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Dedication

To our parents, To our families.

To all friends who supported us.

To all of our teachers from primary to university.

To Algerian students, we hope you'll benefit from this work.

Be thankful to God, who has cherished us with the grace of Islam.

Take in mind that only smart and hard work brings, pride to our nation.

Small steps take us to the beast level.

Thanks

First of all, we would like to thank God for His grace and mercy.

Thanks to him we are here today.

We would like to thank our supervisor Dr. Djeddi Abdelghani.

Assistant professor at University Larbi Tebessi.

For his patience, his availability and above all his judicious advice.

Which contributed to fueling our reflections.

We would also like to thank the jury teachers.

For giving us the honor of her time and the privilege of listening.

And for evaluating our humble effort.

We want to thank our parents for supporting us.

Our friends for the support and the good advice.

We would like to thank All of our teachers from primary to university.

Summary

ملخص

الماء أحد أهم مصادر الحياة، و على قدر أهميته إلا أن مصادر توفيره قليلة منها الأمطار، الأنهار و المياه الجوفية، و بسبب مجموعة من العوامل كالتّغيرات المناخية و الزّيادة السّكانية، ظهرت صعوبات في توفير المياه العذبة. و لحل هذه المشكلة قام الإنسان على مر التّاريخ بابتكار عدة طرق منها تحلية مياه البحر.

يتعرض هذا العمل للمياه من حيث الوفرة على سطح الأرض و طرق تحليته، و كيف تطورت هذه العملية لتصبح أحد أهم الصناعات، و انتشارها حول العالم و خاصة في بلدنا الجزائر.

و فيه نقوم بعرض أهم التّكنولوجيات الصّناعية المستخدمة في تحلية المياه، و نختار منها تقنية التّناضح العكسي. بالإضافة إلى تعريف بالأنظمة و الأجهزة اللّازمة للتّحكم في محطات تحلية المياه. و في هذا الجزء نقوم بوضع نموذج برنامج للتحكم في العملية بالاستعانة بنظام TIA-Portal و المبرمج بلغة LADDER. و نقوم أيضا بالاعتماد على هندسة SCADA التي تمكنّنا من التّحكم في العملية و مراقبة سيرها بالاستعانة بالمحرك WinCC المدمج في TIA-Portal.

الكلمات المفتاحية: تحلية المياه، التناضح العكسي، التشغيل الآلي و المراقبة، البرمجة الصناعية، المحاكات.

Abstract

Water is one of the most important sources of life, and as important as it is, the sources of its provision are few, including rain, rivers, and underground water, and due to a number of factors such as climatic changes and population increase, difficulties have arisen in providing fresh water. To solve this problem, human throughout history invented several methods, including desalinating seawater.

This work exposes water in terms of its abundance on earth, the methods of its desalination, how this process developed to become one of the most important industries, and its spread around the world, especially in our country, Algeria. This work presents the most important industrial technologies used in water desalination, and we choose reverse osmosis technology from them. In addition to an introduction to the systems and devices needed to control water desalination plants. In this part, we develop a prototype program to control the process using the TIA-Portal system programmed in LADDER logic, and we also rely on SCADA architecture, which enables us to control the process and supervise its progress using the WinCC integrated in the TIA-Portal.

Keywords: desalination, reverse osmosis, automation and supervision, industrial programming, Tia-Portal, WinnCC Flexible, SCADA, LADDER.

Résume

L'eau est l'une des sources de vie les plus importantes et, aussi importante soit-elle, ses sources d'approvisionnement sont rares, notamment la pluie, les rivières et les eaux souterraines, et en raison d'un certain nombre de facteurs tels que les changements climatiques et l'augmentation de la population, les difficultés ont surgi en fournissant de l'eau douce. Pour résoudre ce problème, l'humain à travers l'histoire ont inventé plusieurs méthodes, y compris le dessalement de l'eau de mer.

Cet ouvrage expose l'eau sous l'angle de son abondance sur terre, les méthodes de sa dessalement, comment ce procédé s'est développé pour devenir l'une des industries les plus importantes, et sa diffusion dans le monde, notamment dans notre pays, l'Algérie. Cet ouvrage présente les technologies industrielles les plus importantes utilisées dans le dessalement de l'eau, et nous en choisissons la technologie d'osmose inverse. En plus d'une introduction aux systèmes et dispositifs nécessaires pour contrôler les usines de dessalement de l'eau. Dans cette partie, nous développons un prototype de programme pour contrôler le processus à l'aide du système TIA-Portal programmé en logique LADDER, et nous nous appuyons également sur l'architecture SCADA, qui nous permet de contrôler le processus et de surveiller son évolution à l'aide du logiciel WinCC intégré au TIA-Portal.

Mots clés : dessalement, osmose inverse, automatisation et surveillance, programmation industrielle, TIA-Portal, WinCC Flexible, SCADA, LADDER.

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Symbols and abbreviations

m^3	The cubic meter it is the volume of a cube with edges one meter in length.
kWh	The kilowatt-hour is a composite unit of energy equal to one kilowatt (kW) times one hour.
V	The volt is the derived unit for electric potential.
°C	The degree Celsius is a unit of temperature.
Gal	Gallon, a measure of volume of approximately four liters.
Pa	Pascal unit used to measure pressure.
Psi	The pound per square inch is a unit of pressure or of stress.
J_w	The solvent mass.
A_w	The water permeability constant
ΔP	The difference in pressure.
$\Delta\pi$	The difference in osmotic pressure.
π_f	The osmotic pressure in the feed side.
π_p	The osmotic pressure in the permeate side.
C	Concentration is the abundance of a constituent divided by the total volume of a mixture.
Q_w	The volumetric flow.
Sa	The membrane surface area.
ρ_w	The water density.
J_s	The solute mass flux.
B_s	The solute permeability coefficient.
$\dot{Q}_s$	The solute mass flow rate
T_R	The membrane rejection.
Da	The Dalton or unified atomic mass unit is a unit of mass widely used in physics and chemistry.
PH	Is a scale used to specify the acidity or basicity of an aqueous solution.
CO_2	Carbon dioxide is a chemical compound.
NaOCL	Sodium hypochlorite is a chemical compound.
CL	Chlorine is an inorganic compound.
$Na_2S_2O_5$	Sodium metabisulfite is an inorganic compound.

MSF	Multi-Stage Flash distillation.
MED	Multi-effect distillation.
VC	Vacuum compressor.
OS	Osmosis.
RO	Reverse Osmosis.
DO	Direct Osmosis.
GCC	Cooperation Council for the Arab States of the Gulf.
PLC	Programmable logic controllers.
PC	Personal Computer.
HMI	Human Machine Interface.
DCS	Distributed control system.
SCADA	Supervisory Control and Data Acquisition.
HP	High Pressure.
DC	Direct Current.
TIA-Portal	Totally Integrated Automation Portal.
OB	Organization Block.
FC	Function.
FB	Function Block.
DB	Data Block.
LD	Ladder.
ST	Structured Text.
SFC	Sequential Function Charts.
FBD	Fonction Block Diagram.
IL	Instruction List.
Grafcet	Graphe Fonctionnel de Commande des Étapes et Transitions.

General introduction

General introduction

We begin our work with the words of God who says: “And We have made from water all living things”. Drinking water is a finite natural resource and a public right, it is essential for life and health. Water is essential for leading a life of dignity. It is known to be abundant on earth, but it mainly occurs in the form of seawater (97%). However, seawater contains nearly 100 times more salt than the limit set by the WHO (World Health Organization) for human consumption [1]. Out of more than 7 billion human beings, more than 1.1 billion do not have access to drinking water today, and more than 2.6 billion do not have a sanitation system [2]; to remedy this problem, the Algerian authorities have decided that one of the adequate solutions for our country, which has a coastline of 1200 km, is the desalination of seawater. Therefore, seawater desalination has become an industry in Algeria, and like all industries, technological developments and the need for competitiveness increasingly lead to the automation of production systems [3].

The main objective of our work is to present how to control and supervise an industrial desalination process using Programmable Logic Controllers (PLC) which is provides a tailor-made solution for the needs of adaptation and flexibility, where these types of equipment can control any process in an automatic mode, also collects and shows supervision data.

The structure of this work is the next: The first chapter introduces generalities on the status of drinking water on the planet plus generalities on the desalination process and desalination plants around the world and in Algeria. The second one explains the structure of a desalination plant, it presents the basic technologies used in the desalination plant; the installation of a desalination plant...etc. The third chapter touches on the automation system which is used to control the desalination process, and a simple tutorial of "TIA Portal", how to use it, languages integrated, HMI design, and the difference between automation systems architecture. The last chapter presents a simple simulation of the program prototype on how to control and supervise the desalination plant using SCADA. This work ends with a general conclusion and perspectives.

Chapter I

Generalities in water desalination

I.1. Introduction:

It is easier and more economical to find sources of freshwater to be treated (surface water such as lakes and rivers, or groundwater) than to desalinate seawater.

But the need to desalinate seawater is growing in many parts of the world. During the years 1950 to 2019, global water consumption became very important because of the increase in population, from 2.5 billion inhabitants in 1950 to 7.7 billion in 2019 plus industrial production [2].

And in countries affected by drought, current and future water needs are growing efficiently. It goes without saying that needs of this magnitude can only be met and satisfied if humanity has recourse to unconventional water resources, such as water recycling and desalination.

Desalination has been an important source of water since 1964. Where desalination plants are found in regions with hot climates, relatively low and unpredictable rainfall, and where water resources cannot meet industrial, agricultural, and consumer demands [3], which makes the desalination of seawater a growing industry.

In this chapter, we will look at the distribution of fresh water on earth and why this resource is scarce. We will also see the history of desalination and seawater desalination stations around the world and in Algeria.

I.2. Distribution of freshwater on the planet:

An amount equivalent to 97% of the planet's water is saline water and only a fraction corresponding to 3% consists of fresh water as shown in fig. I.1. About 68.7% of this fresh water on the planet is in the ice caps of the poles and 30.1% is constituted by underground aquifers in remote areas.

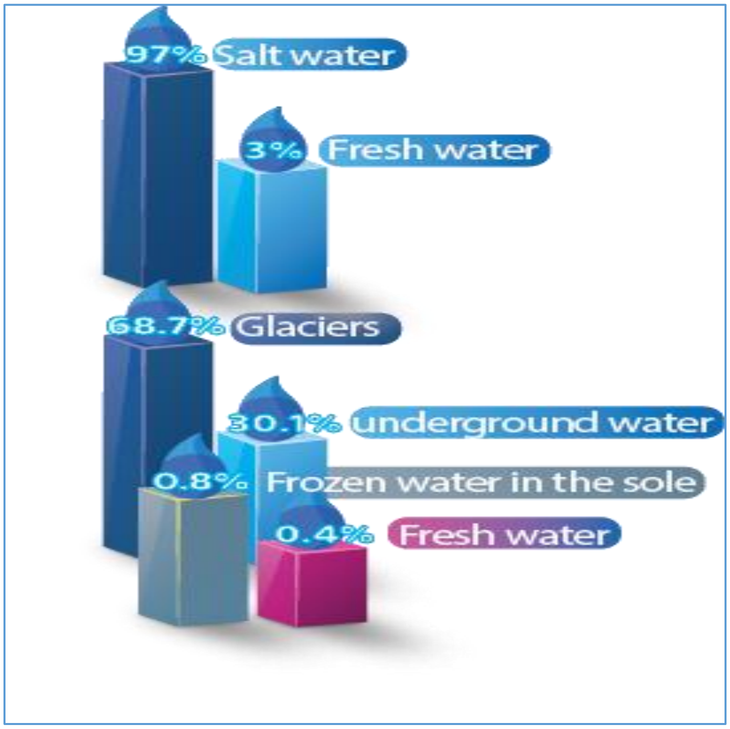

Figure I.1: Water distribution in the world.

Indeed, only a tiny fraction of freshwater (less than 1% of total freshwater, or 0.4% of global water stock) is available in rivers, lakes and reservoirs; and is easily accessible to humans for direct use.

In addition, the distribution of the freshwater stock and flow is very uneven, in fact, 10% of countries own 60% of the resource [4].

The global comparison of the coefficients of water availability in relation to the population highlights the disparities between the continents. We will notice the pressures exerted on Asia which shelters more than half of the world population and possesses only 36% of the water resources of the planet.

Fig. I.2 shows the percentage of drinking water in glaciers, rivers, lakes, underground aquifers, and so on.

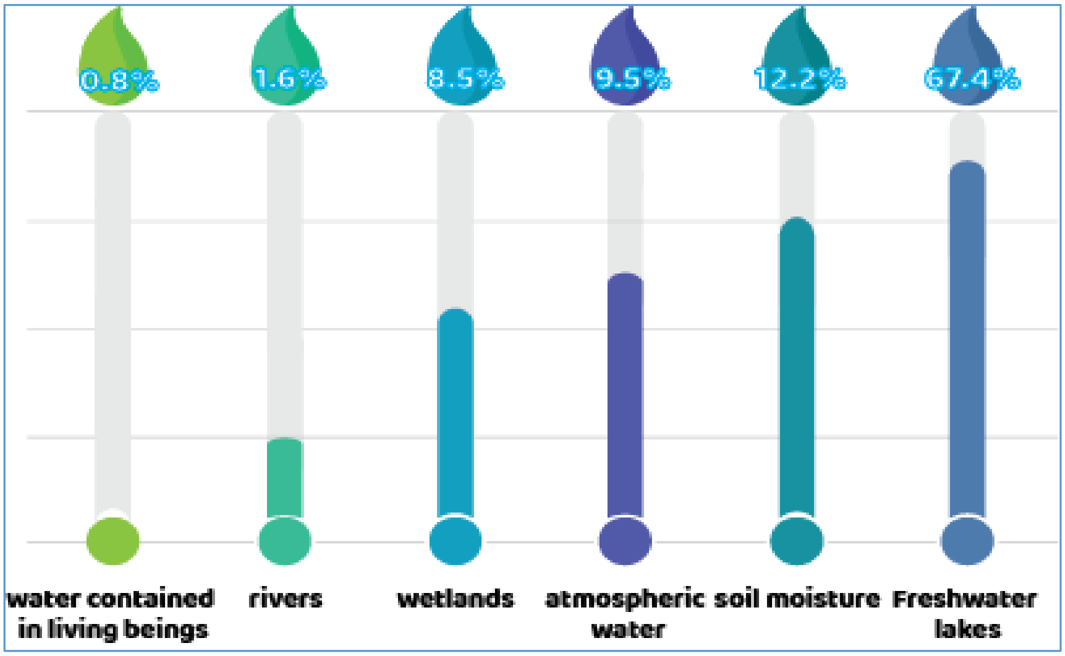

Figure I.2: Drinking water distribution in the planet.

I.3. Desalination history:

Desalination has a long history in both mythology and practice. An early and illustrative reference appears in the bible (exodus 15:22-26) and is widely considered to be about desalination [5].

When Moses and his people came to marah. they could not drink the water of marah because it was bitter; and the people grumbled against Moses, saying "what shall we drink?" and he cried to the LORD, and the LORD showed him a log (kind of tree), and he threw it into the water, and the water became sweet.

Early scientific descriptions of desalination centered around the application of distillation. And in his meteorological, Aristotle wrote the "salt water when it turns into vapor becomes sweet and the vapor does not form salt water again when it condenses" [6].

Distillation is a process used to create fresh water from seawater at larger scales starting in the 1930s. Distillation technique remained a major approach to water desalination until the development of membranes [1], where desalination has been used for thousands of years, as Greek sailors used to boil water to get fresh water away from the salt, as shown in fig.I.3 Romans used clay filters to trap salt.

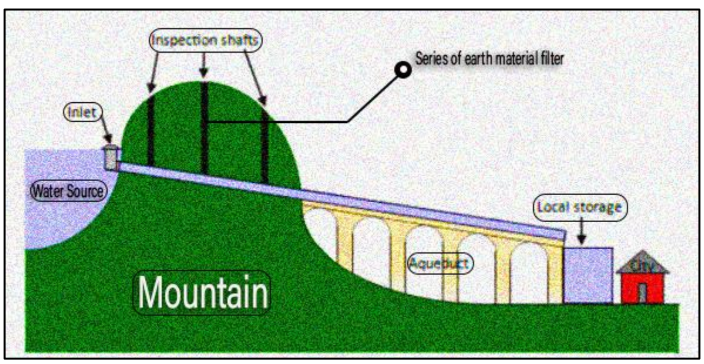

Figure I.3: Clay filter used in the Roman nation [4].

Ancient Roman aqueduct engineering included setting ponds, channels or ducts large enough for inspection, and vertical access shafts that allowed air ventilation; Most of the aqueduct systems used gravity flow.

The first recognized large-scale water filtration system as shown in fig.I.4. Was invented in 1804 by john Gib, a Scottish engineer; This system used a series of earth material filters to purify water supplying a bleaching plant in Paisley, Scotland. In this system, the water passed from a stone-filled channel into a settling basin and then moved successively through a gravel filter and a sand filter prior to entering a central water storage basin. And then the water was sold to the public [7].

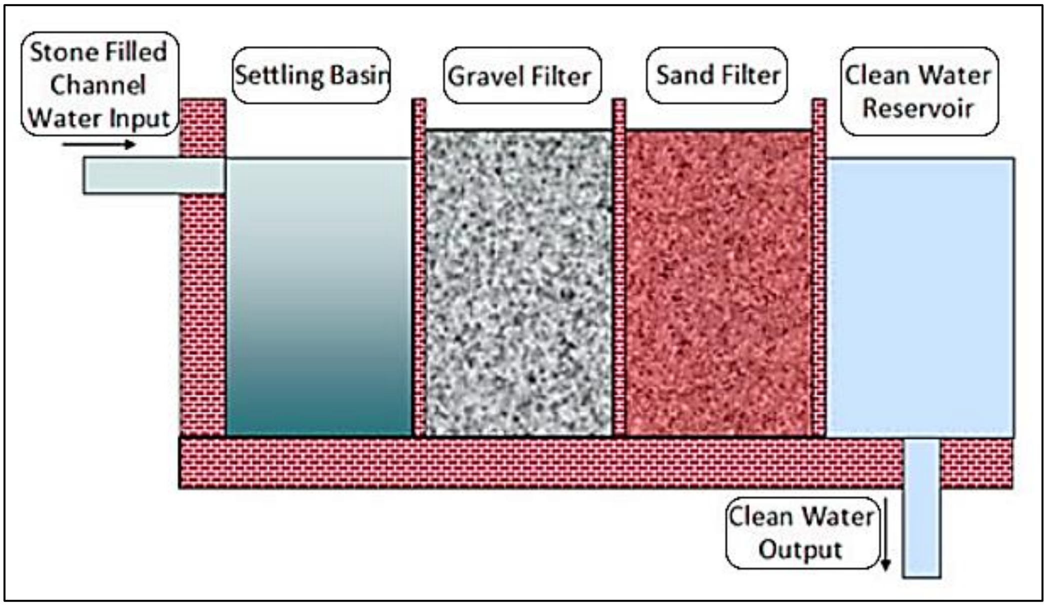

Figure I.4: Updated clay filter used in 1804 by John Gibb [4].

I.4. Desalination plants around the world:

Today's sophisticated methods still generally use the concepts of distillation or filtration.

There are more than 15,000 desalination plants around the world where the biggest plants are generally in the United Arab Emirates, Saudi Arabia, and occupied Palestine [8] as shown in fig.I.5.

Saudi Arabia has some of the largest desalination facilities in the world including “the Shuaiba” complex, it produces over 880 million liters per day, and the “Al Jubail” complex produces over 800 million liters per day.

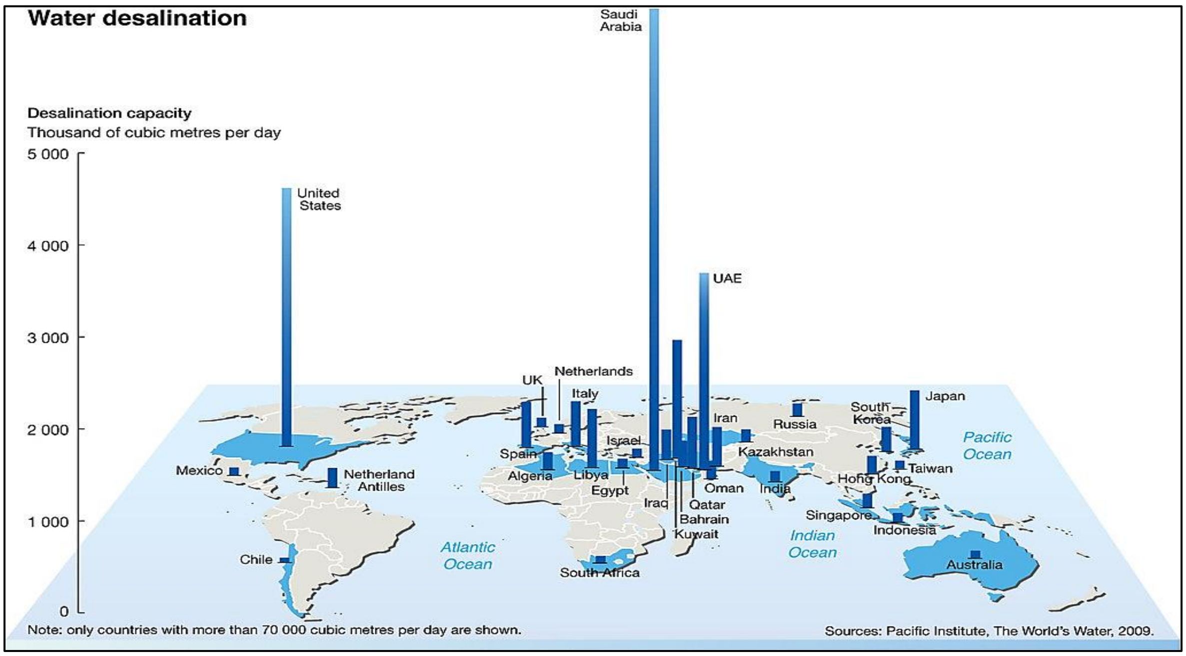

Figure I.5: Desalination plant around the world [8].

Occupied Palestine's “Soreq” plant produces 540 million liters per day, and Algeria's “Magtaa” plant produces 500 million liters per day.

There are about 270 desalination plants in Australia, most of them small-scale plants to desalinate seawater or brackish water for a range of uses; including drinking water, supplies for communities or tourist destinations, industrial processes, irrigation of sports grounds, and agricultural uses [3].

The 10 biggest desalination plants are mainly positioned around the Mediterranean, around the Persian Gulf and the Arabian Peninsula, on the coasts of India, the southern United States, China, Australia, and Japan, for a total abstraction of 52 million m³ per day as shown in table I.1. The Arabian Peninsula accounts for more than a third of the withdrawals, 13% go to the United States and 8% to Spain.

Table I.1: The biggest desalination plant in the world.

Rank	Name	Countries	Size Delivering	Technologies
1	Ras Al khir	Saudi Arabia	1036000 m3/day	MSF/OS
2	Taweelah	UAE	909,200 m3/day	OS
3	Shuaiba 3	Saudi Arabia	880,000 m3/day	MSF/OS
4	Jubail Water and Power Company	Saudi Arabia	800,000 m3/day	MED
5	Umm Al Quwain	UAE	682,900 m3/day	OS
6	DEWA Station M	Dubai	636,000 m3/day	MSF
7	Sorek	Occupied Palestine	624,000 m3/day	OS
8	Jubail 3A IWP	Saudi Arabia	600,000 m3/day	OS
9	Sorek 2	Occupied Palestine	570,000 m3/day	OS
10	Fujairah 2	UAE	591,000 m3/day	MED/OS

Regions that suffer from scarcity of freshwater are located in Asia and North Africa as shown in fig I.6, which make almost all of the desalination plants are occupied around the continent of Asia [3].

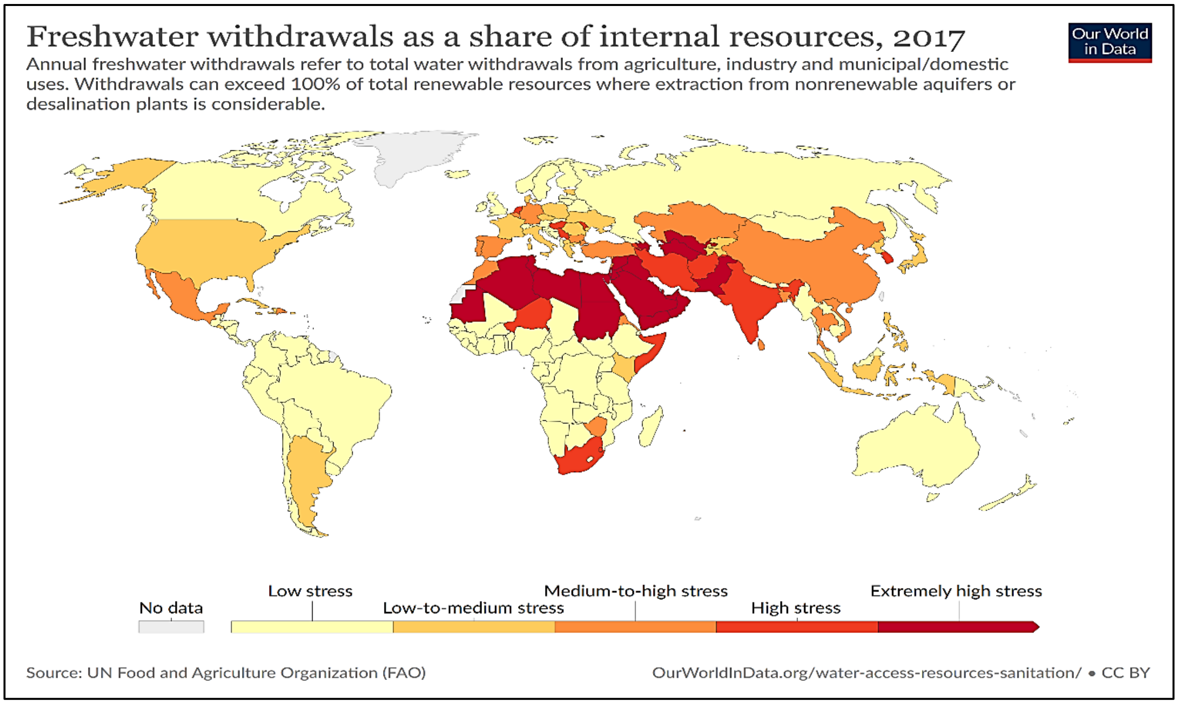

Figure I.6: Regions with scarcity risk [2].

I.5. Desalination plants in Algeria:

Algeria is the largest country in Africa and is not endowed with many sources of freshwater. Consequently, nearly 40 percent of Algeria's population is water-stressed.

Algeria is 95 percent arid in addition 80 percent is a desert and the minimal rainfall it receives is seasonal. Much of its water is sourced from a few reservoirs (long-distance transfers) and the desalination industry. Over-exploitation of water resources is also a significant risk, especially in the southern and central parts of the country, where groundwater is the most reliable source of water.

Algerian groundwater withdrawals are approximately double the recharge rate; with 3 billion m³ withdrawn every year and 1.5 billion m³ renewed; as a result, Algeria's aquifers have become increasingly contaminated and saline [3].

Algeria’s water scarcity problems are not limited to the sparsely-populated southern and central parts of the country. Three-quarters of Algerians live in cities, which is mainly due to large numbers of people moving from rural to urban areas.

As Algerians continue to protest about the country’s government, demonstrations have also broken out in eastern Algeria, where protesters have demanded better access to drinking water.

The protests occurred in Hammamet, near the town of Tebessa, where tensions have continued to rise since the government allowed a mineral water factory to exploit local spring water. According to locals, a lack of access to water has been a problem in the area for some time, but the situation has grown worse since the factory began operating.

Under all the painful conditions, the government's best choice is to invest money in desalination plants.

Algeria has more than 20 desalination plants in 2019 distributed along the 14 coastal wilayas as shown in fig I.7, providing 17% of the water consumed in the country and supplying 6 million people. The country plans to increase the number of desalination plants to 43 [9].

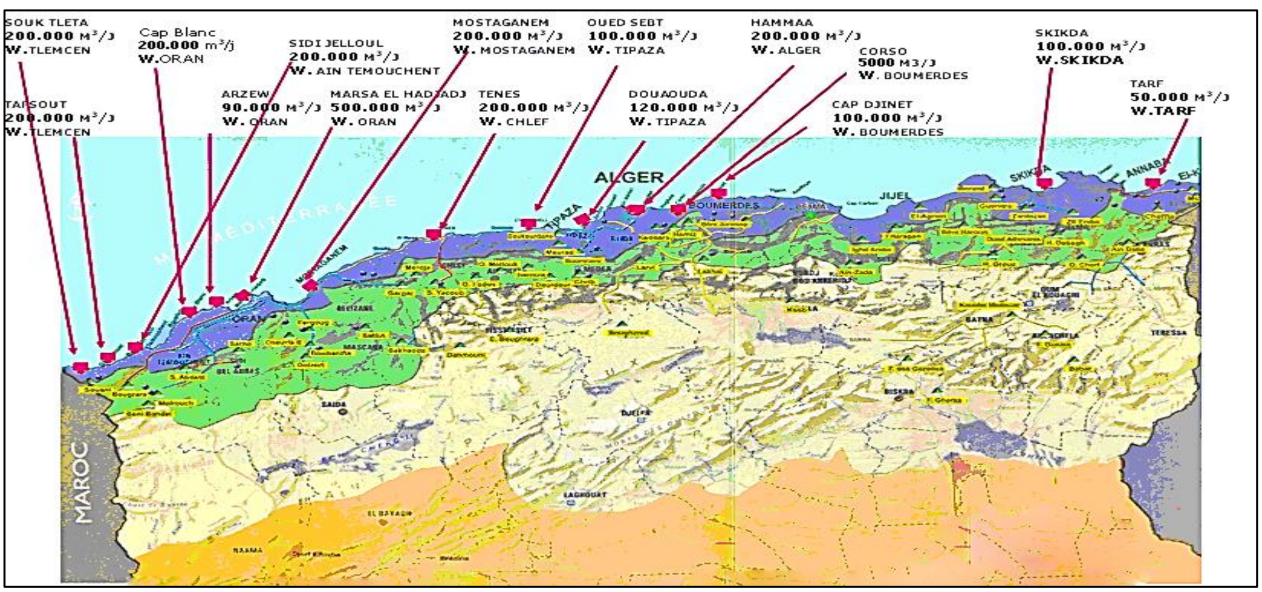

Figure I.7: Desalination plants in Algeria [9].

The following table shows the list of desalination plants in Algeria:

Table I.2: List of desalination plants in Algeria.

Province name	Size of drinking water delivered ($m^3/jour$)	Number of desalination plant
Chlef	205000	2
Bejaia	400000	2
Tizi ouzou	2500	1
Alger	2277500	4
Jijel	200000	1
Skikda	100000	1
Annaba	160000	1
Mostaganem	200000	1
Oran	800500	4
Boumerdes	100000	1
Taref	50000	1
Tipaza	320000	3
Ain Timouchent	200000	1
Totale		23

I.6. Conclusion

In response to the increasing demands of water, caused by the huge increase in population and the fact that the animal and plant part of the ecological system also needs freshwater, while the amount of this source of life on earth is very limited.

One of the best solutions is the desalination of seawater which has been used for a long time, there are many plants around the world, mainly in the Mediterranean and the Middle East.

In Algeria, there are more than 20 stations along the coast and they produce a considerable amount of freshwater for different uses, the largest station is that of Magtaâ in Oran.

In the next chapter, we will present the desalination technologies used in industry, including the general structure of a desalination plant.

Chapter II
Desalination Plant

II.1. Introduction:

As we saw in the previous chapter, desalination plants around the world can solve a large part of drought problem, especially in the middle-east and the Maghreb.

In this chapter, we will get inside those plants; to see how the desalination process works, technologies and equipment.

II.2. Technologies used in desalination plants:

Today, desalination can be realized using several technologies. where a desalination plant includes different processes to obtain freshwater, among which the desalination unit is the most energy expensive component.

Desalination technologies can be classified based on different ways; for example, based on "working principle" or based on "the main energy input", as shown in fig.II.1; and for economic purposes, it can be aliment using a renewable energy source.

II.2.1. Classification based on working principle:

In this type of classification there are three main categories "Evaporation and Condensation", "Filtration" and "Crystallization" as shown in fig.II.1, and all other working principle are under these techniques.

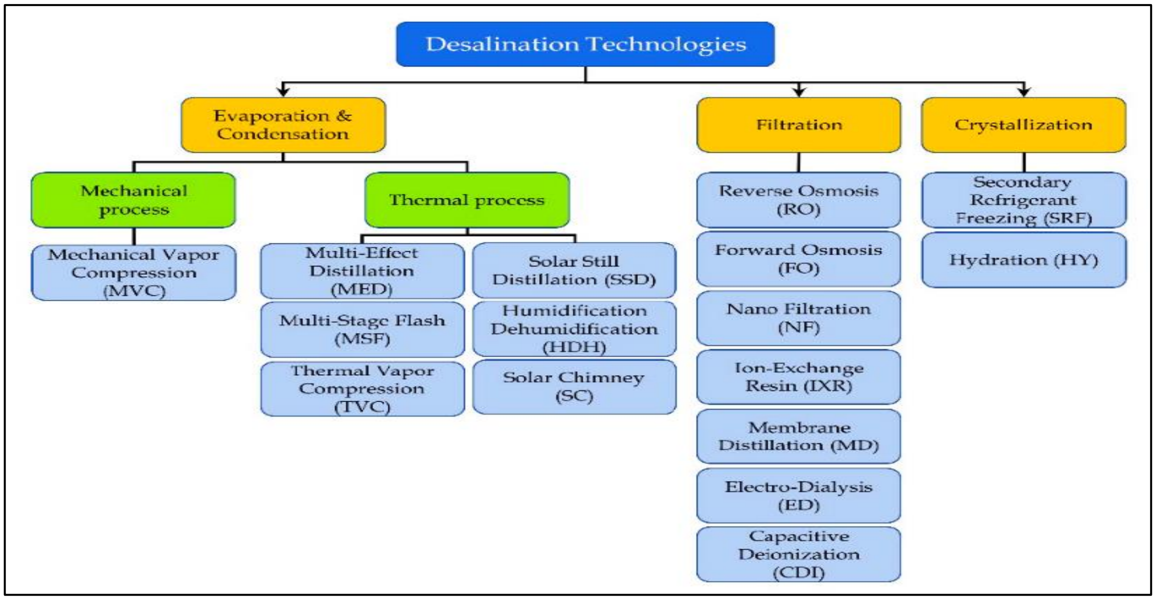

Figure II.1: The classification of desalination technologies based on working principle [10].

Evaporation and Condensation technologies are the first desalination techniques to be historically introduced and used for civil freshwater production.

The idea is to supply thermal energy to seawater, producing a vapor, and then condensate it. This energy can be generated by using the heat from a thermal process or through a mechanical process.

In case of **Filtration** technologies, all solutions are essentially based on a semipermeable membrane, a layer that shows a different mode of crossing behavior according to the sizes or nature of molecules.

The Crystallization category comprises techniques that extract freshwater producing ice as intermediate product [10].

II.2.2. Classification based on the main energy input:

This type of classification is realized by considering the kind of energy mainly required to run the process as shown in fig.II.2, This aspect is important for selecting renewable energy sources to supply the desalination process.

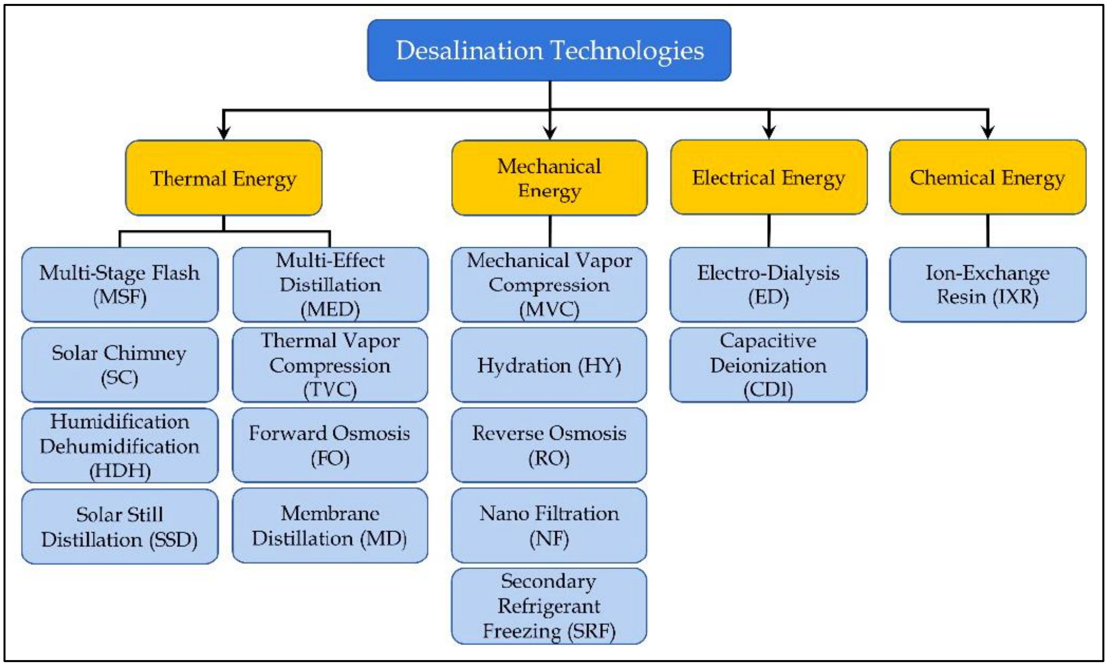

Figure II.2: The classification of desalination technologies based on energy input [10].

From fig.II.2 the main energy sources to power the desalination process are:

- Thermal Energy
- Mechanical Energy
- Electrical Energy
- Chemical Energy

Thermal Energy input could be supplied by solar thermal or geothermal energy sources.

The group that require a Mechanical Energy as input comprises, are characterized by the presence of pumps and compressors (like in Reverse osmosis works with a high-pressure pump), which require a major part of the total energy demand for the process.

The last two categories have limited examples. Electrodialysis and Capacitive Deionization desalination require the generation of an electric field between two electrodes, separated by an anion membrane and a cation membrane in this case, electricity is the only way to supply the process.

In order to supply the desalination process with a renewable energy source, we divide renewable energy into two power factor the one that produces electrical energy and that produce thermal energy as showns in fig.II.3.

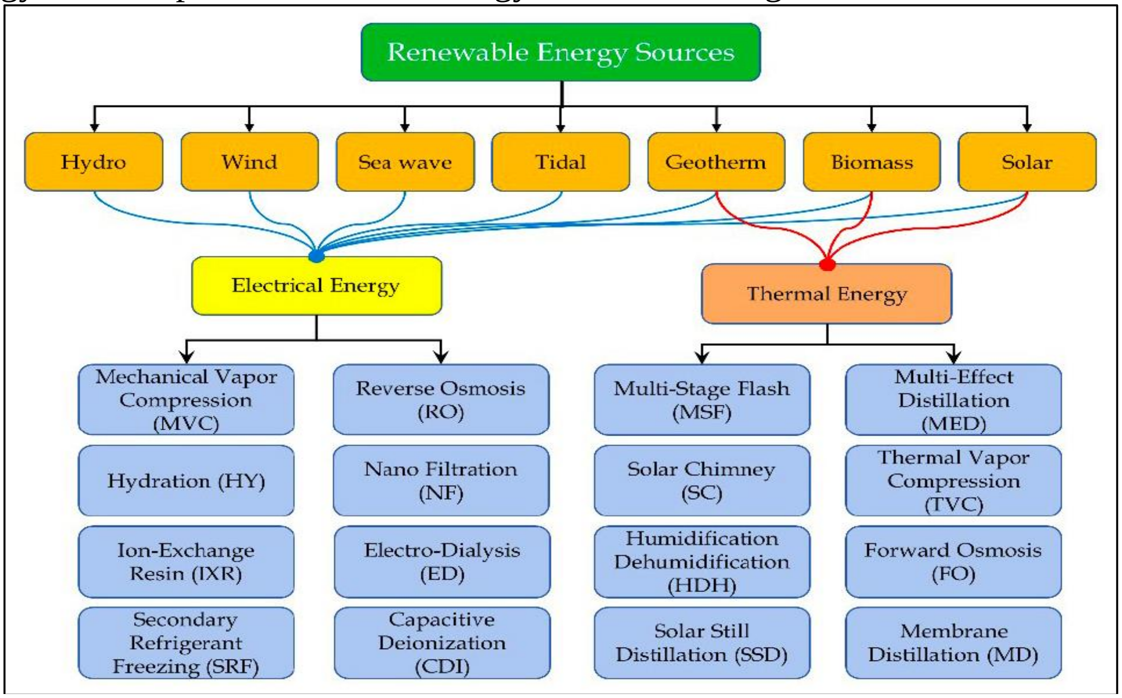

Figure II.3: Possible coupling between desalination technologies and renewable energy sources [10].

Each technology consumes an amount of energy to work where table. II.1 [4] shows the performance need to install each one:

Table II.1: Performance assessment of desalination technologies.

Desalination technology	Feed Water	Energy consumption (kWh/m3)	Thermal energy (kwh/m3)	Operation temperature (°C)
MSF	Seawater, Brackish water	2.5-3.5	12	90-110
MED	Seawater, Brackish water	1.5-2.5	6	70
TVC	Seawater, Brackish water	1.6-1.8	14.6	63-70
MD	Seawater, Brackish water	0.6-1.8	54-350	80
RO	Seawater, Brackish water	3.5-5	-	Ambient
ED	Brackish water	1.5-4	-	Ambient

We will present in the next section the most used technologies in industry and try to understand each concept.

a. Multi-Stage Flask (MSF):

Historically, MSF was the first commercially available thermal desalination technology applied to the production of potable water on a large scale, which explains its popularity where over 80 percent of thermally desalinated water today is produced in MSF plants.

The first MSF plant was realized in the 1950s in Scotland and after few years it became the most used desalination technology.

MSF is also commonly used on ships and along the coastline in several parts of the world, like USA, Middle East and Korea [11].

The MSF process work with an initial heat supply, and electricity is required to run the several pumps distributed along with the desalination plant.

The plant can be conceptually divided into two sections: the first is the brine heater section, where the feedwater receives heat from an external supply, and the latter one is the heat recovery section, where the thermal energy is recovered to preheat the feedwater.

The saline feedwater is firstly used as cooling water for the condenser and then as a raw source to produce freshwater as shown in fig. II.4 [10]. The saline water increases its temperature progressively, flowing inside the pipes and forming the heat exchangers inside the flash stages.

To start the process, the saline water is heated inside the brine heater by using steam usually spilled from a power plant. This steam condenses inside the brine heater (outside the tube bundle), so it can be reused in the steam power plant.

As the saline feedwater flows inside pipes in the brine heater and in the flash stages, the maintenance operations are simpler than in MED.

For this reason, MSF is the most widespread thermally-driven desalination technology, representing 17.6% of the total installed desalination capacity in the world.

This technology is able to satisfy a freshwater demand of about 4000 to 57,000 m3/day, requiring heating at 90 °C–110 °C [12].

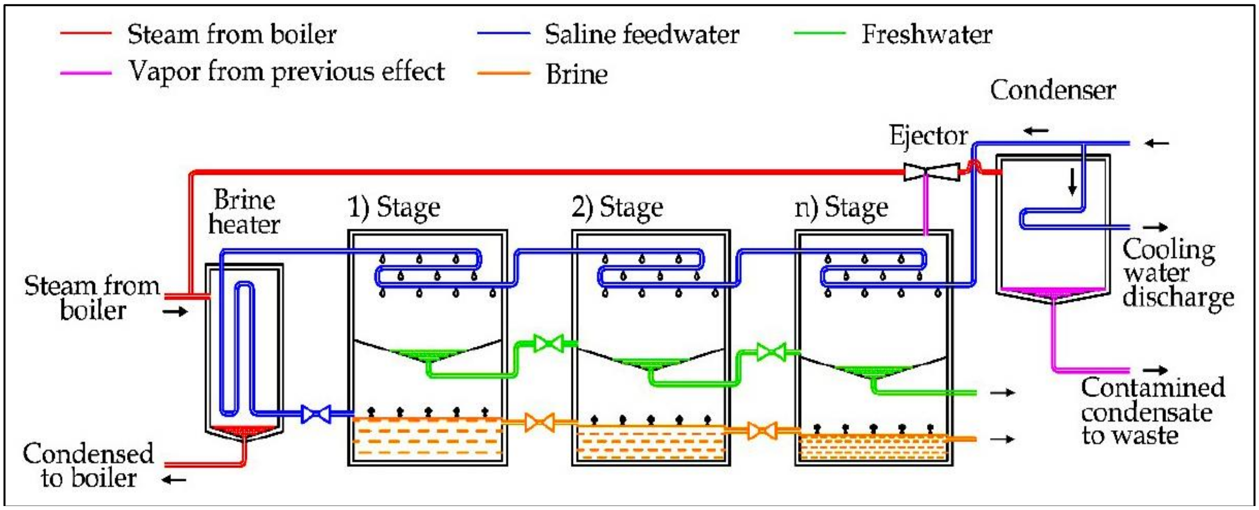

Figure II.4: A schema of a Multi-Stages Flash (MSF) desalination unit [10].

b. Multi-Effect Distillation (MED):

The first MED plant was realized in Kuwait in the 1950s, using a triple-effect submerged tube evaporator. Despite being one of the first technology for desalination to be introduced, MED did not spread because it is particularly affected by the scaling problem on the pipes in comparison with other thermally supplied desalination technologies [13].

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 into these tubes. This heat transfer at the same time results in condensation of the vapor to freshwater [14].

In general, as shown in fig.II.5 [1], this plant is composed of a steam supply, several effects, heat recovery exchangers, a condenser and a venting system.

In detail, the saline water can be split into two lines, in order to recover the thermal energy of freshwater and brine produced by the system, after this step, saline water is used as cooling fluid for the condenser, then preheated by using the heat recovery exchangers that are supplied by the steam produced in each effect chamber.

The preheated water is sprayed in the first chamber on the evaporator surface, producing a thin film to promote rapid boiling and evaporation thanks to the low pressure inside the chamber and the external thermal energy supply [15].

The vapor produced inside this chamber is transferred by pipes to the following chamber. As the pressure inside the second chamber is lower than the first one, the boiling temperature is also lower. In this way, it is possible to condensate the vapor produced in the first chamber inside the pipes and at the same time produce another vapor inside the second chamber.

This process is repeated in the subsequent chambers in the same way, using the steam generated in the previous flash chamber to produce more vapor at lower pressure. In the last chamber, the vapor is finally condensed inside the condenser, cooled by the saline feedwater.

The brine produced in the previous chambers is usually transferred inside the subsequent chambers, in order to force the extraction of more freshwater.

The pressure inside the chambers is kept below the atmospheric conditions by using a dedicated vacuum system. The energy efficiency of MED units depends on the number of effects, normally ranging between 4 and 21 [16].

MED units are used to produce freshwater with a flowrate ranging from 2000 to 20,000 m3/day. To improve the energy efficiency, MED can be coupled with a Thermal or Mechanical Vapor Compression unit; The biggest desalination plants are concentrated in China and the Middle East [17].

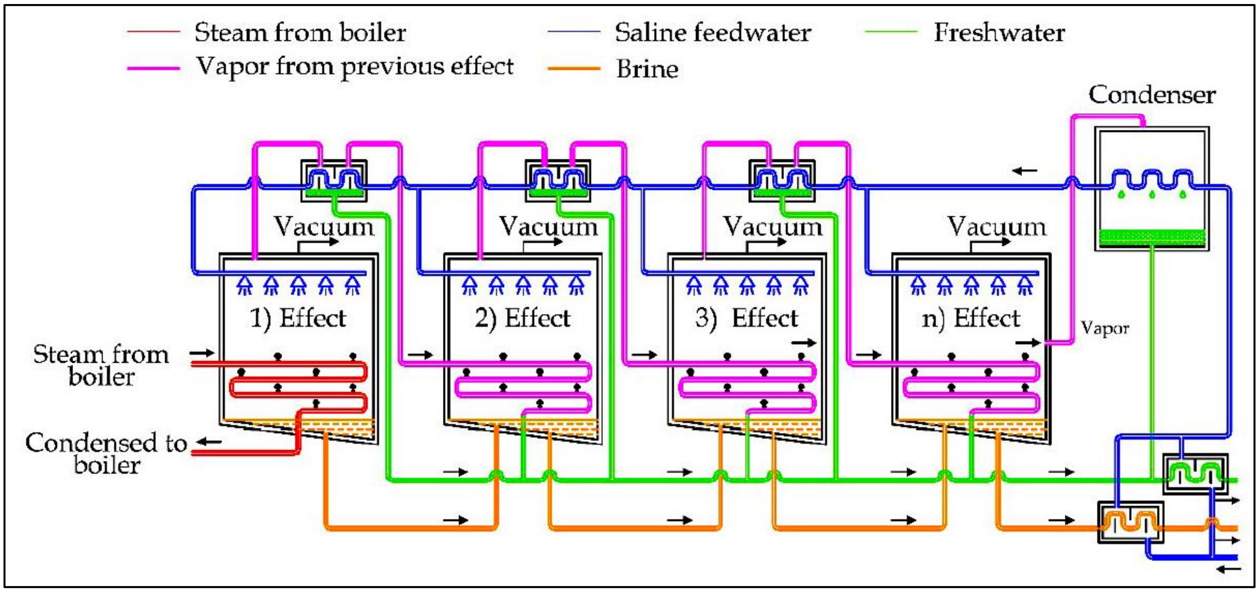

Figure II.5: A schema of a Multi-Effect Distillation (MED) unit [10].

c. Vapor Compression (VC):

Vapor Compression is one of the most used technology in the desalination sector, based on the liquid-vapor phase transition.

The heat source for vapor compression (VC) systems is compressed vapor produced by a mechanical compressor or a steam jet ejector rather than a direct exchange of heat from steam as shown in fig.II.6 [10].

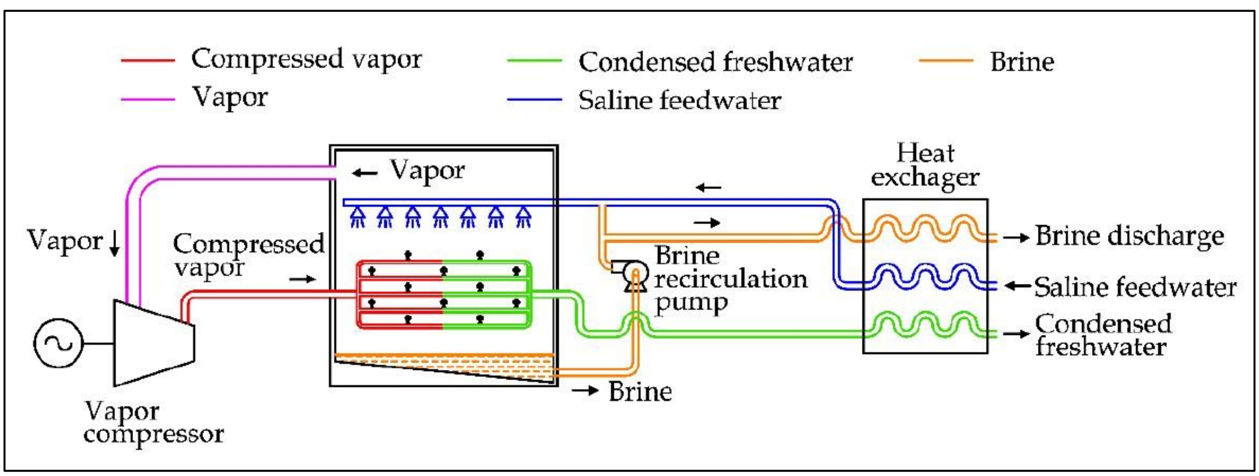

Figure II.6: A schema of a simple Mechanical Vapor Compression desalination unit [10].

VC and MED work based on similar principles as shown in fig.II.7 [14], however while in MED the steam produced by source water evaporation is introduced and condensed in a separate condenser located in the downstream effect, in VC the steam generated from the evaporation of new source water sprayed on the outside surface of the heat exchanger tubes is recirculated by the vapor compressor and introduced into the inner side of the same heat exchanger tubes in which it condenses to form distillate.

In VC systems the source water is evaporated and the vapor is conveyed to a compressor.

The vapor is then compressed to increase its temperature to a point adequate to evaporate the source water sprayed over tube bundles through which the vapor is conveyed.

As the compressed vapor exchanges its heat with the new source water being sprayed on the evaporation tubes, it is condensed into pure water. A feedwater preheater (plate-type heat exchanger) is used to start the process and reach evaporation temperature [18].

Mechanical VC essentially requires electricity to run the process therefore, a small stand-alone desalination unit can be realized to satisfy a freshwater demand ranging from 100 to 3000 m3/day [17].

VC desalination has found applications mostly in small municipal and resort water supply systems, as well as industrial applications. The total amount of power required for the operation of mechanical VC systems is typically 8 to 12 kWh/m3 (30 to 45 kWh/1000 gal) of product water [14].

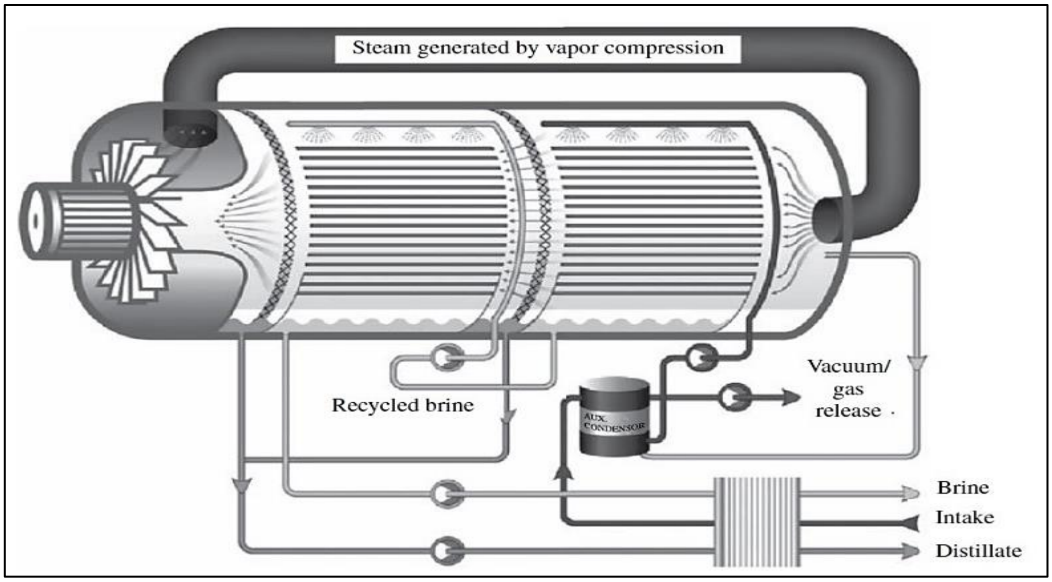

Figure II.7: Schematic of a VC system [14].

d. 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 is forced under pressure through a semipermeable membrane. Where this 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 [14].

What that means? In nature, if two solutions with different concentrations of solutes are separated by a semipermeable membrane, the solvent flows spontaneously from the more diluted solution to the more concentrated one, in order to balance the energy potential of both solutions, as shown in “case a” fig. II.8.

This flow can be progressively reduced if an increasing external pressure gradient $\Delta\rho$ is applied to the semipermeable membrane, as shown in “case b” fig.II.8.

The exact value able to stop the solvent flow is defined as Osmotic Pressure $\Delta\rho_{osm}$, as shown in “case c” fig. II.8.

If the external pressure gradient is greater than the osmotic pressure, the solvent flow is inverted, so the solvent can be extracted from the concentrated solution as shown in “case d” fig.II.8 [19].

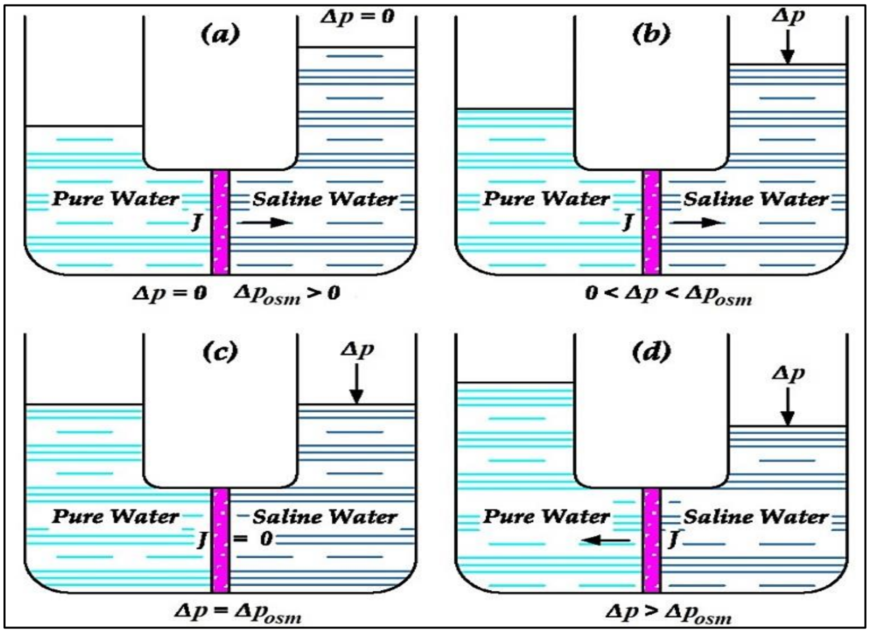

Figure II.8: The phenomenon of osmosis, according to the external pressure applied [10].

- **Development of equation**

Many mechanistic and mathematical models have been proposed to describe RO membranes. Models that adequately describe the performance of RO are very important since these are needed in the design of RO units.

The model based on solution diffusion is the most used. It is based on the diffusion of the solvent and the solute through a membrane. This model supposes that both the solute and solvent dissolve at the membrane surface and diffuse across it [20].

- **Solvent and solute transport equation**

The solvent mass flux J_W which is generally water, can be expressed by Fick’s law. It depends on P, the pressure difference across the membrane and the osmotic pressure difference of the solution across the membrane:

$$J_W = A_W(\Delta P - \Delta_\pi) \tag{2.1}$$

where:

J_w The solvent mass.

ΔP The pressure differences.

A_w Is the water permeability constant.

Δ_π The difference in osmotic pressure on both sides of the membrane. It can be expressed like this:

$$\Delta\pi = \pi_f - \pi_p \tag{2.2}$$

where:

π_f The osmotic pressure in the feed side

π_p The osmotic pressure in the permeate side.

The osmotic pressure π is approximately a linear function of solute concentration:

$$\pi = \alpha C \tag{2.3}$$

where:

α Is a proportionality coefficient.

C Is the solute concentration.

- **Volumetric flow**

The volumetric flow Q_w can be expressed as:

$$Q_w = \frac{J_w Sa}{P_w} \tag{2.4}$$

Where:

Sa Is the membrane surface area.

P_w Is the water density.

For the flux it is assumed that the chemical potential difference due to pressure is negligible and so the driving force is almost entirely due to concentration difference. From Fick's Law, the solute mass flux is:

$$J_S = B_S(\Delta C) \tag{2.5}$$

Where:

B_S The solute permeability coefficient.

Note: the solute permeability coefficient is a function of the solute composition and membrane structure.

And the solute mass flow rate $\dot{Q}_S$ is expressed as:

$$\dot{Q}_S = J_S Sa = B_S Sa(C_f - C_p) \tag{2.6}$$

The membrane rejection is defined as the fraction of solute present in the solution which is stopped the membrane:

$$T_R = \frac{C_f - C_P}{C_f} = 1 - \frac{C_P}{C_f} \tag{2.7}$$

where:

T_R Is the membrane rejection.

C_f The feed side concentration.

C_P The permeate side concentration.

Using the relation for the solvent and solute flux, solute rejection for the solution-diffusion model can be expressed as:

$$\frac{1}{T_R} = 1 + \frac{B_S \rho_W}{A_W}\left(\frac{1}{\Delta P - \Delta \pi}\right) \tag{2.8}$$

Fig.II.9 visualizes the phenomenon of osmosis: until the external pressure gradient is lower than the osmotic pressure, the solvent flows from the more diluted solution to the more concentrated one [19].

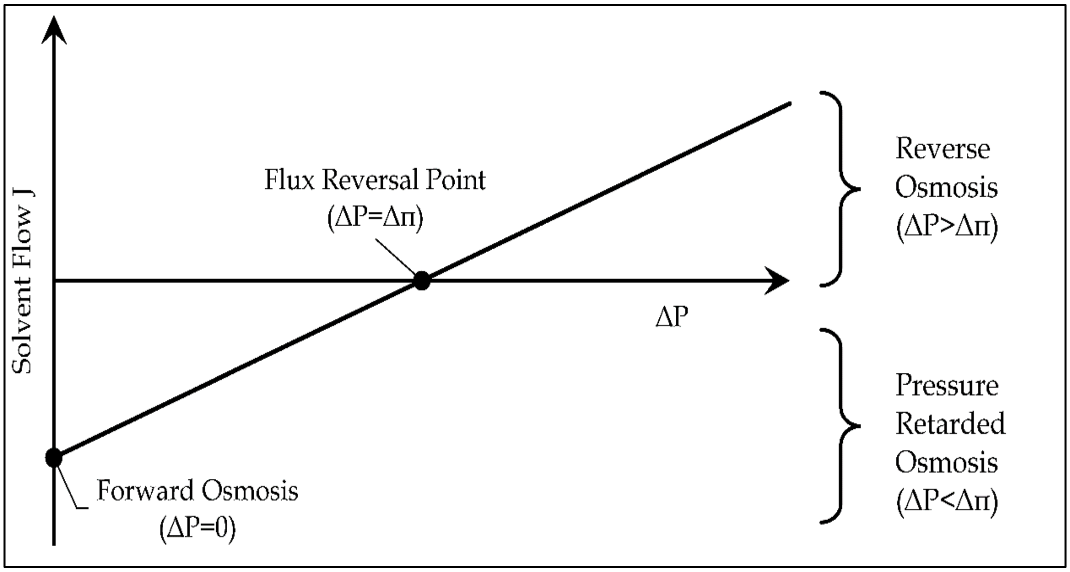

Figure II.9: Solvent flow as a function of the external pressure gradient.

As shown in fig.II.10 [14], the sizes and types of solids removed by RO membranes as compared to other commonly used filtration technologies, 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.

Usually RO membranes remove over 90 percent of compounds, 200 Daltons (Da) or more.

This means that they can remove practically all suspended solids, protozoa, bacteria, viruses, and other human pathogens contained in the source water.

Note: One Da is equal to 1.666054×10^{-24} g; In terms of physical size, RO membranes can reject well solids larger than 1 (Angstrom) Å.

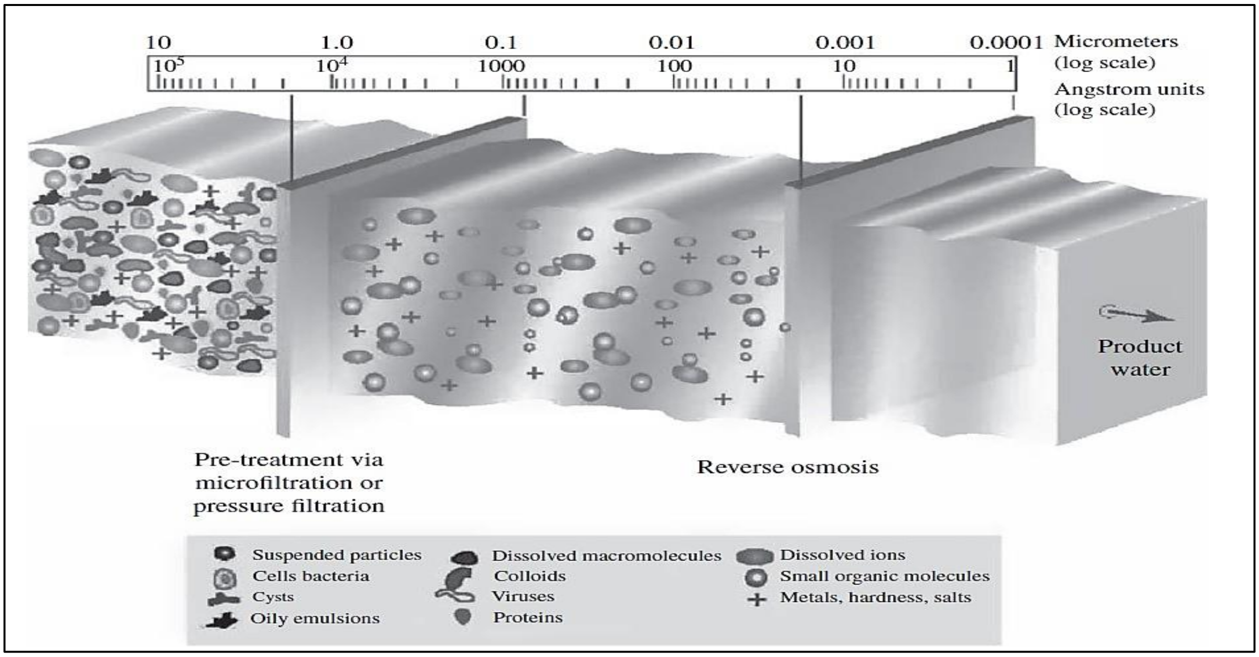

Figure II.10: Contaminant removal by RO membranes [14].

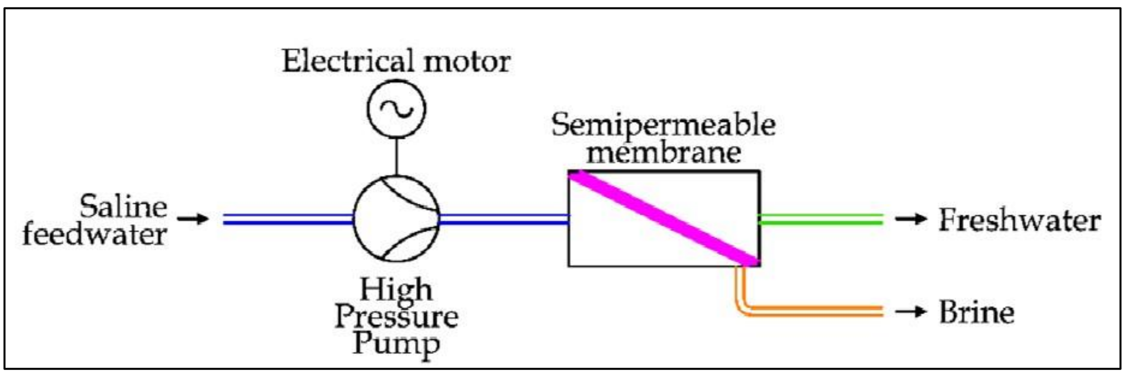

Figure II.11: A diagram of a simple Reverse Osmosis (RO) desalination unit [10].

According to the International Desalination Association, for 2011, reverse osmosis was used in **66%** of installed desalination capacity, and nearly all new plants. Other plants mainly use thermal distillation methods: multiple-effect distillation and multi-stage flash [3].

II.3. Desalination Plants Structure

In our thesis we focused on the RO technology cause it's the most used in industry. The table.II.2, shows technologies used in Gulf Cooperation Council (GCC) countries in 2017.

Table II.2: Existing desalination plants in GCC countries (2017).

Technology	KSA	UAE	Kuwait	Qatar	Oman	Bahrain	Total
MSF	1,078	1,307	702	387	158	91	3,723
MED	3	315	0	3	0	111	432
RO	1,054	153	0	1	10	44	1,262
VC	0	0	0	0	0	0	0
ED	0	0	0	0	0.01	0	0
Total	2,135	1,776	702	391	168	246	5,417

The plant has the following sequences: seawater catchment, pretreatment, RO, post-treatment, storage, and brines management; The RO system is the most complex and the one that has the greatest importance in the production freshwater [14], and as shown in fig. II.12 this is the general concept of most desalination plants that using Reverse Osmosis.

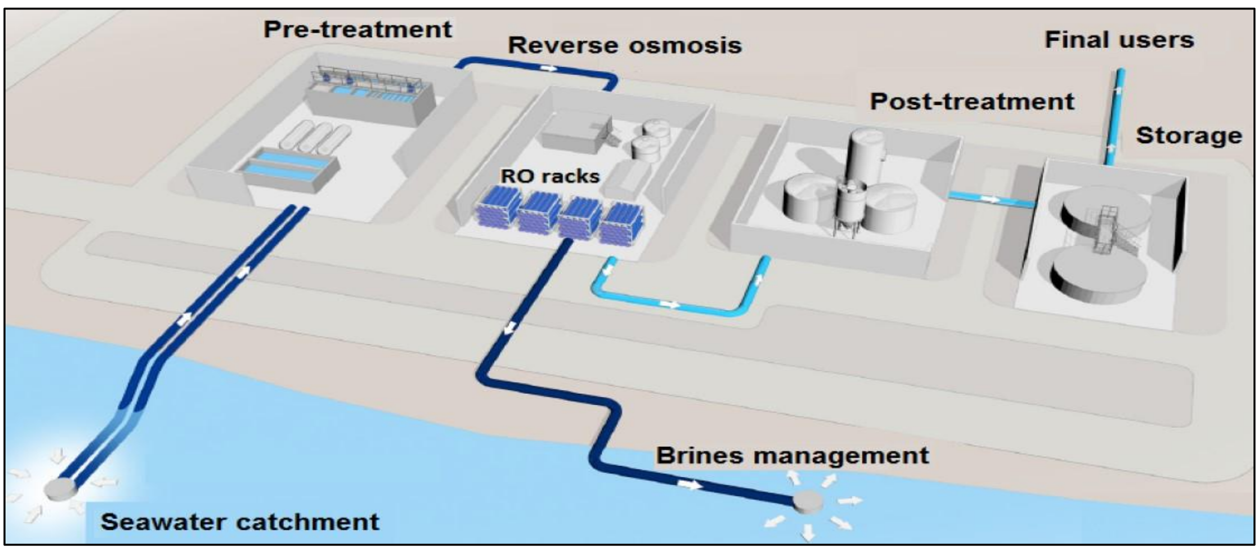

Figure II.12: Diagram of the industrial seawater reverse osmosis (RO) desalination plant [15].

II.3.1. General concept of the industrial desalination Process

- **Seawater Catchment**

Before treating it, the water is collected in a tank (Seawater catchment) to ensure a continuous supply to the installation. This tank can be made of fiberglass and covered with special paint that does not react with water particles in order to reduce the risk of contamination [21].

- **Pre-Treatment:**

After its capture and storage, the water must be conveyed along the treatment circuit by pumps to pressurize the circuit to a pressure sufficient for the filters such as the sand and carbon filters, in this case if the pressure reach 10 Psi then the system is in danger and the pressure needed to be clean for this reason there is a backwash cleaning system integrated in each filter start every time the pressure reach 7 Psi.

And to ensure that the system want goes down it is advisable to have two pumps, one in service and the other in reserve.

- **Pre-Treatment: Sand Filter**

The sand filter is widely used to remove the largest particles such as those floating on the surface of the water, they are found in almost any reverse osmosis membrane treatment unit. The filter has several layers of sand with different properties (materials, grain size). The filtration takes place in 3 stages, the first where the impurities are extracted from the water, the second where the impurities grow and adhere to the sand, the third is the elimination of algae and other unwanted particles [14].

- **Pre-Treatment: Carbon Filter**

The activated carbon filter has a design similar to that of sand filters, it has porous carbon granules capable of absorbing volatile substances on the phenomenon of adsorption. The activated carbon filter completes the water treatment process, eliminate: bacteria, hypochlorite, hydrocarbons, as well as metals.

After a certain duration of operation of the filter, however, it is necessary to avoid its saturation which would cause the release of filtered elements. In this case, a desaturation occurs through a periodic washing of the filter procedure.

The porosity of activated carbon makes it very good support for denitrifying bacteria (removes nitro and nitrogen compounds) and dechlorifying bacteria. The more water is in contact with the activated carbons, the better its efficiency, this principle is used, for example, to dechlorinate water [21].

- **Reverse osmosis process**

This module is the main element of this process, it contains the filtration membrane, it generates good quality water and part of the latter will be rejected or recycled according to the needs of the processes; And as we described in the previous section, the RO Technology work with Semi-Permeable Membrane will let the solvent through (the solute does not pass) to balance the concentration. The difference in concentration creates pressure, called osmotic pressure. To reverse the passage of the solvent and increase the difference in concentration, it is necessary to apply a pressure greater than the osmotic pressure as shown in fig.II.13 [14], and since the pressure is the controlling factor of the process the 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 and when the pressure more than 60 Psi this could expose the membrane to explode.

Note: 1 Psi = 6894.76 Pa

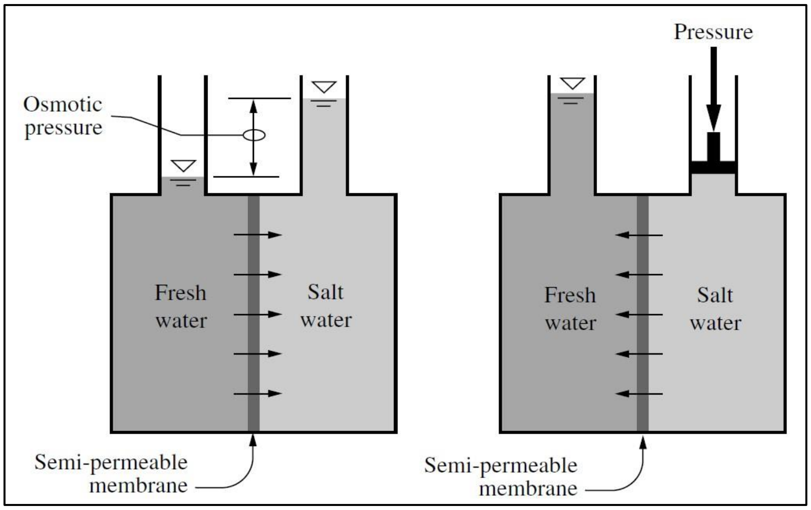

Figure II.13: Reverse Osmosis working principle [14].

- **Post-Treatment**

The water resulting from the reverse osmosis treatment is free of all minerals and not consumable, a remineralization (addition of minerals) is necessary to make this water drinkable. The automatic injection of CO2, NaOCL, $\mathbf{Na_2S_2O_5}$ and CL to regulate PH and CL value in the water.

The latter is carried out by vessels, equipped with distribution pipes and dosing pumps.

Finally, the water goes to the storage and it's ready to be distributed, without missing the part of water that goes to the **Brines Management** as salt for other uses.

II.3.2. Installation of the desalination plant:

Seawater is fed into catchment zone and then filled into a vessel; the water from the tank goes to the pretreatment zone using pumps, in which the water is filtered with different filters and then goes to the reverse osmosis stage through a high-pressure pump, after all it comes the final step in the post-treatment area.

- **Station power supply**

This area is intended to supply the other areas of the plant, we take as an example the Honaine desalination plant, located in Tlemcen, Algeria it is composed of **two SONELGAZ input lines of 220 kV** for each line we have [22]:

  - Current transformers CT.
  - Motorized automatic disconnector (Line disconnector).
  - Voltage transformers TP. (Line input).
  - Disconnector with earth connection (Malt disconnector).
  - Motorized automatic switch (Line circuit breaker).
  - Motorized automatic disconnector (Guide disconnector).
  - Line coupling bar (Coupling Disconnector).
  - Measurement voltage transformers 220 kV / 110 V TP.
  - Motorized disconnector (Transformer disconnector).
  - Automatic switch (Transformer circuit breaker).
  - Protective Lightning Rods.
  - 45 MVA 220 kV / 10 kV transformer.

- **Seawater catchment.**

This area is as we described in the previous section it's to collected the source water in a vessel to ensure continuous supply to the installation; in this area, as a real example, the Honain plant is equipped with **11 pumps**, 10 active and 1 for emergency purpose [22].

- **Pretreatment.**

In this area different way are used all over the world but for the same reason: to get the cleanest form of water before get it treated by the desalination technology; After this area, the pumped water should be clean of largest particles, ammonia, iron or manganese in solution, unwanted mineral and organic matter, pathogenic bacteria and viruses.

- **RO Model**

A water desalination technology that uses membranes to give pure water and brines, from an engineer perspective, as shown in fig.II.14, we described the concept of RO technology:

  - **Reverse Osmosis membrane structure, and materials**

A semi-selective membrane is a membrane allowing certain transfers of materials between two media that it separates, while prohibiting others or more generally favoring some over others [3].

Membrane are most often made of cellulose acetate or synthetic polymers; they can be flat or tubular or hollow fibers obtained by spinning polymers. It characterized by their qualities of chemical stability (PH, oxidants, chlorine… etc.), thermal stability, microbiological stability (bacterial degradation for cellulose acetate membranes) and mechanical resistance [23]; their cost occurs in 40% to 50% of investment in a reverse osmosis unit.

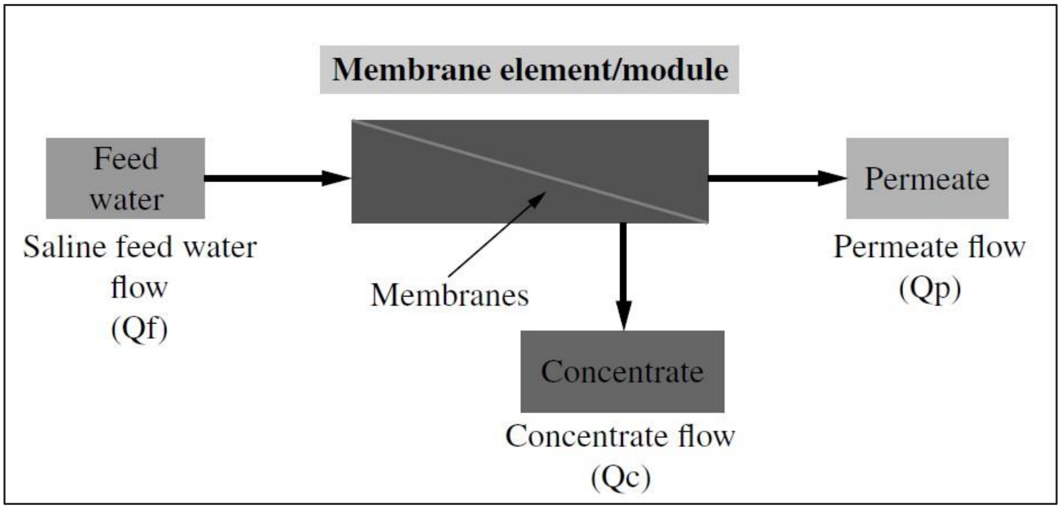

Figure II.14: General schematic of Reverse Osmosis system [14].

Membranes also differ by the material of the membrane polymer and by structure and configuration. Based on their structure, membranes can be divided into two groups: conventional thin-film composite and thin-film nanocomposite.

Based on the thin-film material, conventional membranes at present are classified into two main groups: polyamide and cellulose acetate. Depending on the configuration of the membranes within the actual membrane elements (modules), RO membranes are divided into three main groups: spiral-wound, hollow-fiber, and flat-sheet (plate-and-frame) [14].

- **Membrane Performances**

Permeability

It represents the voluminal or mass flow crossing the membrane per unit of the membrane surface.

Resistance

The resistance of the membrane to pressure, temperature, and chemical agents. We note that selectivity and permeability depend directly on pressure and temperature. A membrane is always used within well-defined limits of Pressure, Temperature, and PH.

Lifetime

Each membrane has a lifespan, beyond which the membrane will not perform (drop in yield and performance, degradation of condition, wear… etc.).

Conversion rate

In the case of membrane technologies, the flow of the fluid to be filtered can be continuous and tangential. The fraction of liquid flow that passes through the membrane is called the conversion rate of the separation operation.

Selectivity

The selectivity of a membrane is in general, defined by the rejection rate (also called retention rate) of the species (salt, macromolecule, particle) that the membrane is supposed to retain [24].

- **Modules**

To be implemented, the membranes must be mounted in supports called modules. A pressure-resistant enclosure is always necessary; and here are the four main types of modules that are marketed:

- **Tubular modules**

A tubular module fig.II.15, contains several tubes which can be in series or in parallel. The water to be treated circulates inside and the permeate is purified outside the tubes. The tubes form tangential flow channels. It is the only type of module that can be mechanically cleaned with a foam ball system that scrape the walls of the tubes [25].

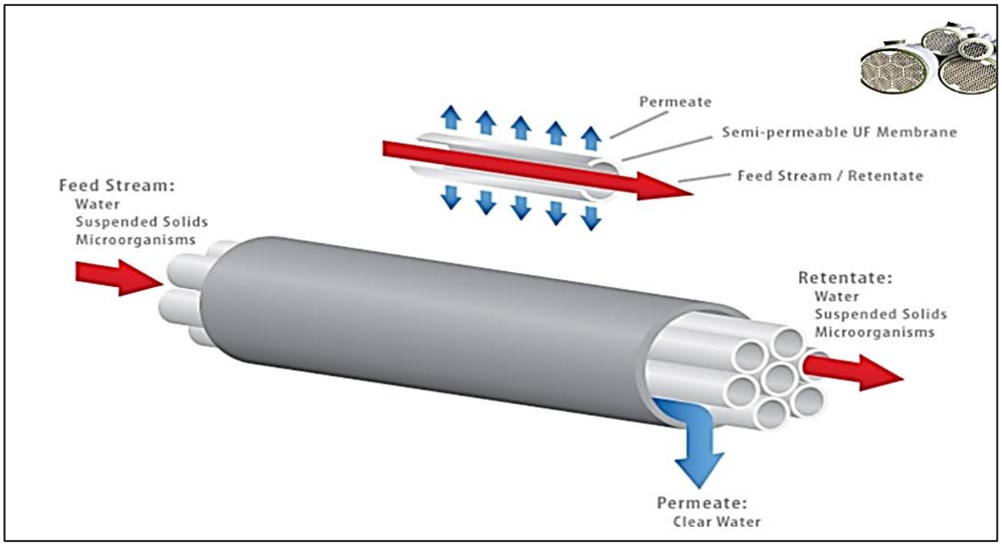

Figure II.15: Tubular module [19].

- **Hollow fiber modules**

Hollow fiber modules fig.II.16, The hollow fibers are assembled in parallel according to two configurations:

- ✓ **Inside-out configuration:** is the case for tubular modules, the water to be treated circulates inside the fibers and the permeate is recovered outside the fibers.
- ✓ **Outside-inside configuration:** the water circulates outside the fibers and the permeate is recovered inside the fibers; The circulation between the fibers is free.

In both cases, the membranes are assembled in bundles and their ends are embedded in plugs of glue which isolate the permeate from the water to be treated.

An industrial module can be made up of tens of thousands of fibers. Hollow fibers support backwashing [25].

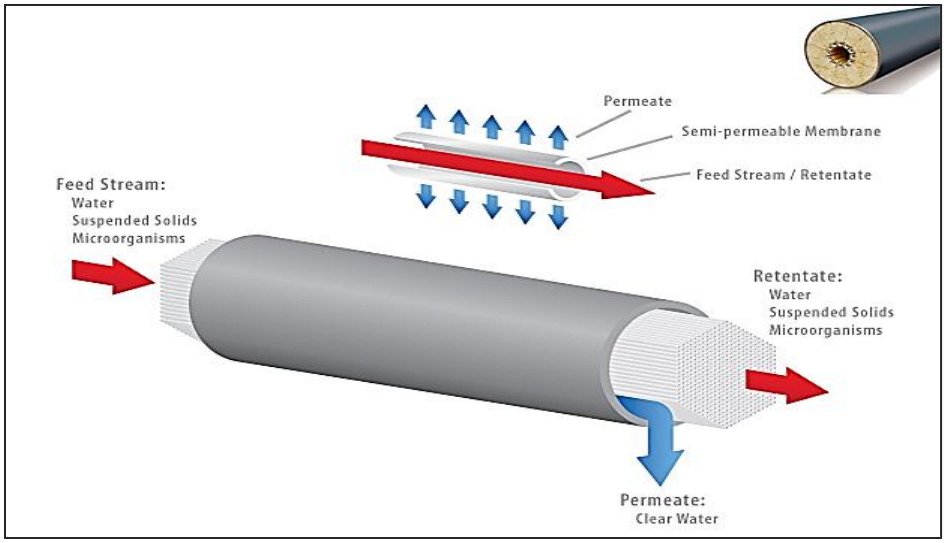

Figure II.16: Hollow fiber module [19].

- **Flat modules**

Flat modules fig.II.17 are the oldest and simplest: the membranes are stacked in mille-feuilles separated by intermediate frames which ensure the circulation of fluids [25].

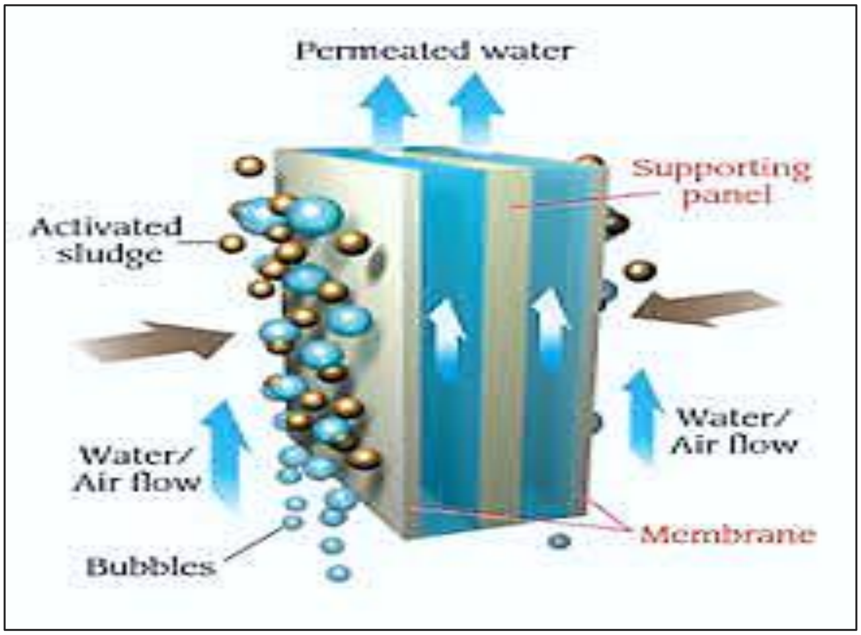

Figure II.17: Flat Module schematic [19].

- **The spiral modules**

Within the spiral modules fig.II.18, a flat membrane is rolled up on itself around a porous tube which collects the filtrate. A multilayer cylinder is thus obtained where the permeate flows along a spiral path towards the porous tube while the feed circulates axially in the channels [25].

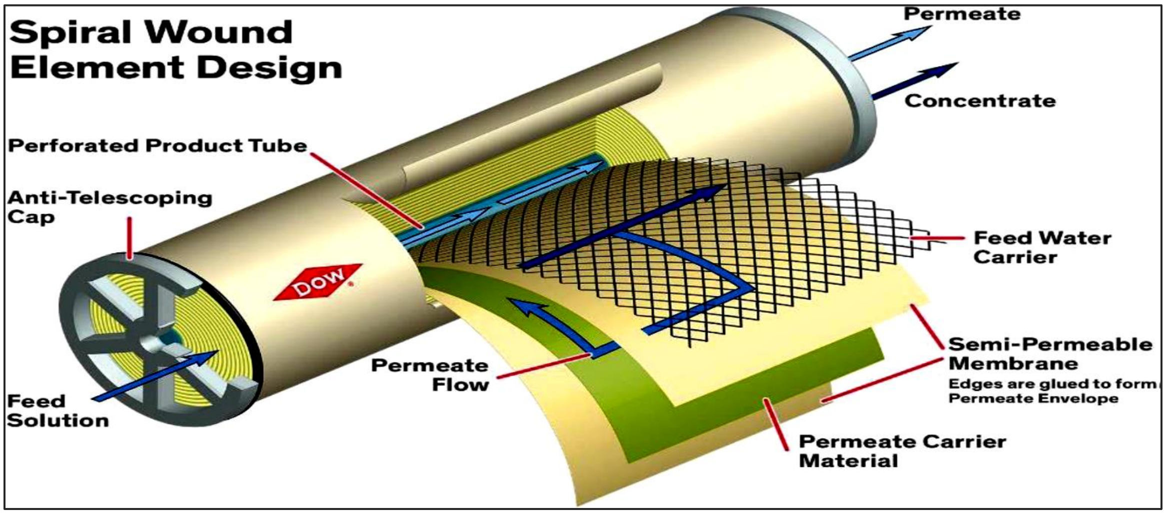

Figure II.18: Spiral module schematic [19].

- **Post treatment**

Using an automatic dispenser, there will be an addition of some chemical element to adjust PH and Chlorine value in the water from vessels.

- **Storage tank**

Here where pure water is stored and ready to be delivered to its destination.

- **Control room**

The desalination plant has established a control-command architecture to **monitor** and control the physical process and the associated equipment.

In the control room there are supervision screens equipped with a system which is distributed with an advanced process automation platform, integrates **DCS** topologies and **SCADA**. And the operations engineer communicates with the operator by walkie-talkie.

II.3.3. Equipment

1. Actuators

The desalination plant includes several types of actuators depending on their use. It is composed of motors, pumps, and valve.

- **Motors**

Industrial engines fig.II.19, uses a wide variety of machines powered by various energies. However, electrical energy is preponderant because for reasons techniques most mechanical devices used in industry are driven by electric motors.

Figure II.19: Motor.

- **Pumps**

To deliver the different existing liquids, different pumps are used:

  - **Feed pumps**: This type of pump is used to supply the plant (the filters) with raw water fig.II.20, they are single-stage centrifugal pumps with an axial suction port with a flow rate of 537.4 m3/h. It is self-regulating and generates a flow and not pressure [26].

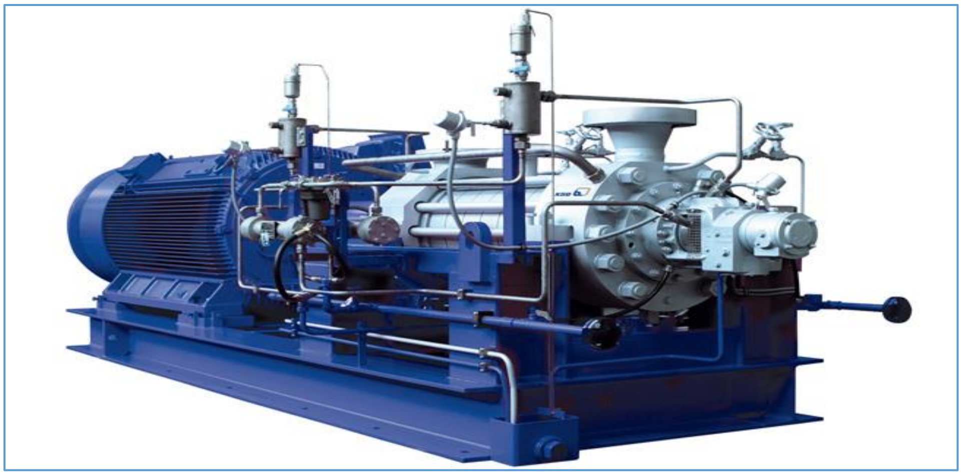

Figure II.20: Feed pump.

- **Dosing pumps**: They are used to dose chemicals (sodium hypochlorite…etc.) fig.II.21 with a maximum flow of 7.5×10^{-3} m3/h [22].

Figure II.21: Dosing pump.

- **Delivery pumps**: This type of pump fig.II.22 is used to send pressurized water from the filtered water tank to the filters with a flow rate of 114.1 m3/h and ahead of 26.5 m [13].

Figure II.22: Delivery pump.

- **High-pressure pumps (HP):** The high-pressure pumps fig.II.23 supplying the reverse osmosis modules are intended to send water under high pressure. The supply pressure values are in the range of 60 to 80.

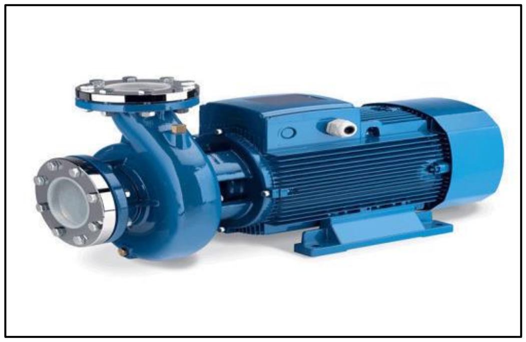

Figure II.23: HP Pump.

- **Valves**

Like any actuator it acts on a quantity which can be a two-way valve fig, II.24 or three-way valve. The controlled quantity will be a pressure, a flow, a level, a temperature, a concentration ratio.

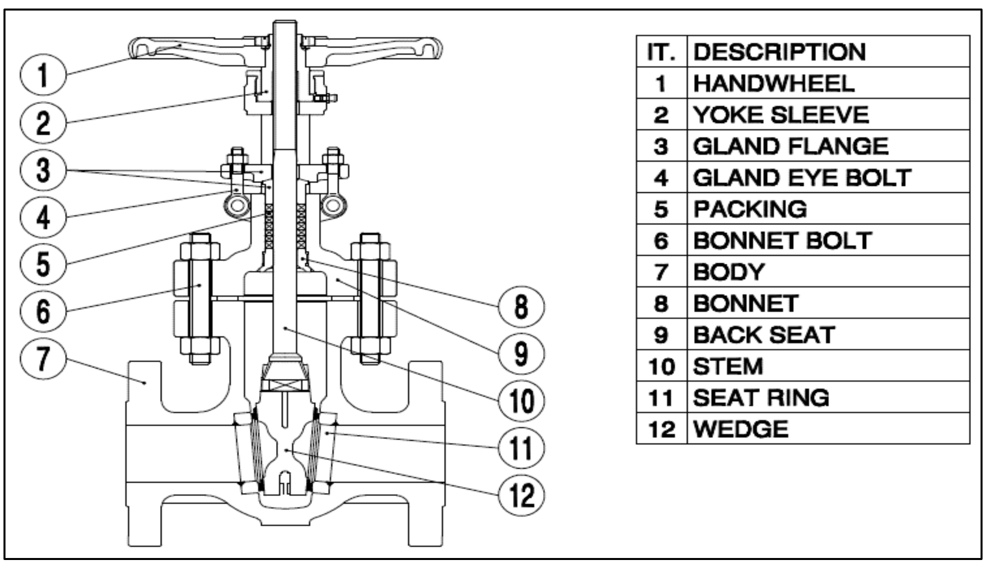

Figure II.24: two-way valve structure.

2. **<u>Sensors</u>**

The most important equipment in the installation is the sensors, which send alerts and feedbacks about the status of the plant equipment, it could be pressure, temperature, conductivity…etc.

- **Flow meter**

In general, flowmeters fig.II.25 are used to measure the flow of steam, gas or liquid. But also, in regulation and dosage [27].

Figure II.25: Flow meter.

- **Level transmitter**

It is a level probe which is used for hydrostatic level measurement in tanks. When the level probe is immersed in a liquid, a column of liquid above it. This column increases when the depth of immersion increases and it exerts with its weight a hydrostatic pressure on the measuring system as shown in fig. II.26.

it could also use digital one; in a vessel case one to detect if it's empty and other to detect full status.

Figure II.26: Level transmitter.

- **Pressure Indicator and pressure transmitter**

These sensors are used for pressure measurement and transmission. The element of bumblebee shrinks under pressure, its movement is converted by an inductive sensor into an electrical signal. Pressure transmitters are suitable for all liquids and gases which are not highly viscous, and are suitable for corrosive media and atmospheres.

- **Pressure Indicator**

Pressure gauges fig.II.27 are used for measuring the pressure of liquids and gases when the latter are not highly viscous or crystallized [28].

Figure II.27: Pressure indicator.

- **Pressure transmitter**

Pressure transmitters fig.II.28, are used to measure the pressure of a liquid or gas, they incorporate a strain gauge with a thick layer as a measuring medium. The pressure is converted into an electrical signal.

Figure II.28: Pressure Transmitter.

- **Temperature transmitter**

This transmitter fig.II.29 are designed for transforming the effect of heating or cooling on their components into an electrical signal. They can magnify temperature signals and then output them to standard DC signals.

Figure II.29: Temperature transmitter.

- **PH and redox transmitter**

This device fig II.30 measures and regulates, depending on the configuration, the PH or the redox potential of aqueous solutions. The main areas of application are the water and waste water sectors, in general the signal converter has two analogue inputs.

Figure II.30: PH and redox transmitter.

- **Conductivity meter**

A conductivity meter is a sensor that measures the ability of a solution to conduct current between two electrodes. the unit of conductivity meter is us/cm².

3. Other Equipment

- **Static mixers**

Static mixers fig.II.31, are designed to mix liquids in the water treatment, chemical and food industries. They are used in continuous processes, and provide fast and particularly effective mixing between fluids, thus ensuring a homogeneous solution at the outlet.

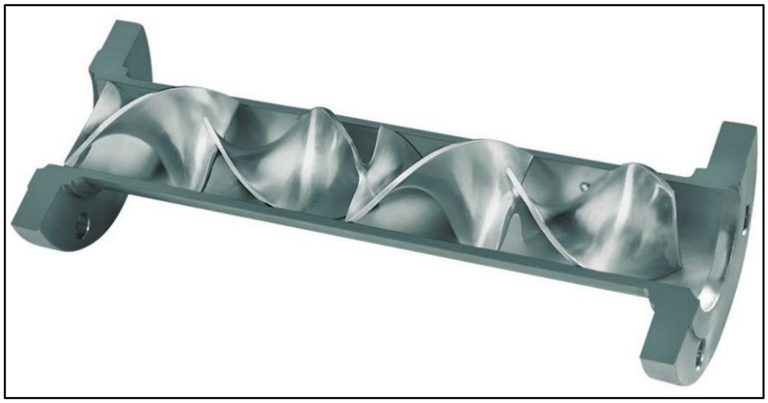

Figure II.31: Static mixers.

- **Pipes**

Hydraulic lines come in a variety of shapes, sizes and functions, these pipes can be closed tubes or channels or various successions along their entire length, and convey liquids on all scales of distance.

- **The filtered water tanks**

The filtered water stored in a vessel (Tanks) with a different capacity, depends on the need.

- **Dosage groups**

In each dosing group the level of the product to be dosed is checked, and the proper functioning of the dosing pumps is checked, this process could be realized by timers and checking sensors.

- **Sodium hypochlorite (NaOCL) dosage group**

This chemical element is dosed to adjust the PH water value (It helps to increase PH value), where it should be between 6.5 and 8.5 for the drinking water as WHO declared in 2004.

- **Carbon dioxyde (CO_2) dosage group**

This chemical element is used also to regulate water PH value, where the injection of CO_2 reduce the PH close to 5 makes the process of demineralization more efficient.

Carbon Dioxide CO2 will react with Calcium Hydroxide [Ca (OH)2] (or commonly known as Lime) to form Calcium Carbonate [CaCO3] [Hytex].

$$CO_2\ (g) + Ca(OH)_2(aq)\ CaCO_3 + H_2O$$

- **Sodium Metabisulfite ($Na_2S_2O_5$) dosage group**

It is used to remove chlorine from drinking water after treatment [29].

- **Chlorine dosage group**

Also, a weak injection of disinfectant often chlorine to protect the water from recontamination, where 4 milligrams per liter are considered safe in drinking water.

II.4. Conclusion

The desalination station is a very structured plant, it produces a good water quality pacing through several methods of treatment; Starting with pretreatment to get the feedwater ready for the desalination process using the technology needed, where it gives pure water and salt, then the post-treatment section where the water injects with minerals item is needed. it's simple as that without missing the cleaning and the maintenance system to make sure the plant equipment works on high performance. Behind this structured work, there is a powerful system that controls the equipment and supervises the process.

Chapter III

Automation of desalination plant

III.1. Introduction:

To ensure the desalination process works easily and well, without human intervention it needs to be an automatic process.

In this chapter, we will present the software and algorithm that helps to automate control, and supervise the desalination process.

III.2. Automation system and PLC controllers:

Any industrial system can work with both options manual mode with human intervention, or with automatic mode with less human intervention, with the help of some equipment and mathematical logic thinking.

III.2.1. Automation system:

An automation system is definitely a preferred choice when we speak about complex and harmful processes, almost any process can be automated, with the purpose of saving time and money and also helping eliminate human errors.

Rather than manual processes where the control and supervision are handled only with the operator's intervention, the automation system gives the operator all information about errors and system status, fig III.1 shows the structure of an automation system beside fig III.2 shows the structure of the manual system.

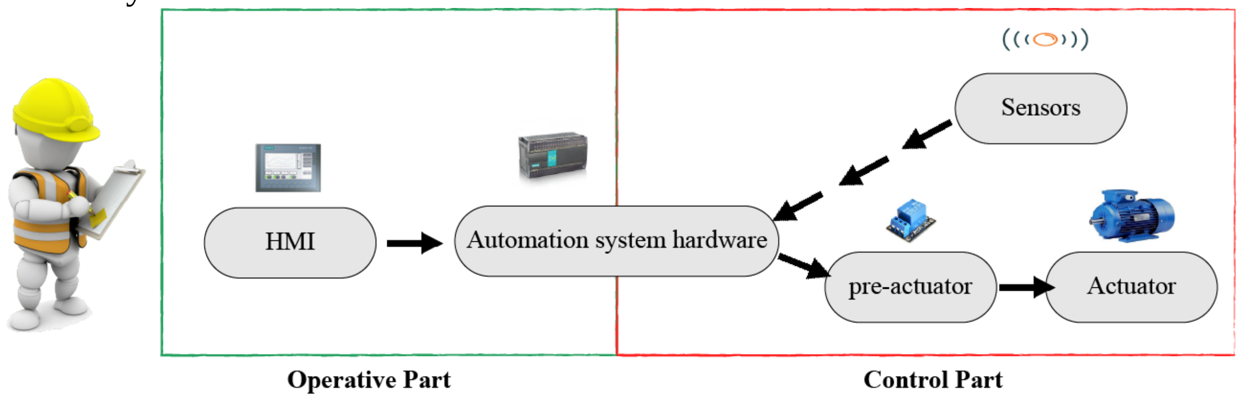

Figure III.1: Automation system structure.

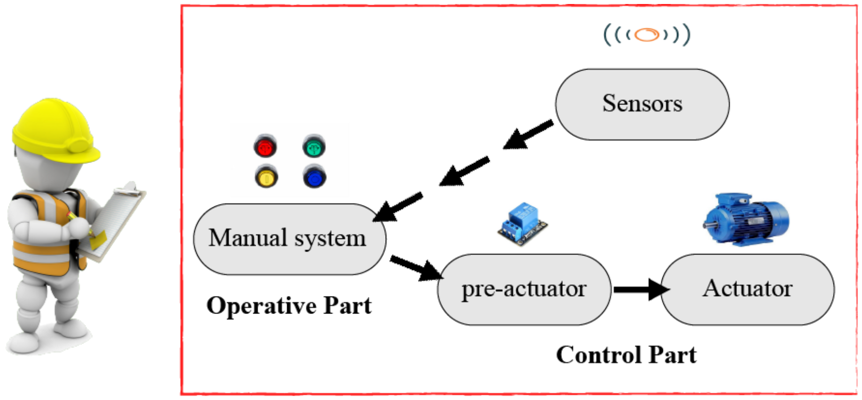

Figure III.2: Manual system structure.

III.2.2. PLC controllers:

Programmable Logic Controllers in general is the main device that helps engineers to automate manual processes, fig.III.3 shows different models from different companies.

Figure III.3 : PLC controllers.

We take as an example SIEMENS PLCs cause it's the most used PLCs in the world [30].

Fig.III.4 shows the structure and module of SIEMENS PLCs. and as presented in general there are 7 modules. The first one is usually the power supply module (PS), and the second is the CPU module, where all signals of output and input will be treated, The IM module is used to connect a two PLCs, then D for digital input/output modules, and A for analogic input/output modules; in those modules, we can place our actuators and sensors.

Sometimes there are additional modules like FM, the function module which is an additional module to process complex signals independently and send feedback to the CPU; and the CP module for communication between modules and the PC.

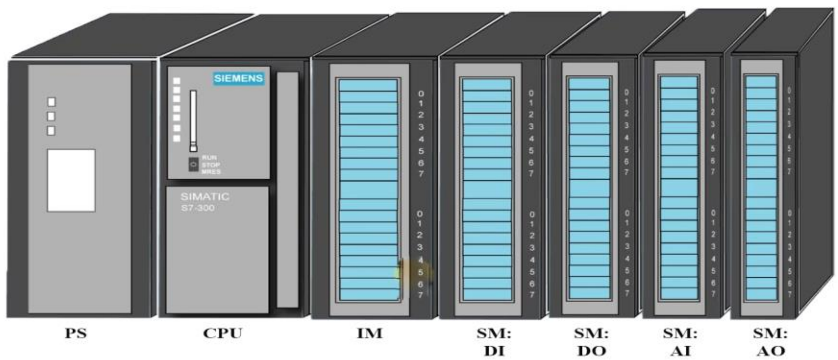

Figure III.4: Siemens PLC modules.

III.3. Introdcution to TIA-Portal :

Totally Integrated Automation Portal is the last environment developed by SIEMENS, which helps engineers to create programs for automated systems.

In this software, engineers can configure process control materials, and create control programs and supervision interfaces.

III.3.1. TIA-Portal tutorial:

This section presented the TIA-Portal interface, how to work with projects, where to add programs and supervision interfaces …etc.

a. TIA-Portal workspace:

The version presented in our work is TIA-Portal V16 and fig III.5 shows the opening page.

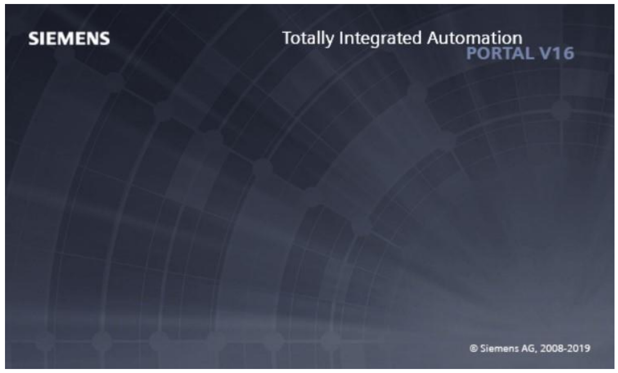

Figure III.5: TIA-Portal V16 Opening.

When we open TIA-Portal software we get this window like fig. III.6 shows, and as presented there are 3 main sections.

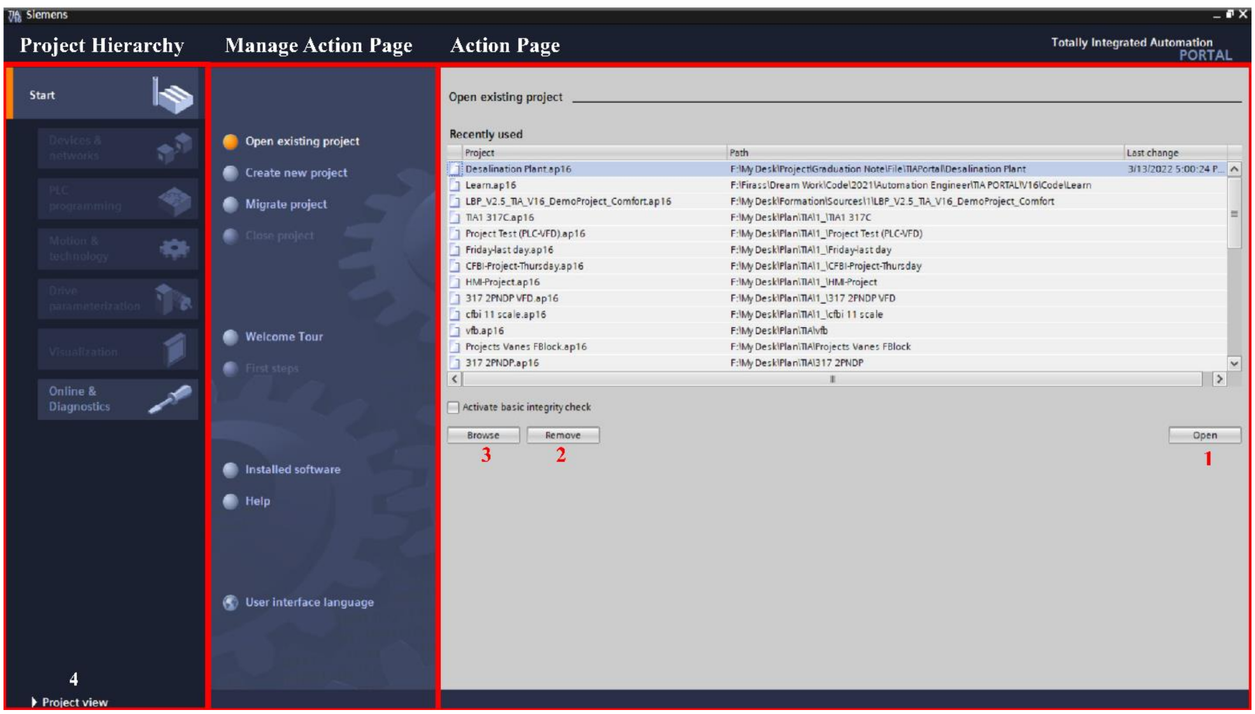

Figure III.6: First page in TIA-Portal.

“Project Hierarchy”: shows the options to create and maintain any project; the “Manage Action Page”: where engineers can change what “Action Page” shows.

For example, when we click on “Installed software” it shows the installed software of the current version, see fig.III.7.

The “Action page”: shows actions to take with project, software, and support help, as an example fig III.6 shows options to “Open (1)” “Remove (2)” or “Browes (3)” existing projects.

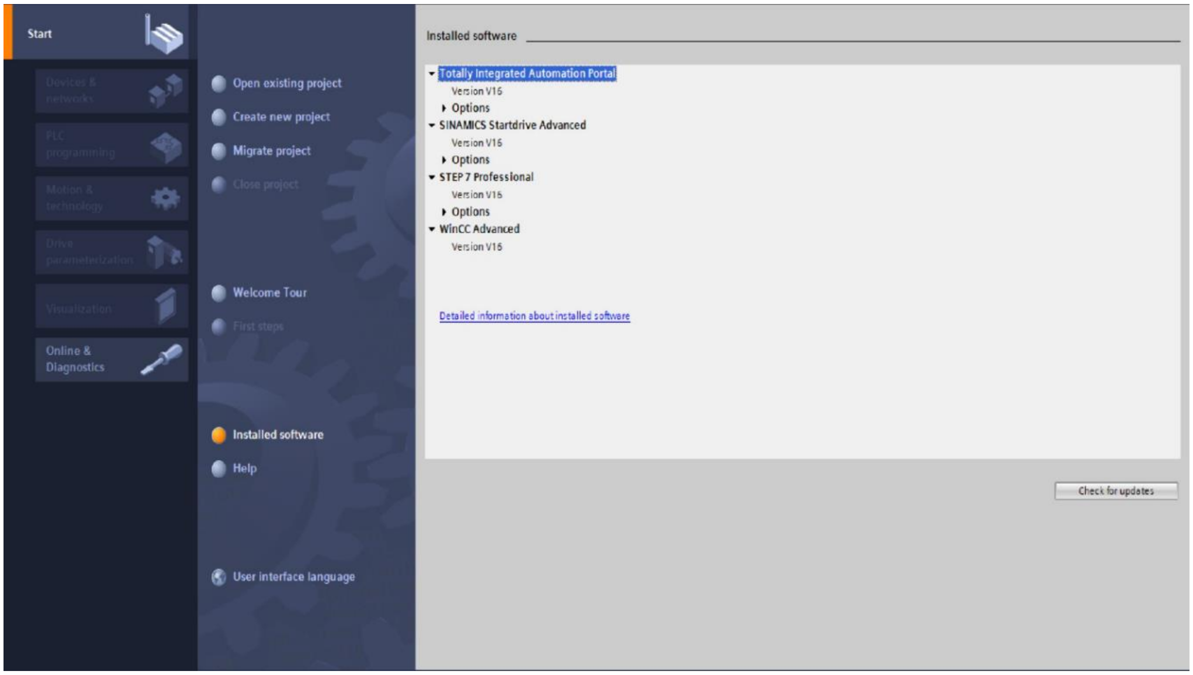

Figure III.7: Installed software page.

“Project View (4)” button it’s to open the main window of any automation system project like it presented in fig.III.8.

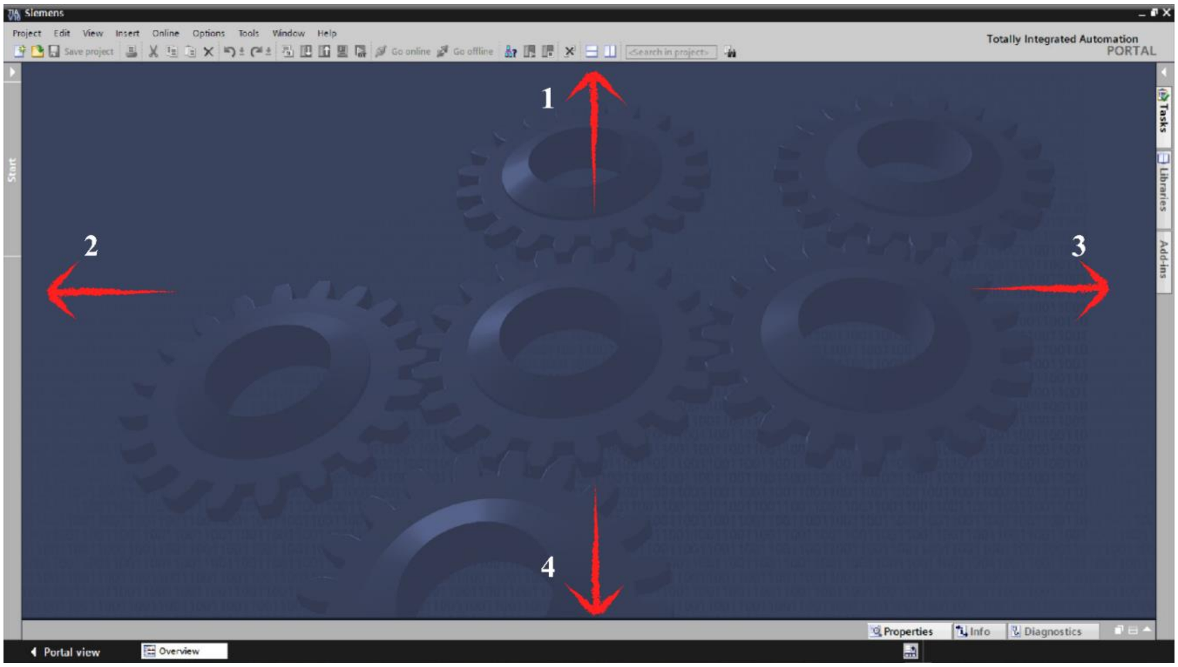

Figure III.8: Project view window.

Where “1” is the tool panel, “2” is the project hierarchy, “3” is the task panel and libraries, and “4” is the properties panel.

The more important panel is the project hierarchy panel where engineers can add programs, functions, data, and HMI designs like fig.III.9 shows.

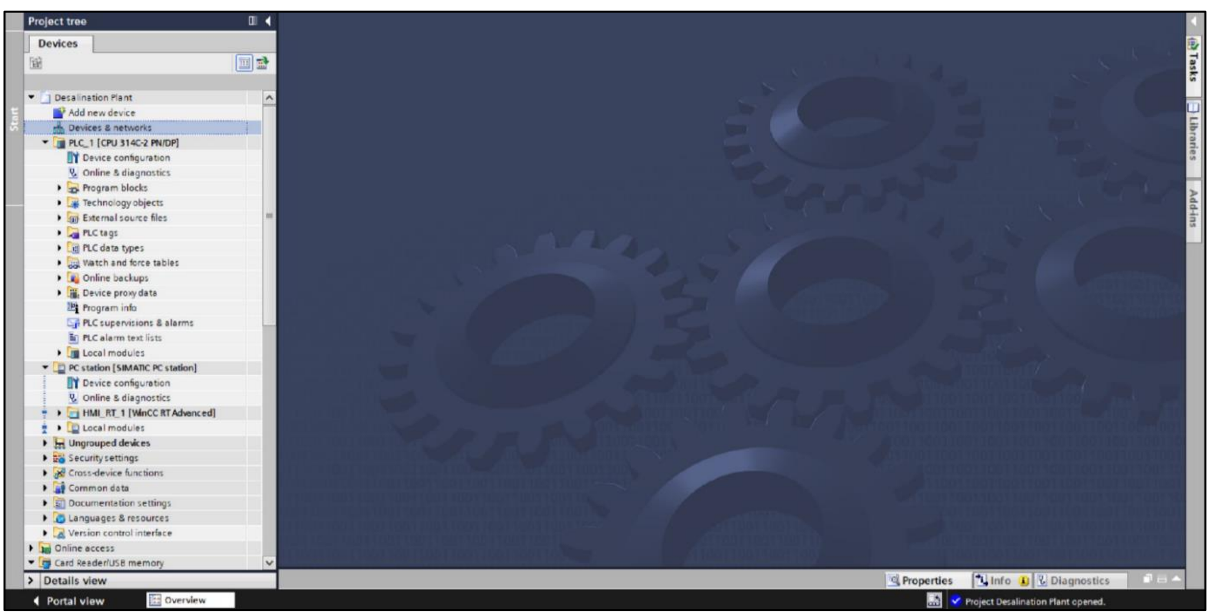

Figure III.9: Project tree window.

b. TIA-Portal and how to work on project:

In this part, we are going to work with different actions in the project hierarchy. So the first step to working on a project in TIA-Portal is to open an existing project or create a new one, then add devices using “Add new device” in the project hierarchy panel.

In the window shown in fig.III.10 Engineers can add PLCs, HMI, drivers, and PC systems. So in this step engineer can configure the hardware needed for the automated system.

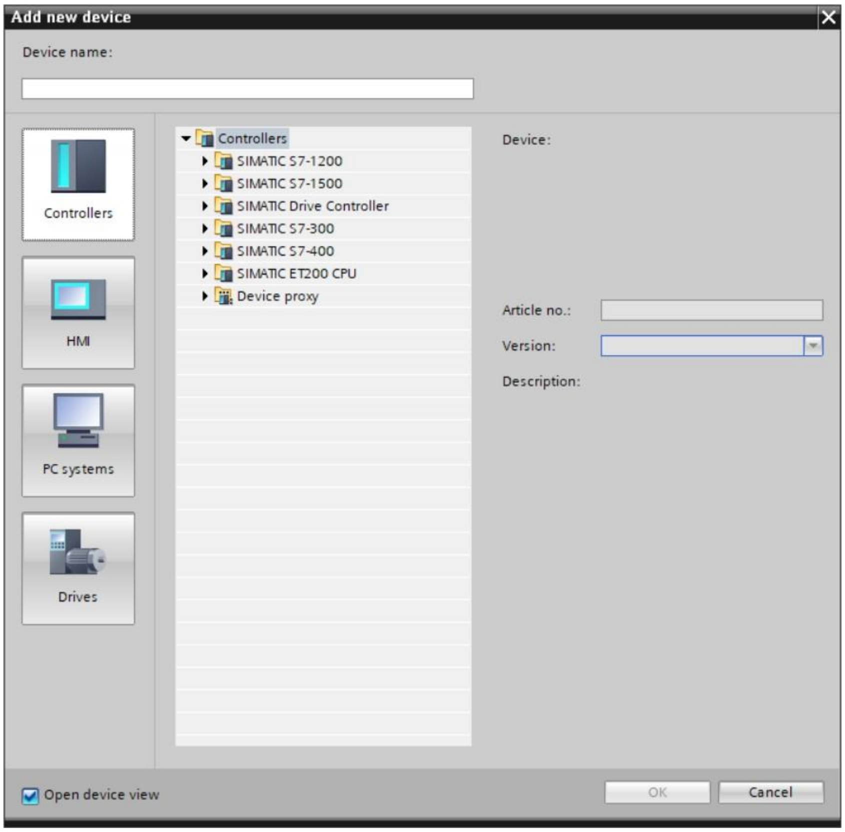

Figure III.10: Hardware window.

When finally materials are chosen we go to “Devices and network” to connect hardware with each other as presented in fig. III.11 Shows a PLC connected with a PC station using a PROFINET cable.

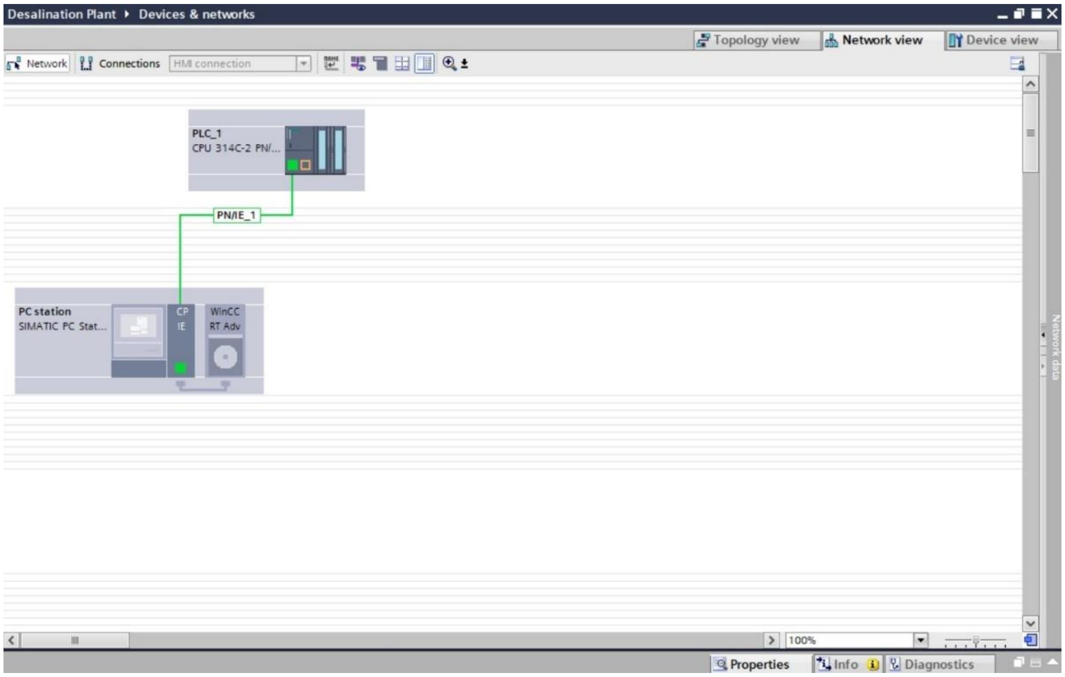

Figure III.11: Devices and Networks window.

The most important part is the control program we can say this part is the most complex part of the whole procedure, and in industrial life sometimes it takes a lot of time to maintain or automate an industrial process.

In TIA-Portal as shown in fig.III.12 There are four types of blocks to create any program.

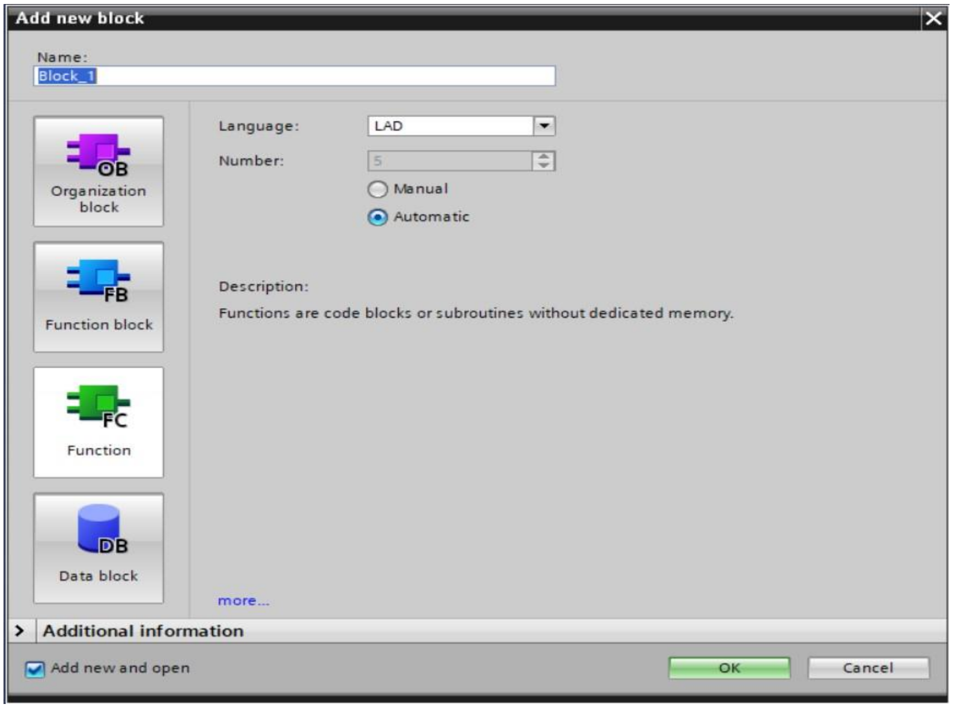

Figure III.12 : Bloc types window.

“OB” is the organization block it’s the main block, it’s like a loop program where the CPU is executed repeatedly to check inputs-outputs and conditions; the FB block is the function block where you can import or create blocks of codes like algorithms to use it in different programs, and FC blocks the functions this block is really helpful, it helps divided big program to multiple functions and call it in the organization block (OB). Last but not least DB data block, in this block engineer, can store SCADA data, input-output variables, and alarms; briefly, all data can be stored here.

Usually, the organization block is created by default when engineers configure hardware; fig.III.13 shows an example of a program section where OB block and some functions are created.

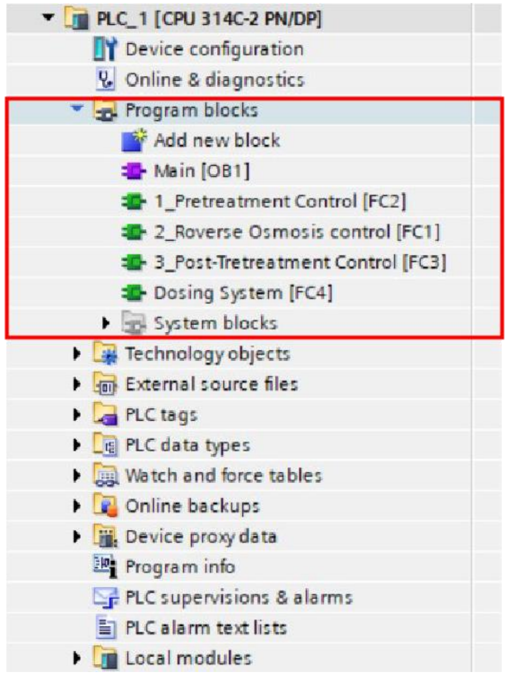

Figure III.13: Program blocks section.

So a preferred step to create a new project for an automation system is to start and create a data block and declare all variables like fig.III.14 shows, then create each mini-process in a separate function, and finally integrate all functions in the organization block.

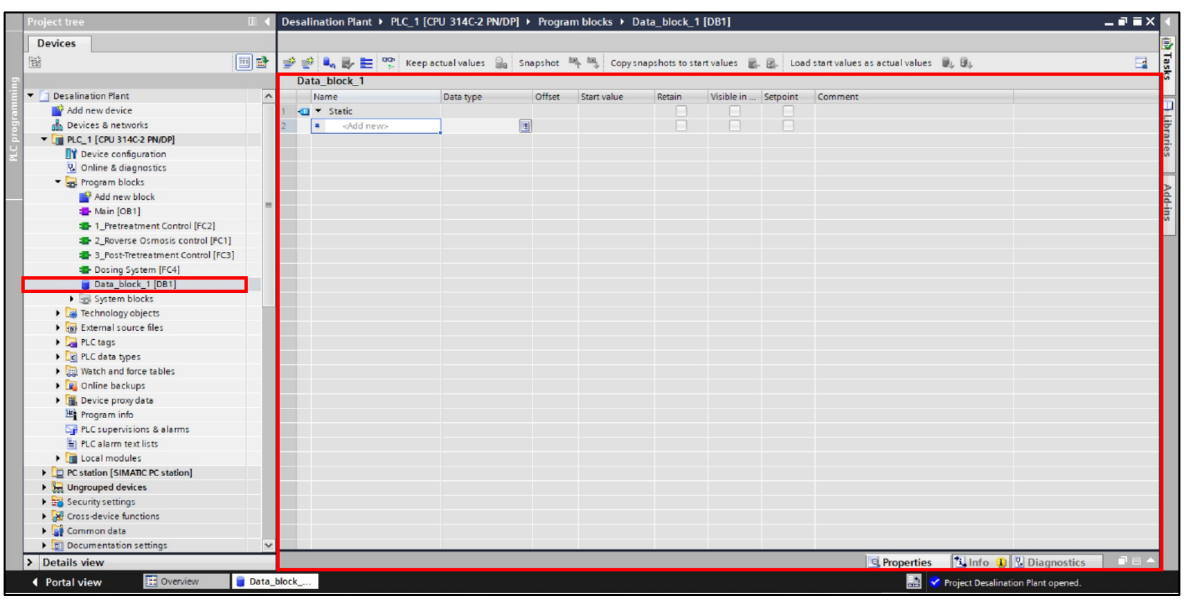

Figure III.14: Data block window.

When the program is verified and worked well, the engineer creates a supervision design by adding screens on the HMI or PC station section as shown in fig.III.15 And this step is the final step.

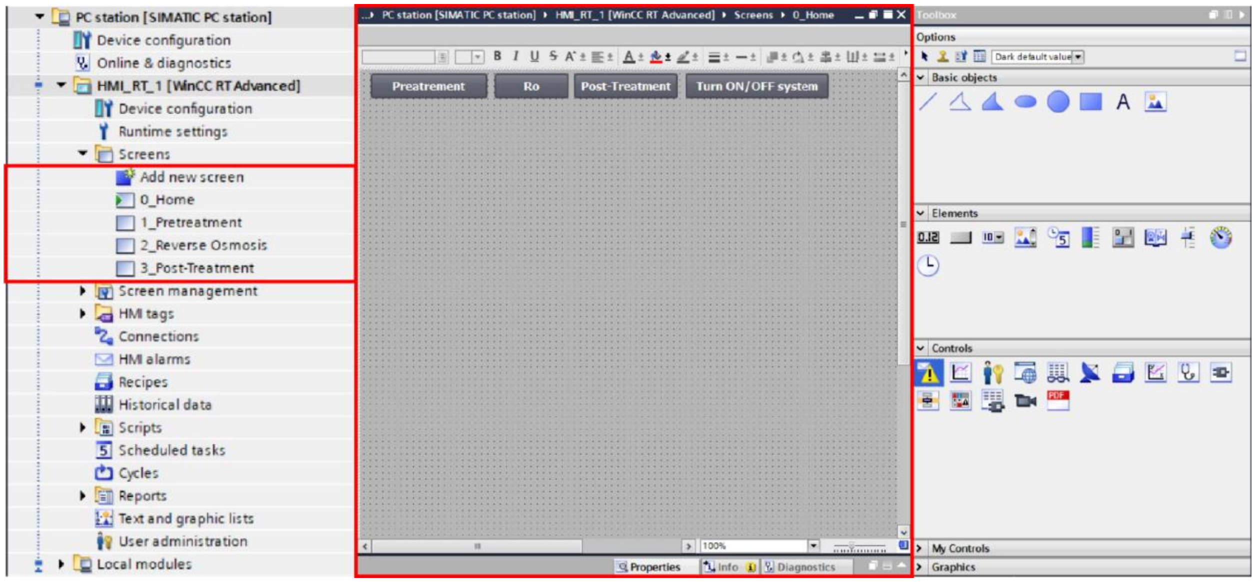

Figure III.15: HMI or PC station section.

c. Programming languages in TIA-Portal:

Like any development software or an IDE, TIA-Portal has an integrated languages and they are five: LD, SFC, FBD, ST and IL.

III. 3.2. Programming languages:

a. Ladder diagram (LD)

The ladder Diagram was originally modeled from relay logic which used physical devices, such as switches and mechanical relays to control processes. The ladder Diagram utilizes internal logic to replace all, except the physical devices that need an electrical signal to activate them [31].

The ladder diagram is built in the form of horizontal rungs with two vertical rails that represent the electrical connection on relay-logic schematics.

The engineer can program all the necessary input conditions to affect the output conditions, whether logical or physical.

b. Sequential Function Charts (SFC) in also can be called Grafcet

In Sequential Function Charts, engineers use steps and transitions to achieve the end results.

Steps act as a major function in the program. These steps house the actions that occur when programming them to happen. This decision can be based on timing, a certain phase of the process, or the physical state of the equipment.

Transitions are the instructions that engineers use to move from one step to another step by setting conditions of true or false.

Unlike traditional flowcharts, Sequential Function Charts can have multiple paths. The engineer can use branches to initiate multiple steps at one time.

c. Function Block Diagram (FBD)

The Function Block Diagram is also a graphical type of language; the FBD describes a function between inputs and outputs that are connected in blocks by connection lines. Function Blocks were originally developed to create a system in that engineers could set up many of the common, repeatable tasks, such as counters, timers, PID Loops… etc.

Engineers programs the blocks into sheets and then the PLC constantly scans the sheets in numerical order or is determined by connections that engineer program between the blocks [31].

d. Structured Text (ST)

The fourth PLC Programming Language is the Structured Text. This language is a textual-based language.

Structured Text is a high-level language that is like Basic, Pascal, and C; it is a very powerful tool that can execute complex tasks utilizing algorithms and mathematical functions along with repetitive tasks.

The code uses statements that are separated by semicolons and then either inputs, outputs, or variables are changed by these statements. The engineer must write out each line of code and it uses functions such as FOR, WHILE, IF, ELSE, ELSEIF AND CASE.

e. Instruction Likst (IL)

The Instruction List is also a textual-based language. The Instruction List language resembles Assembly Language. When an engineer uses this PLC Programming Language, he will use mnemonic codes such as LD (Load), AND, OR… etc. The Instruction List contains instructions with each instruction on a new line with any comments he might want to annotate at the end of each line [38].

III.3.3. HMI and SCADA design:

HMI and SCADA meanings make a big problem for beginners, so the next part explains the difference between these meanings.

Human Machine Interface (HMI) like it says is all interfaces that the engineer or operators deal with it. Fig. III.16 is a good example.

But Supervisory Control and Data Acquisition (SCADA) is a system architecture that focused on supervision and control of the processes and it has a huge capacity for data collection and saving in a data center like maintenance register in old factories.

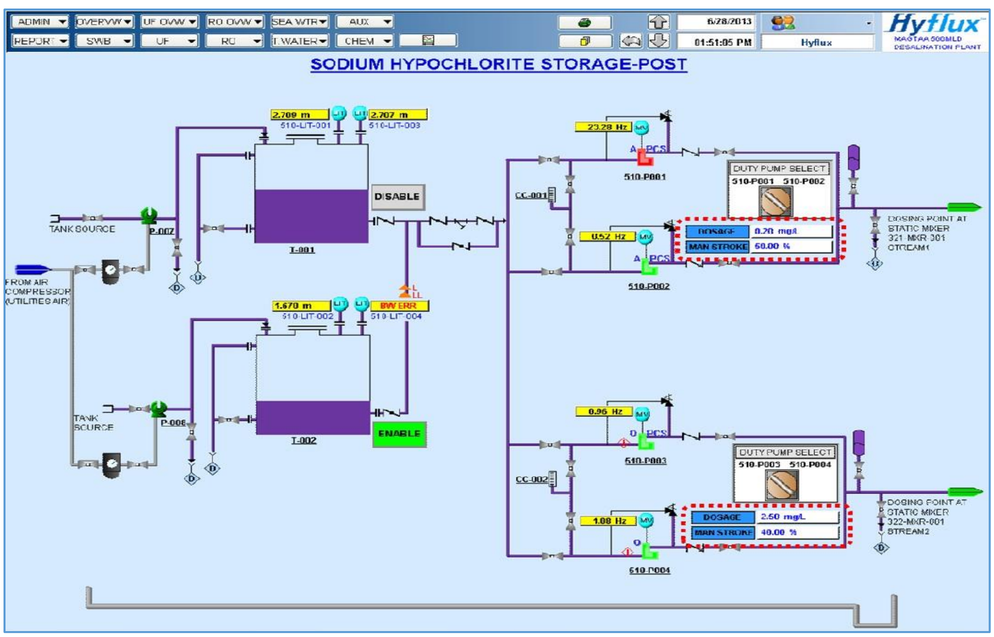

Figure III.16: A human machine interface of NaOCl Dosing Pump Dosage process [40].

III.4. Automation of the desalination process:

So as we presented in the previous chapter about the desalination process, just a small reminder to make things clear.

Seawater desalination is a process that starts with water intake from the source chosen (sea), the water intake would be handled with the help of pumps, which leads the water by tubes to the pre-treatment zone, where the water is filtered from big objects like human trash, microscopic organisms, and all dangerous items, then again with help of another type of pumps (HP pumps) wich push the water into RO membranes that take out dirty water from pure water; and last but not least pumps lead pure water to post-treatment where the water became drinking water.

Finally, the drinking water is stocked in tanks where it's ready to be delivered fig. III.17 shows a diagram of the process.

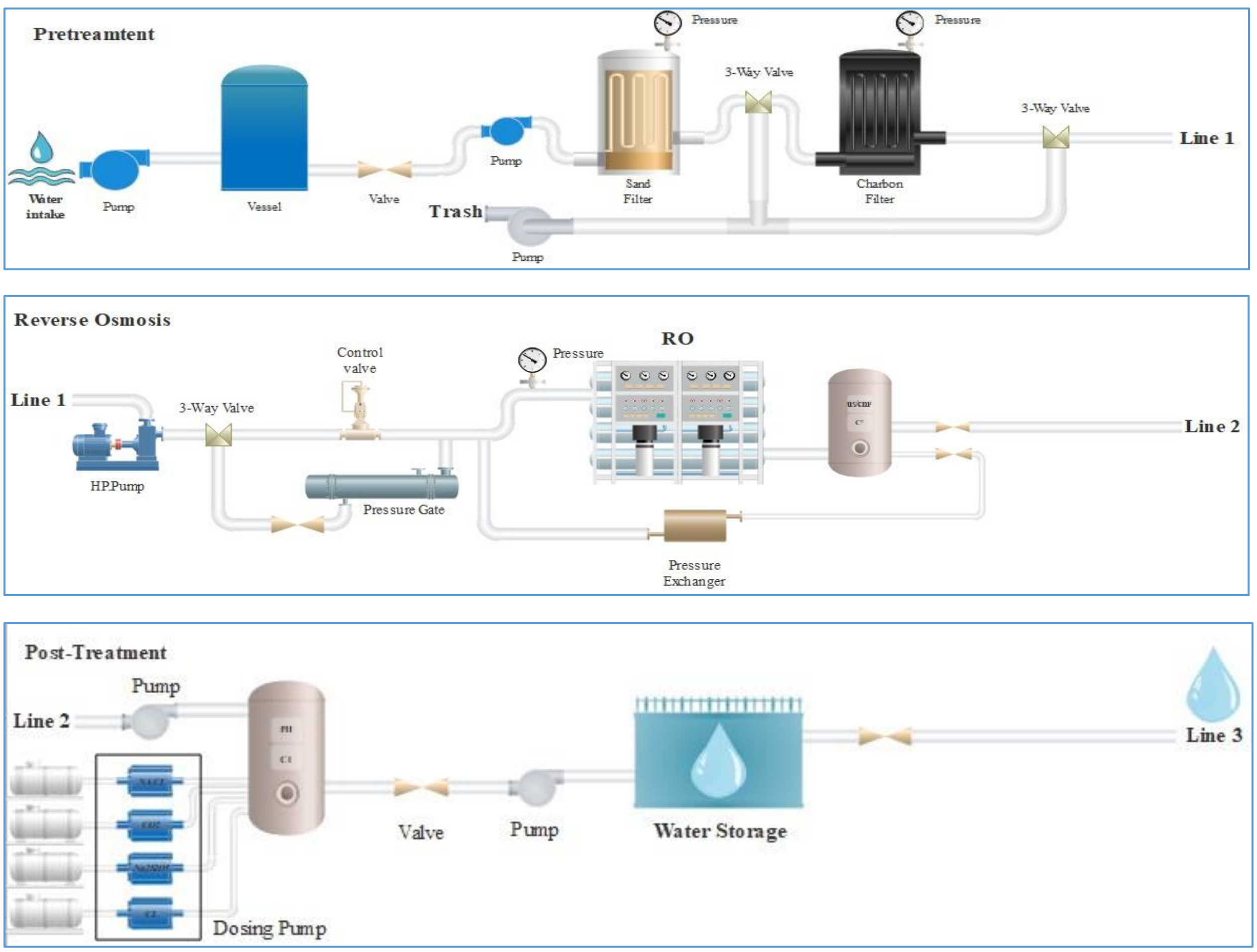

Figure III.17: Desalination Process Diagram.

III.4.1. Automation algorithm:

The automation system is working with a very precise algorithm just to avoid as maximum as possible errors. That algorithm is like a way of functioning of all instructions, signals, alarms, equipment, and even software. Fig. III.18 shows the functioning algorithm of the desalination process.

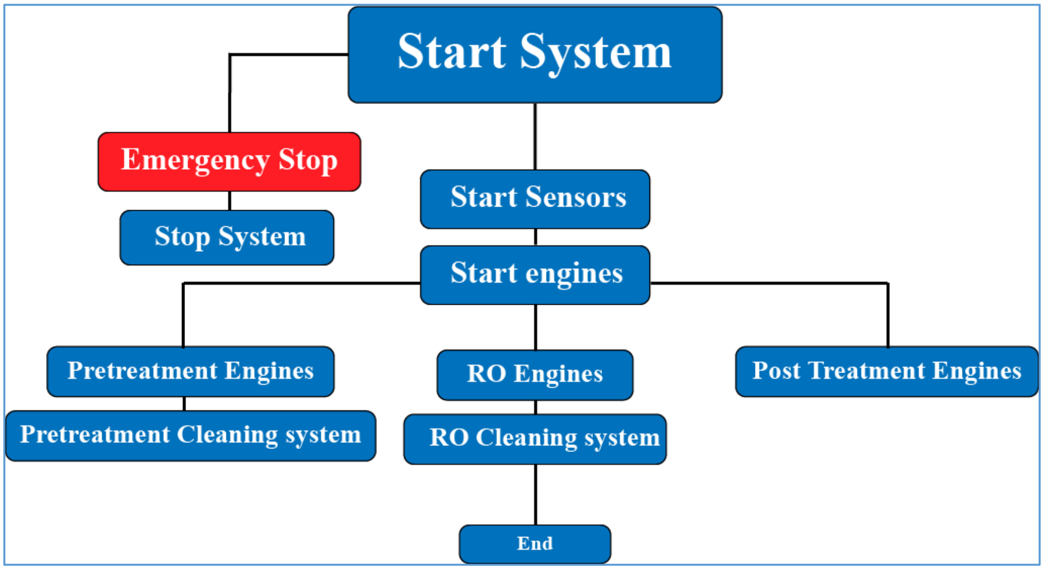

Figure III.18: Functioning algorithm of the desalination process.

III.4.2. Grafcet:

Graph Fonctionnel de Commande des Étapes et Transitions, it is a method of representation and analysis of automation systems, particularly well adapted to systems with sequential evolution (desalination sequence in our case) which can be broken down into steps and transitions. It is derived from the mathematical model of Petri.

Fig.III.19 shows the desalination process with a simple Grafcet prototype that presented the different steps and transitions of the process.

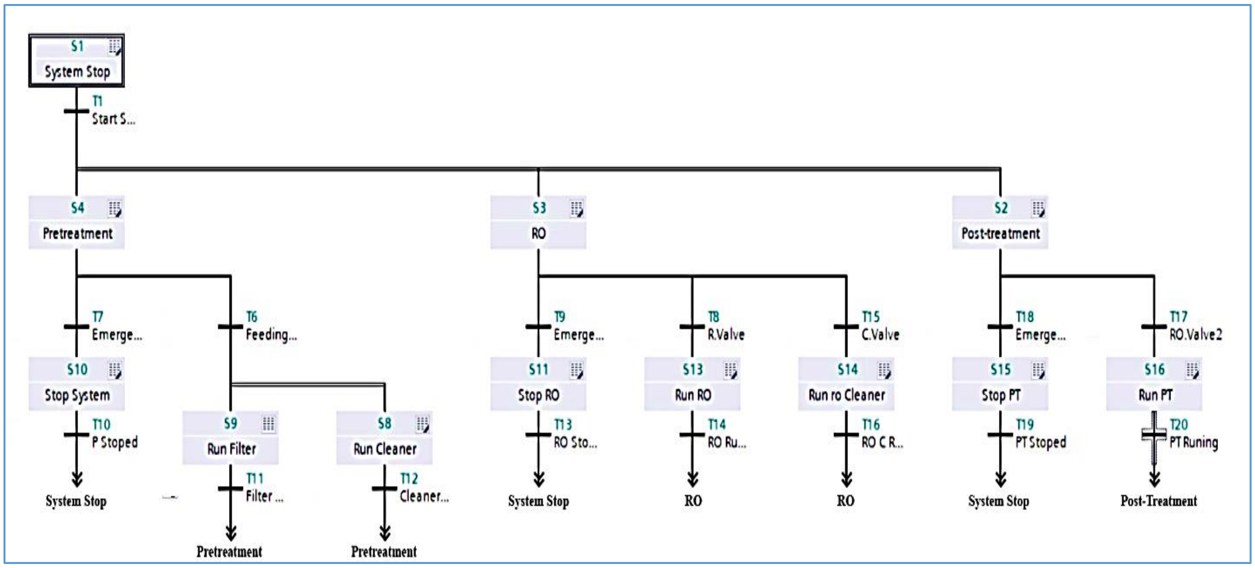

Figure III.19: Grafcet digram of the desalination process.

The diagram shows the main three controlled sequences of the desalination process: pretreatment, reverse osmosis, and post-treatment. Where each sequence has an emergency stop by default plus a running system and a cleaner; but Post-treatment works only with a running system.

III.5. Control architecture

To control industrial systems many architectures are in use; like PLCs, DCS, and SCADA where PLCs are the core and the simplest method as shown in fig.III.20 HMI connected to a PLC connected to the controlled hardware.

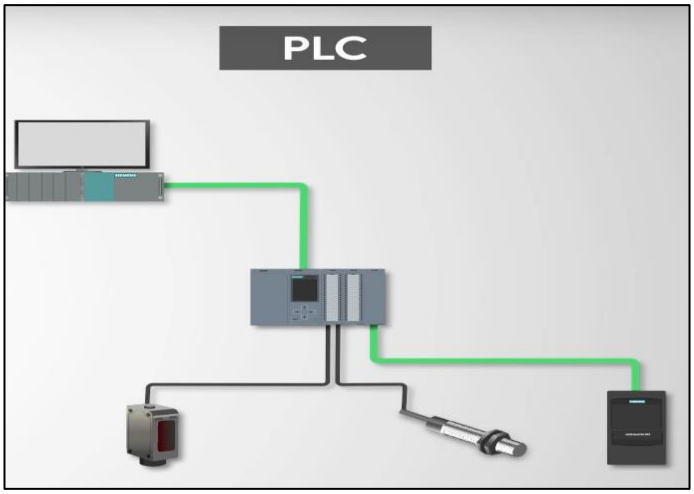

Figure III.20: PLC architecture.

DCS architecture is more complex and scaled as shown in fig. III.21 Distributed Control Systems are designed this way: an operator station (control room) where the supervision screens, the second stage could be composed of servers, archives, and engineering stations where data are created, transferred, and saved; and the final stage where we find PLCs, Sensors, and Actuators. This combination of software and hardware are connected to each other using different protocols like Profinet, Profibus, Fiber optic, and Ether cat.

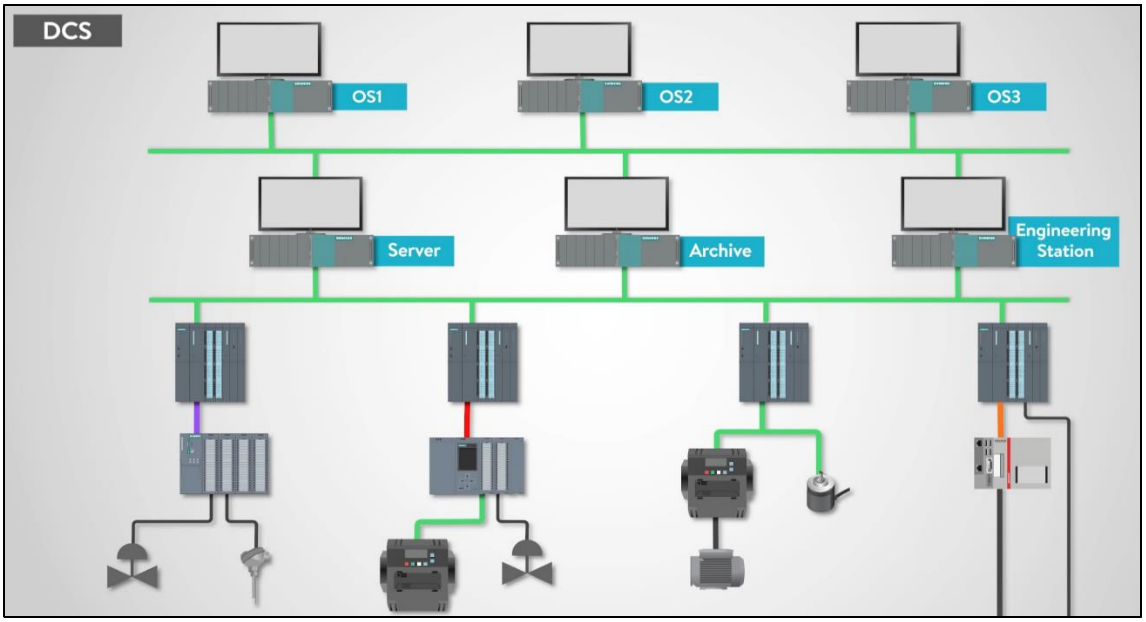

Figure III.22: DCS architecture.

SCADA (Supervision Control And Data Acquisition) this architecture is very sophisticated nowadays; where industrial processes could be controlled remotely from anywhere as shown in fig. III.23.

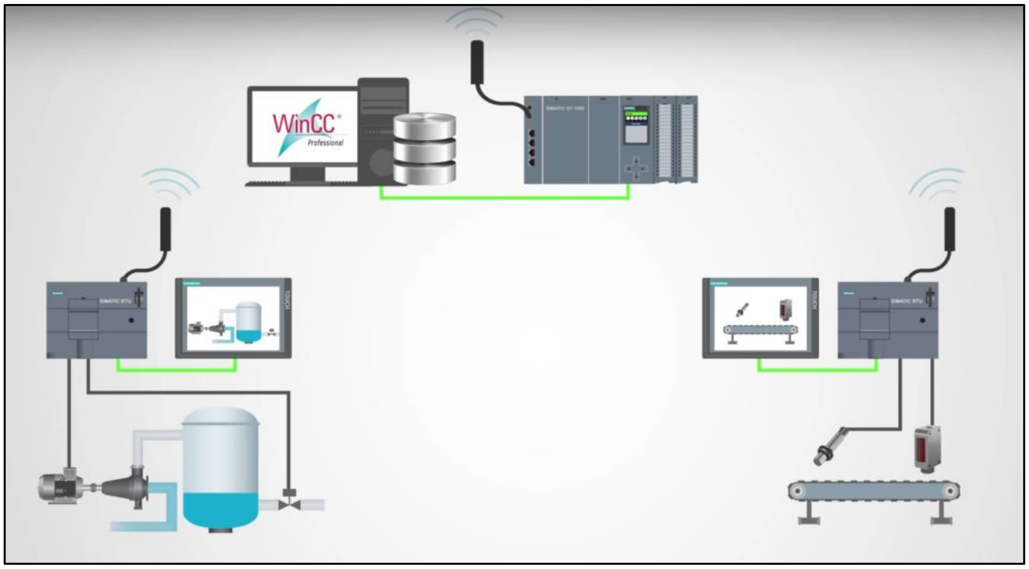

Figure III.23: SCADA architecture.

SCADA and DCS have concept similarities (control and supervise) but these are the main differences:

- SCADA with the presence of RTU (Remote Terminal Unit) and SQL (Structured Query Language) integration becomes a remoted control system.
- Networked SCADA is designed to work with PLCs varying vendors where DCS can't.
- DCS comes with a predefined function and architecture and is ready to use.

III.6. Conclusion

In this chapter, we distinguish between automated and manual systems, we presented a simple tutorial for PLCs programming software TIA-Portal an abstract of the automation and supervision of the desalination process and the control algorithm.

In the next chapter, we will see the simulation of the control program and the human machine with SCADA.

Chapter IV

Control and supervision simulation

IV.1. Introduction

This chapter contains system specification and control philosophy including the simulation of SCADA and control program in TIA-Portal.

IV.2. System Specification (work book)

To accomplish the process objective which is to produce drinking water, a bunch of equipment is needed. With the purpose of choosing the right equipment and creating a simple prototype for our simulation, we used Hyflux: 500 MLD Seawater Desalination plant DBOO Project at MAGTAA [40], see annex: A.

Note: The specifications or workbook it's varied from a large scale of concepts and needs, but the main objective is to reach the goal (the needed production) in our case is drinking water.

IV.3. Control methodology

The desalination process is divided into three main sequences: pretreatment, reverse osmosis, and post-treatment; which makes our program structure like this: Three functions each one controlling a sequence and one for the dosing system as shown in fig.IV.1.

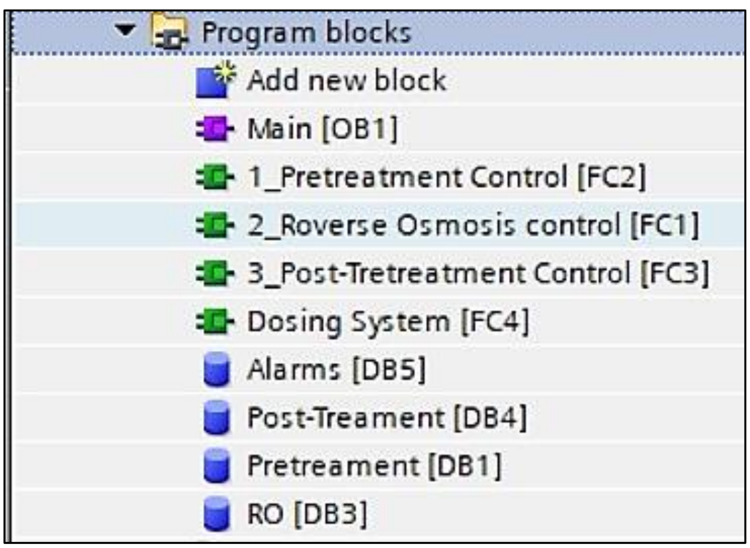

Figure IV.1: Program blocks

The process should work in an automatic mode which is the main objective of our work. Where the control philosophy is like this:

a. pretreatment:

- **Control**
  - Feeding pumps fill the feeding vessel with water.
  - If the first level sensor is ON, start 10 seconds delay and turn ON the feeding filter pump and open the valve.
  - If the pressure in the Sand or Carbon filter is higher than 10 Psi turn ON the cleaning system.
  - If the pressure in the Sand or Carbon filter reaches 15 Psi stops the system for maintenance.
  - If the pressure is normal (less than 10 Psi) deliver water to the next sequence (RO).

- **Measure**
  - Pressure sensor in the sand filter.
  - Pressure sensor in the carbon filter.
- **Alarms**
  - High pressure emergency alarm (Sand filter): Pressure higher than 15 Psi.
  - High pressure emergency alarm (Carbon filter): Pressure higher than 15 Psi.

b. Reverse Osmosis:

- **Control**
  - If the delivery valve in the pretreatment sequence is open turns ON the high-pressure pump to feed the RO filter.
  - If the pressure is lower than 60 Psi Open the control valve depending on the pressure value.
  - If the water is in the quality vessel turns ON the mixer.
  - If the pressure is higher than 60 Psi turn ON the cleaning system.
  - If the pressure is higher than 70 Psi turn OFF the system for maintenance.
  - If the conductivity of the water is higher than 1500 us/cm² refilter the water.
  - If the temperature is higher than 25 C° refilter the water.

- **Measure**
  - Pressure sensor in RO filter.
  - Conductivity sensor in the water quality vessel.
  - Temperature sensor in the water quality vessel.
- **Alarms**
  - High pressure alarm: pressure is higher than 60 Psi
  - High pressure emergency alarm: pressure is higher than 70 psi.
  - High conductivity alarm: conductivity is higher than 1500 us/cm².
  - High temperature alarm: temperature is higher than 25C°.

c. Pre-treatment

- **Control**
  - If the delivery valve in the RO sequence is open turns ON the feeding vessel in the post-treatment sequence.
  - If the quality vessel is full turn ON the 60-second timer for water regulation.
  - If the water is in the quality vessel turn ON the mixer.
  - If PH and CL values are good turn ON the feeding pump and open the valve of the water storage.
- **Measure**
  - PH sensor.
  - CL sensor.
  - Level sensor.
- **Alarms**
  - Level sensor alarm in quality vessel alarm.
  - Level sensor alarm in storage vessel alarm.

IV.4. Hardware configuration

To control the process, as shown in fig.IV.2 we need PLC Siemens CPU 314C-2PN/DP which comes with two integrated modules one analogic [5-Input, 2-Output] and the other digital [16-Input, 16-Output], for additional connections MPI port for PC adapter and two port Profinet for other connections, also we need two more modules, one holds 2 analogic Input and the other 2 Outputs, And finally a digital module that holds 16 Input and Output.

All these modules are alimented with the Power supply at the start of the rack.

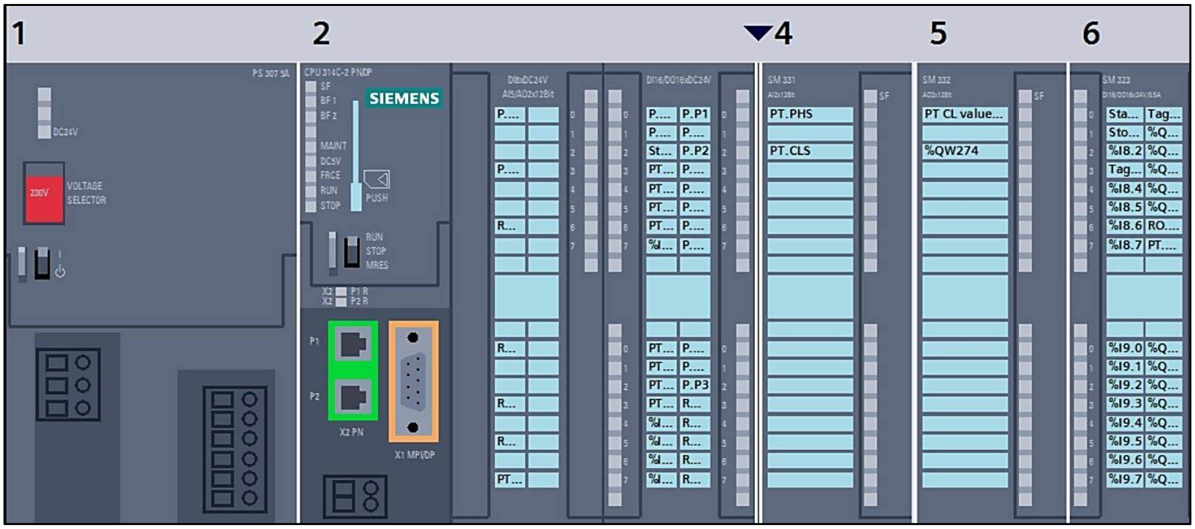

Figure IV.2: PLC modules.

For control and supervision purposes, we need a PC station as shown in fig.IV.3, this PC runs WinCC flexible software integrated by TIA-Portal to display the supervision interface.

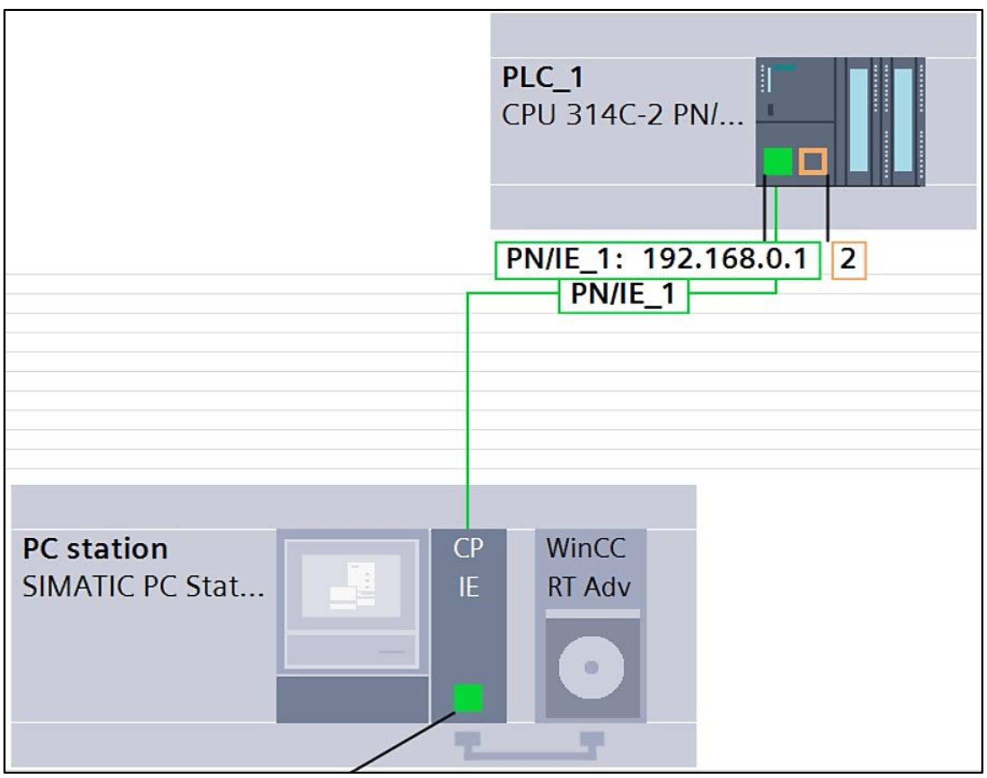

Figure IV.3: PC station.

IV.5. Ladder program

Ladder logic was originally a written method to document the design and construction of relay racks as used in manufacturing and process control.

In this part, we presented the simulation of the program that controls the different sequences in the desalination process.

IV.5.1. Main block

This block runs the program in a loop to make sure all functions in the process are working well.

As shown in fig.IV.4 the program is one network that runs all functions together in an automatic mode. At the start of the network this variable (%DB1.DBX0.0: "Pretreatment"."Start System") is for the SCADA control and this one (%I8.0: "Start System") is for manual control.

P-TRIG function block is for hardware protection; this method is used by automation engineers as a protection program function, besides, on the other hand instrument engineers use hardware like fusible or timer to protect devices.

Note: P-TRIG is a usable solution by automation engineers who create industrial programs to make sure that hardware (Motors for example) turns ON or OFF by reviving one signal (continues signal is not read to protect hardware from fast reboot).

The SR function named "Run/Reset (SR)" is to save working order on stop or run status.

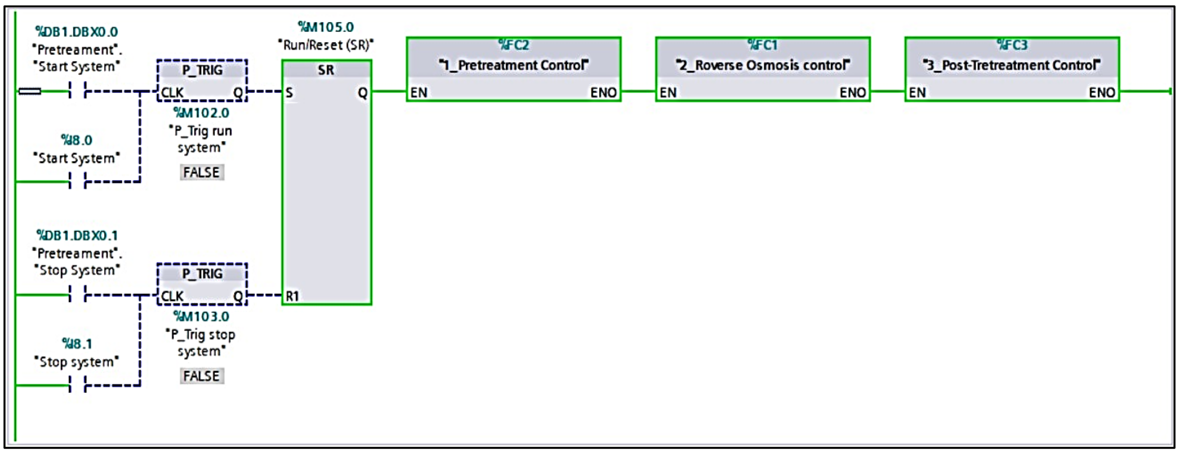

Figure IV.4: Main block.

PLC inputs/Outputs	SCADA interface
- **Specifications:** P for Pretreatment ❖ %i8.0: Start system manually. ❖ %i8.1: Stop system manually. ❖ %M105.0: The start and reset memory.	- **Specifications:** ❖ %DB1.DBX0.0: Start system from SCADA ❖ %DB1.DBX0.1: Stop system from SCADA

IV.5.2. Pretreatment function block:

This function contains 9 networks as shown in fig. IV.5, these networks are shown sequentially from: fig. IV.6 to fig. IV.14.

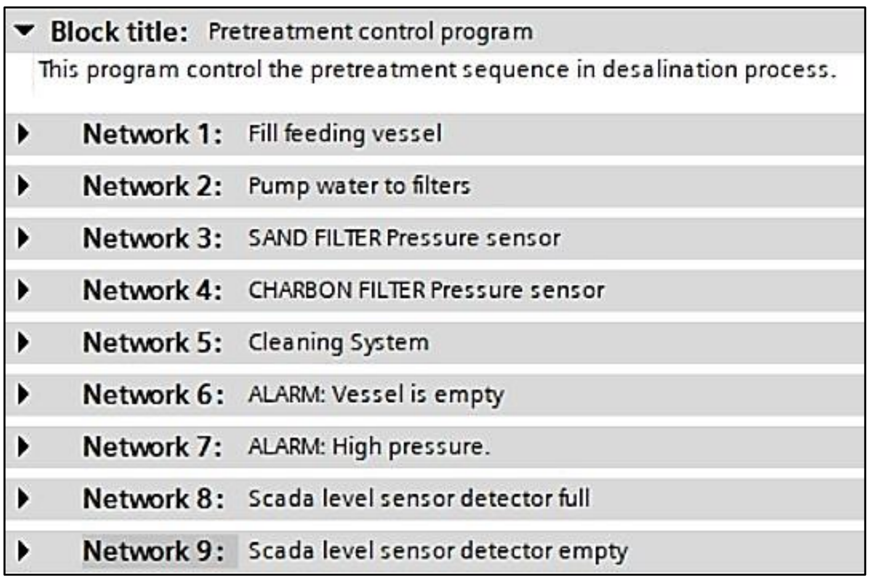

Figure IV.5: pretreatment control function.

a. **Fill feeding vessel:** This network is to control the feeding pump; so when one or more of the following conditions is true, the feeding pump turns off: the two of the level sensors in the tank are activated or the pressure in the sand or carbon filter is higher than 15 Psi, the other outputs is for SCADA display like “%DB1.DBX0.3-Pretreament.P.P1”.

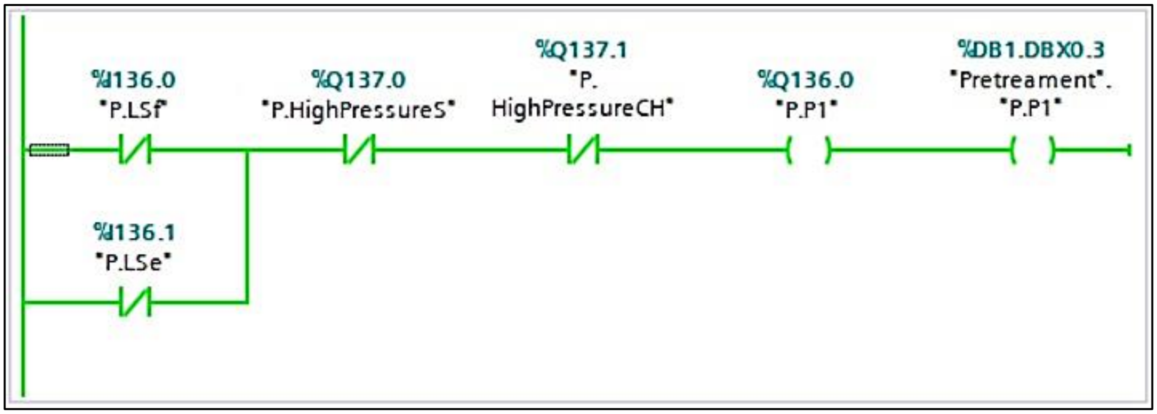

Figure IV.6: Network 1 in pretreatment function.

b. Pump water to filter: This network is to feed the filters with water; so when the first level sensor is activated "P.Lse" a timer of 5 seconds starts, then the output is to open the valve and pump and push the water ("P.V1" for the valve and "P.P2" for the pump) the other outputs are for SCADA display like "DB1.DBX0.2-Preatreament.P.V1".

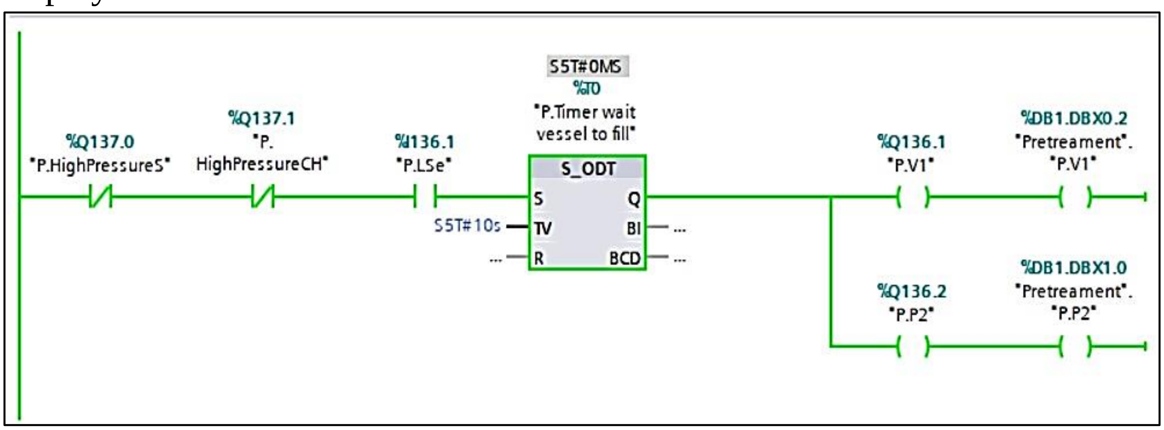

Figure IV.7: Network 2 in pretreatment function.

c. Sand filter pressure sensor: This network changes the direction of 3 way-valve "P.3Vsw1" depending on the pressure value in the filter "%MD4-P.Sand pressure sensor" (cleaning or Carbon filter direction), so when the pressure is under 10 Psi, this valve "P.3Vsw1" is opened to the filter direction, and when the pressure is higher than 10 Psi it turns to cleaner system direction, the other outputs is for SCADA display.

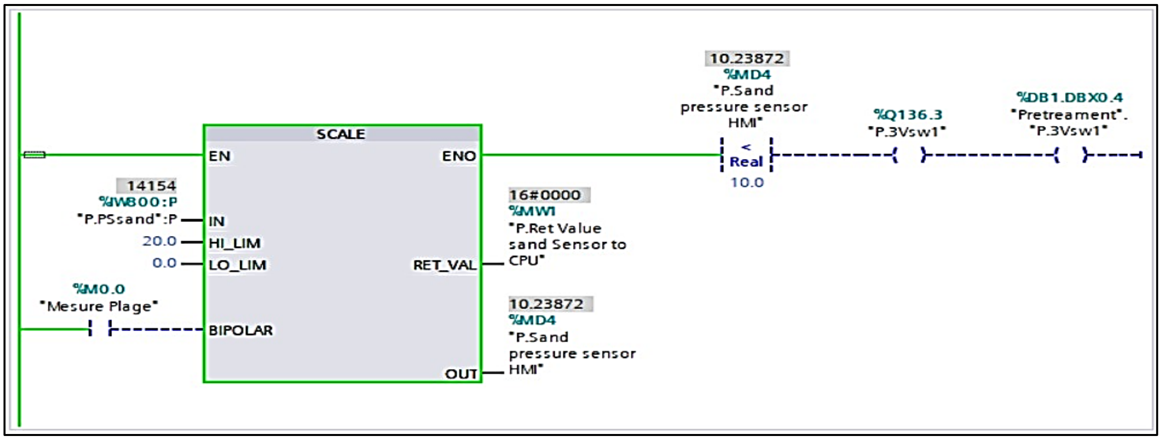

Figure IV.8: Network 3 in pretreatment function.

d. Carbon filter pressure sensor: This network changes the direction of 3 way-valve “P.3Vcw1” depending on the pressure value in the filter (cleaning or RO filter direction), so this network does the same work as the previous one with the carbon filter, the other outputs is for SCADA display.

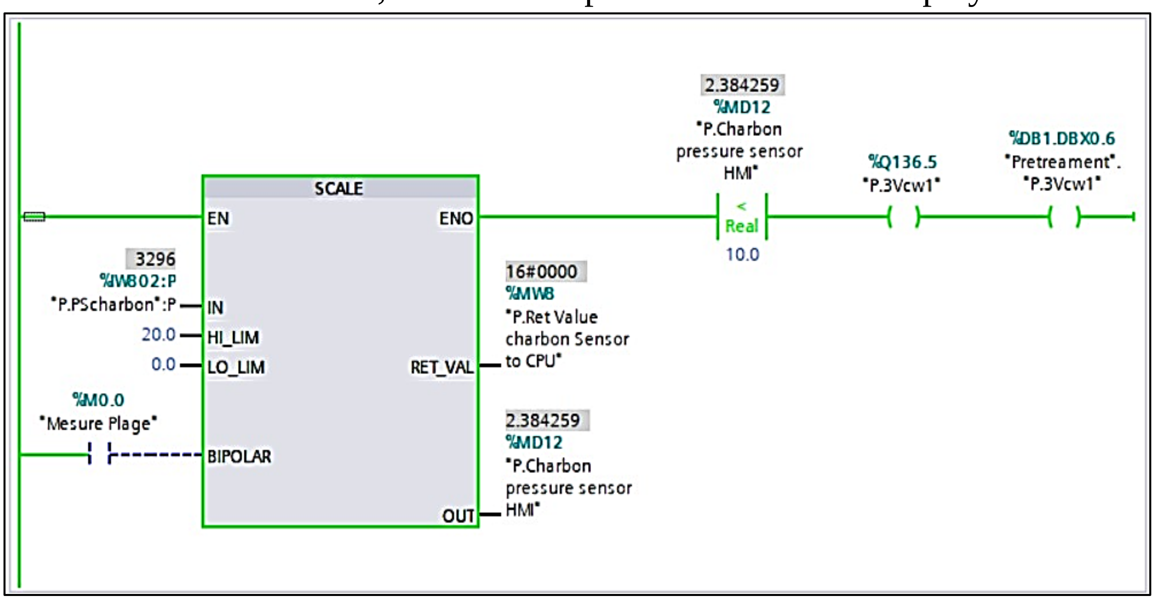

Figure IV.9: Network 4 in pretreatment function.

e. Cleaning system: This network is to controls the cleaning system, so when one of the pressure sensors (the sensor in the sand filter “P.Sand sensor HMI” or in the carbon filter “P.Charbon pressure sensor HMI”) is higher than 10 Psi it turns on the pump for the cleaning system “P.P3”; the other outputs is for SCADA display.

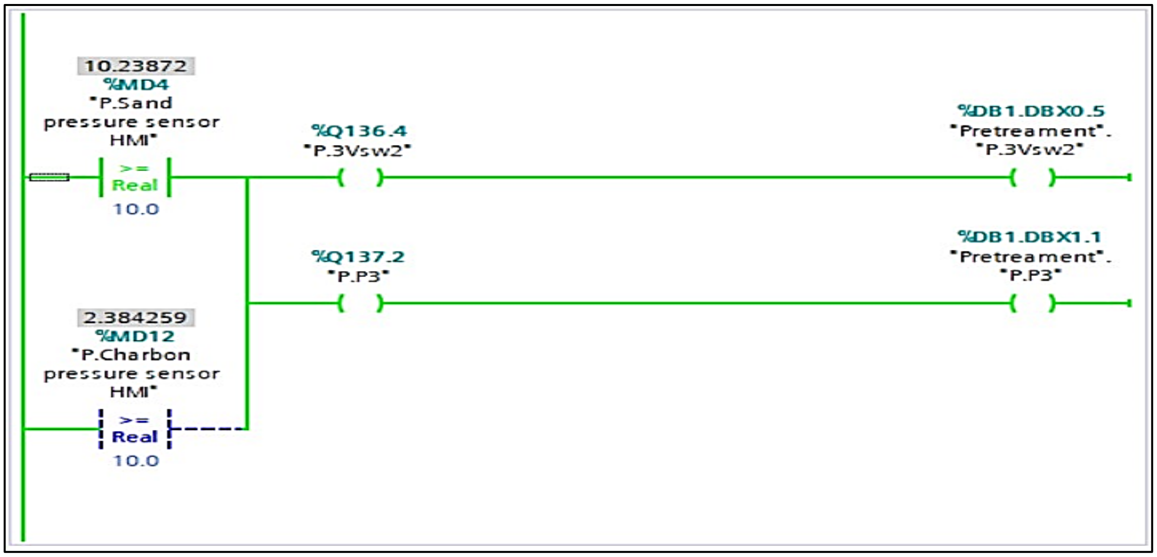

Figure IV.10: Network 5 in pretreatment function.

f. Alarm: vessel is empty: This network signals a red alarm "P. EmptyTankAlarm" when the feeding vessel is empty (The first level sensor is activated "P. LSe") the other outputs is for SCADA display.

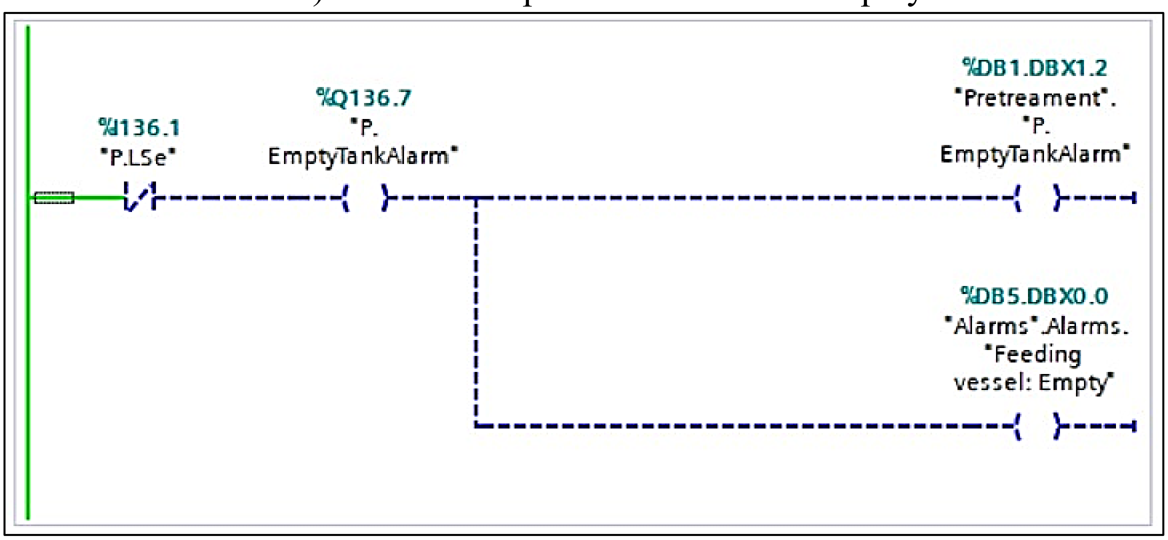

Figure IV.11: Network 6 in pretreatment function.

g. ALARM: High pressure: This network signals a red "P. HighPressureS" alarm and stop the pumps "P.P1" and "P.P2", the other outputs is for SCADA display.

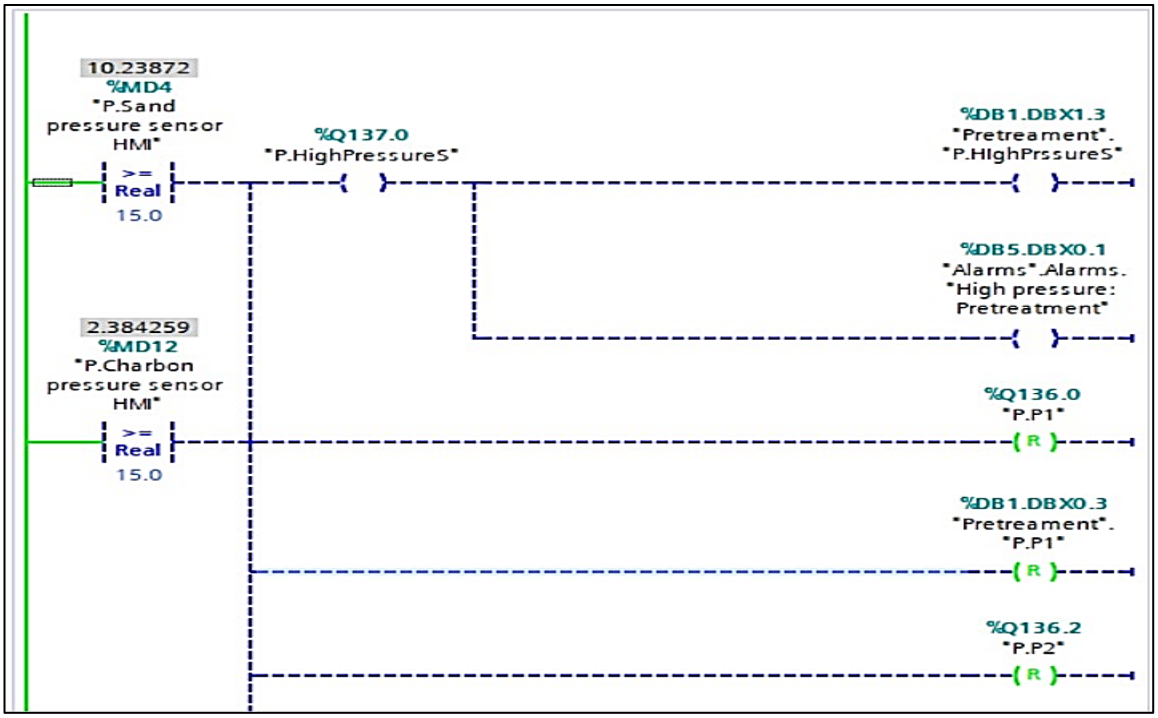

Figure IV.12: Network 7 in pretreatment function.

h. Scada level sensor detector full: This network signals the status of the level sensor in the feeding vessel if it's full, so when "P.LSf" is true the output would be displayed as a blue detector in the SCADA interface.

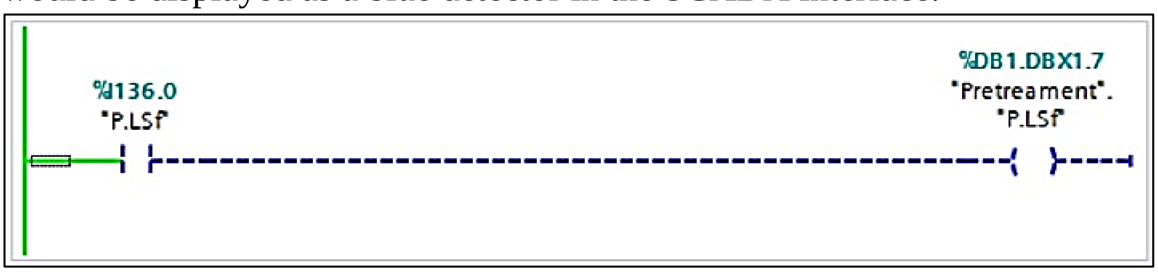

Figure IV.13: Network 8 in pretreatment function.

i. Scada level sensor detector empty: This network signals the status of the level sensor in the feeding vessel if it's empty, so when the "P.LSe" is true is displayed as a blue detector in the SCADA interface.

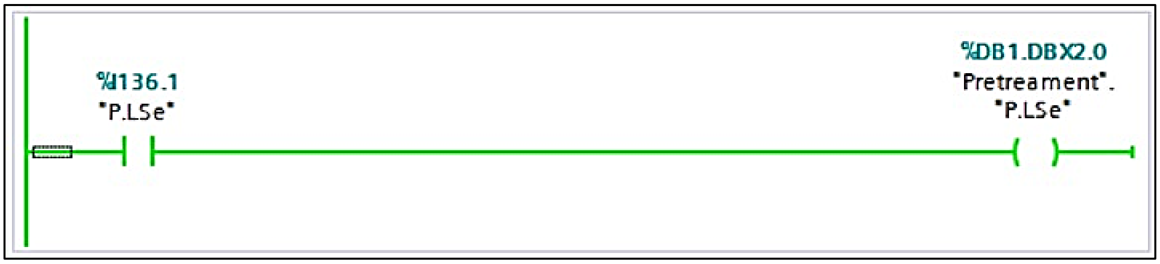

Figure IV.14: Network 9 in pretreatment function.

PLC inputs/Outputs	**SCADA interface**
- **Specifications:** P for Pretreatment ❖ P.P1: feeding pump. ❖ P.LSe: first level sensor in the vessel. ❖ P.LSf: last level sensor in the vessel. ❖ P.P2: feeding filter pump. ❖ P.V1: feeding filter valve. ❖ P.PSs: pressure sensor of the sand filter. ❖ P.PSc: pressure sensor of the charbon filter. ❖ P.3Vs: 3-way valve next to sand filter. ❖ P.3Vc: 3-way valve next to carbon filter. ❖ w1/w2: way 1 (filter direction) – way 2 (cleaner direction).	- **Specifications:** ❖ %DB1.DBX2.0: first level sensor in the vessel. ❖ %DB1.DBX2.0: last level sensor in the vessel. ❖ %DB1.DBX0.3: feeding filter pump. ❖ %DB1.DBX0.2: feeding filter valve. ❖ %MD4: pressure sensor of the sand filter. ❖ %MD12: pressure sensor of the carbon filter. ❖ %DB1.DBX0.4: 3-way valve next to sand filter. ❖ %DB1.DBX0.6: 3-way valve next to carbon filter. ❖ %DB1.DBX1.3: High pressure alarm. ❖ %DB1.DBX1.2: Empty vessel alarm

IV.5.3 Reverse Osmosis function block

This function contains 13 networks as shown in fig.IV.15. These networks are shown with explanation sequentially from fig.IV.16 to fig.IV.28.

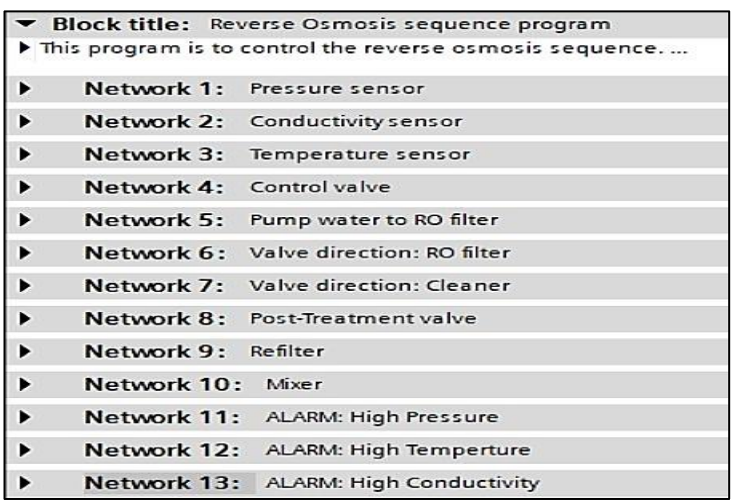

Figure IV.15: Reverse osmosis control function.

a. **Pressure sensor:** This network generates pressure values "RO.PS" between the pressure sensor the reverse osmosis filter and PLC and the values displayed in SCADA interface using this memory "RO. Pressure HMI".

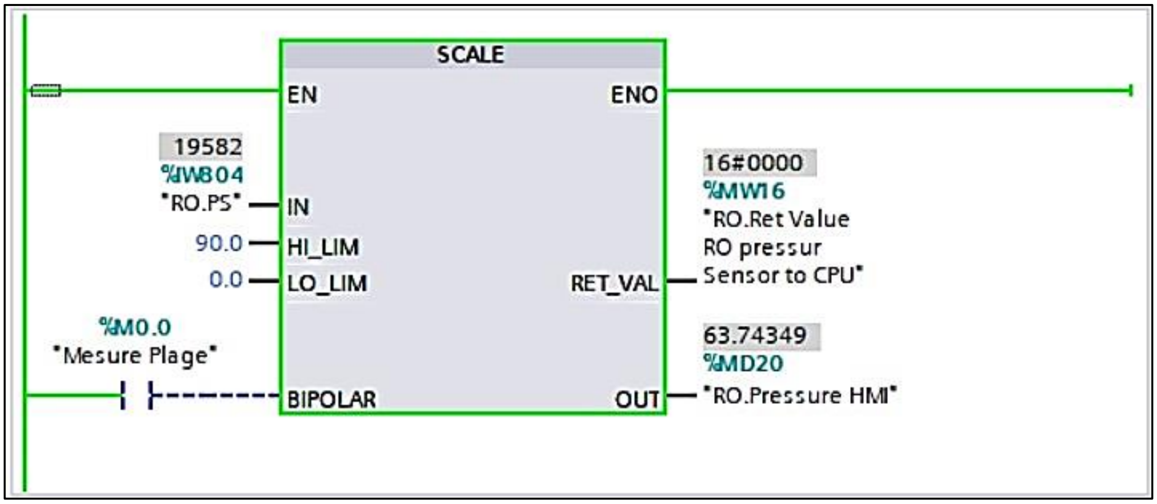

Figure IV.16: Network 1 in reverse osmosis function.

b. **Conductivity sensor:** This network generates conductivity value between the conductivity sensor "RO.CS" and PLC; the values stored in this memory "RO.Condi value HMI" and displayed in the SCADA interface.

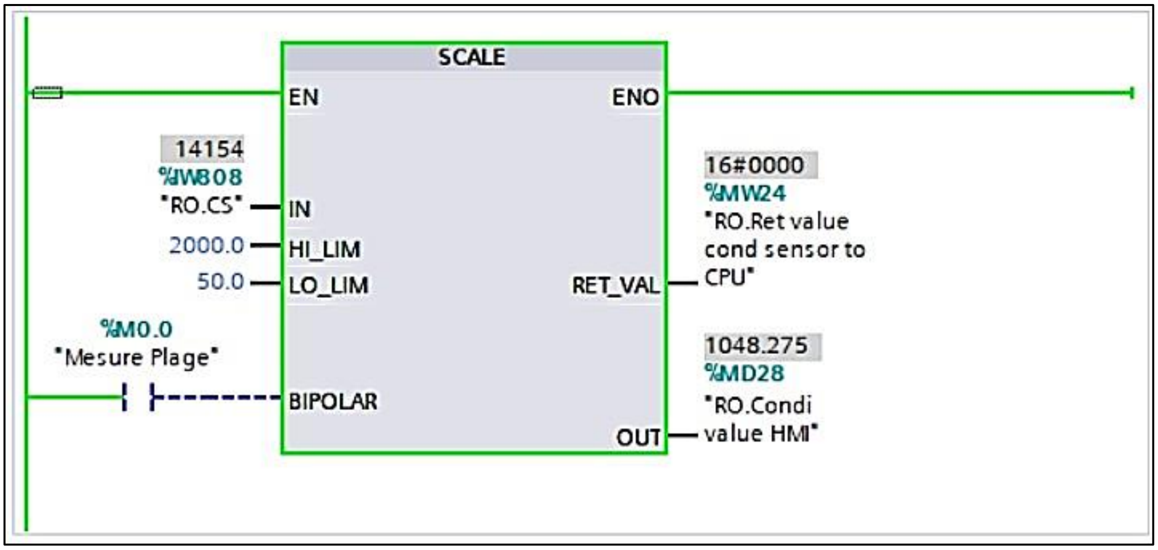

Figure IV.17: Network 2 in reverse osmosis function.

c. **Temperature sensor:** This network generates temperature value between the temperature sensor "RO.TS" and PLC; the values stored in this memory "RO. Temp value HMI" and displayed in SCADA interface.

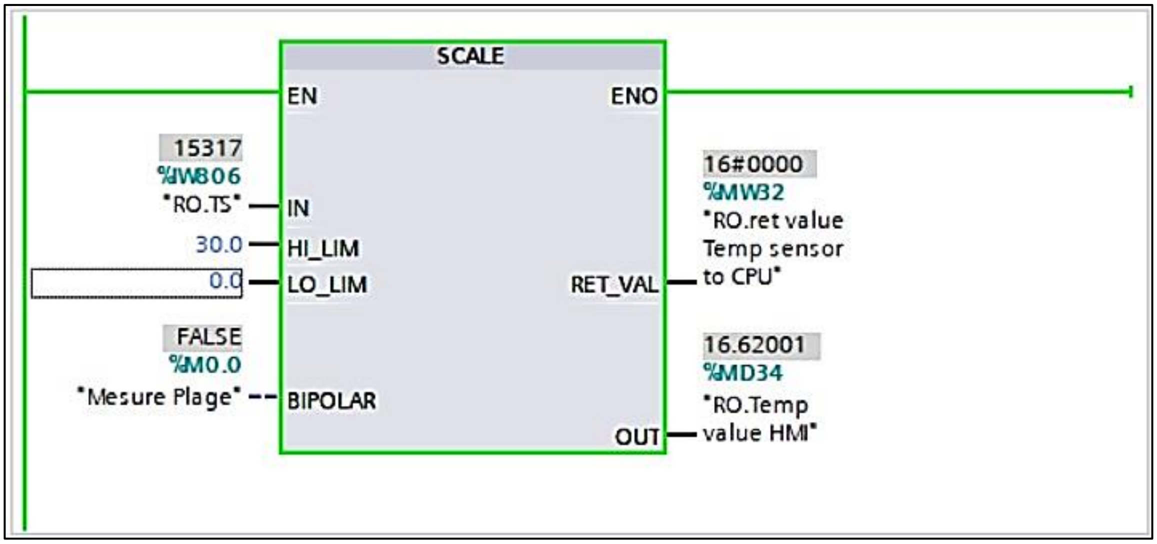

Figure IV.18: Network 3 in reverse osmosis function.

d. **Control valve:** This network is to control the opening status of the control valve "RO.ControlV"; so it takes values from the input, which is the pressure sensor "RO.PS", by using SCALE it sends numeric values to the PLC which is stored in this memory "RO.O/C control value"? and then sends the control signal by using UNSCALE; which convert a numeric value to analogic signal.

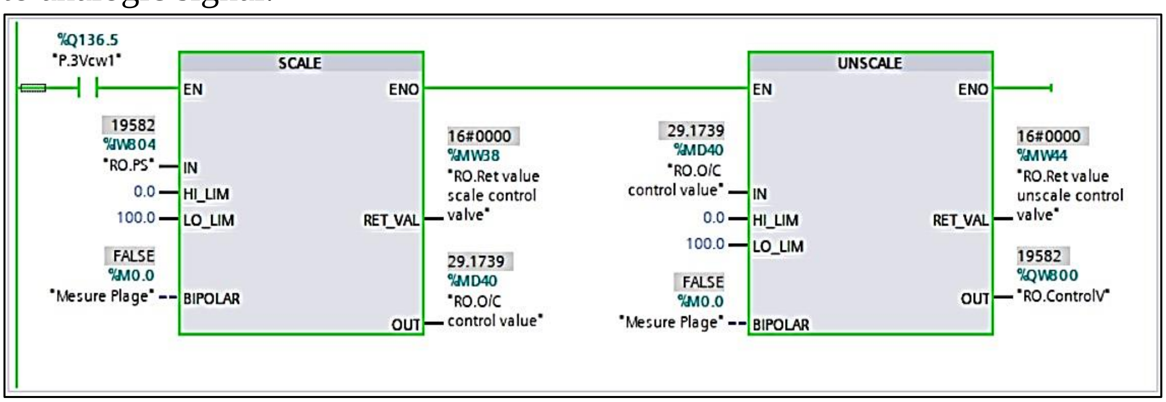

Figure IV.19: Network 4 in reverse osmosis function.

e. **Pump water to RO filter:** This network is to control the HP-Pump, So when all alarms are turned off (“RO. High Pressure Alarm” “RO.High Condi alarm” and “RO.High Temp alarm”) and the valve is open the high-pressure pump would work, and the other outputs are for SCADA display.

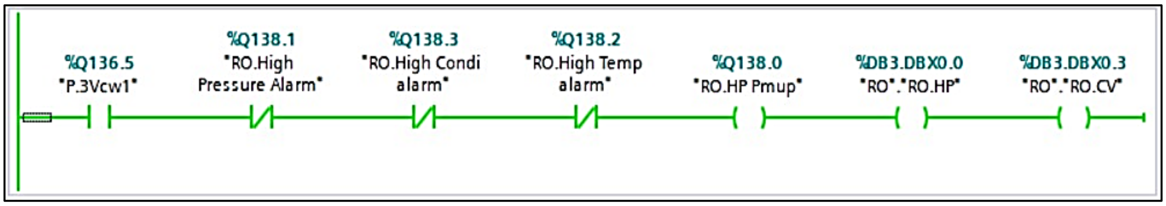

Figure IV.20: Network 5 in reverse osmosis function.

f. **Valve direction RO filter:** This network turns ON the direction of the 3 way-valve to the filter side, So when the pressure in the RO filter “RO.Pressure HMI” is less than 60 Psi the valve “RO.3Vw1” would be open, and the other outputs are for SCADA display.

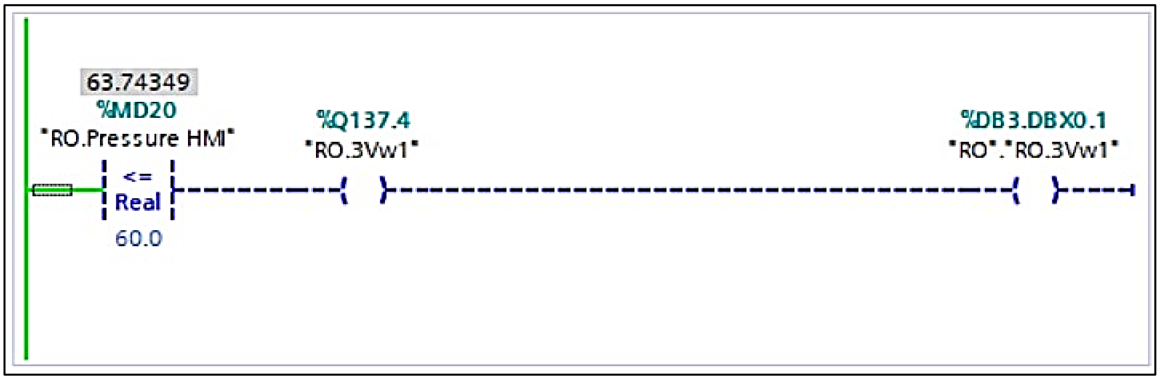

Figure IV.21: Network 6 in reverse osmosis function.

g. **Valve direction: cleaner:** In this network when the pressure is higher than 60 Psi it opens the valves of the cleaning system “RO.V1” and “RO.3Vw2”, and the other outputs are for SCADA display.

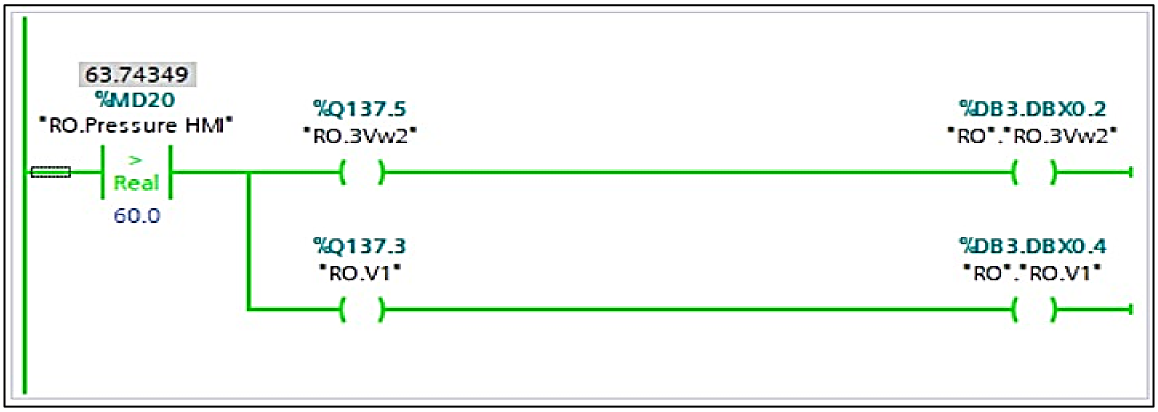

Figure IV.22: Network 7 in reverse osmosis function.

h. Post-Treatment valve: This network opens the delivery valve, so when the conductivity of the water "RO.Condi value HMI" is between 1500 us/cm and 400 us/cm and a timer of 5 seconds start and then opens the valve "RO.V2", and the other outputs are for SCADA interface.

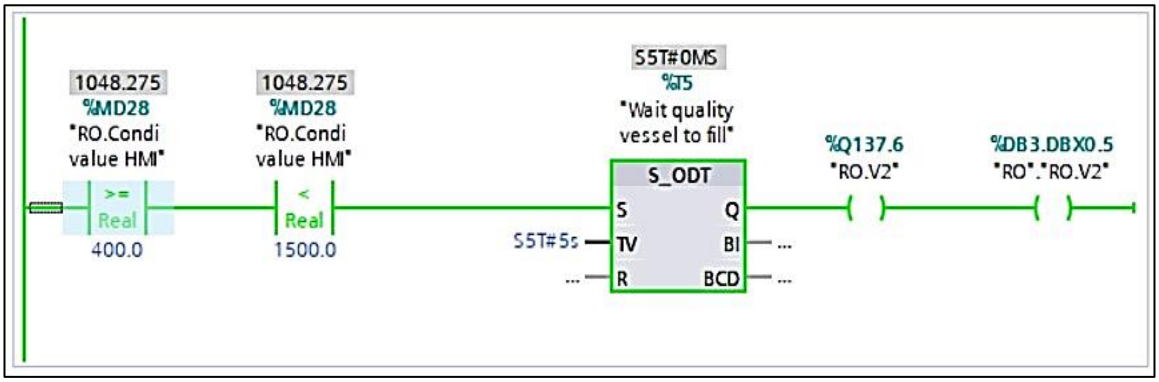

Figure IV.23: Network 8 in reverse osmosis function.

i. Refilter: This network opens the re-filter valve, when the conditions of "Post-Treatment valve" network are not true, and the other outputs are for SCADA interface.

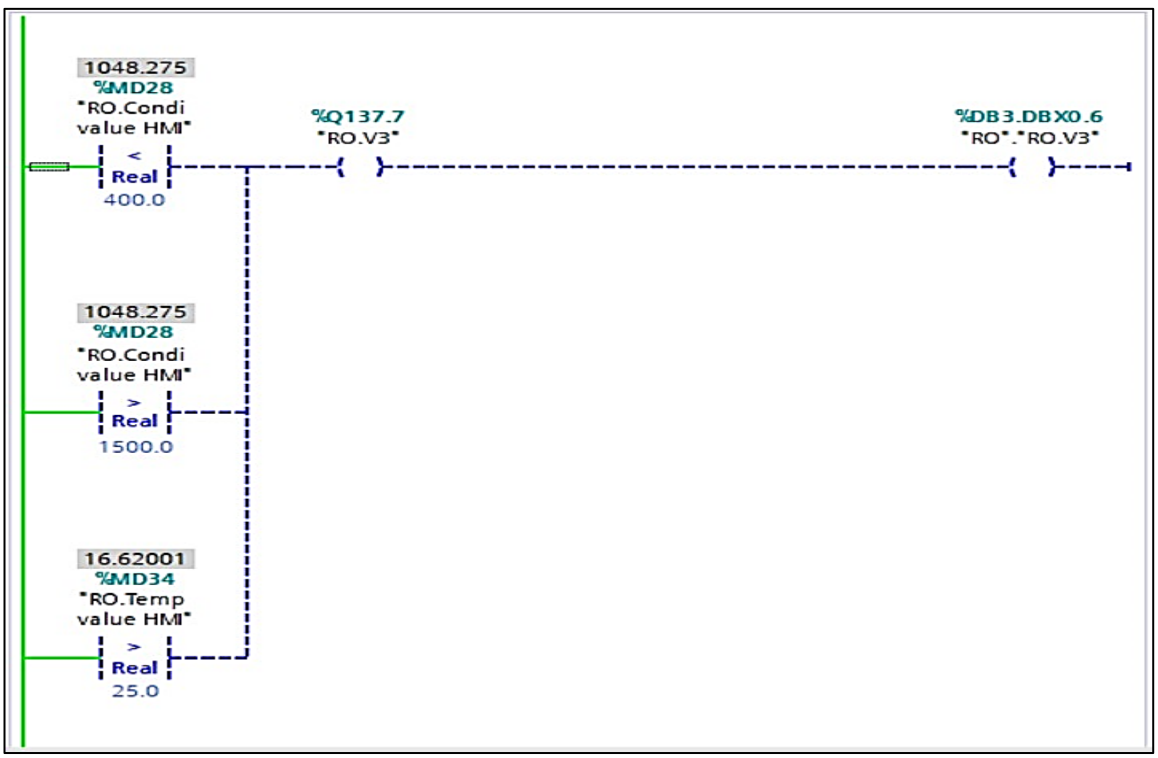

Figure IV.24: Network 9 in reverse osmosis function.

j. **Mixer:** This network turns ON the mixer inside the quality vessel when the high-pressure pump is running "RO.HP Pump".

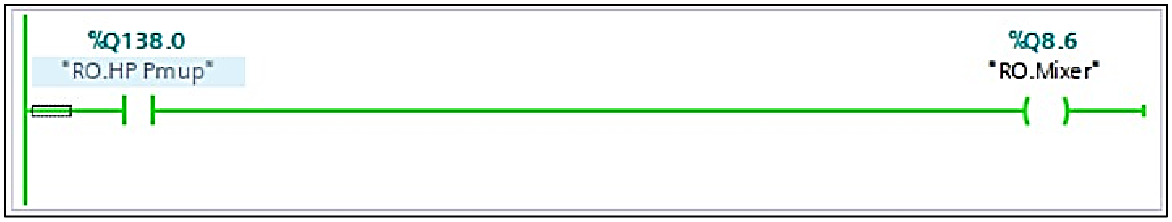

Figure IV.25: Network 10 in reverse osmosis function.

k. **Alarm: High pressure:** This network signals an alarm "RO.High Pressure Alarm" and turns OFF the pump and valves "RO.HP Pump" and "RO.3Vw1" if the pressure reaches 70 Psi.

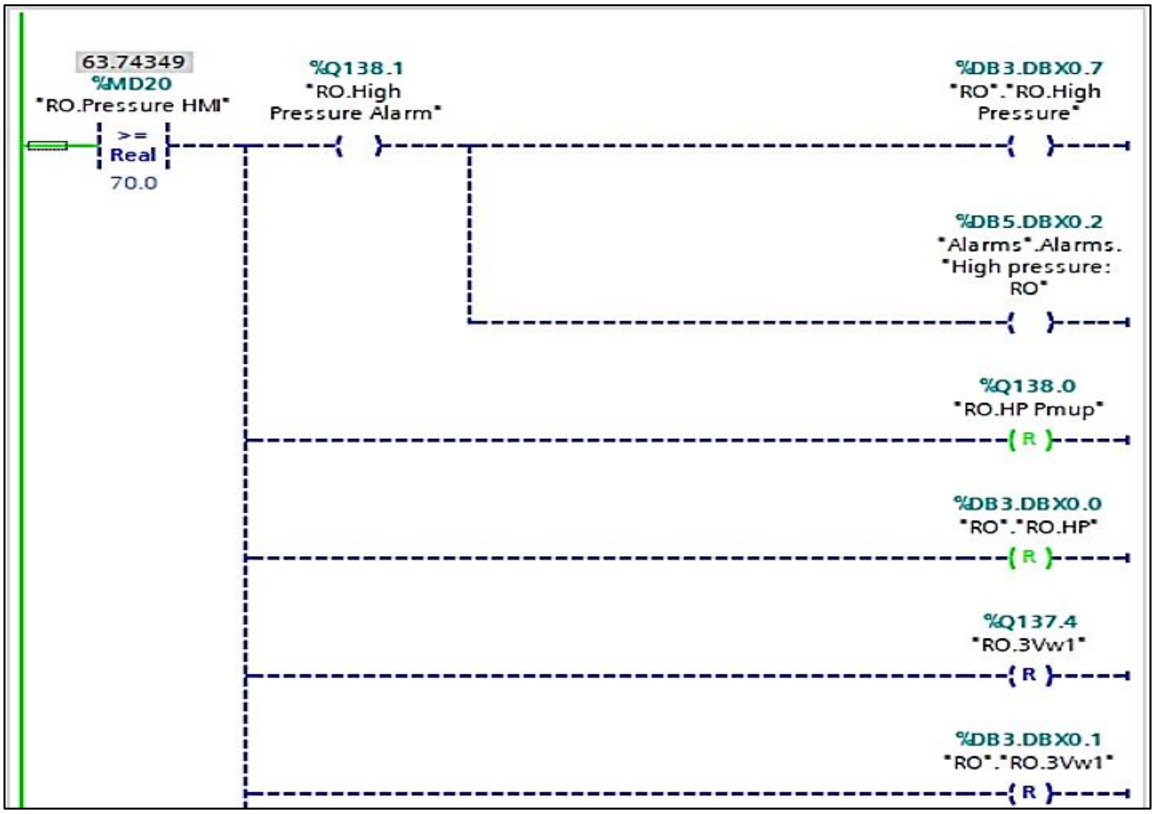

Figure IV.26: Network 11 in reverse osmosis function.

l. Alarm: High Temperature: This network signals an alarm and turns OFF the delivery valve if the temperature is higher than 25 C°.

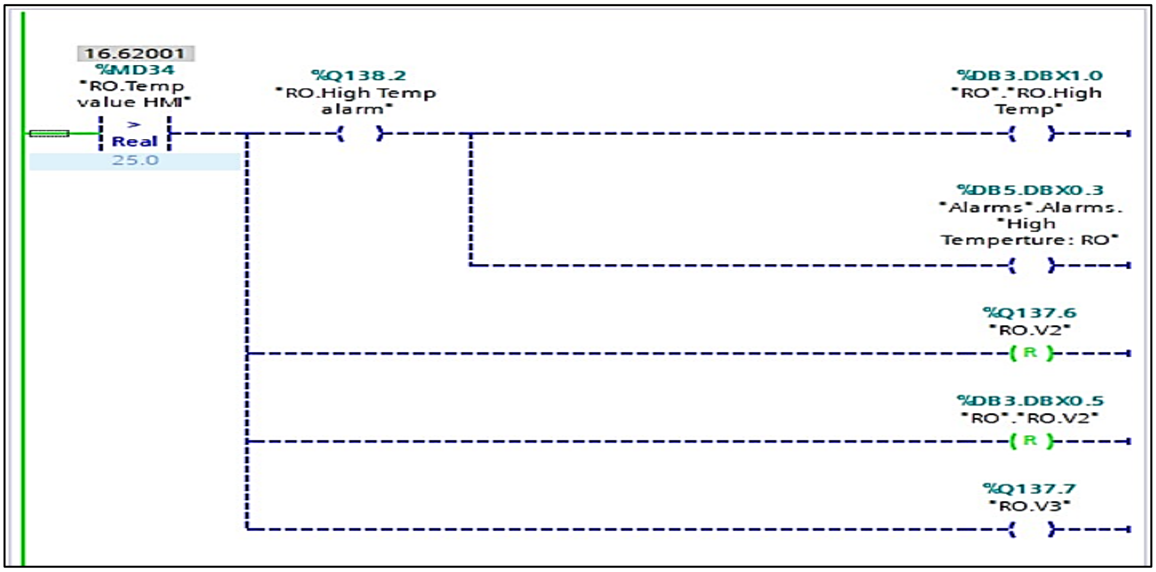

Figure IV.27: Network 12 in reverse osmosis function.

m. Alarm: High Conductivity: This network signals an alarm and turns OFF the delivery valve if the conductivity is higher than 1500 us/cm².

Figure IV.28: Network 13 in reverse osmosis function.

PLC inputs/Outputs	SCADA interface
- **Specifications:** RO for Reverse Osmosis ❖ RO.HP pump: high pressure pump. ❖ RO.V1: Valve 1 ❖ RO.ControlV: Control valve. ❖ RO.3Vw1: Three way valve direction 1. ❖ RO.3Vw2: Three way valve direction 2. ❖ RO.V2: Valve 2. ❖ RO.V3: Valve 3. ❖ RO.Mixer: mixer. ❖ RO.PS: Pressure sensore. ❖ RO.TS: Temperature sensor. ❖ RO.CS: Conductivity sensor. ❖ RO.Ret Value RO pressur Sensor to CPU: Error value of the pressure transmiter ❖ RO.Pressure HMI: pressure value displayed in HMI. ❖ RO.Ret value cond sensor to CPU: Error value of the conductivity transmiter. ❖ RO.Condi value HMI: Conductivity value displayed in HMI. ❖ RO.ret value Temp sensor to CPU: Reverse Osmosis-error value of the temperture transmiter. ❖ RO.Temp value HMI: Reverse Osmosis-temperture value displayed in HMI. ❖ RO.Ret value scale control valve: Reverse Osmosis-error value of the control valve transmitter(feedback). ❖ RO.O/C control value: Reverse Osmosis-Opening and closing percentage displayed in HMI. ❖ RO.Ret value unscale control valve: Reverse Osmosis-error value of the control valve transmiter. ❖ RO.High Pressure Alarm: Reverse Osmosis-high pressure alarm. ❖ RO.High Temp alarm: Reverse Osmosis-high temperature alarm. ❖ RO.High Condi alarm: Reverse Osmosis-high conductivity alarm.	- **Specifications:** ❖ %DB3.DBX0.0: high pressure pump. ❖ %DB3.DBX0.4: Valve 1 ❖ %DB3.DBX0.3 : Control valve. ❖ %DB3.DBX0.5: Valve 2. ❖ %DB3.DBX0.6: Valve 3. ❖ %MD20: Pressure sensor. ❖ %MD34: Temperature sensor. ❖ %MD28: Conductivity sensor. ❖ %MD40: Opening status of the control valve. ❖ %DB3.DBX1.1: High conductivity alarm. ❖ %DB3.DBX1.0: High temperature alarm.

IV.5.4. Post-Treatment

This function contains 8 networks as shown in fig.IV.29, these networks are shown with explanation sequentially from fig.IV.30 to fig.IV.37.

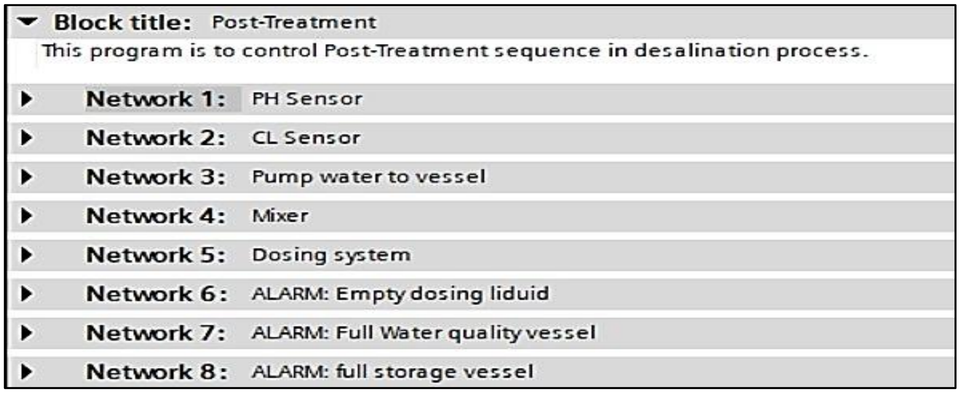

Figure IV.29: Post-Treatment control function.

a. PH Sensor: This network generates PH sensor values “PT.PHS” and display the value in SCADA interface using this memory “PT.PH sensor HMI”.

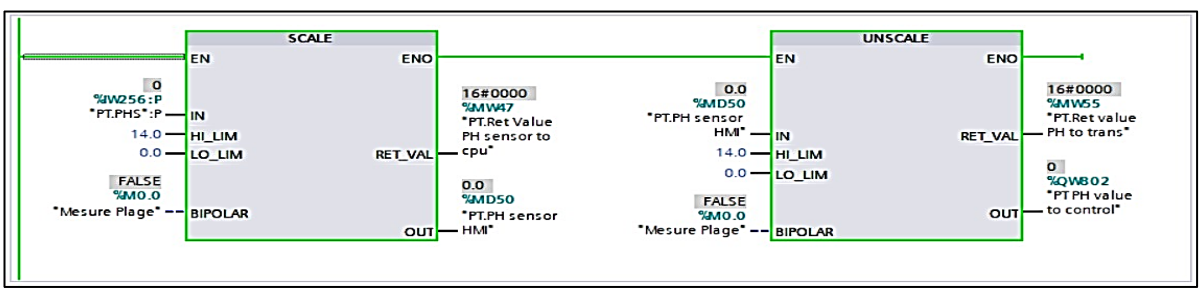

Figure IV.30: Network 1 in post-treatment function.

b. CL Sensor: This network generates CL sensor values “PT.CLS” and display values in SCADA interface using this memory “PT CK value HMI”.

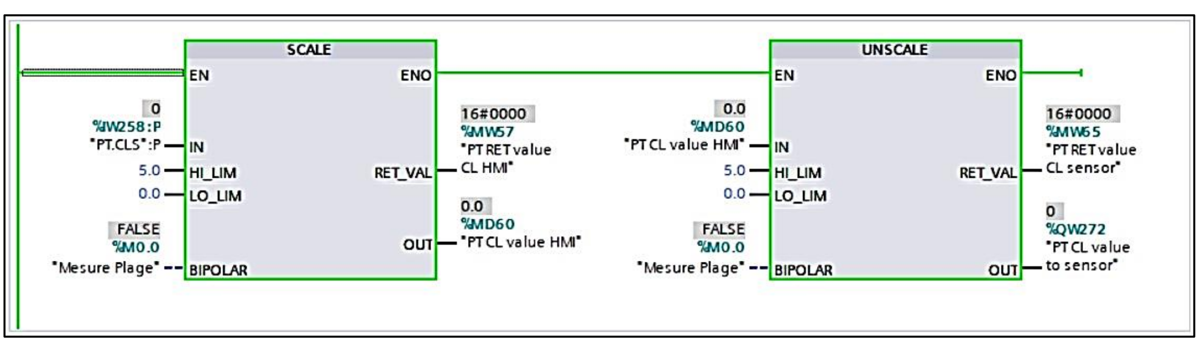

Figure IV.31: Network 2 in post-treatment function.

c. **Pump water to vessel:** This network is to control feeding pump, so when these alarms are turned off "PT.Alarm empty dosing liquid", "PT.Alarm: full water vessel" and "PT.Alarm: full quality vessel" and this valve is open "RO.V2" the pump is turn ON, and the other outputs are for SCADA interface.

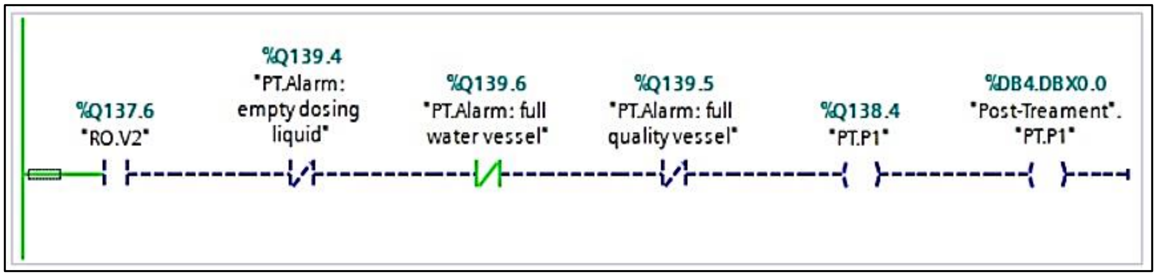

Figure IV.32: Network 3 in post-treatment function.

d. **Mixer:** This network is to run mixer of the quality vessel, when the first sensor is activated "PT.LSqe".

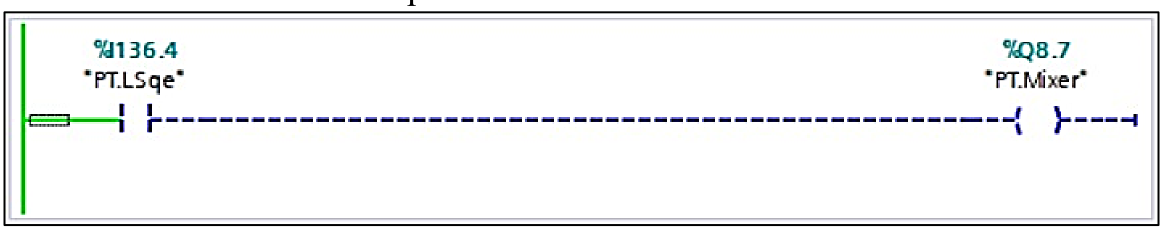

Figure IV.33: Network 4 in post-treatment function.

e. **Dosing system:** This function controls the hardware that doses liquids (CO2 or CL or NaOCL or $Na_2S_2O_5$) in the quality vessel.

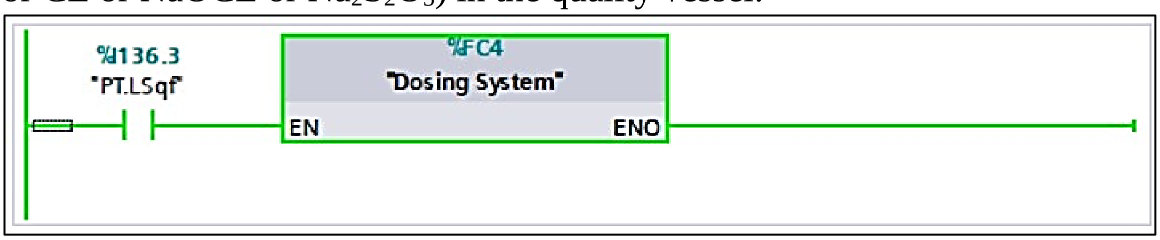

Figure IV.34: Network 5 in post-treatment function.

f. **Alarm: Empty dosing liquid:** This network is to signal an alarm "PT.Alarm empty dosing liquid" when one of the of the liquids vessels is empty "PT.Lse(NACL)", PT.Lse(CO2), "PT.Lse(Na2)" or "PT.Lse(CL)" and stop the dosing pumps the other outputs is for SCADA interface display.

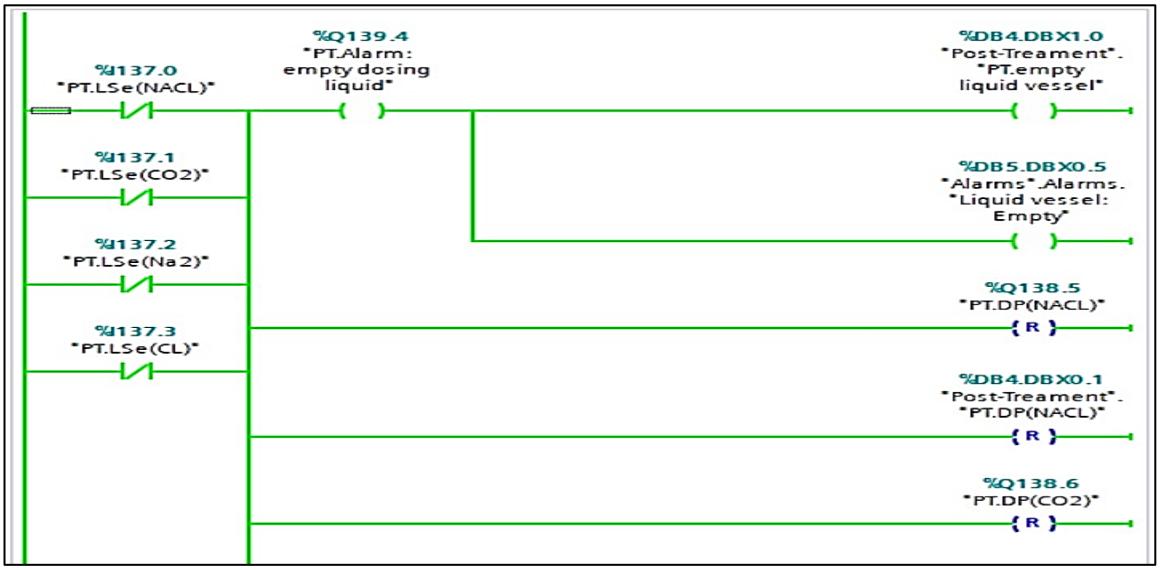

Figure IV.35: Network 6 in post-treatment function.

g. **Alarm: Full Water quality vessel:** This Network is to signal an alarm "PT.Alarm: full quality vessel" if the quality vessel is full and stop the feeding pump "PT.P1" the rest is for SCADA outputs interface.

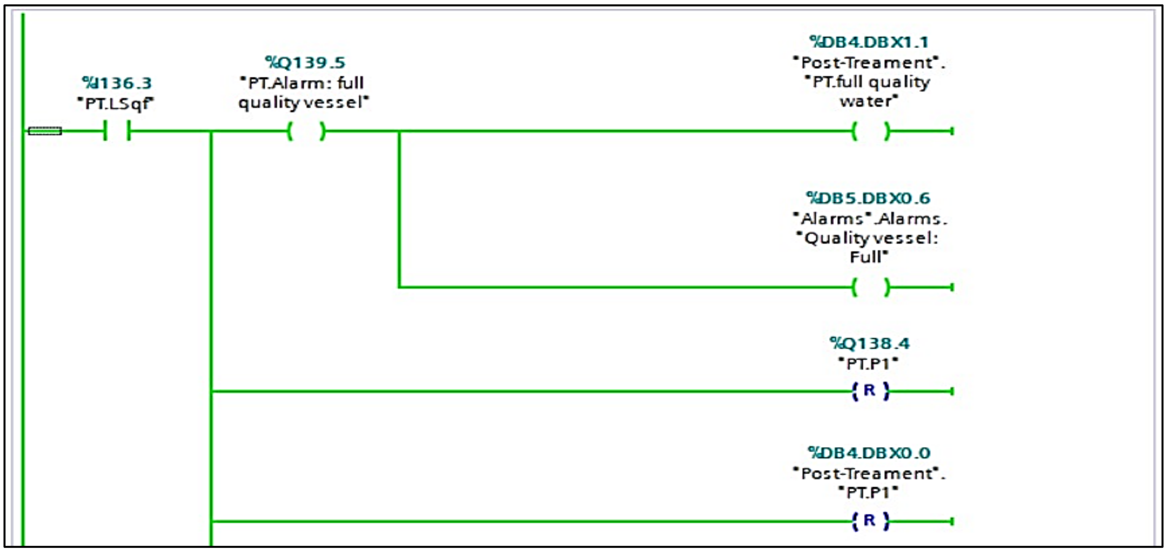

Figure IV.36: Network 7 in post-treatment function.

h. **Alarm: full storage vessel:** This network is to signal an alarm “PT.Alarm: full water vessel” if the storage vessel is full and turns OFF the pump and valve “PT.P2” and “PT.V1”, the other outputs is for SCADA interface display.

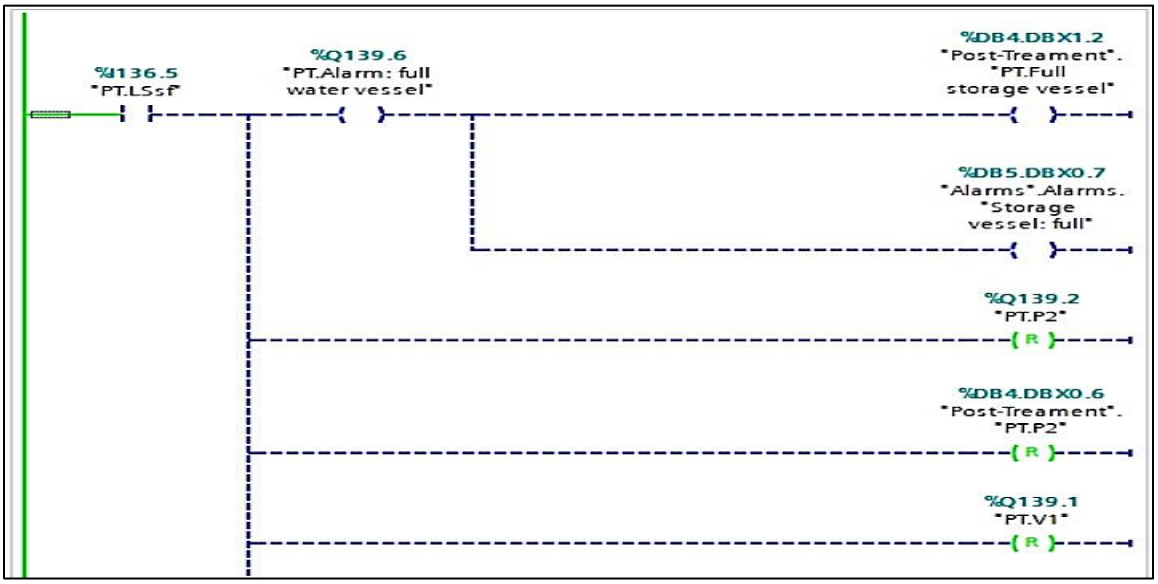

Figure IV.37: Network 8 in post-treatment function.

PLC inputs/Outputs	SCADA interface
- **Specifications:** PT for post-treatment ❖ PT.P1: Pump 1 ❖ PT.DP(NaOCL): Dosing pump of NaOCL ❖ PT.DP(CO2): Dosing pump of CO2 ❖ PT.DP(Na2): Dosing pump of Na2 ❖ PT.DP(CL): Dosing pump of CL ❖ PT.V1: Valve 1 ❖ PT.P2: Pump 2 ❖ PT.V2: Valve 2 ❖ PT.Time to prepare water: Time to repair water ❖ PT.Mixer: Mixer ❖ PT.LSqf: Level sensor of the quality vessel (full status) ❖ PT.Lsqe: Level sensor of the quality vessel (empty status) ❖ PT.LSsf: Level sensor of the storage vessel (full status) ❖ PT.Lsse: Level sensor of the storage vessel (empty status) ❖ PT.PHS: PH sensor status ❖ PT.CLS: CL sensor status ❖ PT.Ret Value PH sensor to cpu: Error value of the PH transmiter ❖ PT.PH sensor HMI:PH values displayed in HMI ❖ PT PH value to control:PH value transmiter feedback ❖ PT RET value CL HMI:Error value of the CL sensor. ❖ PT CL value HMI: CL value displayed in HMI. ❖ PT.LSe(NaOCL): Level sensor of NaOCL vessel. ❖ PT.LSe(CO2): Level sensor of CO2 vessel. ❖ PT.LSe(Na2): Level sensor of Na2 vessel. ❖ PT.LSe(CL): Level sensor of CL vessel. ❖ PT.Dosing Timer: Dosing timer. ❖ PT.Alarm: empty dosing liquid: Alarm of empty dosing vessel. ❖ PT.Alarm: full quality vessel:Alarm level sensor if the quality vessel. ❖ PT.Alarm: full water vessel: Alarm of the level sensor in storage vessel. ❖ PT.Time to prepaire water: Time to repaire water.	- **Specifications:** ❖ %DB4.DBX0.0: Pump 1 ❖ %DB4.DBX0.1: Dosing pump of NaOCL ❖ %DB4.DBX0.2: Dosing pump of CO2 ❖ %DB4.DBX0.3: Dosing pump of Na2 ❖ %DB4.DBX0.4: Dosing pump of CL ❖ %DB4.DBX0.5: Valve 1 ❖ %DB4.DBX0.6: Pump 2 ❖ %DB4.DBX0.7: Valve 2 ❖ %DB4.DBX1.1: Level sensor of the quality vessel (full status) ❖ %DB4.DBX1.0: Empty liquid vessel alarm. ❖ %DB4.DBX1.0: Level sensor of the quality vessel (empty status) ❖ PT.PHS: PH sensor status ❖ PT.CLS: CL sensor status ❖ %DB4.DBX1.2:Level sensor of the storage vessel (full status) ❖ %MD50:PH values displayed in HMI ❖ %MD60:CL value displayed in HMI

The dosing system function inside the post-treatment function is shown in the next figures from fig.IV.38 to fig.IV.44.

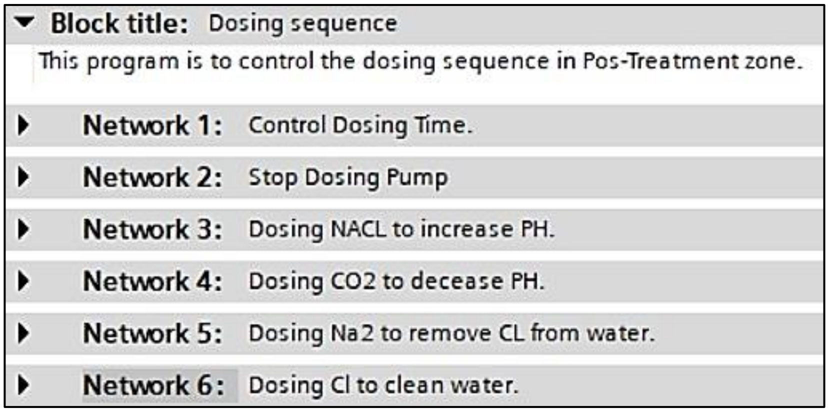

Figure IV.38: Dosing system function.

a. **Control Dosing time:** This network is to control the running time “Stop_Dosing” of the dosing pumps and store the order in this memory “Stop pump”.

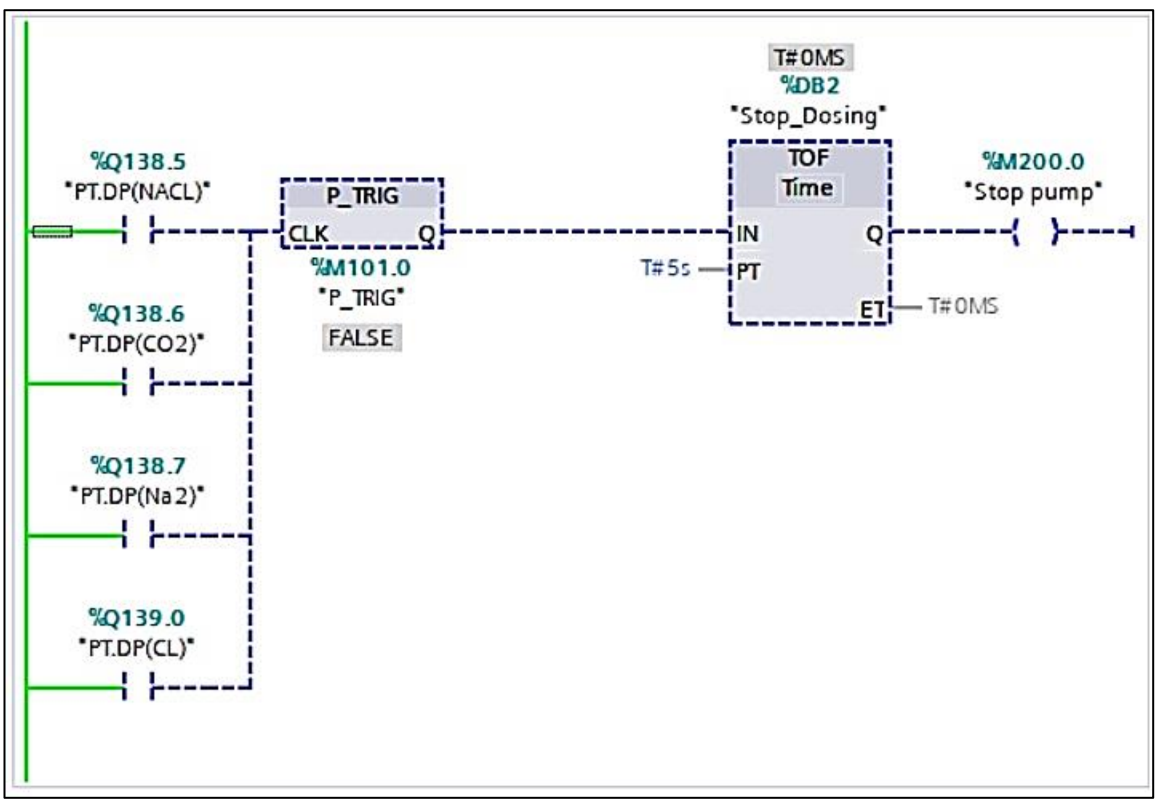

Figure IV.39: Network 1 in dosing system.

b. **Stop dosing pump:** This network is to stop the dosing pump using this memory “Stop pump” and the output would be all of the dosing pumps are turned OFF “PT.DP(NACL)” “PT.DP(CO2)” “PT.DP(Na2)” and “PT.DP(CL)”, and the other outputs is for SCADA interface display.

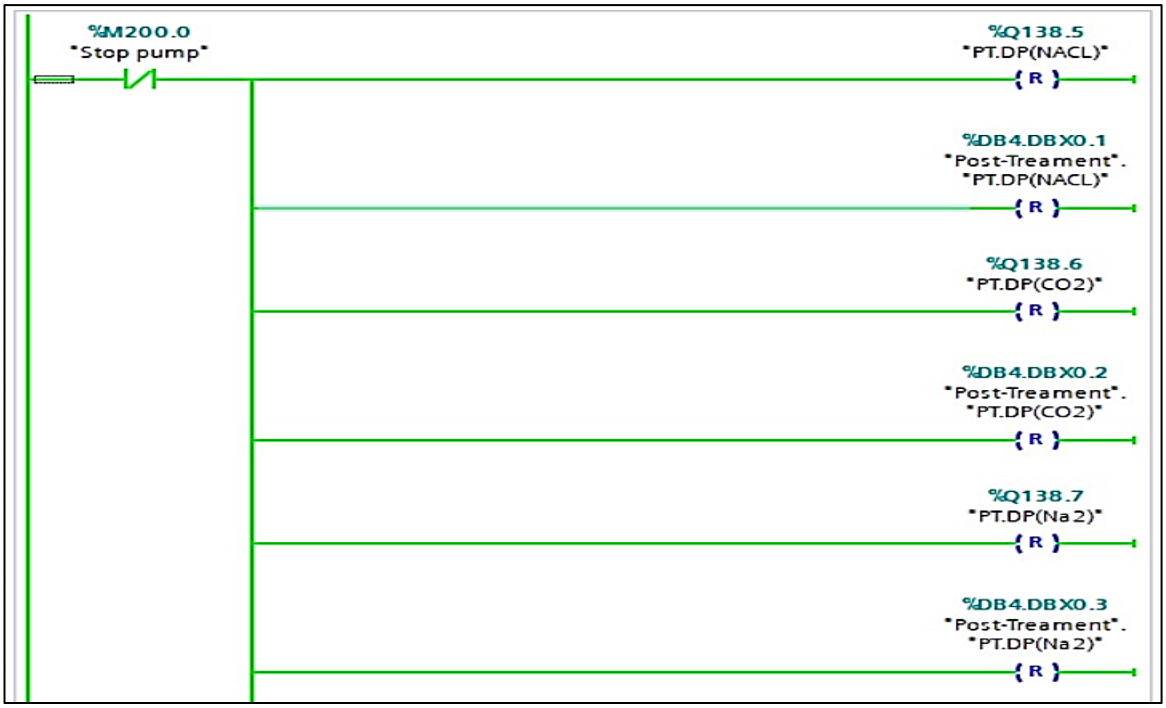

Figure IV.40: Network 2 in dosing system.

c. **Dosing NaOCL to increase PH:** This network controls the value of PH in the water, so when PH value less than or equal 5 and the NaOCL vessel if not empty “PT.Lse(NACL)” the dosing pump of NaOCL runs “PT.DP(NACL)”.

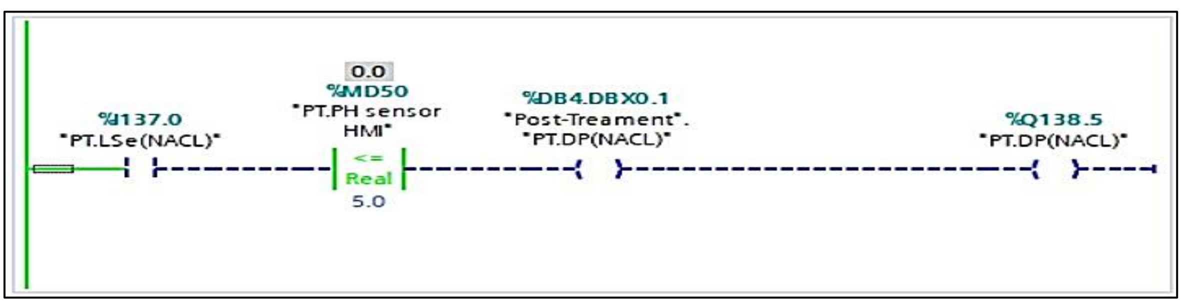

Figure IV.41: Network 3 in dosing system.

d. **Dosing CO2 to decrease PH:** This network works with same principle of the previous network to dose the CO2.

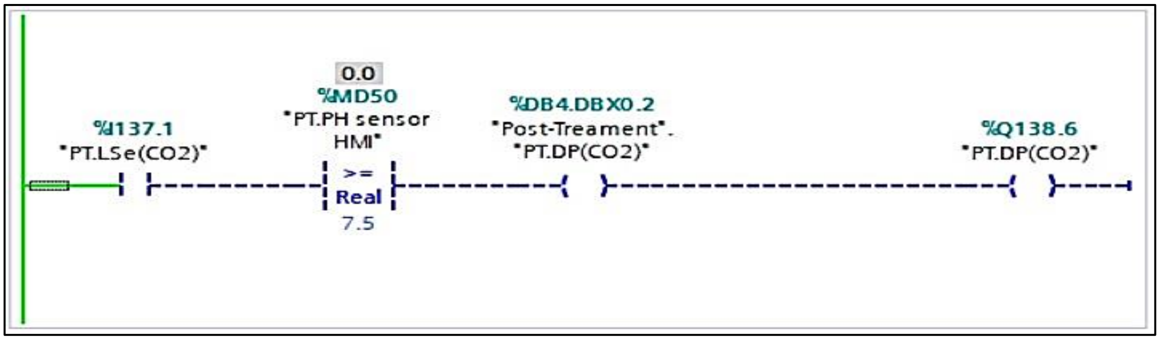

Figure IV.42: Network 4 in dosing system.

e. **Dosing $Na_2S_2O_5$ to remove Cl from water:** This network works with same principle of the previous network to dose the $Na_2S_2O_5$.

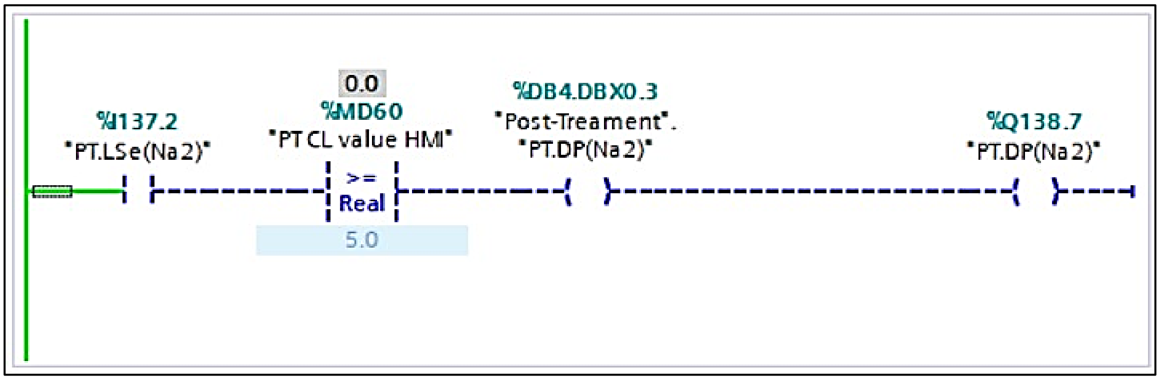

Figure IV.43: Network 5 in dosing system.

f. **Dosing CL to clean the water:** This network works with same principle of the previous network to dose the CL.

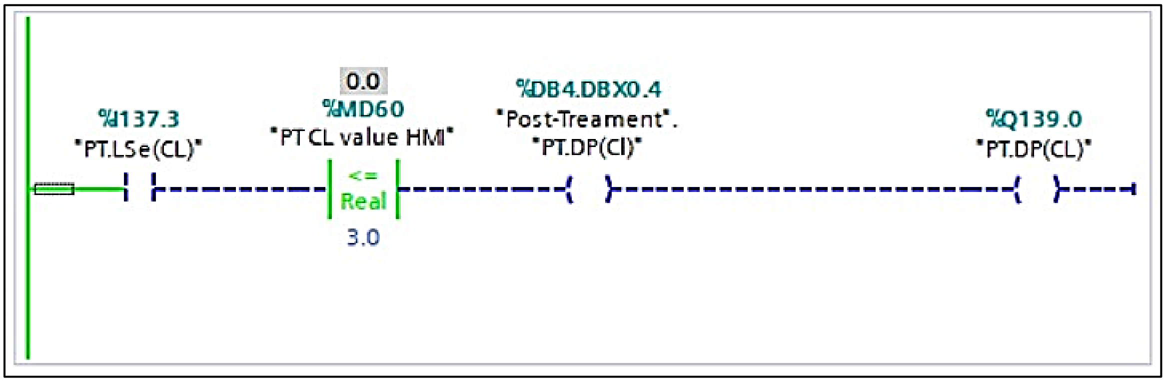

Figure IV.44: Network 6 in dosing system.

IV.6. SCADA and HMI design of the desalination process

Here is the HMI of the supervision and control using SCADA, as shown in fig.IV.45, the system starts with an elegant interface that shows the status of the different part of process, it shows the alarms signal like conductivity and temperature…etc., also the values of PH and CL in the post-treatment zone, and it gives the engineer the options to change the view to see the other zones and stop and start the system.

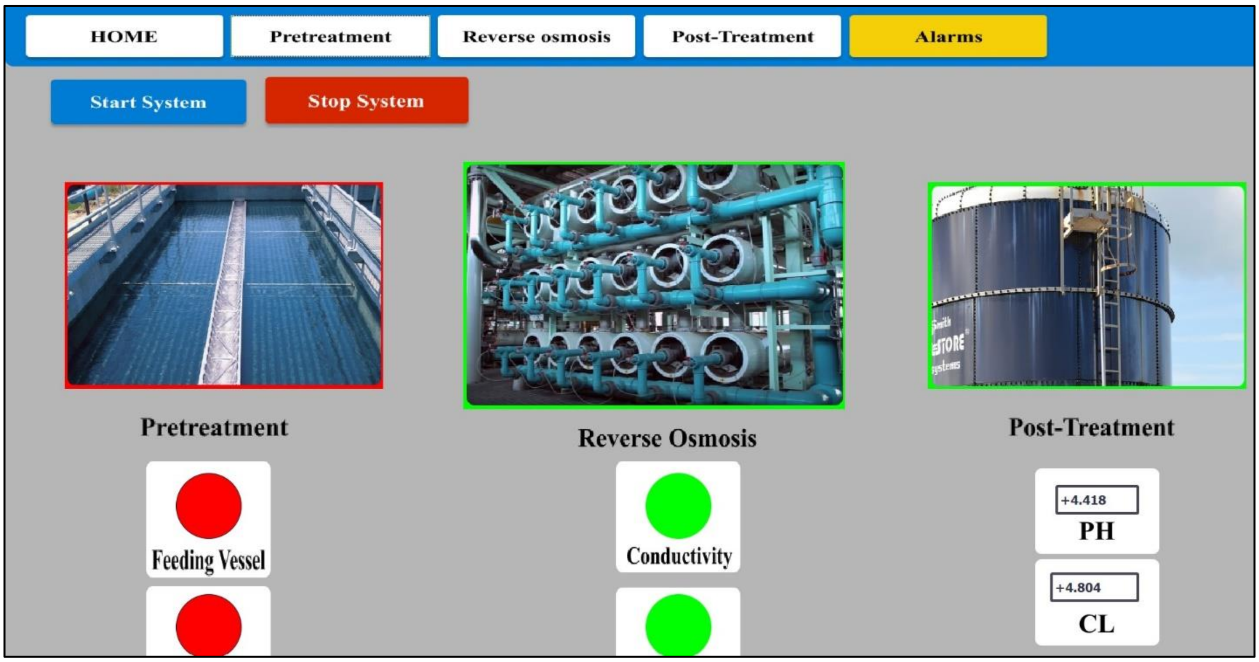

Figure IV.45: dashboard view.

This SCADA contains four interfaces: dashboard, pretreatment, reverse osmosis, post-treatment, and alarms.

The pretreatment view as shown in fig.IV.46 shows the status of the sequence with two control buttons to start and stop the system, also the values of pressure inside each filter (sand and carbon filter).

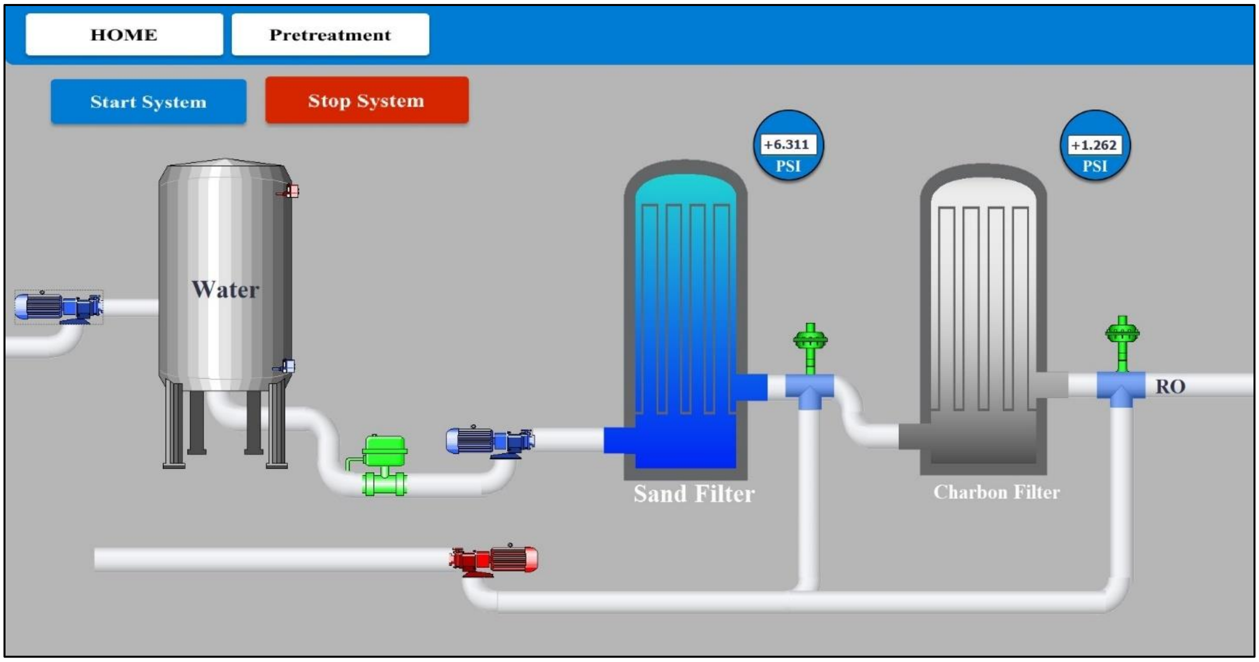

Figure IV.46: pretreatment view.

The reverse osmosis view as shown in fig.IV.47 shows the status of the sequence with two control buttons to start and stop the system, also the measure of conductivity, temperature, pressure and the percentage of the opening status of the control valve.

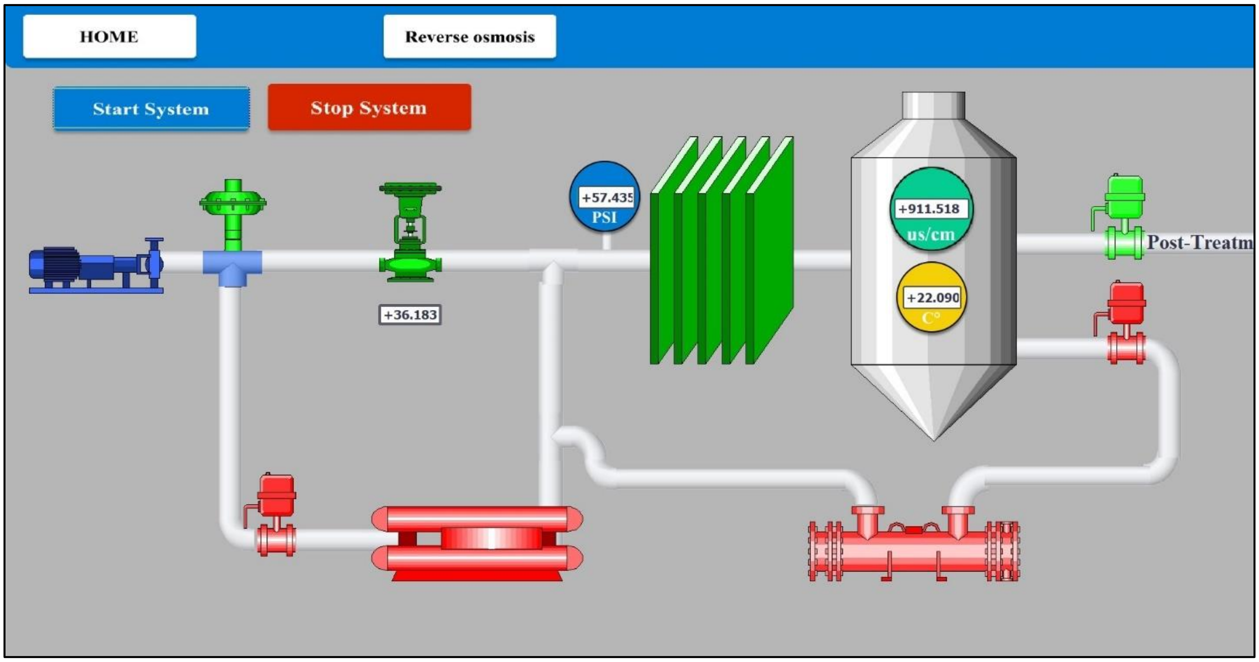

Figure IV.47: reverse osmosis view.

The post-treatment view as shown in fig.IV.48 shows the status of the sequence with two control buttons to start and stop the system, and the measure of the PH and CL.

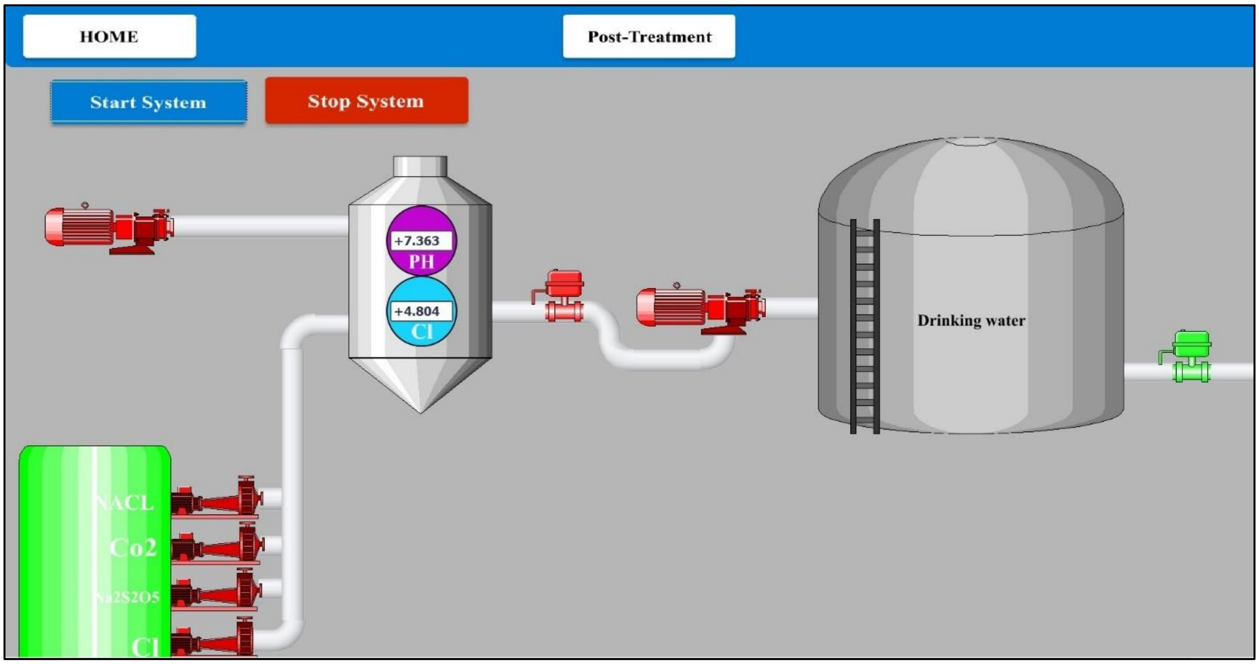

Figure IV.48: post-treatment view.

And the alarms view as shown in fig.IV.49 shows the alarms with two categories yellow for normal emergency and red the high emergency which needs maintenance intervention.

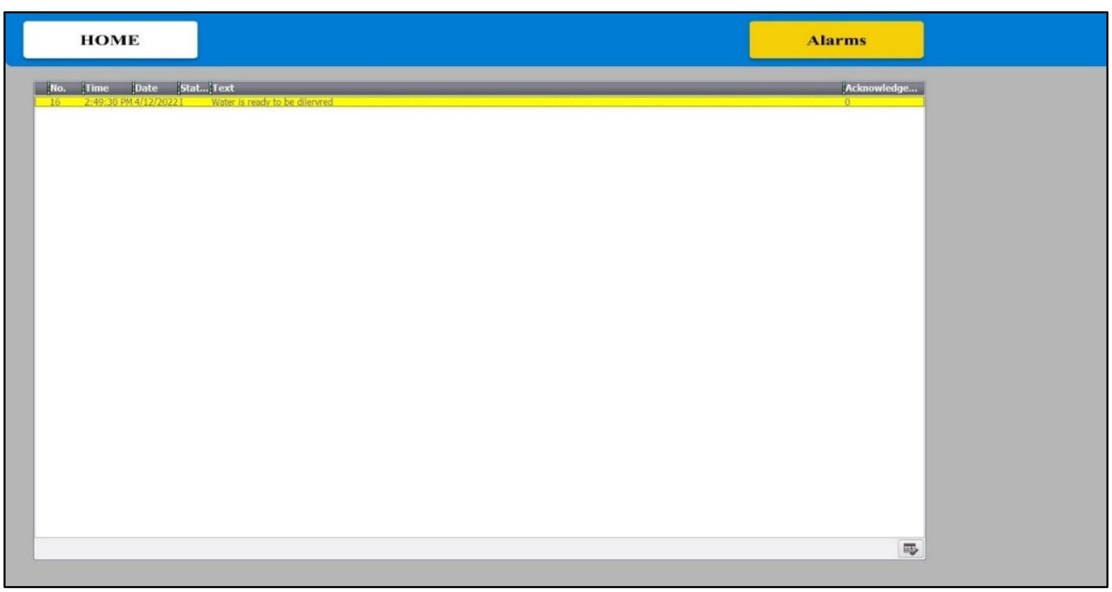

Figure IV.49: alarms view

IV.7. Conclusion

In this chapter, we successfully created and simulate a Ladder program that controls the desalination process (Reverse Osmosis technology), and with the help of WinCC, we run the SCADA that controls and supervises the process.

The program contains input and output variables (the process equipment), a logic program (Ladder in our case), a data block to store and control data from the process, and finally an HMI view.

General conclusion

Conclusion

Nowadays we know that industrial automation is a growing industry and it gives us valuable income.

Our work presented the automation and supervision of the desalination process. And with the help of TIA-Portal software from Siemens, we create a SCADA program prototype for a desalination plant.

We start our work with an overview of the situation the world faces, in finding water sources. This leads to a water desalination solution; this last should be at a large scale to provide water to people. And automated systems are the best option to gain the best result.

We used TIA-Portal and WinCC flexible provided by Siemens, to create the SCADA program; this control architecture helps engineers control and supervise the industrial process, from one control room.

To create the program, we used the Hytex maintenance manual Oran desalination plant in Algeria as a reference for our prototype (see annex: B). So our hardware configuration was a PLC Siemens 314C-2PN/DP with three other modules for analogic and digital input-output; this PLC is used to control pumps, high-pressure pumps, and receive feedback from several types of sensors in different sequences of the process.

We used ladder logic to create the control program and a PC station to run SCADA interfaces. the process is divided into three sequences: pre-treatment, reverse osmosis, and post-treatment; each one is controlled by a function program, and all of them are integrated into one main block (OB).

We used Grafcet only to simplify the process before creating the ladder program because it's the easiest way to simplify any complex process.

Finally, we did make a simulation of the control and supervision of the desalination process, which gives us satisfying results.

And this work end with a general conclusion and several perspectives like participating in a real SCADA project of a desalination station, also the control can be upgraded to be remotely controlled.

Annex A

Workbook

Name	Path	Data Type	Logical Address	Comment	Hmi Visible	Hmi Accessible	Hmi Writeable
P.LSf	Data Input	Bool	%I136.0		True	True	True
P.LSe	Data Input	Bool	%I136.1		True	True	True
P.PSsand	Data Input	Int	%IW800		True	True	True
P.PScharbon	Data Input	Int	%IW802		True	True	True
Mesure Plage	Data Input	Bool	%M0.0		True	True	True
P.Ret Value sand Sensor to CPU	Data Input	Word	%MW1		True	True	True
P.Sand pressure sensor HMI	Data Input	Real	%MD4		True	True	True
P.Ret Value charbon Sensor to CPU	Data Input	Word	%MW8		True	True	True
P.Charbon pressure sensor HMI	Data Input	Real	%MD12		True	True	True
P.Timer wait vessel to fill	Data Input	Timer	%T0		True	True	True
Stop P System	Data Input	Bool	%I136.2		True	True	True
RO.PS	Data Input	Int	%IW804		True	True	True
RO.TS	Data Input	Int	%IW806		True	True	True
RO.CS	Data Input	Int	%IW808		True	True	True
RO.Ret Value RO pressur Sensor to CPU	Data Input	Word	%MW16		True	True	True
RO.Pressure HMI	Data Input	Real	%MD20		True	True	True
RO.Ret value cond sensor to CPU	Data Input	Word	%MW24		True	True	True
RO.Condi value HMI	Data Input	Real	%MD28		True	True	True
RO.ret value Temp sensor to CPU	Data Input	Word	%MW32		True	True	True
RO.Temp value HMI	Data Input	Real	%MD34		True	True	True
RO.Ret value scale control valve	Data Input	Word	%MW38		True	True	True
RO.O/C control value	Data Input	Real	%MD40		True	True	True
RO.Ret value unscale control valve	Data Input	Word	%MW44		True	True	True
PT.LSqf	Data Input	Bool	%I136.3		True	True	True
PT.LSqe	Data Input	Bool	%I136.4		True	True	True
PT.LSsf	Data Input	Bool	%I136.5		True	True	True
PT.LSse	Data Input	Bool	%I136.6		True	True	True
PT.PHS	Data Input	Int	%IW256		True	True	True
PT.CLS	Data Input	Int	%IW258		True	True	True
PT.Ret Value PH sensor to cpu	Data Input	Word	%MW47		True	True	True
PT.PH sensor HMI	Data Input	Real	%MD50		True	True	True
PT.Ret value PH to trans	Data Input	Word	%MW55		True	True	True
PT PH value to control	Data Input	Int	%QW802		True	True	True
PT RET value CL HMI	Data Input	Word	%MW57		True	True	True
PT CL value HMI	Data Input	Real	%MD60		True	True	True
PT RET value CL sensor	Data Input	Word	%MW65		True	True	True
PT CL value to sensor	Data Input	Int	%QW272		True	True	True
PT.LSe(NACL)	Data Input	Bool	%I137.0		True	True	True
PT.LSe(CO2)	Data Input	Bool	%I137.1		True	True	True
PT.LSe(Na2)	Data Input	Bool	%I137.2		True	True	True
PT.LSe(CL)	Data Input	Bool	%I137.3		True	True	True
PT.Dosing TImer	Data Input	Timer	%T2		True	True	True
Tag_2	Data Input	Bool	%M100.0		True	True	True
P_TRIG	Data Input	Bool	%M101.0		True	True	True
Stop pump	Data Input	Bool	%M200.0		True	True	True
Start System	Data Input	Bool	%I8.0		True	True	True
Run/Reset (SR)	Data Input	Bool	%M105.0		True	True	True
Stop system	Data Input	Bool	%I8.1		True	True	True
P_Trig run system	Data Input	Bool	%M102.0		True	True	True
P_Trig stop system	Data Input	Bool	%M103.0		True	True	True
Tag_1	Data Input	Bool	%I8.3		True	True	True
Tag_3	Data Input	Bool	%Q8.0		True	True	True
Close valve timer	Data Input	Timer	%T4		True	True	True
Stop dump timer	Data Input	Bool	%M200.5		True	True	True
Wait quality vessel to fill	Data Input	Timer	%T5		True	True	True
Tag_4	Data Input	Word	%MW500		True	True	True

Name	Path	Data Type	Logical Address	Comment	Hmi Visible	Hmi Accessible
P.P1	Data Output	Bool	%Q136.0		True	True
P.V1	Data Output	Bool	%Q136.1		True	True
P.P2	Data Output	Bool	%Q136.2		True	True
P.3Vsw1	Data Output	Bool	%Q136.3		True	True
P.3Vsw2	Data Output	Bool	%Q136.4		True	True
P.3Vcw1	Data Output	Bool	%Q136.5		True	True
P.3Vcw2	Data Output	Bool	%Q136.6		True	True
P.EmptyTankAlarm	Data Output	Bool	%Q136.7		True	True
P.HighPressureS	Data Output	Bool	%Q137.0		True	True
P.HighPressureCH	Data Output	Bool	%Q137.1		True	True
P.P3	Data Output	Bool	%Q137.2		True	True
RO.ControlV	Data Output	Int	%QW800		True	True
RO.V1	Data Output	Bool	%Q137.3		True	True
RO.3Vw1	Data Output	Bool	%Q137.4		True	True
RO.3Vw2	Data Output	Bool	%Q137.5		True	True
RO.V2	Data Output	Bool	%Q137.6		True	True
RO.V3	Data Output	Bool	%Q137.7		True	True
RO.HP Pmup	Data Output	Bool	%Q138.0		True	True
RO.High Pressure Alarm	Data Output	Bool	%Q138.1		True	True
RO.High Temp alarm	Data Output	Bool	%Q138.2		True	True
RO.High Condi alarm	Data Output	Bool	%Q138.3		True	True
PT.P1	Data Output	Bool	%Q138.4		True	True
PT.DP(NACL)	Data Output	Bool	%Q138.5		True	True
PT.DP(CO2)	Data Output	Bool	%Q138.6		True	True
PT.DP(Na2)	Data Output	Bool	%Q138.7		True	True
PT.DP(CL)	Data Output	Bool	%Q139.0		True	True
PT.V1	Data Output	Bool	%Q139.1		True	True
PT.P2	Data Output	Bool	%Q139.2		True	True
PT.V2	Data Output	Bool	%Q139.3		True	True
PT.Alarm: empty dosing liquid	Data Output	Bool	%Q139.4		True	True
PT.Alarm: full quality vessel	Data Output	Bool	%Q139.5		True	True
PT.Alarm: full water vessel	Data Output	Bool	%Q139.6		True	True
PT.Time to prepaire water	Data Output	Timer	%T1		True	True
RO.Mixer	Data Output	Bool	%Q8.6		True	True
PT.Mixer	Data Output	Bool	%Q8.7		True	True

Annex B

Hardware

- **Power supply:**
  - PS 307 5A
  - Load supply voltage 120/230VAC:24VDC/5A
  - 6ES7 307-1EA00-0AA0
- **CPU:**
  - CPU 314C-2 PN/DP
  - Work memory 192KB; 0.6ms/1000 instructions; DI24/DO16; AI5/AO2 integrated; 4 pulse outputs (2.5kHz); 4 channels counting and measuring with 24 V (60kHz) incremental encoders; integrated positioning function; PROFINET interface and 2 Ports; MRP; PROFINET CBA; PROFINET CBA Proxy; TCP/IP transport protocol; combined MPI/DP interface (MPI or DP master or DP slave); multi-tier configuration up to 31 modules; capable of sending and receiving in direct data exchange; constant bus cycle time; routing; firmware V3.3.
  - 6ES7 314-6EH04-0AB0
- **SM 331 AI 2x12BIT_1**
  - Analog input module AI2 x U/I/R/RTD/TC; 14 bits of resolution; accuracy appr. 1%; grouping 2; common mode voltage appr. 2.3VDC; configurable diagnostics; hardware interrupts; 20-pin front connector.
  - 6ES7 331-7KB02-0AB0
- **SM 332 AO 2x12BIT_1**
  - Analog output module AO2 x U/I 12bits of resolution; accuracy appr. 0.6%; grouping 2; common mode voltage appr. 3VDC; configurable diagnostics; configurable substitute value for output; 20-pin front connector.
  - 6ES7 332-5HB01-0AB0
- **SM 323 DI 16/DO 16x24VDC/0.5A_1**
  - Digital input / output module DI16/DO16 x 24DCV/0.5A; DI-grouping 16; DO-grouping 8; input delay appr. 1.2..4.8ms fix; input type 1 (IEC 61131); 4A per group; 40-pin front connector.
  - 6ES7 323-1BL00-0AA0

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