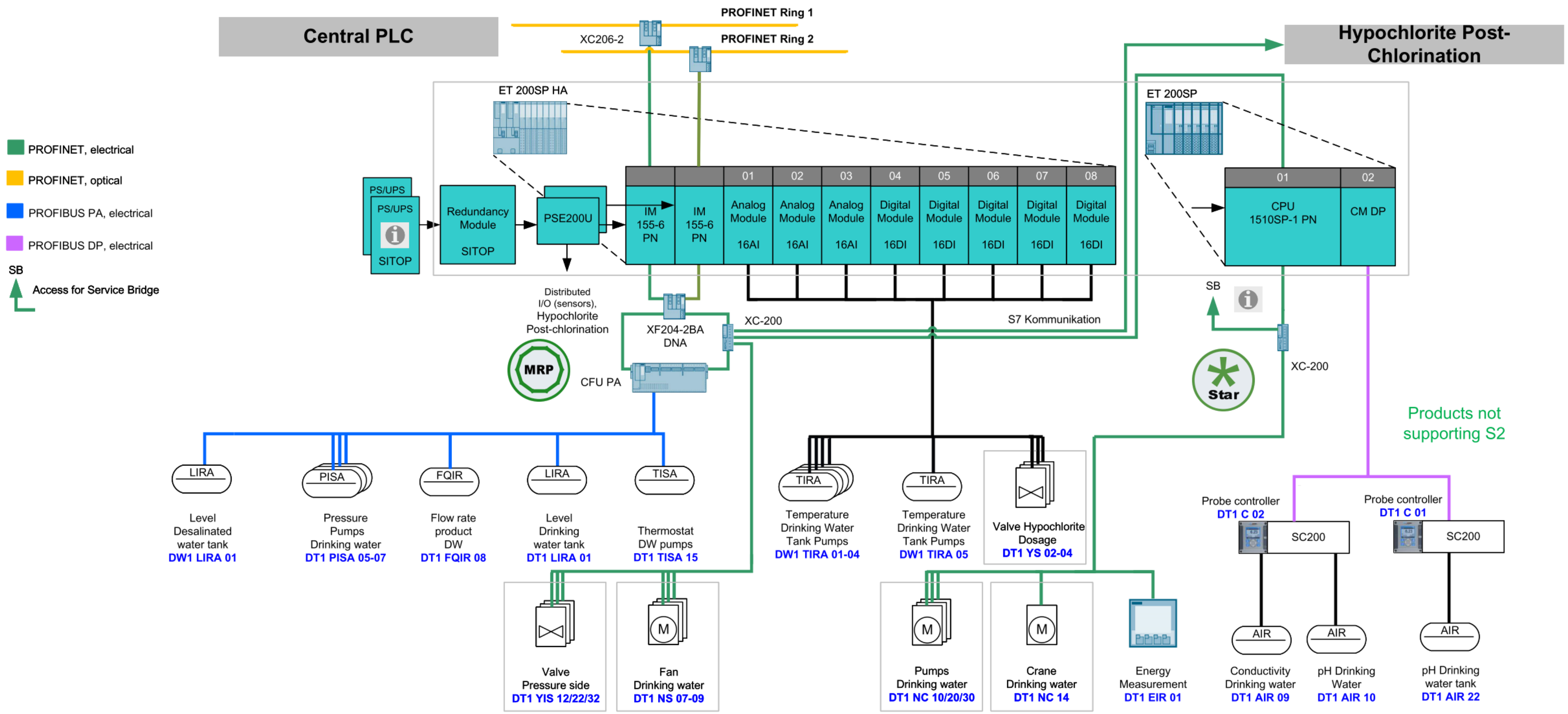
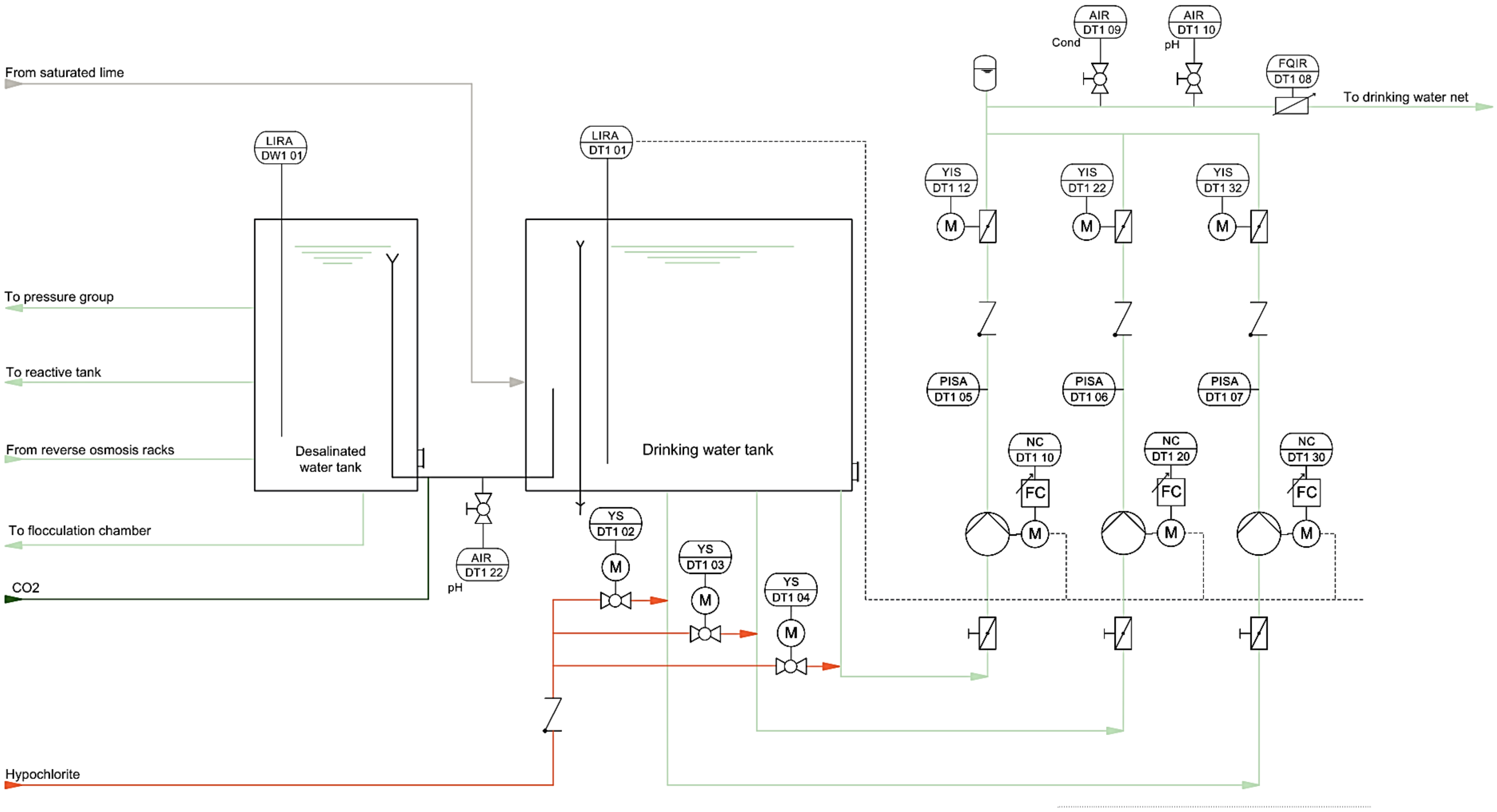
Annexes

ANNEX A : AUTOMATION CONFIGURATION



ANNEX B : P&I DIAGRAM



ANNEX C : AUTOMATION CONFIGURATION