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MASTER

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Title:

Automation and Supervision of the Boiler Sootblowing System Using S7-300

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DEDICATION 1

To express my heartfelt gratitude to all those who contributed in many ways to the success of this project.

*To **Allah**, who is always there when I am in need. Thank you for guiding me and giving me strength in my everyday life. Your mercies and protection have been my constant support.*

*To my dear parents, **Toumi Mourad** and **Gabour Fariza**, thank you for supporting my dreams, providing me with everything I needed, and working tirelessly to shape who I am today. Accomplishing this is my way of making you proud, just as I am proud to be raised by such wonderful people.*

*To my beloved sisters, **Nadia**, **Lyna**,and **Hibat Errahmane**, and my precious brother, **Sid Ahmed**, thank you for everything you have done for me. You are truly the best siblings anyone could ever have.*

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To my friends, thank you for being such good company and for your unwavering support. Your encouragement and friendship mean the world to me, and I am grateful for all the wonderful moments we've shared together.

Toumi Nesrine

DEDICATION 2

First and foremost, I thank Allah for his guidance and blessings and for granting me the strength and perseverance throughout my journey.

*To my incredible mother, **Troum Saadia**, whose unwavering love and belief in me have been the stepping stone upon which I've built my life. Thank you for the countless sacrifices you've made, the late nights you stayed up listening to my anxieties, and the unwavering confidence you instilled in me even when I faltered.*

*To the cherished memory of my late father, **Sirine Said**. Your absence is deeply felt, and while tears well up knowing you can't be here to celebrate in person, I know you're cheering me on. This accomplishment is for you, Dad. You live on in every step I take*

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ABSTRACT

This project addresses a critical issue identified by the refinery of Algiers regarding the absence of a program for the sootblowing system. The sootblowing system is essential for maintaining operational efficiency in industrial settings. It employs steam technology across three distinct sequences; pre-heating, manual and automatic. Our project not only delivers the Step 7 program required for the effective operation of the sootblowing system but also incorporates a human machine interface HMI. This last one facilitates system supervision enhancing user experience and ensuring coherent monitoring and control. Through the integration of both software and user interface design, this project offers a comprehensive solution to optimize the functionality and performance of the sootblowing system at the refinery of Algiers.

LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Actuator Sensor
(AS)
Arithmetic and Logic Unit
(ALU)
Burner Management System
(BMS)
Central Controller
(CC)
Central Processing Unit (CPU)
(CPU)
Communication Processor
(CP)
Data Block
(DB)
Decentralized Peripherals
(DP)
Distributed Control Systems
(DCS)
Erasable Programmable Read Only Memory
(EPROM)
Expansion Unit
(EU)
Function
(FC)
Function Block
(FB)
Function Block Diagram
(FBD)
Function Modules
(FM)
Graphical User Interface
(GUI)
Highway Addressable Remote Transmitter
(HART)
Human Machine Interface
(HMI)
Insertable Kenetic
(IK)
Instruction List
(IL)
Interface Module
(IM)
Internet Protocol
(IP)
Ladder Diagram
(LAD)
Maximum Continuous Rating
(MCR)
Medium Pressure
(MP)
Motor-operated valve
(MOV)
Multi Point Interface
(MPI)
Organization Block
(OB)
Power Supply
(PS)
Process Field Bus
(PROFIBUS)
Process Field Network
(PROFINET)
Programmable Logic Controller
(PLC)
Proportional Integral Derivative
(PID)
Random Access Memory
(RAM)
Read Only Memory
(ROM)
Resistance temperature device
(RTD)
Sequential Function Chart
(SFC)
Signal Modules
(SM)
Sootblowers Logic Cabinet
(SLC)
Sootblowers Power Cabinet
(SPC)
Sootblowers Push-Button Station (SPBS)
(SPBS)
Structured Text
(ST)
Supervisory Control And Data Acquisition
(SCADA)
Transmission Control Protocol
(TCP)
User Datagram Protocol
(UDP)

GENERAL INTRODUCTION

Human beings have always been responsible for performing tasks, but as tasks became more complex and demanding, their limited performance capabilities became apparent. As industries expanded and technological advancements increased the complexity of tasks, it became clear that human performance alone could not keep pace with the growing demands for efficiency, precision, and speed. This led to a desire to make these tasks easier and faster, ultimately giving rise to the concept of automation.

Automation engineering seeks to reduce or even eliminate human intervention in processes. The roots of this field can be traced back to the ancient Greeks, who were the first to show an interest in automating processes. They invented many devices that operated independently, often referred to as automata (meaning acting of one's own will) [1].

Today, automation engineering can be applied to a wide range of scenarios across various domains, including the gas and oil industry.

Since boilers are essential components in the oil and gas industry, they are prone to accumulating deposits and soot on their furnace surfaces. To control the level of ash and deposits on the heat transfer sections, a system known as sootblowing is introduced [2].

Sootblowing, an integral cleaning system utilized in industrial settings, employs specialized devices known as sootblowers to effectively remove accumulated soot deposits. These devices utilize steam to dislodge and expel soot from internal furnace tubes, ensuring optimal performance and efficiency in boiler operations.

At the Algiers refinery, in Boiler Feed Water and Steam unit 751, two similar boilers are installed, necessitating an operational sootblowing system. However, the existing system is out of service because the seller did not create the necessary program.

The objective of this project is to develop an automatic sootblowing system using a Programmable Logic Controller (PLC), which is advantageous for managing complex programs efficiently. This project involves three key components: creating the automatic sootblowing program, simulating the system using Step 7 software, and developing a Human Machine Interface (HMI) for supervision using WinCC software.

To this end, the present project is divided into five chapters, each covering the main aspects of the study. The first chapter provides a general presentation of the refinery and its units. The second chapter focuses on control systems and instrumentation. The third chapter describes the sootblowing system of boilers and offers a detailed look at sootblowers. The fourth chapter outlines the software (STEP 7, WinCC) and hardware (PLC) used for the program. The fifth chapter discusses the program and supervision of the project, summarizing the results and simulations. Finally, a general conclusion is presented, encapsulating what we have accomplished in the project, while also discussing potential avenues for further improvements and future developments.

CHAPTER 1:

Presentation of the Algiers Refinery

1.1 Historic

The Algiers Refinery is a unit for treating and refining crude oil. It was established in 1960 by a French company named 'Foster Wheeler'.

Operations commenced in 1964, with the complex costing 27 billion cents.

Its purpose is to process crude oil from HASSI MESSAOUD, as well as condensates from HASSI R'MEL, to meet the growing fuel consumption demands of the national market.

From January 10, 1964 until 1971, the refinery was supplied by tankers from the BEJAIA oil port and the Algiers oil port, and then through a pipeline with a diameter of 26 inches to the storage facility. Starting in 1979, a connection from BENI-MANSOR was made using a 24-inch diameter pipeline linking HMD/BEJAIA. An oil pipeline with a diameter of 16 inches and a length of 131 km was established to supply the refinery directly, with an hourly flow rate of $500m^3$.

1.2 Geographic location of the refinery

The refinery is situated 5 km south of the city of EL-HARRACH and 20 km from the capital ALGIERS at a location known as SIDI ARCINE, and it occupies an area of 182 hectares.

Figure 1.1: Aerial View of the Algiers Refinery.

1.3 Off-sites

The refinery has:

- **Tank farm**: it has 53 containers of different types (with a fixed roof and a floating roof) of a global capacity of 352100m^3 in which 200000m^3 are for crude oil.

- **Mixing and ethylation station**: for the production of automotive fuels.

- **Pumping stations**: they ensure the shipment of finished products to various NAFTAL depots and to the oil port through a network of pipelines.

- **Spheres**: contains 9 spheres of 15000m^3each for the storage of LPG and two tanks.

- **Loading ramp for LPG trucks.**

- **Petroleum port**: equipped with three loading and unloading berths as well as a deballasting and hydrocarbon skimming system.

It is equipped with:

1- A pipeline network connecting the oil port to the NAFTAL and RA1G depots.

2- A dock contains 03 loading/unloading berths.

3- A deballasting station

4- A fire protection system.

- **Laboratory**: The Algiers refinery has a laboratory where they analyze various products resulting from the refining process.

This laboratory is divided into 2 sections:

  - Quality control section.
  - Chemistry section.

- **Security**: Their main role is to protect humans, environment and material goods.

1.4 The main reasons to consider for transitioning to maintenance

- Technological evolution.
- Regulatory constraints.
- Automation.
- Depreciation.
- Cost.

1.5 Different types of maintenance

We can essentially distinguish two main types of maintenance:

- Reactive maintenance
- Preventive maintenance

1.5.1 Reactive maintenance

The maintenance performed following an equipment failure.

1.5.2 Preventive maintenance

Preventive maintenance is maintenance performed with the intention of reducing the probability of equipment failure or degradation of a service provided. It involves prepared, planned, and scheduled maintenance intervention before the likely date of failure occurrence.

It aims to prevent equipment failures during operation.

1.6 Main categories of maintenance

Maintenance is important as it aims to prolong the lifespan of equipment and enhance productivity. Within the refinery, maintenance is divided into several crucial categories, each serving its own vital purpose. These categories are organized as follows :

- Planning
- Mechanics
- Electricity
- Piping and boilermaking
- Logistics
- Instrumentation

1.7 The organogram of Algiers refinery

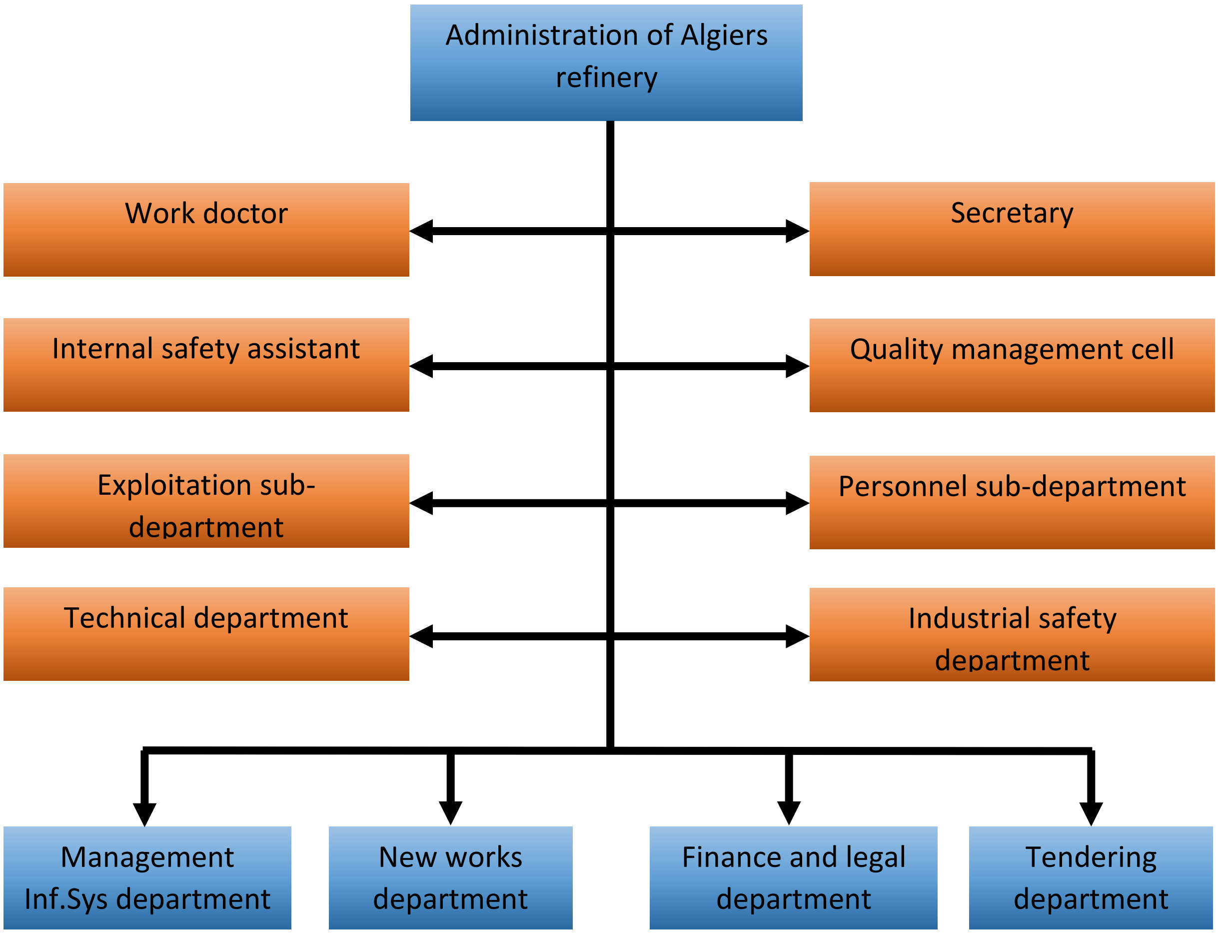


Figure 1.2: The organogram of Algiers refinery.

1.8 Units of Algiers refinery

1.8.1 Unit of atmospheric distillation U100

The objective of the Atmospheric Distillation Unit (ADU) is the primary separation of crude oil to produce direct blends of distillates (after appropriate downstream treatment processes) and feedstocks for other downstream processing units.

The crude oil feed is preheated relative to the product and circulating reflux before undergoing initial fractionation in the pre-vaporization column.

A pre-vaporization column separates the unstabilized naphtha from the pre-vaporized crude.

The pre-vaporized crude is then routed to another preheating stage relative to the product and circulating reflux before passing through a heater.

The pre-vaporized crude fractionation is carried out in the crude column and associated side-stream rectifiers.

The unstabilized naphtha from the pre-vaporization column is then processed in the debutanizer.

The products are cooled and transferred to intermediate storage or treated as necessary.

The unit is designed to operate with RA1G crude oil.

The definition of RA1G crude oil quality is provided by the OWNER based on standard crude oil analysis.

- **Process chemistry:** According to the crude oil quality analysis provided by the OWNER, the crude oil has a K value of 12.19, which classifies it as paraffinic.

- **The capacity of ADU U100:** The modernization of the entire distillation section will ensure the processing of 3,645,000 tons per year of RA1G crude oil.

- **Feedstock Quality:** The definition of the quality of RA1G crude oil is provided by the OWNER based on standard crude oil analysis. These reports provide the crude oil's API gravity, K value, sulfur content, and product yield.

- **Products fractions:** The following fractions must be produced in the atmospheric distillation unit:

  - Light fractions (gaseous effluent and LPG) for feeding the gas plant (GP).
  - Total naphtha for feeding naphtha hydrotreating unit (NHT).
  - Kerosene for storage
  - Light diesel for storage
  - Heavy diesel and atmospheric residue for feeding the catalytic cracking of residual fluids.

- **Product fractionation points :**

	Fractionation points TBP (°C)
Stabilized naphtha	C5-140
Heavy naphtha	140-165
Kerosene	165-240
Light diesel	240-345
Heavy diesel	345-365
Atmospheric residue	365

Table 1.1: Product fractionation points.

1.8.2 Gas Plant Unit U-300

The existing gas plant (GP/U-300) currently processes the following LPG streams:

- LPG from the stabilizer of the Atmospheric Distillation Unit (ADU/U-100).
- LPG from the Catalytic Reforming Unit (U-200).

The existing Catalytic Reforming Unit (U-200) will be dismantled.

A new Catalytic Reforming Unit (CCR) (U-520) will be installed, and the existing gas plant will be able to collect LPG as follows:

- LPG from the stabilizer of the Atmospheric Distillation Unit (ADU/U-100).
- LPG from the new CCR unit (U-520)

The design capacity for the modernization of the gas plant will be consistent with the capacities of the ADU and the new CCR unit.

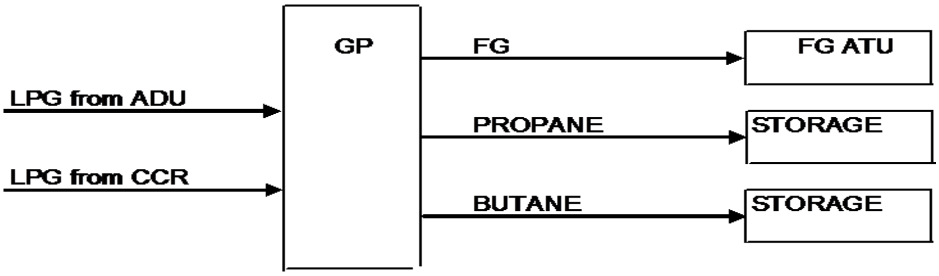


Figure 1.3: Simplified flow diagram.

1.8.3 MS block unit Comprises 3 units

1.8.3.1 U500 - Naphtha Hydrotreating Unit (NHT)

The objective of the naphtha hydrotreating unit is to produce clean hydrotreated feeds to supply the isomerization unit (Unit 510) and the Reforming unit (Unit 520). These feeds must have sufficiently low levels of contaminants, such as sulfur, nitrogen, water, halogens, diolefins, olefins, mercury, arsenic, and other metals, to avoid affecting downstream units.

The naphtha hydrotreating unit is fed with straight-run naphtha from the upstream crude oil distillation. This naphtha contains concentrations of contaminants that are detrimental to reforming and isomerization catalysts, thus requiring pretreatment.

This process, designed and licensed by Axens, consists of three consecutive operations:

- Naphtha treatment in an adiabatic reactor on a fixed-bed bimetallic catalyst in a hydrogen environment. A moderately high temperature ranging from 280°C to 310°C is necessary to promote these chemical reactions (Reaction Section).
- Stripping of the hydrotreated crude product to remove light fractions, gaseous products including hydrogen sulfide (H2S), and water (Stripper Section).
- The wide-cut naphtha is then separated into specified fractions to feed the isomerization unit with light naphtha and the Reforming unit with heavy naphtha (Separator Section).

A sulfur guard bed is installed on the bottom stream of the stripper to protect downstream units from dissolved H2S carried over during stripper upsets. Similarly, a mercury guard bed is placed on the desulfurized naphtha to remove any trace of mercury present in the naphtha sent to downstream units.

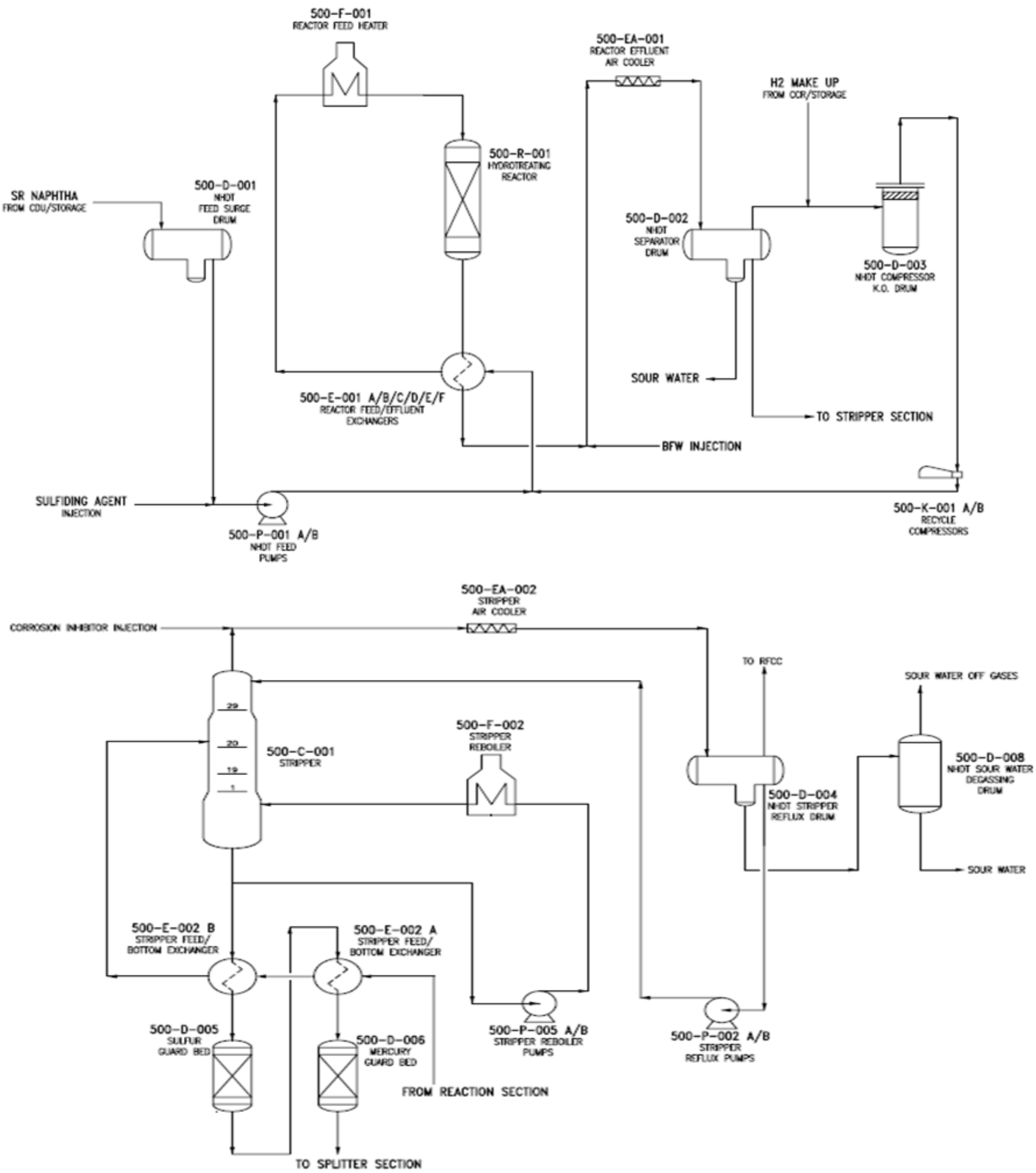
The naphtha hydrotreating process is a catalytic refining process that uses the Axens HR-516 hydrotreating catalyst and a hydrogen-rich gas stream to decompose organic sulfur and nitrogen compounds in the straight-run naphtha. Additionally, the NHT unit serves to separate the straight-run naphtha into light and heavy naphtha to respectively feed downstream isomerization and Catalytic Reforming (CCR) units.

The naphtha hydrotreating process is used to remove catalyst poisons from the light naphtha isomerization catalyst before feeding the downstream isomerization unit.

The HR-516 hydrotreating catalyst used in the hydrotreating process consists of an alumina base impregnated with cobalt and molybdenum oxide compounds. The catalyst is insensitive to most poisons that affect dehydrogenation/isomerization reactions. The HR-516 is delivered in oxide form and is sulfided by injection of sulfiding agents.

The high performance of the Catalytic Reforming unit and the isomerization unit largely depends on the efficiency of the naphtha hydrotreating unit.

The figure below presents a schematic of the Reaction Section processes of the NHT unit.



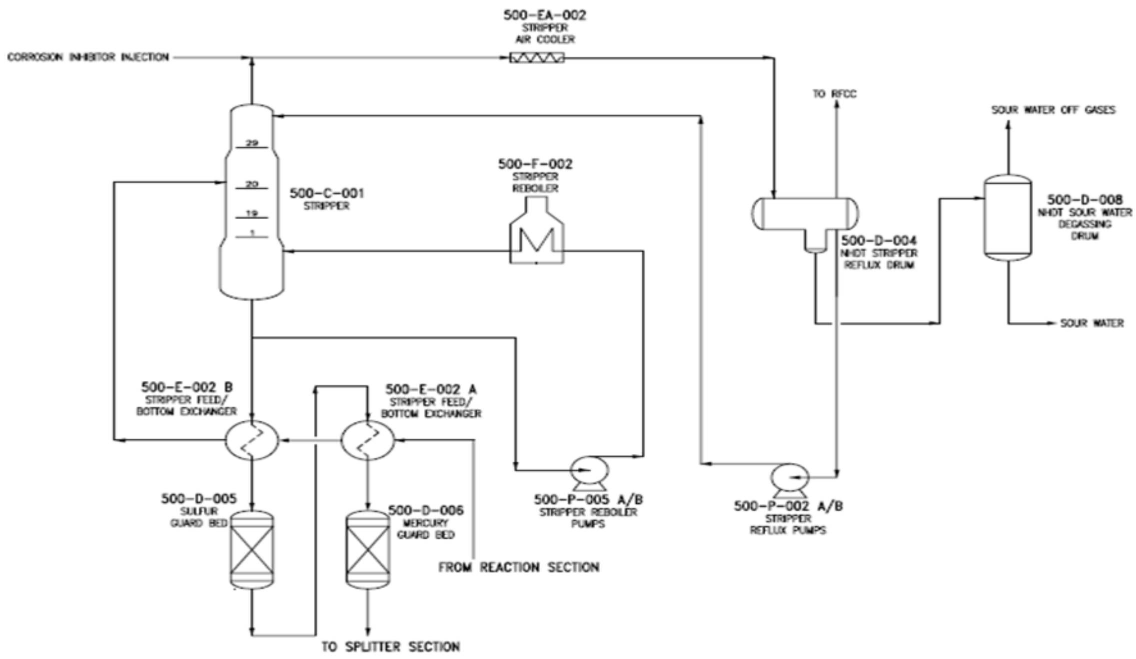


Figure 1.4: NHT unit reaction section.

1.8.3.2 U510 - Light Naphtha Isomerization Unit (ISOM)

The objective of this process is to improve the Research Octane Number (RON) and Motor Octane Number (MON) of the light naphtha feed (mainly C5/C6) before blending into the fuel pool. The light naphtha fraction typically has a high content of normal isomers, resulting in a low octane number (usually < 68). The isomerization process converts, at equilibrium, a portion of these low-octane normal isomers into branched isomers with a higher octane number.

1.8.3.3 U520 - Catalytic Naphtha Reforming Unit (CCR)

Octanizing® is the registered trademark of the Licensor (Axens) for the continuous catalytic regeneration reforming process.

The Octanizing® process aims to produce high-octane reformate, one of the main components of the gasoline stock, as well as a hydrogen-rich gas.

The Octanizing® feed is either straight-run naphtha or cracked naphtha, typically blended with straight-run naphtha. Due to the systematic presence of contaminants and the specific characteristics of cracked naphtha, some form of pretreatment of the naphtha is always required.

Octanizing® is a catalytic naphtha reforming process based on technology owned by the Licensor. It consists of two sections :

- Catalytic reforming of the naphtha itself, including reactors, heaters, effluent recovery, and stabilization;
- Catalyst circulation and continuous regeneration involving solid handling and moving bed technology.

The reforming reactions take place in the mobile bed catalytic reactors, from which the catalyst is removed, regenerated, and recycled. Catalyst circulation and regeneration occur on a continuous basis with full automatic control of all operations.

A high temperature (around 500°C) is required to promote the chemical reactions that improve octane number. Hence, preheating of the feed is necessary for this process.

Additionally, some of the desirable reactions are highly endothermic, leading to the majority of the catalyst being separated across multiple reactors with intermediate heaters.

1.8.4 U530 - Residual Fluid Catalytic Cracking Unit (RFCC)

The objective of the Residual Fluid Catalytic Cracking Unit (RFCC) is to convert heavy crude oil fractions RCO + HGO from the Atmospheric Distillation Unit (Unit 100) into lighter hydrocarbons of higher value at high temperature and medium pressure in the presence of a catalyst based on finely divided silica and alumina.

During the cracking of large hydrocarbon molecules into smaller molecules, a non-volatile carbonaceous material, commonly referred to as coke, deposits on the catalyst. Vaporization and cracking reactions take place in the "riser-reactor" within approximately two seconds. The coke deposited on the catalyst neutralizes the catalytic cracking activity of the catalyst by blocking access to active catalytic sites. To allow for the regeneration of the catalytic activity of the catalyst, the coke deposited on the catalyst is burned with air in the regeneration vessel 530-R-002.

One of the main advantages of fluid catalytic cracking is the ability for the catalyst to easily circulate between the reactor and regenerator when fluidized with an appropriate vapor phase. In an RFCC unit, the vapor phase on the reactor side consists of vaporized hydrocarbons and steam, while on the regenerator side, the fluidizing medium consists of air and combustion gases. Thus, fluidization allows the hot regenerated catalyst to come into contact with the fresh feed; the hot catalyst vaporizes the liquid feed and catalytically cracks the vaporized feed to form lighter hydrocarbons. Once the gaseous hydrocarbons are separated from the spent catalyst, the hydrocarbon vapor is cooled and fractionated to yield the desired product streams in the main column section.

The separated spent catalyst flows by vapor fluidization from the reactor to the regeneration vessel where the catalyst coke is burned to restore its activity. The combustion of coke releases a large amount of heat. Most of this combustion heat is absorbed by the regenerated catalyst and returned to the reactor by the fluidized regenerated catalyst to provide the heat needed to drive the reaction side of the process. The ability to continuously circulate a fluidized catalyst between the reactor and regenerator allows the RFCC unit to operate efficiently as a continuous process.

The products from the main column section are light catalytic cracking gas oil (LCO) and clarified oil (CLO, sometimes referred to as main column bottoms). For maximum distillate operation, heavy naphtha is blended with the LCO product and the HCO is recycled into reactor column 530-R-001.

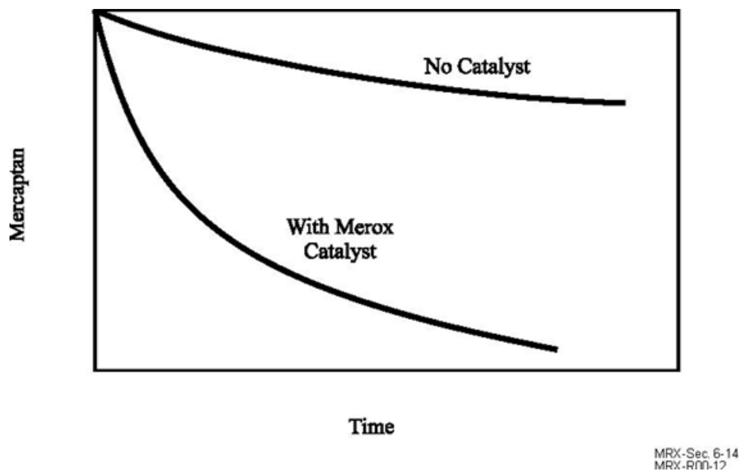


Figure 1.5: Oxidation of mercaptans with air and caustic soda.

This reaction occurs at normal temperatures and at an economically advantageous rate for refinery process end streams.

For lighter products, the operating pressure is controlled slightly above the boiling point to ensure liquid-phase operation; for heavier products, the operating pressure is generally set to maintain dissolved air in the reaction section. Downstream pressure requirements are easily met through appropriately sized product pumps.

1.8.5 U560 - Amine Treatment Unit for Fuel Gas (FGATU)

The objective of the Amine Treatment Unit for Fuel Gas (FGATU) is to reduce the H2S content of the acidic gas produced in the process units of the Algiers refinery through chemical absorption using an amine solution. The circulating amine is a 25% by weight solution of diethanolamine (DEA).

The acidic fuel gas is produced in the following units:

- Atmospheric Distillation Unit/Gas Plant (ADU-100/GP-300)
- Residual Fluid Catalytic Cracking (RFCC-530)
- Naphtha Hydrotreating Unit (NHT-500)

1.8.6 U570 - Acid Water Stripping Unit

The Acid Water Stripping Unit (SWS) is designed to treat combined acid water from the Atmospheric Distillation Unit (ADU-100), the Residual Fluid Catalytic Cracking Unit (RFCC-530), the Naphtha Hydrotreating Unit (NHT-500), the Amine Regeneration Unit (ARU-580), and the Residual Gas Treatment Unit (TGTU-590).

After treatment, the stripped water product is discharged to the Atmospheric Distillation Unit (ADU-100), the Residual Fluid Catalytic Cracking Unit (RFCC-530) for use as wash water for the desalter, or the Effluent Treatment Plant (ETP).

The SWS unit is designed to treat 41.5 t/h of acid water. The unit is capable of treating acid water at capacities ranging from 41% to 110% of the total design feed rates.

1.8.7 U580 - Amine Regeneration Unit

The objective of the Amine Regeneration Unit (ARU) is to provide lean amine to the Fuel Gas Amine Treatment Unit (FGATU) and the Merox Unit by caustic, and to regenerate the rich amine from these two units. The circulating amine is a 25% by weight solution of diethanolamine (DEA).

1.8.8 U711/U710 Cooling Water Networks

The cooling water unit 711 provides cooling water to users within the refinery and is supplied by the raw water unit 701.

The users of unit 711 are as follows:

- The MS Block.
- The RFCC Block.
- The S Block.
- The new storage park (unit 901).
- The new fluid installations (units 751, 781, 810, 830, 840).

The atmospheric distillation unit (U100), the gas plant (U300), and the fluid installation (U750) are still cooled by cooling water unit 710.

The two cooling water units 710 and 711 are completely independent.

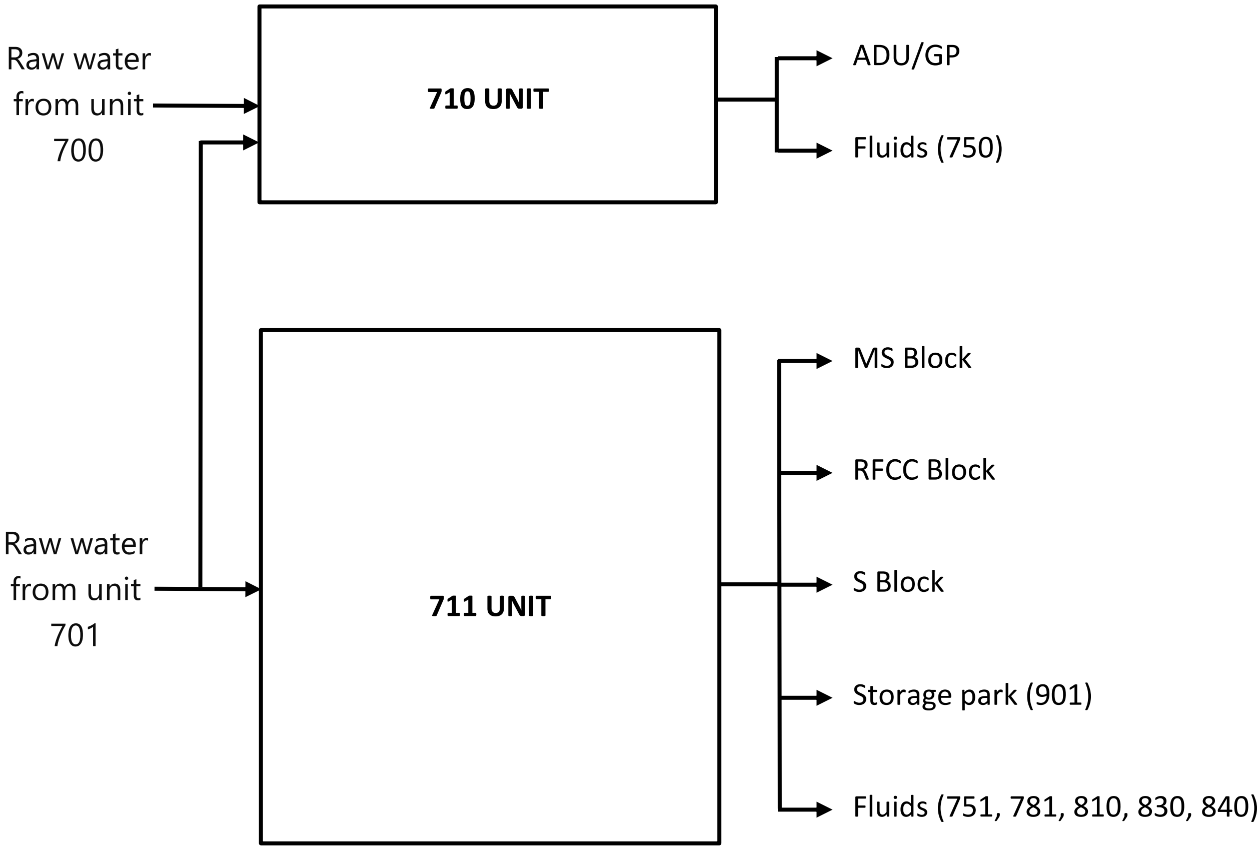


Figure 1.6: Cooling water networks.

1.8.9 U720 Demineralized Water

The demineralized water unit 720 receives raw water from the raw water unit 701 within the refinery and processes this water to convert it into demineralized water.

The demineralized water unit 720 distributes demineralized water to various users within the refinery:

- Make-up water for the boiler feedwater system.
- Solvent for preparing chemical solutions.
- Water for dilution, reaction, and washing purposes.
- Reserved desalted water for the desalter in unit 100 when stripped water and raw water are unavailable.

Note: Demineralized water is also used to fill the cooling loop for sealing equipment (such as compressors and pumps).

1.8.10 U730 Existing Potable Water Network

The existing potable water unit (U730) is currently used to meet the demand for drinking water in existing buildings and as sealing water for flare stacks, as well as to cool export pumps off-site.

This unit is supplied by the raw water unit (U700) via raw water pumps (G 305/306/307). The raw water (quality of water from drilled wells) is filtered and treated with a sodium hypochlorite solution to achieve potable water quality.

After the rehabilitation and adaptation phase, the potable water unit (U730) is retained, and a new set of pumps 730-P-001 A/B (one in operation + one on standby) is implemented and dedicated to new buildings (sanitary facilities) and new safety equipment (safety showers and eyewash stations). These pumps are connected to the existing potable water storage tank.

The new potable water network (from 730-P-001A/B) will be separate from the existing potable water network (from G205/G206).

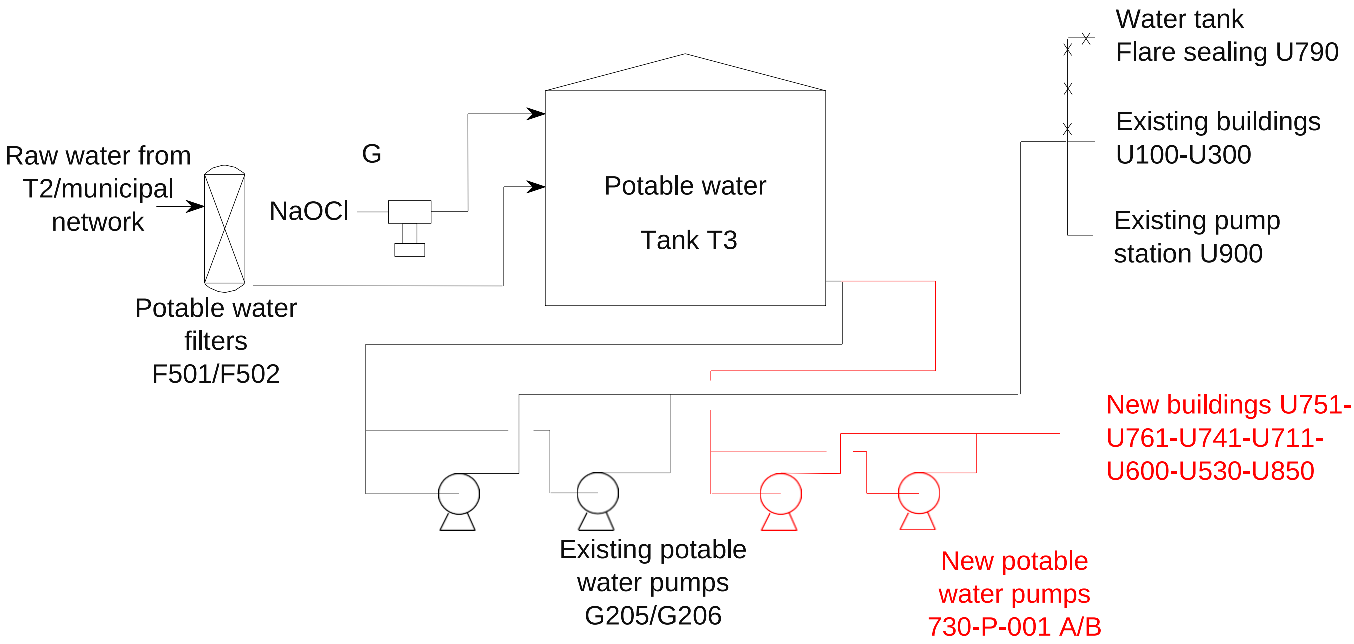


Figure 1.7: Existing potable water network.

1.8.11 U751/U750 Boiler Feed Water and Steam Unit, New and Existing

The boiler feed water and steam systems are part of the new installations for the Algiers refinery and are designated as CPP 751 (Clean Power Plant, or dedicated power plant, meaning electricity production for internal consumption).

This unit is designed to provide steam to consumers in the process unit facilities and to produce high-quality boiler feed water (BFW) used internally by the new boilers and also supplied as high-pressure BFW to various refinery units.

Additionally, the complex is equipped with a Gas Turbine Generator (GTG) and a Steam Turbine Generator (STG) connected to the Electrical Control System (ECS) and covering the electrical needs of the entire refinery.

Electricity is generated by the GTG and STG within the new CPP. If necessary, electricity can also be imported from the Sonelgaz national grid.

High-pressure steam is produced by:

- 2 boilers (at the new CPP level)
- 1 Heat Recovery Steam Generator (HRSG) (at the new CPP U-750 level)
- 2 existing boilers (at the existing CPP level)
- 1 steam generator (at the Residual Fluid Catalytic Cracking unit, RFCC)
- Steam production system (at the MS-Block level).

The BFW is produced by a new deaerator and feeds the boilers of the new CPP and the HP BFW network.

The new CPP receives demineralized water from U-720, pure condensate from the refinery units' collector, and polished condensates from U-830.

STG 751-M-002

Heat Recovery Steam Generator (HRSG) 751-M-003

Diesel storage tank 751-TK-001

Diesel pumps 751-P-004A/B

Diesel filters 751-ST-001 A/B

MP desuperheaters and discharge station 751-TDX-002 A/B & 751-FV-0004.

1.8.12 U761/U760 New and Existing Fuel Oil and Fuel Gas System

The objective of the fuel oil and fuel gas system is to supply fuel to the combustion heaters of the process units as well as the power plant boilers and the Heat Recovery Steam Generator (HRSG) of the new Clean Power Plant (CPP). The boilers and most heaters are of mixed type (using both fuel oil and fuel gas). Small users of fuel gas include the refinery flare system for purging pilots and collectors.

Fuel gas is produced from the refinery's gas effluents and is mainly composed of:

- H2-rich gas from the Catalytic Cracking Unit (CCR)
- Non-corrosive fuel gas from the Fuel Gas Amine Treatment Unit (Unit 560)

Natural gas is used as fuel for the gas turbine in the new CPP (U751), as well as the Residual Fluid Catalytic Cracking unit (RFCC) (U530), as pilot gas, and also as backup fuel when the refinery's fuel gas consumption exceeds the quantity produced.

The fuel oil used as fuel corresponds to internal fuel oil and is produced in the RFCC (CLO). The fuel oil produced in the Atmospheric Distillation Unit (ADU) (HGO+RCO) is used to feed the RFCC (under normal operation). The option to send it to the internal fuel oil network still exists but does not correspond to normal operation.

1.8.13 U781/U780 New and Existing Compressed Air System

Compressed air is necessary in the refinery for the following purposes:

- Instrument air: For operating instruments used in the facility as well as purging certain control panels.
- Compressed air for firefighting taps, catalytic regeneration, furnace decoking, etc.

The compressed air required for the various functions mentioned above is generated at a centralized location within the plant and distributed to various users via collectors. There are two qualities of compressed air produced and distributed:

- Compressed air: Compressed air cooled to ambient temperature. Although this air does not contain entrained water droplets, it is saturated with water vapor undersupply conditions.
- Instrument air: Compressed air cooled to ambient temperature and dried to remove water vapor and meet a dew point according to atmospheric requirements.

The existing compressed air system covers the compressed air needs of the plant and instrument air for existing processing units, namely: Atmospheric Distillation Unit (ADU) (U-100), Gas Plant (GP) (U-300), and corresponding external equipment and facilities. The current system will comply with the modernization requirements of the existing units after rehabilitation.

The new compressed air system will be designed to provide compressed air to the new processing units, new fluid circuits, and new external installations of the rehabilitation and adaptation project, according to the necessary conditions, quality, and quantity.

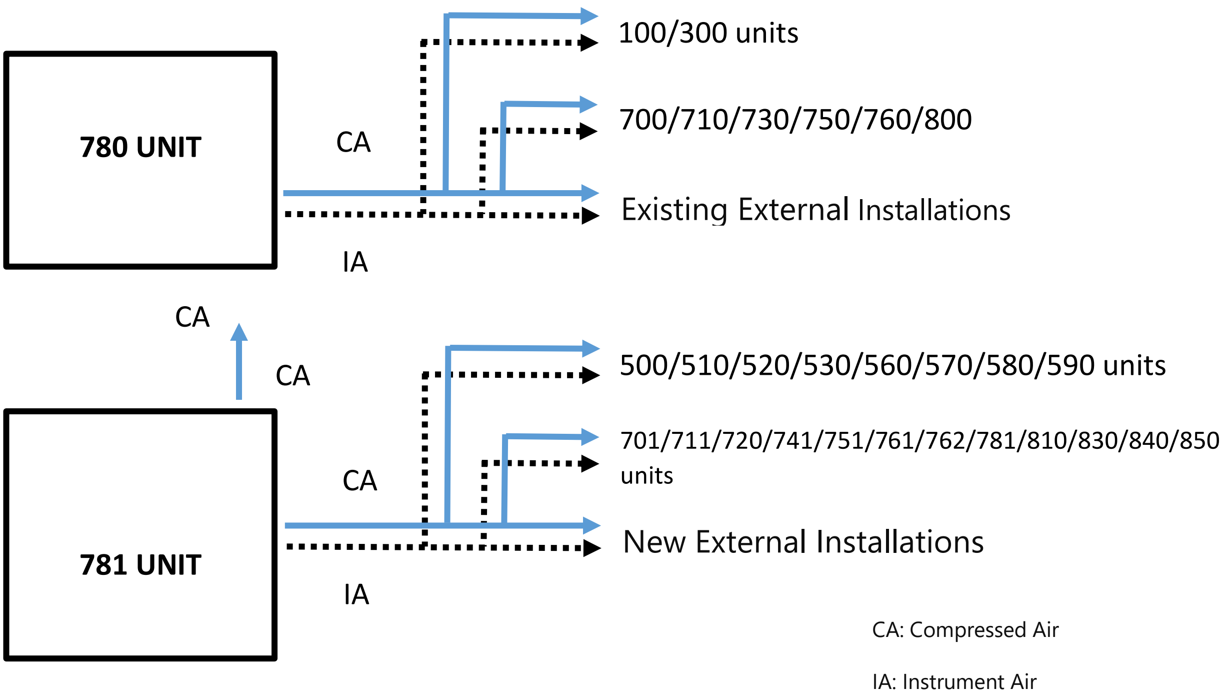


Figure 1.8: Compressed air systems.

1.8.14 U791 Flare network

The flare system safely collects and disposes of the refinery's gaseous hydrocarbon discharge streams, as well as any liquids entrained or condensed within the flare lines. It allows for smokeless processing conditions up to 3% of the design capacity of the main hydrocarbon flare. It is designed to comply with authorized limits for ground-level radiation and noise emissions.

The flare system can operate in the following modes:

- Normal Conditions :

Purge gases are regularly sent to the flare headers, including during maintenance activities, equipment failures, or malfunctions.

- Emergency Conditions / Upsets: These conditions may occur in the following cases:

  - Isolated events causing discharge (isolated failures such as blocked outlet, fully open valve(s), lost gas, compressor shutdown, etc.).
  - Events occurring within the unit, such as fire, and partial fluid failure.
  - General power outage at the refinery.

Two flare subsystems are installed in the Algiers refinery:

1.8.14.1 Hydrocarbon (HC) Flare System

It receives discharges from all refinery units except the sulfur block:

From: ADU (U-100), gas plant - GP (U-300), NHT (U-500), LNISOM (U-510), CCR (U-520), RFCC (U-530), FGATU (U-560), Caustic Mercox (U-600), H2 cylindrical tanks (U-950), LPG spheres (U-910/U-911), current FG unit (U-760), new FG unit (U-761), new CPP unit (U-751), new GN station (U-762), and the connected area.

From the future connection to DHDS (U-540), HPU (U-550), and FCC gasoline desulfurizer (U-610).

1.8.14.2 Acid Gas (GA) Flare System

It receives discharges (gaseous hydrocarbon and acid gas flare discharges) from FGATU (U-560), acid water stripping unit (U-570), amine regeneration unit (U-580), and sulfur recovery unit (U-590).

The acid gas flare header and sub-headers are steam-traced to prevent flare line blockage caused by ammonium hydrogen sulfide solidification (usually from the acid water stripper).

1.8.15 U810 Nitrogen System

The nitrogen production unit comprises a gas and liquid nitrogen production unit with associated facilities for storage and vaporization of liquid nitrogen.

The entire system is designed to ensure:

- Inerting/drying of installations during startup.
- Purging of systems during shutdowns.
- Catalytic regeneration during/after the process.
- Continuous purging of compressor seal joints.
- Coverage of buffer tanks and storage tanks.

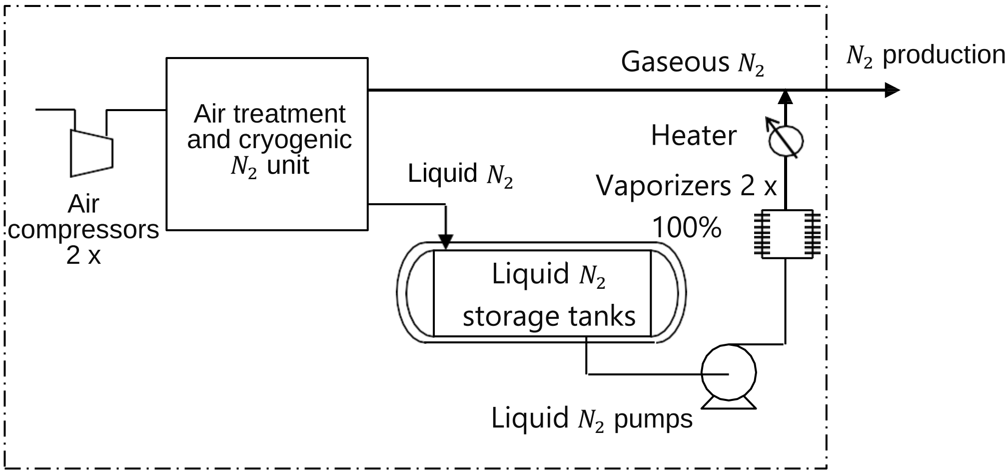


Figure 1.9: Nitrogen systems.

The nitrogen system covers the needs of all processing units, equipment, and external installations, both new and existing, in the refinery.

Under normal operation, gaseous nitrogen supplies the refinery, while liquid nitrogen is sent to three cryogenic storage tanks. Equipped with atmospheric vaporizers, these tanks serve as a backup system during nitrogen production shutdowns or to cope with refinery load peaks.

Process-related activities such as reactor section drying, system purging, catalytic regeneration, etc., require very pure nitrogen. Therefore, the choice is made for a nitrogen production unit based on cryogenic air separation technology.

1.8.16 U830 Condensate Polishing Unit

The Condensate Polishing Unit (CPU) is installed within the new fluid units of the Algiers refinery. This unit serves as a centralized treatment facility for polluted condensates generated by various refinery processing units. The purified condensates from the CPU (U-830) are returned to the deaerator of the new CPP unit (U-751).

The unit comprises:

- A shell-and-tube heat exchanger (polluted/purified condensate exchanger) 830-E-001
- A polluted condensate cooler 830-E-002
- Polluted condensate storage tanks 830-TK-001 A/B
- Polluted condensate feed pumps 830-P-001 A/B
- A condensate polishing assembly 830-M-001
- Purified condensate storage tanks 830-TK-002 A/B

- Purified condensate transfer pumps 830-P-002 A/B.

The neutralization system is shared with unit 720-M-001 and located inside unit U-720. Refer to the operation manual of unit U-720.

The polluted condensates from the modernized units are collected in the existing condensate vessel D3 located in the existing common fluid area U-703 and sent back to the CPU unit for treatment.

1.8.17 U840 Caustic Soda and Hydrochloric Acid

The caustic soda system is designed to meet the requirements of the following facilities:

For washing off gas emissions in the light naphtha isomerization unit (U510).

As a neutralization solution to neutralize the recycling liquid from the washing tank and to neutralize the liquid effluents from the washing tank in the naphtha reforming unit (U520).

For caustic soda treatment of LPG in the caustic Merox treatment unit (U600).

For the regeneration of anionic beds and mixed beds of demineralized water installation (U720) and CPU unit (U830).

For pH regulation of wastewater in the effluent treatment unit (U850).

For neutralizing HCl vapors in the HCl vapor absorber of the caustic soda and hydrochloric acid unit (U840).

Caustic soda will be delivered to the refinery by trucks in the form of solid pellets or a 50% weight solution. Dilution to a 20% weight concentration is done using demineralized water. All treatment units will receive a 20% weight caustic soda solution. Other dilution facilities have been planned within their own zone limits.

The hydrochloric acid circuit is designed to meet the requirements for regenerating cationic beds and mixed beds of the CPU unit (U830) and the demineralized water installation (U720).

Hydrochloric acid will be delivered to the refinery by trucks in the form of a 32% weight solution.

The caustic soda and hydrochloric acid unit consists of the following main equipments:

- Caustic soda dilution installation (solid/liquid unloading system, preparation tank, preparation pumps, cooler)

- Storage tanks for 20% weight caustic soda solution 840-TK-001 A/B

- Transfer pumps for 20% weight caustic soda solution 840-P-001 A/B

- Storage tanks for 32% weight HCl solution 840-TK-002 A/B

- Transfer pumps for 32% weight HCl solution 840-P-002 A/B

- Unloading pumps for 32% weight HCl solution 840-P-003 A/B.

For existing treatment units (ADU and gas plant units), the requirements for caustic soda are met from the existing caustic soda circuit.

1.8.18 U850 New Effluent Treatment Plant

The objective of unit 850 within the Algiers refinery is the treatment of all wastewater generated by the refinery's operations. Wastewater is collected and treated in the new Effluent Treatment Plant (ETP).

Main effluents from the refinery:

Effluents potentially contaminated with hydrocarbons

Mixed water sewerage with hydrocarbons (HY) collected by gravity within the refinery. This includes runoff from hard process areas, protected areas, areas bordered by curbs, truck loading and unloading areas, and tanker areas when there is a risk of hydrocarbon pollution.

These effluents are collected by gravity sewers into two recovery sumps. One recovery sump (850-CC-001) receives effluents from the new treatment units, and another recovery sump (850-CC-016) receives effluents from the existing treatment units. The water collected in both sumps is pumped to the new Effluent Treatment Plant assembly (850-M-001).

1.9 Conclusion

To maintain a stable and safe production rate with superior quality products, the petroleum industry must ensure the proper functioning of its various installations and equipment. For this purpose, it will greatly rely on maintenance services involving multiple disciplines such as instrumentation, electrical work, mechanical engineering, boiler making, and logistics.

CHAPTER 2:

Control Systems and Instrumentation

2.1 Introduction

In the realm of industrial processes, achieving precision, reliability, and safety is essential. Control systems, playing a critical role in achieving these criteria, are responsible for managing and regulating plants and processes to achieve desired performances and outcomes with minimal costs.

2.2 Control system

Control system is a set of interconnected components or devices that directs and regulates the behavior of plants or processes to achieve a desired outcome. It uses sensors, data processing, and actuators to control and monitor the output of a system based on a predetermined set of parameters or conditions.

2.3 Advantages of control systems

- Increasing efficiency and productivity while reducing costs.
- Reducing errors and increasing consistency leading to improved quality and product reliability.
- Instruments can replace human actions, leading to a reduction of human resources.
- Improving safety by reducing the risk of accidents, especially in hazardous environments.

2.4 Types of control systems

There are different types of control systems, including open loop, closed loop, cascade loop, and split range loop control systems. An open loop control system involves an input signal applied directly to the controller, generating an actuating signal that controls the process. This type is susceptible to internal and external disturbances, causing the output to potentially differ from the desired value. In contrast, a closed loop control system measures the system output, compares it with the input, and determines the error. This error is then used to adjust the system output to achieve the desired value.

Cascade control features a multi-loop structure, where the outer loop (master) controller's output becomes the set point for the inner loop (slave) controller. This setup allows the secondary controller to correct disturbances affecting the secondary variable before they impact the primary variable, thus speeding up the loop response by dividing control action between two controllers. Meanwhile, in a split range control loop, the controller’s output (ranging from 0% to 100%) is divided to control two different actuators. For instance, one valve is adjusted when the controller output is between 0% and 50%, and another valve is adjusted when the output is between 50% and 100%.

2.5 Measurement systems

Measurement involves the use of instruments for determining quantities of physical phenomena.

These systems may consist of:

2.5.1 Sensor

Sensing elements that detect and convert desired inputs into a more convenient format for handling.

2.5.2 Signal cconditioning

Intermediate modifying elements used for manipulating or processing the output of the sensor in a suitable form. In industrial processes, this device is known as the transmitter, it converts signals into standard signal forms (typically 4-20 mA for electrical signals).

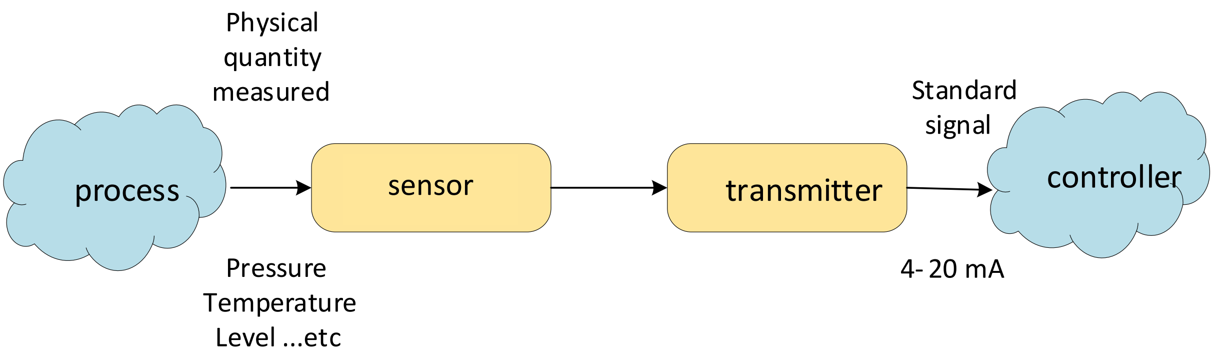


Figure 2.1: Signal conditioning block diagram.

2.6 Transmitters and instruments

2.6.1 Pressure measurement

Pressure is defined as a force per unit area and can be measured in units such as Pascal, bar, or psi.

2.6.1.1 Pressure indicators

Bourdon tube pressure gauges that operate using hollow tubes made of beryllium, copper, or steel, shaped into a unique three-quarter circle (as depicted in Figure 2.2). When pressure is applied, the outer edge of the cross-section with its larger surface area experiences a proportionally larger force than the inner portion. As a result, the diameter of the circle increases, causing the tube to straighten, which results in the movement of its free end. This movement can be linked mechanically to a pointer, which, upon calibration, provides an accurate line-of-sight indication of the pressure [3].

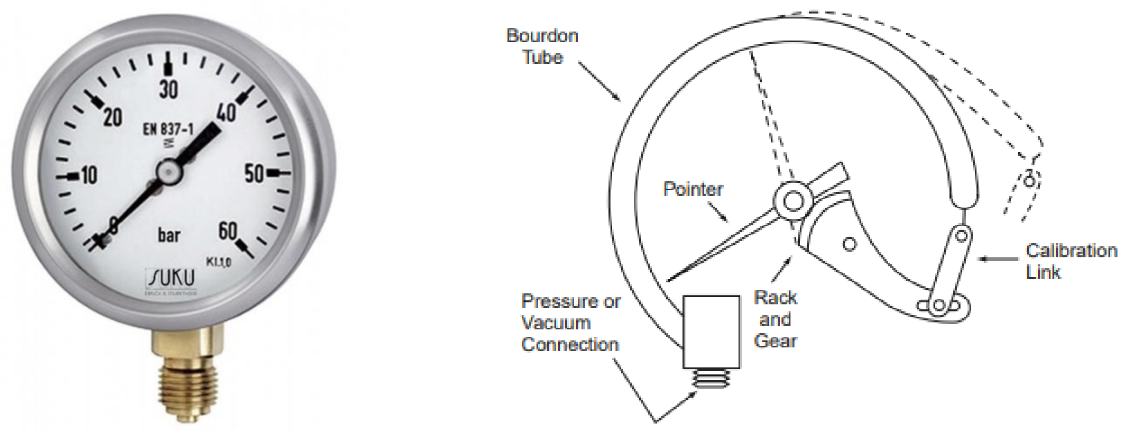


Figure 2.2: Bourdon tube pressure gauge.

2.6.1.2 Diaphragm-based pressure transmitters

Many pressure sensors depend on the distortion of a diaphragm for measurement. It is used to measure gauge, atmospheric, or differential pressure of gas, steam, or fluids.

A diaphragm consists of a thin layer or film of a material supported on an unbending frame. A wide range of materials can be used for the sensing film depending on the application.

When pressure is applied the diaphragm distorts. This movement can be sensed using a strain gauge, piezoelectric, or changes in capacitance [3].

Figure 2.3: Diaphragm-based pressure transmitter.

The sootblowing system incorporates two gauge pressure transmitters, each allocated to a boiler. These transmitters measure pressure within the range of 0 to 22 kg/cm²g based on diaphragm deformation. The output signals, spanning from 4 mA to

20 mA, are transmitted to the controller via the Highway Addressable Remote Transmitter (HART) communication protocol.

2.6.2 Temperature measurement

2.6.2.1 Thermocouple

It consists of two wires of different metals connected at one end. Applying heat to the junction produces a voltage between the two wires that is proportional to temperature exponentially. The other ends form a junction which is called a reference junction.

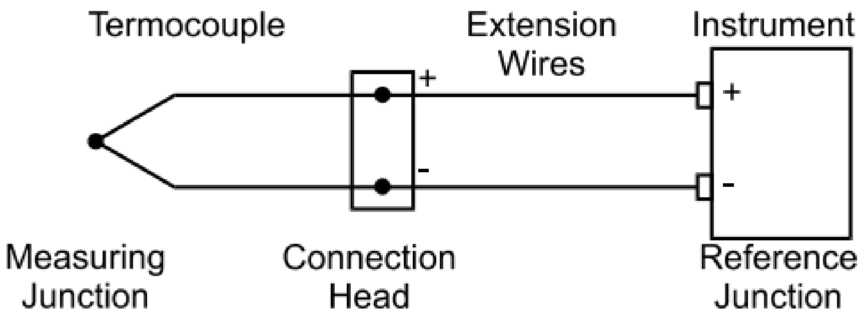


Figure 2.4: Thermocouple temperature sensor.

2.6.2.2 RTD

Resistance temperature device (RTD) is built from selected materials, such as platinum, copper, and nickel, which change resistance with temperature and it is generally wire-wound. The resistance generally increases linearly with temperature; in this case, the device has a positive temperature coefficient. These devices are accurate and can be used to measure temperatures from -170°C to 780°C [4].

The variation of resistance with temperature can be approximated by the linear representation:

$$R(T) = R_0(1 + \alpha T) \quad (1)$$

$R(T)$: the resistance at temperature T.

R_0 : the resistance at a reference temperature, usually 0°C.

α : temperature coefficient related to the material of the RTD.

T : temperature in °C.

In this project, eight three-wire RTD elements, manufactured by TERCOM, are employed for temperature measurement. These RTDs are integrated with YOKOGAWA YT110 temperature transmitters, which support the HART communication protocol to deliver 4-20 mA output signals. Each boiler is equipped with four RTDs, facilitating temperature measurements within the range of 0°C to 300°C.

Figure 2.5: RTD temperature sensor.

2.6.3 Limit switch

Limit switch is an electromechanical device that is used to detect the presence or absence of an object within a specific range of motion or position. It typically consists of a movable actuator linked to an electrical contact. When the actuator comes into contact with the object, it triggers a signal that is transmitted through the contact, indicating the object's presence [5].

Figure 2.6: Limit switch.

2.7 Actuators

An actuator is a part of the final control device that converts electrical signals into physical ones to control the plant.

2.7.1 Control valves

Control valves are the most common element in the domain of the process control industries. Valves control the fluid flow that consists of steam, water, gas, or chemical compounds.

A control valve is simply a variable orifice designed to regulate the flow of process fluid according to the requirements of the process. It consists of three main parts:

- The valve: contains the bonnet and the trim parts as well as the body of the valve.

- The valve actuator: converts a control signal (normally 3-15 psi or 4-20 mA) into the large force or torque that is needed to manipulate a valve [6].

2.7.2 Types of valves

Valves can be classified into 3 types based on their operating functions:

2.7.2.1 Manual control valve

It is a valve that is operated manually by plant personnel. Manual control valves are useful when ease of operation and good manual control is necessary and automatic control is not required. This type is often used when manual control of the process is needed during maintenance or shut down of the automatic system.

Figure 2.7: Manual control valve.

2.7.2.2 ON/OFF control valve

Also called shut-off valve, operates in two states: fully open or fully closed. These valves are frequently used to redirect fluids or process products to different locations.

2.7.2.3 Modulating control valve

Modulating control valve is an automated valve that enables accurate flow control in a system or process. Unlike simple shut-off or isolation valves, this type of valve requires a feedback control system to maintain the desired flow rate.

The core components of a modulating control valve include an actuator, a valve body, and a positioner. The actuator is responsible for moving the valve plug which controls the flow rate, while the positioner receives signals from the process controller to position the actuator accordingly, maintaining the desired setpoint.

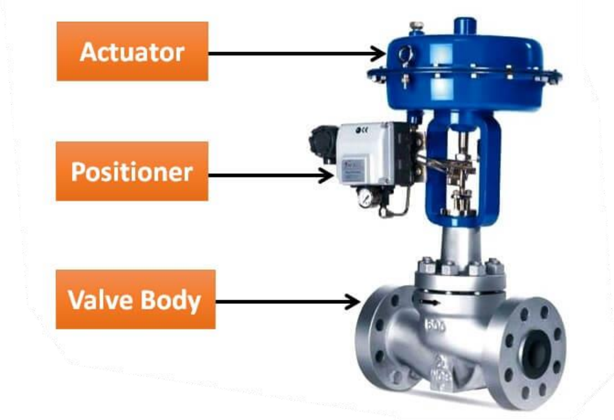


Figure 2.8: Modulating control valve.

2.7.3 Solenoid valve XV

Solenoid valve is a ball-type normally closed pneumatic valve with a model number AP50, made by ALFA VALVOLE with a single-acting piston actuator with model number GT143 SE and limit switches indicating open and closed positions. This type of valve boasts a fail-safe design employing air pressure for opening and a mechanical spring for closure. Controlled by a 24V DC signal, the actuator's electrical coil efficiently directs the airflow, offering seamless performance in various industrial applications.

This valve is specifically designed to function as a condensate drain valve during the sootblowing operation. Its purpose is to eliminate any presence of water droplets on the boiler's surface. This helps to protect the boiler's materials from any possible deterioration. For this purpose, the valve is made open during the preheating sequence and closed when the temperature reaches 250 °C, in other words when the preheating is complete.

Figure 2.9: Solenoid valve XV-1020.

2.7.4 Motor-operated valve (MOV)

Motor-operated valve is the one controlled by a 3-phase high torque electrical stepper motor IQ12F10A made by ROTORK. In addition to a 2-wire position transmitter (4-20 mA) based on hall effect technology to monitor the movement of the actuator, and limit switches indicating open and closed positions. This valve provides three positions for steam control: 0%, 20%, and 100%, rather than just an ON/OFF control.

- **Motor specifications:**
  - A 3-phase power supply of 400V AC at 50 Hz and 24V DC for the control signal.
  - Minimal power: 0.21 KW
  - Nominal current: 1.70 A
  - Starting current: 5.15 A
  - Failure position: locked (in case of power loss it stops at the last position attained).

Figure 2.10: Motor-operated valve MOV.

2.7.5 Motors

Electric motor converts electrical energy into mechanical energy. The motor operates through the interaction of the magnetic fields of the stator and rotor generated by either permanent magnets or current windings. In many industrial processes, an electric motor provides rotary or linear motion to a mechanical load.

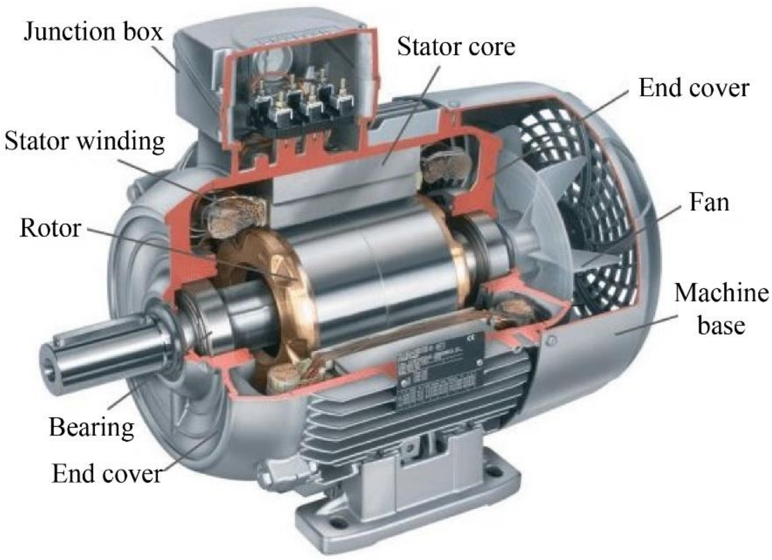


Figure 2.11: Electric motor.

The sootblowing system has three types of sootblowers: rake, retractable, and rotative. Each corresponds to a specific form and location of the tubing being cleaned to ensure efficient performance. All of them use the 3-phase asynchronous electrical motor with varying electrical powers depending on their use. 16 motors are being utilized, 8 for each boiler with 400V AC voltage distributed through the power cabinet.

Motors	**Power supply (V AC)**	**Nominal current (A)**	**Power (KW)**	**Number**
Rotative sootblower motor.	400	0.77	0.25	8
Retractable sootblower motor.	400	1.55	0.55	4
Rake sootblower motor.	400	1.09	0.37	4

Table 2.1: Sootblowers motors characteristics.

2.7.5.1 Stepper motor

A stepper motor is an electromagnetic actuator that can convert digital pulse inputs into analog output shaft motion. It is mainly used in digital control systems. The motor rotates a specific number of degrees in response to an input electrical pulse, and the typical step sizes are 2°, 2.5°, 5°, 7.5°, and 15° for each electrical pulse, depending on the rotor's number of poles. Due to its structure, the motor steps by a fixed angle according to the input train of pulses. As a result, neither a position sensor nor a feedback system to the controller is required to ensure that the desired position is attained [7].

2.8 Conclusion

Control systems are the central components that manage and regulate industrial processes within a plant. Their critical role is widely acknowledged, leading to careful consideration in the design and implementation of control systems, especially in medium and large-scale facilities where many different processes and machines are involved. Despite the recognized importance of control systems, their full optimization may not always be achieved in practice. This highlights an ongoing opportunity to refine and enhance control system design and operation to further improve the efficiency and productivity of industrial processes.

CHAPTER 3:

Sootblowing System Description

3.1 Introduction

A boiler at the Algiers refinery is a kind of enclosed vessel designed to facilitate combustion and transfer water to steam. It operates to deliver steam at a specific pressure and temperature levels, using a defined source of heat to ensure the efficient production of electricity.

With time, boiler surfaces accumulate deposits. This accumulation is a persistent problem in the operation of the boiler. If left unattended, deposits may form completely a thick insulation coating on the walls, significantly reducing:

- Transmission coefficients of heat, resulting in low steam generator efficiency.
- Gas passages in super-heaters by increasing charge losses in circuit.
- Thermal exchanges, that can introduce limitations to operating conditions.

If, for example, significant deposits are allowed to form on the walls of the furnace, the amount of heat absorbed by the boiler's screen tubes for the same heating rate decreases. The temperature of the combustion gases at the furnace outlet increases because the ashes act as a thermal insulator, and the temperature of the superheated and reheated steam cannot be brought back to the nominal value; therefore, the load must be limited.

Finally, excessive fouling of the furnace, as can occur with coal containing easily fusible ashes, can lead to the formation of large clinker blocks, which, when deposited between the superheater tubes, can unacceptably restrict the available passage sections for the combustion gases. Therefore, it is necessary to shut down the boiler to manually remove these deposits.

3.2 Necessity of sootblower

The word “soot” refers to black, carbonaceous fine particles that are formed during the combustion of coal, wood, oil, etc. Soot forms deposits on the walls of the combustors, chimneys, and pipes that convey the flue gas [8].

A sootblower is an essential component of industrial boilers, furnaces, and heaters, which plays a vital role in maintaining efficiency and longevity. These devices remove the buildup of soot, ash, and other deposits from the surfaces of heat transfer equipment, thus improving their thermal efficiency and reducing the risk of operational problems.

Sootblowers prevent these problems and ensure optimal performance. A sootblower removes the buildup of deposits regularly, preventing the accumulation of a thick layer that can impede heat transfer and increase the risk of corrosion.

In addition to preventing operational problems, sootblowers also reduce the frequency and cost of maintenance. Regular cleaning with a sootblower ensures that equipment is not damaged. Additionally, by minimizing wear and tear, prolonging the life of tubes, and preventing the need for premature replacement, sootblowers increase the longevity of heat transfer equipment.

Sootblowers are used in a variety of industries, including power generation, pulp and paper, steel manufacturing, and petrochemicals. In power plants, sootblowers are used to clean the surfaces of boilers and economizers to maintain optimal heat transfer and reduce the risk of corrosion.

In pulp and paper mills, a sootblower is used to clean the recovery boiler, which is responsible for recovering chemicals and energy from black liquor. In steel manufacturing, sootblowers are used to clean the surfaces of blast furnaces and boilers, which are used to produce steel. Sootblowers are used in petrochemical facilities to clean the surfaces of heaters that heat materials such as crude oil.

Figure 3.1: The accumulation of soot on boiler tubes.

3.3 Types of sootblowers

3.3.1 Rotary sootblower

A rotary sootblower is a device that operates by rotating a lance equipped with blowing nozzles or jets to remove the deposits from the surfaces.

A rotary sootblower consists of the following main components:

- Lance: a long, hollow tube equipped with blowing nozzles or jets.
- Motor and gearbox: to rotate the lance.

In the case of a rotary sootblower, the lance is supported by bearings mounted on the sootblower housing or frame. These bearings allow the lance to rotate smoothly within the boiler or furnace.

The sootblower housing or frame is securely attached to the boiler or furnace structure at specific locations where deposits are prone to accumulate such as on heat exchange surfaces or in convection sections. This ensures that the blowing action of the lance covers the desired area.

Rotary sootblower operates as follows:

The motor rotates the lance, causing it to sweep across the surface to be cleaned.

As the lance rotates, the blowing nozzles or jets emit medium, high or low-pressure steam or air onto the surface. The force of the steam or air extracts the soot, ash and other deposits from the surface.

The rotating motion of the lance ensures that the blowing action is operated in a wide area hence effectively cleaning the entire surface.

The operation of the rotary sootblower is controlled by a control system. Operators can schedule cleaning cycles based on operational requirements.

Because they are affixed and do not retract, rotary sootblowers cannot be utilized in the high-temperature areas of boilers.

Figure 3.2: Rotary sootblower.

3.3.2 Retractable sootblower

A retractable sootblower, also known as Insertable Kenetic (IK) is generally the most commonly used type due to its versatility and effectiveness in cleaning boiler and furnace surfaces. This type operates by extending the lance with blowing nozzles or jets into the boiler to dislodge deposits.

A retractable sootblower consists of the following components:

- Lance

- Extension mechanism: this allows the lance to extend into the boiler or furnace and retract back to its original position. It consists of mechanical components such as rods, gears or chains that facilitate the movement of the lance.

- Motor: to power the extension and retraction of the lance.

Like the rotary one, the retractable sootblower is also fixed at specific locations within the boiler where the accumulation of deposits is more likely to happen.

The motor extends the lance into the boiler or furnace to reach the surfaces to be cleaned.

Once the lance is extended, the blowing nozzles or jets emit medium, high or low-pressure steam or air onto the surface. The force of the steam or air dislodges the soot, ash, and other deposits from the surface.

After the cleaning cycle is complete, the motor retracts the lance back to its original position outside the boiler or furnace.

Operators can schedule their cleaning cycles based on operational requirements.

They are suitable for applications involving coal, biomass, oil, or gas-fired boilers.

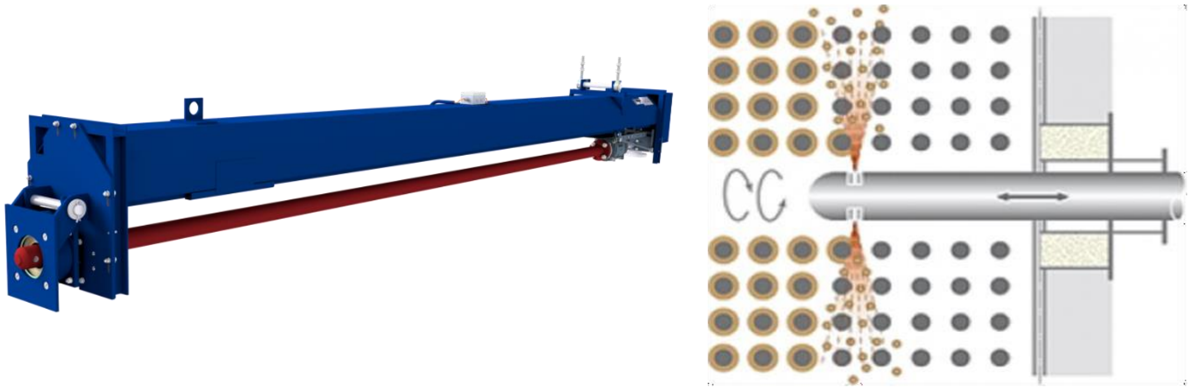


Figure 3.3: Retractable sootblower.

3.3.3 Rake sootblower

The rake sootblower is designed to clean finned heating surfaces: rotating basket-type air heaters, economizers... etc. Unlike retractable sootblowers which extend a lance into the boiler, rake sootblowers use a set of rake-like blades or fingers to scrape or rake the deposits off the surface.

It consists of several main components:

- Set of rake-like blades or fingers arranged in a pattern suitable for scraping the deposits off the surface.

- Mounting mechanism: it consists of brackets, frames, or other support structures that allow it to be positioned and moved across the surface to be cleaned.

- Electric motors, pneumatic actuators, or mechanical linkages to impart motion to the rake assembly to make it move back and forth across the surface ensuring a deep cleaning.

Its operation is done as follows:

The rake assembly is positioned against the surface to be cleaned, and the blades or fingers scrape or rake along the surface, removing the deposits.

The rake assembly moves back and forth across the surface, ensuring that all areas are thoroughly cleaned.

The dislodged deposits fall or are directed into collection bins or ash hoppers for removal from the system.

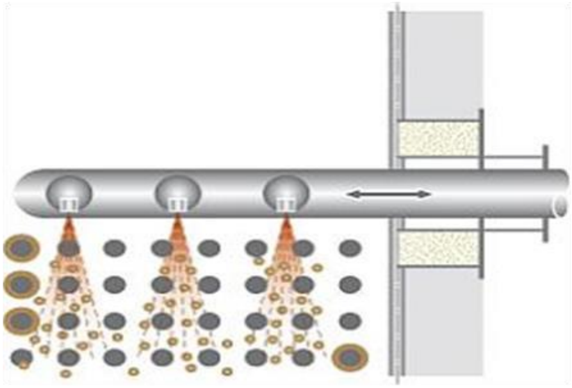


Figure 3.4: Rake sootblower.

3.4 Arrangement of sootblowers in boiler system

At the 751 unit of Algiers refinery, two identical mixed boilers are installed, each with a nominal capacity of 81.5 t/h. These boilers are of the "TITAN M" type from the supplier MACCHI. Both are steam generators with water tubes and natural circulation designed for continuous operation. Each one of them is ignited under positive pressure, and the combustion products traverse the entire length of the furnace before entering the evaporator tube bank.

Each boiler is equipped with an automatic control system and integrated instrumentation with the Burner Management System (BMS), allowing automatic supervision of the boiler and its burner operation.

Each boiler comprises the following main elements:

- **Drums**: The boiler has a steam drum and a water drum.

- **Combustion equipment:** It includes 4 low-NOx front burners. These burners are designed to have the ability to burn two different types of fuels: process gas and fuel oil. They can operate by burning only process gas, only fuel oil, or a mixture of both, provided they are supplied under correct conditions (pressure, temperature, composition, etc.) to ensure the required combustion performance.

- **Evaporation tube bank**: located in the main boiler chamber. It serves to connect the steam and water drums.

- **Superheater**: its function is to obtain dry steam by removing water droplets present in the steam at the steam drum outlet.

- **Economizer**: its objective is to recover heat from the exhaust gases leaving the boiler to heat up the feedwater for optimal efficiency.

- **Mobile fuel pumping skid**: A fuel pumping system, common to both boilers, is provided to feed the fuel collector at the front of the burner. The fuel pumps can supply up to 100% of the maximum continuous nominal fuel flow.

- **Fan**: the boiler is equipped with a single-suction centrifugal fan that provides combustion air to the burners.

- **Sootblowers**: to clean up the heating surfaces of the superheater, evaporation tube bank and economizer pipe with Medium Pressure (MP) steam from the plant collector.

- **Online analyzers** (O2, SO2, NOx, CO) are provided in the emission monitoring system.

The sootblowing system consists of:

Four (4) rotative sootblowers to clean the evaporation tube bank. Each sootblower rotative type is equipped with one (1) three-phase electric motor and one (1) limit switch for stopping after its sootblowing cycle (rest position).

Two (2) retractable sootblowers to clean the superheater bundles and two (2) rake sootblowers to clean the economizer pipe. Each sootblower retractable and rake type is equipped with one (1) three-phase electric motor and two (2) limit switches, one to withdraw (forward position) and one for stopping after its sootblowing cycle (rest position).

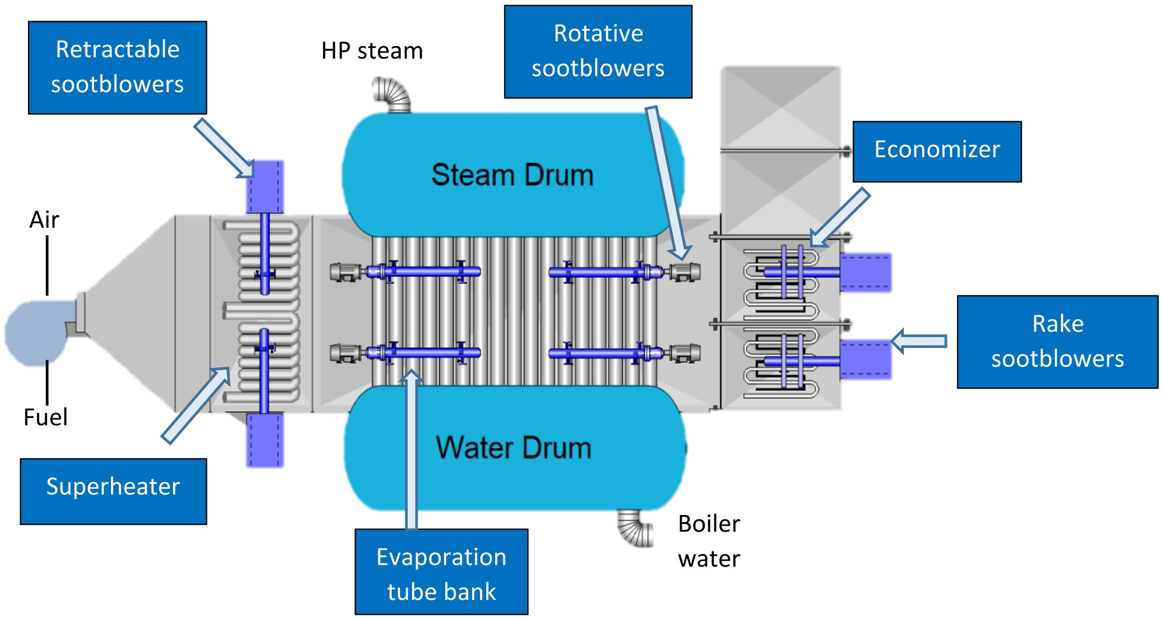


Figure 3.5: Placement of sootblowers by the boiler.

3.5 Description of sootblowers system operation for the different types of sootblowers

The operation of the sootblowing system is divided into three (3) distinct sequences, initiated by a pre-heating sequence and then two (2) modes of sootblowing sequence: auto and manual.

The sootblowing logic sequences will be implemented in the Sootblowers Logic Cabinet (SLC), which contains a Siemens S7-300 PLC. The SLC will interface with the SLP (Sootblowers Local Panel) located on-site and with the Sootblowers Power Cabinet (SPC), which will supply power to all the electric motors of the sootblowers. The SPC will contain the electric starters for the electric motors of the sootblowers and the motorized valve for the MP steam inlet. The limit switches of the sootblowers and the Sootblowers Push-Button Station (SPBS), installed on-site near the relevant sootblower, are connected to the SLC.

Figure 3.6: Sootblowers local panel.

3.5.1 Pre-heating sequence

The pre-heating sequence is always automatically performed before initiating the sootblowing sequence. Whenever the pre-heating sequence is operated successfully, it allows the initiation of the sootblowing sequence in all operating modes.

The following sootblowing permissive conditions must be satisfied before initiating the pre-heating sequence:

- Boiler running (US-1064 boiler load ≥ 40% MCR).
- MP steam to sootblowers motorized valve closed (MVSC-1020).
- MP steam pressure greater than 7 bar.
- All sootblowers in remote mode.
- All sootblowers in rest position.
- Sootblowers condensate drain pneumatic valve closed (XSC-1020).
- No “Electrical faults” present.
- No “Sootblowing failure” alarm present and reset (UA-1056A/B).
- No “Travelling time out” alarm present.

When all the above permissive are satisfied the <Sootblowing permissive> indication (UL-1050A/B) is switched on.

If the <Local / Remote> selector on the SLP is selected to <Local> position, the preheating sequence must be initiated using the <Start Sootblowing> push button (HS-1060B) on this panel. Conversely, if the <Local / Remote> selector on the SLP is in the <Remote> position, the preheating sequence starts at the end of the delay.

As soon as the sequence is started, the following steps are performed automatically:

- Automatic opening of sootblowers condensate drain pneumatic valve(XV-1020).
- Automatic opening to 20% of the motorized valve for the MP steam inlet (MOV-1020).
- After five minutes or when the sootblowers steam piping temperature has reached the prefixed temperature (TT-1020/TT-1021/TT-1022/TT1023: 250°C), automatic opening of the motorized valve for MP steam to the sootblowers at full position.
- Automatic closing of sootblowers condensate drain pneumatic valve.

Once the sootblowers condensate drain pneumatic valve is closed, the pre-heating sequence is completed and the <Pre-heating complete> lamp (UL-1052A/B) will be switched on.

The pre-heating sequence is stopped if one of the following conditions occurs:

- <Sootblowing stop> push-button (HS-1061B) activated by operator from SLP.
- <Sootblowing emergency stop> push-button (HS-1063A) activated by operator from SPC.
- <Sootblowing emergency stop> push-button (HS-1063B) activated by operator from SLP.
- No boiler running (boiler load < 25% MCR).
- Failure of the motorized valve supplying MP steam to the sootblowers to fully open.
- Failure of the sootblowers condensate drain pneumatic valve to close.

In case one of the above conditions occurs, the following steps will be automatically performed:

- Automatic closing of the motorized valve.
- Automatic closing of sootblowers condensate drain pneumatic valve.

- In case of a failure of one of the valves, the <Pre-heating failure> alarm (UA-1053A/B) will be switched on.

3.5.2 Sootblowing sequence

The sootblowing sequence will automatically proceed if the <Sootblowing Auto / Manual> selector switch (HS-1058) is set to the <Auto> position. If the switch is set to <Manual>, the sequence will remain idle, awaiting operator actions from the SLP.

3.5.2.1 Sootblowing sequence in manual mode

The sootblowing sequence in “Manual mode” requires a manual start requested by the operator to perform the sootblowing.

The start of each sootblower is not chronological but depends on operator’s choice.

As soon as the pre-heating sequence has been completed successfully, the operator shall use the commands from SLP.

The <Sootblowing running> signals (UL1054A/B) are switched on indicating that the sootblowing sequence is ready to start.

From the SLP, the operator can choose the sootblower to put in service by the switch selector <Sootblower Selection> (HS-1065) and can be started by pressing the <Start> push-button (HS-1066).

Regardless of the location of operation, the <Running> signals (MIR-10XXA/B) are switched on indicating that the sootblower is on.

The selected sootblower will complete its cycle and be automatically stopped when it reaches its rest position or if the operator presses the <Stop Reverse> push-button (HS-1067) from SLP.

The operator can decide whether to perform more sootblowing cycles for the same sootblower without limitation of cycle number.

The sootblowing sequence is directly stopped if at least one pre-heating stop condition is activated.

In case one of the above conditions occurs, the following steps will be automatically performed:

- Stop the running sootblower (return to its rest position).
- Automatic closing of the motorized valve.
- Automatic closing of sootblowers condensate drain pneumatic valve.
- <End of sootblowing> signals (UL-1055A/B) are switched on.

3.5.2.2 Sootblowing sequence in automatic mode

The sootblowing sequence in <Automatic mode> is performed based on a defined order.

As soon as the pre-heating sequence has been completed successfully, the <Sootblowing running> signals are switched on indicating that the sootblowing sequence is ready to start.

The programmed logic will activate one sootblower at a time according to the defined sequence below:

- Rake sootblower on economizer A (X04A).
- Rake sootblower on economizer B (X04B).
- Retractable sootblower on superheater A (X02A).
- Retractable sootblower on superheater B (X02B).
- Rotative sootblower on evaporator A (X03A).
- Rotative sootblower on evaporator B (X03B).
- Rotative sootblower on evaporator C (X03C).
- Rotative sootblower on evaporator D (X03D).
- Rake sootblower on economizer A (X04A).
- Rake sootblower on economizer B (X04B).

Before starting the automatic sequence, it is possible to exclude sootblowers from the sequence using the <Include / Exclude> selector switch (MXHS-10XXB) provided on SLP.

The sequence shall be automatically stopped after the last included sootblower has completed its cycle and the following steps will be automatically performed:

- Automatic closing of the motorized valve.
- <End of sootblowing> signals (UL-1055A/B) are switched on.
- <Sootblowing running> signals (UL-1054A/B) are switched off.
- Start timer <waiting time for next cycle>.
- <Waiting time for next cycle> signals (UL-1070A/B) are switched on.

The automatic sootblowing sequence is also stopped if at least one pre-heating stop condition is activated.

After the automatic sootblowing sequence is completed, the waiting time for the next cycle timer is initiated. This timer is set to eight hours (8h), and when it expires, the automatic sootblowing sequence will be activated again automatically if all start permissive are satisfied.

The operator can again initiate an automatic sootblowing cycle by pressing the <Sootblowing start> push button.

In case one of the following sootblower alarms occurs the automatic sootblowing sequence is interrupted:

- Sootblower failing to start.

- Sootblower traveling time-out (in case the sootblower didn’t return to its rest position in more than 8 minutes and 20 seconds)
- Sootblower electrical fault (electric motor fault)

As soon as the operator needs to address the failure, such as manually retracting the sootblower experiencing issues and resetting the relevant alarm, the sequence will continue, skipping to the next sootblower in the defined sequence.

3.5.3 Motor test

The SPBS can be used for motor tests if the following conditions are satisfied:

- No boiler running (boiler load < 25% MCR)
- Motorized valve closed.

The operator can test a sootblower electric motor by selecting <Local> position in the <Local / Remote> selector switch on SPBS and pressing the relevant <Start> push-button for rotative sootblowers or <Forward> push-button for retractable/rake sootblowers.

For retractable/rake sootblowers the operator can reverse the motor by pressing the relevant <Backward> push-button.

If the <Local / Remote> selector switch remains in <Local> position, the sootblower shall be excluded from the sootblowing auto sequence, the signal out of sequence (MXHL-10XXB) to SLP is switched on, and the signal sootblower included in auto sequence (MXHL-10XXA) is switched off.

3.6 Conclusion

The sootblowing system is a critical component for the efficient operation of boilers at the Algiers refinery. This chapter provides a detailed description of the system’s functionality, emphasizing the manufacturer’s specifications.

CHAPTER 4:

Programmable Logic Controller and HMI

4.1 Introduction

In the past, control systems relied on elaborate hard-wired relay circuits to execute binary signal logic operations. However, a pivotal shift occurred in 1968 when engineers at General Motors Company introduced the first programmable logic controller (PLC) offering a revolutionary alternative. Since then, the realm of industrial process control has revolved dramatically, marked by innovations like Distributed Control Systems (DCS) and Human-Machine Interfaces (HMI). Consequently, tasks such as wiring, programming, monitoring, and supervision have become significantly more efficient and accessible than ever before [9].

4.2 Advantages of digital control systems

- Digital control is less susceptible to noise or parameter variation in instrumentation.
- Very high accuracy and speed are possible through digital processing.
- Complex control laws and signal conditioning algorithms can be easily programmed.
- High reliability in operation using dedicated microprocessors for various control tasks.
- Digital control allows the user to perform intricate scheduling and collect alarms and trend data for troubleshooting problems.
- Fast data transmission over long distances which facilitates remote control and monitoring.
- Cost-effective with low operational voltages (0-24V) [10].

4.3 Choice of the controller

Choosing a Programmable Logic Controller (PLC) involves several considerations to ensure it meets the needs of industrial processes including:

- Input/Output requirements: evaluating the number and types of inputs/outputs needed while considering expansion options for future scalability.
- Environmental requirements: although most PLCs are robust and designed for harsh environments, specific conditions can affect PLC performance.
- Central Processing Unit (CPU) speed must match application requirements where complex logic is handled faster.
- Storage capacity and specialized functions availability for optimal performance.

- Compatibility with various communication protocols for seamless integration enabling efficient data exchange with other devices or systems.

4.4 Programmable logic controller (PLC)

It is a type of computer commonly used in industrial and commercial control applications. It differs from office computers in the types of tasks it performs and in the hardware and software it requires. While their applications vary widely, PLCs perform a wide range of tasks. It is a device that receives input data such as measurements from instruments, compares it to a programmed set point and generates output signals to take appropriate actions to meet the desired behavior.

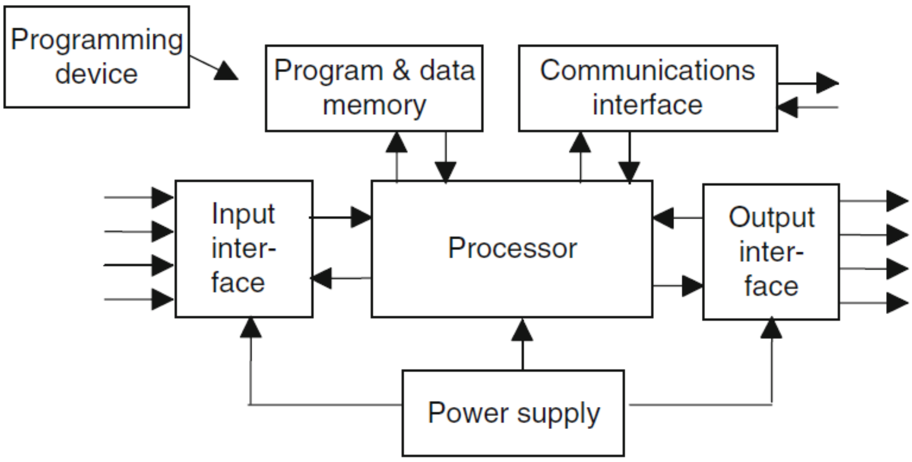


Figure 4.1: PLC architecture.

4.5 Function mode of a PLC

For conventional data processing, programs are usually processed once only from top to bottom and then terminated. However, this is not the case for PLCs, where the program is continually processed cyclically as follows:

- Before the execution of the program, the status of the inputs is stored in the image table i.e. a separate memory area accessed during a cycle. As a result, the status of an input is unchanged during a program cycle even if it has physically changed.
- Once the program has been executed, it automatically jumps back to the beginning repeating the same process.
- Similar to inputs, outputs are stored and only physically switched at the end of the cycle according to the program being processed.

The time taken by the PLC to execute a single program and update the image table output is known as cycle time. The cycle time can range from 1 to 100 milliseconds, depending on the length of the program.

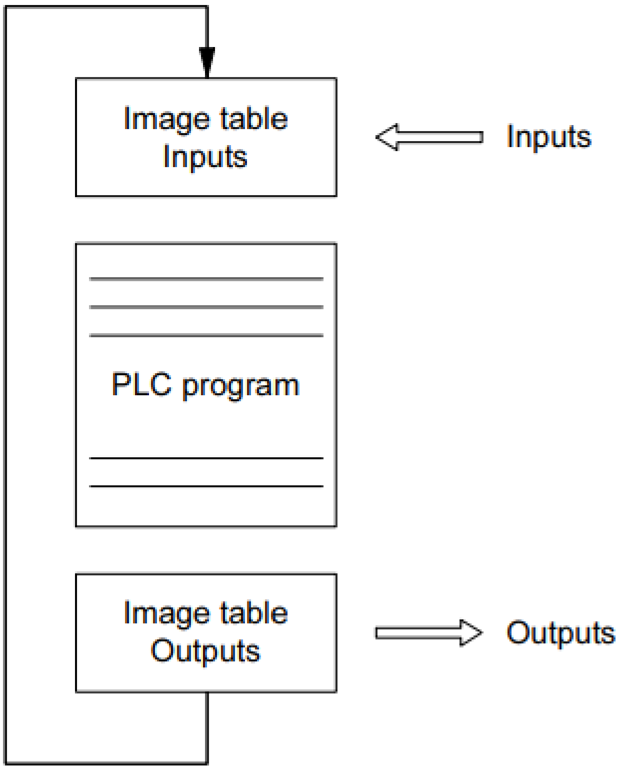


Figure 4.2: Cyclical processing of a PLC program.

4.6 Programming languages

There are five programming languages that have different functionalities and structures. The languages can be mixed in any way within a PLC project.

Ladder diagram (LAD): is a graphic programming language derived from the circuit diagram of wired relay controls [11].

Function block diagram (FBD): represented by graphically interconnected blocks. It originates from the logic diagram for the design of electronic designs.

Instruction list (IL): is a textual assembler-type language formulated from control instructions containing an operator and an operand.

Structured text (ST): is a high-level language based on Pascal that enables the formulation of complex applications, including selection (IF…THEN…ELSE) and repetition (FOR, WHILE) instructions.

Sequential function chart (SFC): is a language suitable for structuring sequence-oriented control programs into steps and transitions interconnected by directed links. SFC requires storing status information of steps, thus it can only be formulated in the main program or function blocks.

4.7 Program blocks:

blocks that contain the control logic of the control program

Organization block (OB): defines the structure of the program. Every program must have at least one organizational block (OB1) which is the main program block, or can be structured using multiple blocks.

Function (FC): a program portion that can be used repeatedly to process input data and generate corresponding output data. Output data of an FC is not stored automatically, thus, storing elements must be created.

Function block (FB): a program portion that can be used repeatedly to process data and generate corresponding outputs. Function blocks can be used to store intermediate results making them more versatile than functions. This storing element is called an instance data block (DB).

Data block (DB): a DB is an addressable storage zone of a program user's data. They can be divided into two types:

- Instance data block: used to store intermediate results of a specific function block.
- Global data block: used to store data used by any program block in a structured manner.

4.8 PLC S7-300

The SIMATIC S7-300 is a modular mini-PLC system designed for low to mid-performance ranges, with a wide selection of modules that enable optimal adaptation to automation tasks and flexible use through simple implementation of distributed structures and versatile networking [12].

The SIMATIC S7-300 has the following modules:

4.8.1 The Central Processing Unit (CPU)

The CPU is composed of two main units, namely the Control Unit and the Arithmetic and Logic Unit (ALU), along with a few internal memory units. The Control Unit is responsible for fetching instructions and generating control signals, while the ALU performs arithmetic and logic operations and stores the results in the accumulator.

Memory units are essential components that are used to store the firmware and user program. The firmware is a permanent software part that is written in a ROM or EPROM, supplied by the manufacturer, and cannot be changed or lost. Its purpose is to provide necessary instructions for the device to communicate appropriately with other hardware. Whereas, the user program data is usually stored in the RAM where they are easily modified.

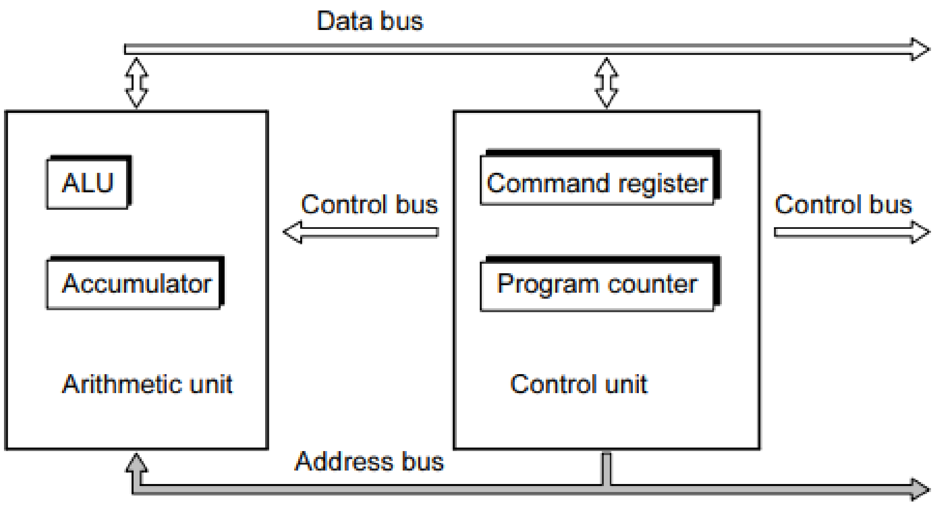


Figure 4.3: CPU architecture.

The CPU used in this project is the CPU315-2DP central processing unit of the SIMATIC S7-300 family with the following characteristic specifications:

- An integrated MPI communication interface.
- An integrated PROFIBUS DP master/slave interface.
- 256 KB work memory.
- Step 7 V5.5 or higher programming package.
- 24 V DC power supply.

4.8.2 Signal modules (SM)

For digital and analog inputs/outputs. The role of input modules is to convert incoming signals into signals that the CPU can process. On the other hand, output modules perform the opposite task by converting processed signals generated by the CPU into digital or analog signals that can be used by the actuators.

4.8.3 Communication processor (CP)

Communication modules for the data exchange via bus systems (AS-Interface, PROFIBUS, and PROFINET/Industrial Ethernet), and point-to-point connections.

The communication processor used in this project is the CP 343-1 Lean connecting the SIMATIC S7-300 to Industrial Ethernet via TCP/IP and UDP connections.

4.8.4 Function modules (FM)

For high-speed counting, positioning(open-loop/close-loop), and PID control.

4.8.5 Interface module (IM)

In case the user requires more than 8 slots for the modules, the SIMATIC S7-300 can be expanded up to 32 modules distributed across the central controller (CC) and a maximum number of 3 expansion units (EUs). For this reason, the IM is used for connecting multi-rack configurations where each CC/EU has its own IM. Furthermore, the CPU comes with an integrated MPI communication interface.

Here the IM 153-1 is used to connect the expansion units that contain the I/O modules to the central unit where the CPU and CP are placed [13].

4.8.6 Power Supply (PS)

The power supply selection is based on the requirements of the individual modules within the automation system.

Module	Reference	Number	Typical current consumption (A)	Maximum current consumption (A)
CPU315-2 DP	6ES7 315-2AH14-0AB0	1	0.85	3.5
IM153-1	6ES7 153-1AA03-0XB0	1	0.35	2.5
CP 343-1 Lean	6GK 7343-1CX10-0XE0	1	0.16	0.2
AI8x12Bit	6ES7 331-7KF02-0AB0	1	0.03	0.08
DI32x24VDC	6ES7 321-1BL00-0AA0	3	0.015	0.239
DO32x24VDC/0.5A	6ES7 322-1BL00-0AA0	2	0.11	0.27
Total			1.655	7.537

Table 4.1: Typical and maximum current consumption calculation.

According to the calculations, the optimal choice of power supplies is: QUINT-PS 100-240V AC voltage at frequencies 50/60Hz and 24V DC voltage and current of 10A or 20A.

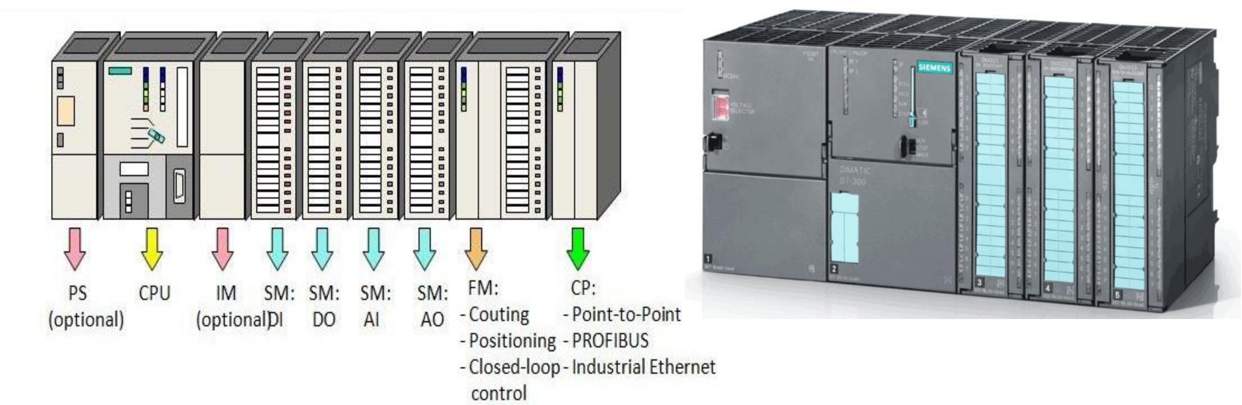


Figure 4.4: PLC S7-300 modules configuration.

4.9 Distributed control systems (DCS)

DCS is a type of control system that involves the distribution of control across the entire system, rather than having a centralized control mechanism, with each subsystem controlled by one or more controllers. Such distribution enhances system reliability by preventing subsystem failures from affecting the rest of the system [14].

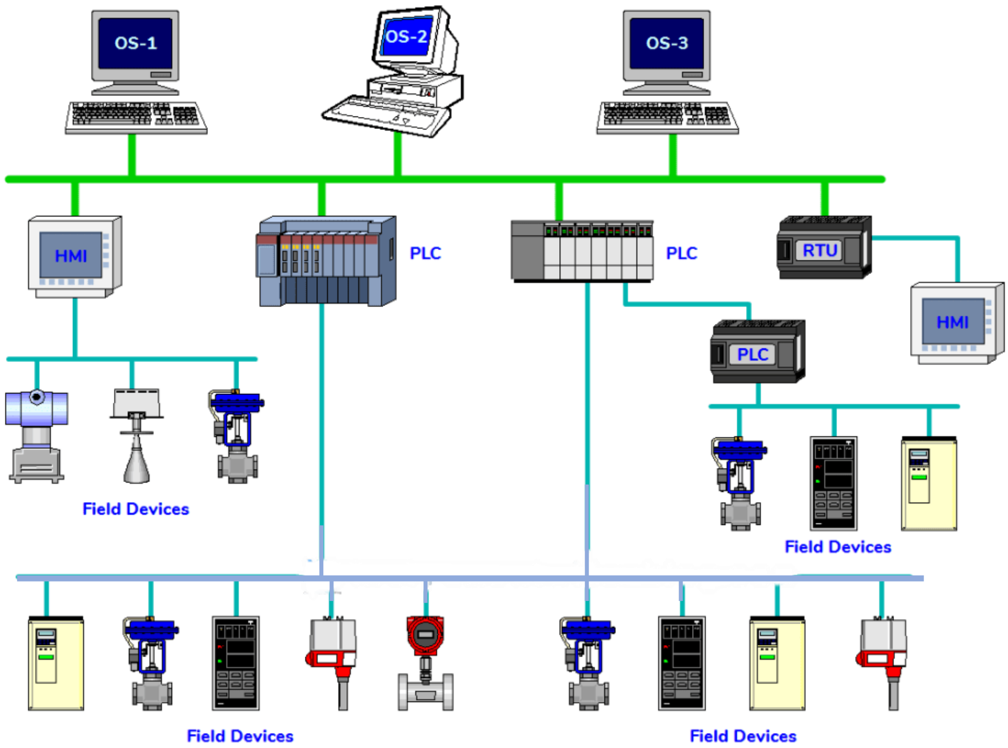


Figure 4.5: Distributed control system diagram.

4.10 Human Machine Interface (HMI)

HMI is a user interface that enables communication between humans and machines through data acquisition and visualization.

In the field of industrial instrumentation, HMI provides numerous benefits that streamline and optimize processes including:

- Allowing operators to monitor and control industrial equipment and processes more efficiently, resulting in increased productivity, reduced downtime, and improved product quality.
- Providing real-time data acquisition and analysis, leading to better decision-making and faster response times.

- It is a user-friendly interface, making it easier for operators to interact with machines and perform tasks, improving operational efficiency, safety, and profitability.

The original method of supervision involved transmitting signal statuses and data to the Distributed Control System (DCS). However, we have developed a new approach for this project by suggesting an HMI touch panel for enhanced supervision and control.

Figure 4.6: HMI touch panel.

4.11 Software description

SIMATIC Step 7 V5.7 and SIMATIC WinCC V8.0 are integral components of Siemens automation software suite, designed to facilitate robust control and monitoring of industrial processes. These tools enable automation engineers to efficiently program, configure, and diagnose PLC systems while providing comprehensive visualization, data acquisition, and alarm management for enhanced operational control.

4.11.1 SIMATIC Step 7 V5.7

The SIMATIC step 7 V5.7 is a comprehensive software designed for programming, configuring, testing and diagnosing Siemens PLCs. It empowers automation engineers to create robust and efficient control systems for industrial applications. The SIMATIC Step 7 V5.7 offers various basic features and functions, including:

- **Project management:**
  - Effortlessly create, open, archive and retrieve projects
  - Organize project folders for hardware configuration, program blocks and libraries.
- **Hardware Configuration:**
  - Configure PLC's hardware settings.

- Add and configure modules such as CPUs, I/O modules, communication processors, and other hardware components.

- Set the network parameters and address assignments.

- **Programming:**

- Develop programs using the various programming languages.

- Create and manage program blocks (OBs, FBs, FCs, DBs).

- Utilize libraries and predefined functions for efficient programming.

- **Simulation and Diagnostics:**

- Use simulation tools to test programs before deploying them to the actual hardware.

- Monitor and debug programs using features like breakpoints and diagnostic functions.

- **Communication and Networking:**

- Set up communication between PLCs and other devices using various communication protocols such as PROFINET, PROFIBUS, and Industrial Ethernet.

- Configure and manage network settings for reliable communication.

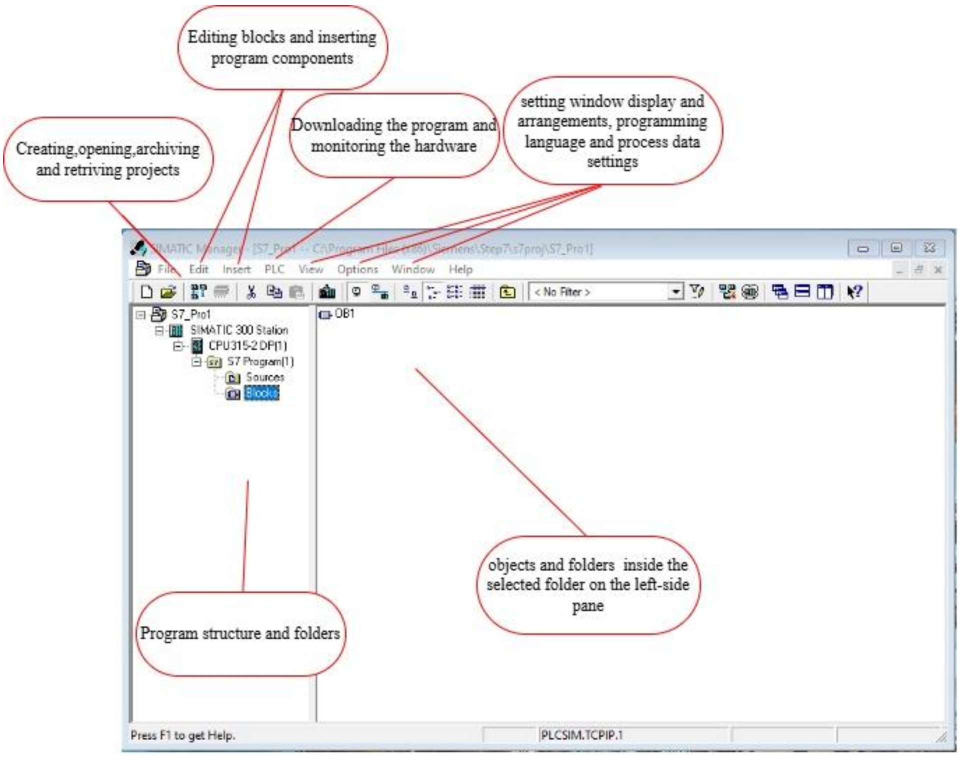


Figure 4.7: SIMATIC Step 7 main window.

4.11.2 SIMATIC WinCC V8.0

SIMATIC WinCC is a powerful and versatile Supervisory Control and Data Acquisition (SCADA) and human-machine interface (HMI) system developed by Siemens. It is designed to provide comprehensive monitoring, control, and optimization of physical processes in a wide range of industries and infrastructure applications. Here are some key features and functionalities of SIMATIC WinCC:

- **Process visualization:** WinCC offers a Graphical User Interface (GUI) for visualizing and monitoring industrial processes. It allows the creation of dynamic process displays, trends, alarms, and reports using a wide range of graphical objects and libraries.
- **Data acquisition and logging:** WinCC can acquire data from various sources, such as programmable logic controllers (PLCs). It supports multiple communication protocols, including industrial Ethernet, serial interfaces, and fieldbus systems. The acquired data can be logged, archived, and analyzed for historical trends and reporting.
- **Alarm management:** The system provides advanced alarm management capabilities, including alarm logging, prioritization, filtering, and notification. Alarms can be displayed on process screens, sent via email or text messages, or integrated with external systems for further processing.
- **User management and security:** WinCC offers robust user management and security features, including user authentication and access control. This ensures that only authorized personnel can access and interact with the system, enhancing overall system security.
- **Integration with Siemens automation products:** WinCC seamlessly integrates with other Siemens automation products, such as SIMATIC S7 PLCs, SIMATIC HMI panels, and SIMATIC IT production management software. This integration enables efficient data exchange and coordinated control across various automation components.

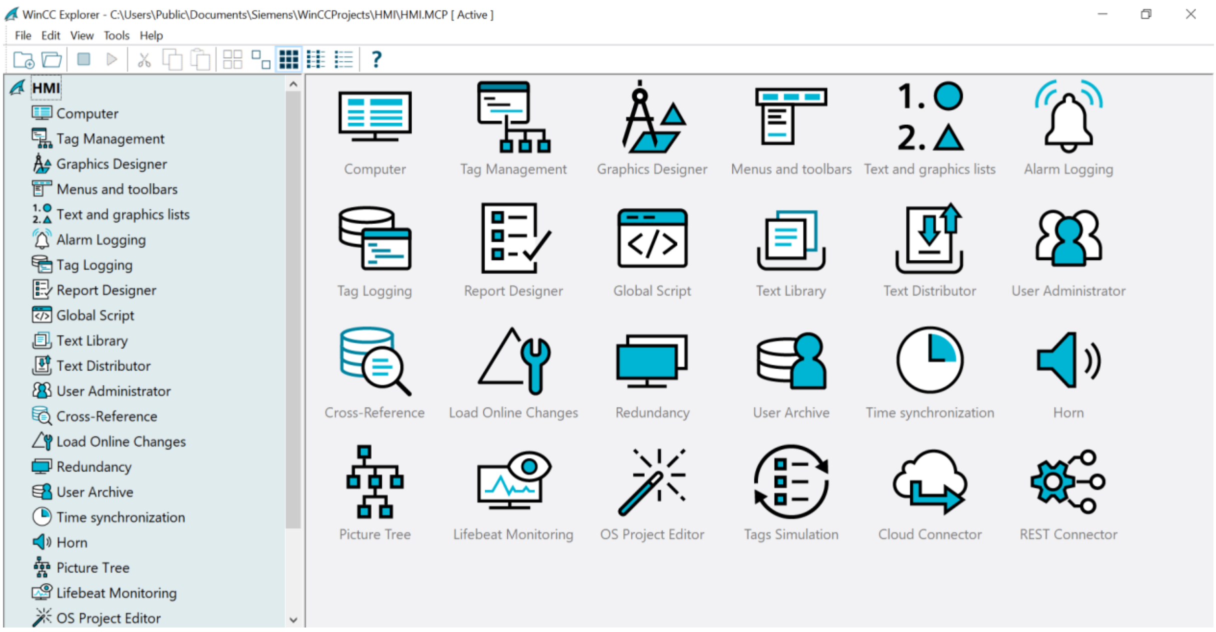


Figure 4.8: SIMATIC WinCC explorer main window.

4.12 Conclusion

At the end of this chapter, the programming hardware and software were introduced, covering the Programmable Logic Controller (PLC) and its programming languages, Step 7 software, as well as the Human-Machine Interface (HMI) software (WinCC). These tools were presented with the aim of enhancing the efficiency and effectiveness of project design and execution.

CHAPTER 5:

Simulation and Results

5.1 Introduction

In the realm of industrial automation, precise programming and robust system configuration are crucial for ensuring smooth operation and maintenance. This chapter provides detailed insights into the intricate process of programming with Siemens Step7 V5.7 software and supervision with WinCC V8.0 software. The main focus is the development and organization of a Programmable Logic Controller (PLC) program and design of the HMI interface. The programming phase utilizes various features of the Siemens Step7 software, such as hardware configuration, symbol table management, and the creation of functional blocks tailored for specific operational tasks. The primary goal of this chapter is to offer a comprehensive understanding of the methodologies utilized in configuring and programming PLC and HMI systems for efficient industrial automation.

5.2 Programming

After considering the conditions for selecting various instruments and PLC modules, the next step is to create a list of signal symbols and define the program organization. This development phase utilizes Siemens Step7 v5.7 software, which facilitates PLC programming and supports various functions, including hardware configuration, selection of communication protocol parameters, simulation, and diagnostics.

5.3 Hardware configuration

The hardware configuration helps in configuring the parameters of the PLC, input/output modules, communication modules …etc.

The figure 5.1 represents the Hardware configuration of this project.

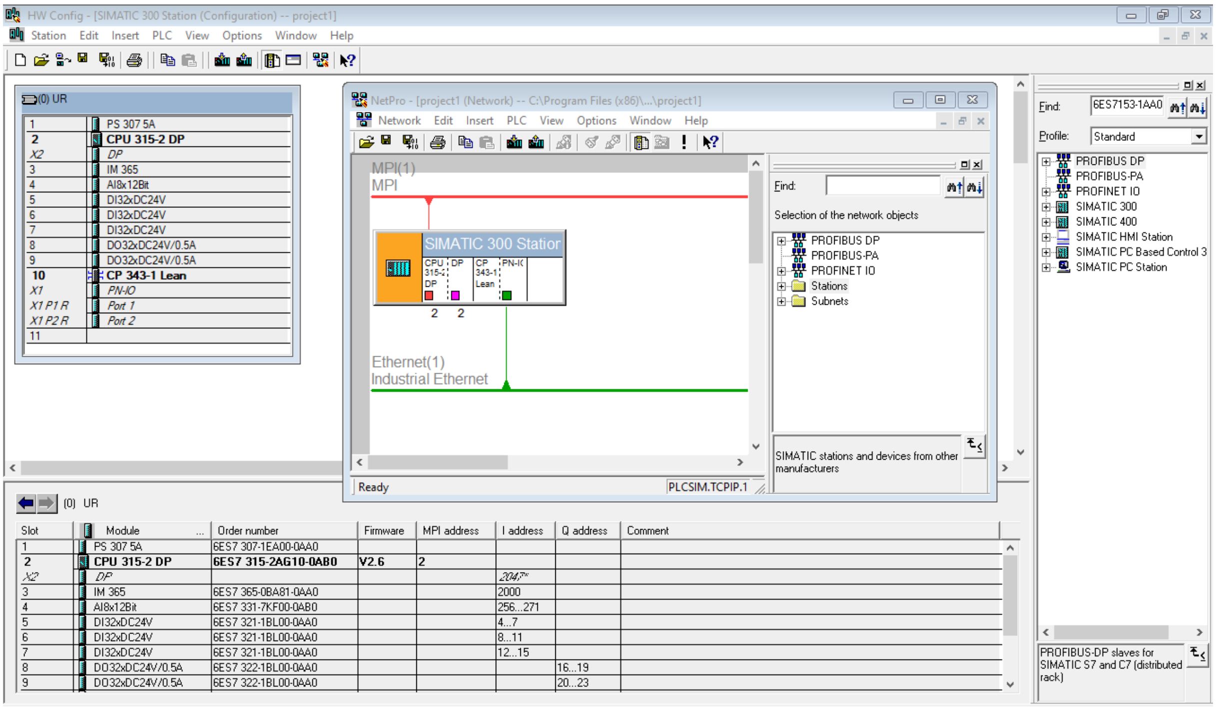
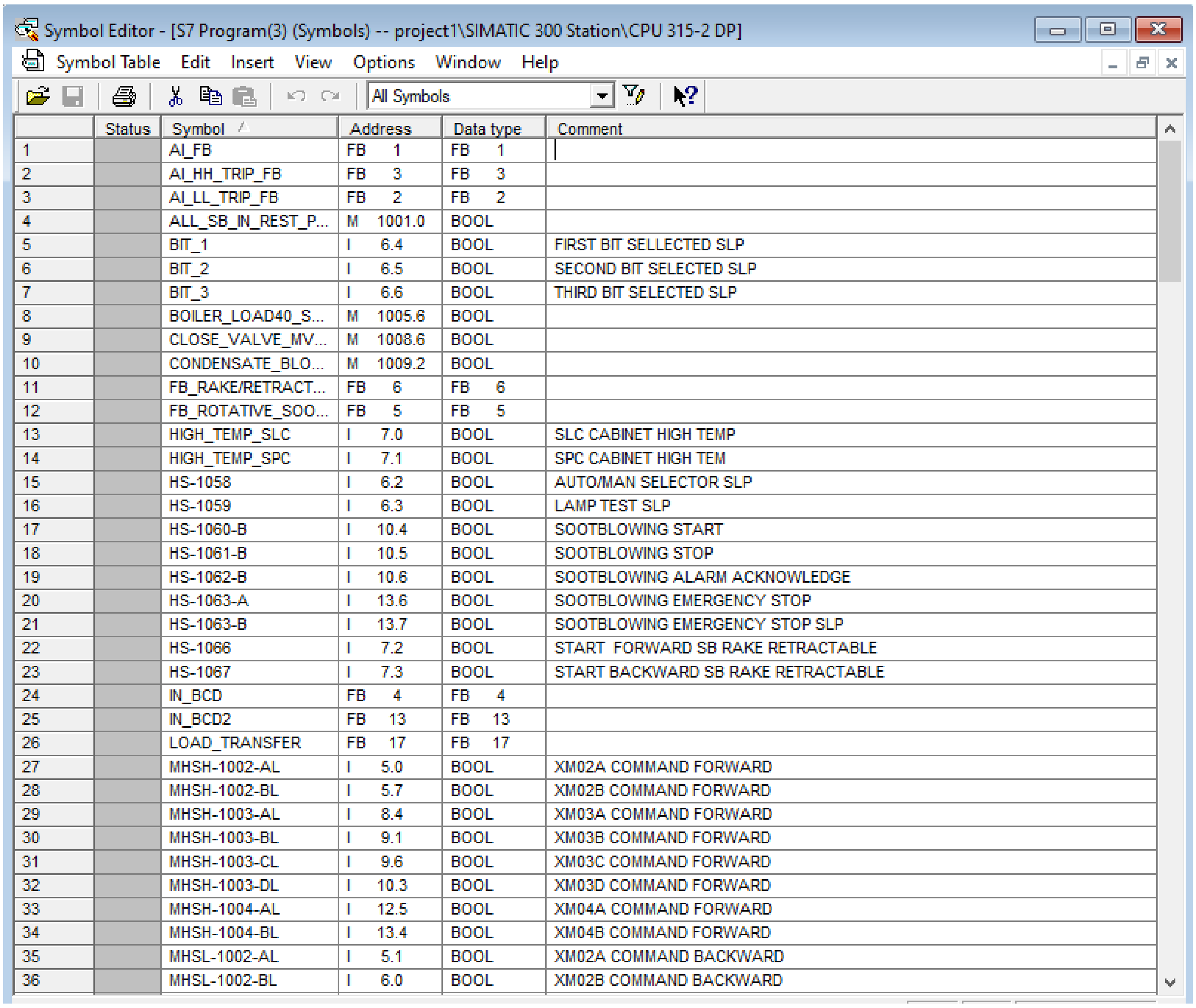


Figure 5.1: Hardware configuration.

5.4 Symbol table

The symbol table plays a vital role in the PLC programming environment. It acts as a guide for defining and handling symbols, which are user-friendly labels assigned to memory addresses, inputs, outputs, and other PLC variables. Employing descriptive names instead of raw memory addresses enhances program comprehension, organization, and documentation, making the PLC program easier to understand and maintain.



	Status	Symbol	Address	Data type	Comment
1		AI_FB	FB 1	FB 1	
2		AI_HH_TRIP_FB	FB 3	FB 3	
3		AI_LL_TRIP_FB	FB 2	FB 2	
4		ALL_SB_IN_REST_P...	M 1001.0	BOOL	
5		BIT_1	I 6.4	BOOL	FIRST BIT SELLECTED SLP
6		BIT_2	I 6.5	BOOL	SECOND BIT SELECTED SLP
7		BIT_3	I 6.6	BOOL	THIRD BIT SELECTED SLP
8		BOILER_LOAD40_S...	M 1005.6	BOOL	
9		CLOSE_VALVE_MV...	M 1008.6	BOOL	
10		CONDENSATE_BLO...	M 1009.2	BOOL	
11		FB_RAKE/RETRACT...	FB 6	FB 6	
12		FB_ROTATIVE_SOO...	FB 5	FB 5	
13		HIGH_TEMP_SLC	I 7.0	BOOL	SLC CABINET HIGH TEMP
14		HIGH_TEMP_SPC	I 7.1	BOOL	SPC CABINET HIGH TEM
15		HS-1058	I 6.2	BOOL	AUTO/MAN SELECTOR SLP
16		HS-1059	I 6.3	BOOL	LAMP TEST SLP
17		HS-1060-B	I 10.4	BOOL	SOOTBLOWING START
18		HS-1061-B	I 10.5	BOOL	SOOTBLOWING STOP
19		HS-1062-B	I 10.6	BOOL	SOOTBLOWING ALARM ACKNOWLEDGE
20		HS-1063-A	I 13.6	BOOL	SOOTBLOWING EMERGENCY STOP
21		HS-1063-B	I 13.7	BOOL	SOOTBLOWING EMERGENCY STOP SLP
22		HS-1066	I 7.2	BOOL	START FORWARD SB RAKE RETRACTABLE
23		HS-1067	I 7.3	BOOL	START BACKWARD SB RAKE RETRACTABLE
24		IN_BCD	FB 4	FB 4	
25		IN_BCD2	FB 13	FB 13	
26		LOAD_TRANSFER	FB 17	FB 17	
27		MHSH-1002-AL	I 5.0	BOOL	XM02A COMMAND FORWARD
28		MHSH-1002-BL	I 5.7	BOOL	XM02B COMMAND FORWARD
29		MHSH-1003-AL	I 8.4	BOOL	XM03A COMMAND FORWARD
30		MHSH-1003-BL	I 9.1	BOOL	XM03B COMMAND FORWARD
31		MHSH-1003-CL	I 9.6	BOOL	XM03C COMMAND FORWARD
32		MHSH-1003-DL	I 10.3	BOOL	XM03D COMMAND FORWARD
33		MHSH-1004-AL	I 12.5	BOOL	XM04A COMMAND FORWARD
34		MHSH-1004-BL	I 13.4	BOOL	XM04B COMMAND FORWARD
35		MHSL-1002-AL	I 5.1	BOOL	XM02A COMMAND BACKWARD
36		MHSL-1002-BL	I 6.0	BOOL	XM02B COMMAND BACKWARD

Figure 5.2: Symbol table.

5.5 Signals description

In the following, we present the description of alarm signals, statuses, and commands necessary for the process described in chapter 3.

Description of commands and status signals displayed on the local panel:

Description	Tag
Sootblowing permissive lamp	UL-1050B
Pre-heating running lamp	UL-1051B
Pre-heating complete	UL-1052B
Pre-heating failure	UA-1053B
Sootblowing running lamp	UL-1054B
Sootblowing complete	UL-1055B
Sootblowing failure	UA-1056B
Solenoid valve XV1020 open	XLO-1020
Solenoid valve XV1020 close	XLC-1020
Sootblowing in Auto/Man selector	HS-1058
Start sootblowing push-button	HS-1060B
Stop sootblowing push-button	HS-1061B
Waiting time for auto sequence lamp	UL-1070B
Sootblowing emergency stop push-button	HS-1063B
Sootblowing alarm acknowledge push-button	HS-1062B
Lamp test push-button	HS-1059
Start forward rake/retractable sootblower push-button	HS-1066
Start backward rake/retractable sootblower push-button	HS-1067

Table 5.1: SLP Commands and status signals description.

For each sootblower, we have the following symbols:

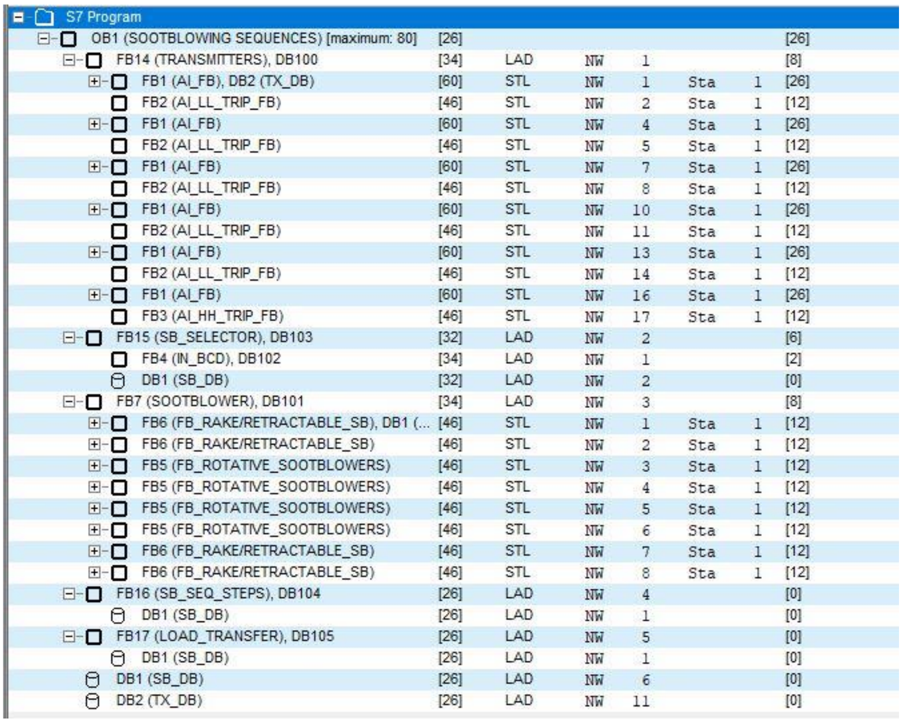
Description	Tag
Sootblower running lamp	MIR-100X-YB
Sootblower fault lamp	MXA-100X-Y
Sootblower out of sequence lamp	MXHL-100X-YB
Sootblower included/excluded selector	MXHS-100XYB
Sootblower available button	MXSL-100X-Y
Sootblower in rest position button	MSC-100X-Y
Sootblower local/remote	MSHL-100X-YL
Sootblower command backward push-button	MHSL-100X-YL
Sootblower command forward push-button	MHSH-100X-YL

Table 5.2: Sootblowers commands and status signals description.

5.6 Program organization

This project is primarily coded using LAD, a graphical programming language resembling wired relay connections, making it easier for engineers to understand and facilitate maintenance operations.

In this project, a structured program was established, divided into multiple function blocks (FBs) that contain different parts of the program. Each FB is responsible for a specific task and is called to the organizational block when necessary.



S7 Program							
OB1 (SOOTBLOWING SEQUENCES) [maximum: 80]	[26]						[26]
FB14 (TRANSMITTERS), DB100	[34]	LAD	NW	1			[8]
FB1 (AI_FB), DB2 (TX_DB)	[60]	STL	NW	1	Sta	1	[26]
FB2 (AI_LL_TRIP_FB)	[46]	STL	NW	2	Sta	1	[12]
FB1 (AI_FB)	[60]	STL	NW	4	Sta	1	[26]
FB2 (AI_LL_TRIP_FB)	[46]	STL	NW	5	Sta	1	[12]
FB1 (AI_FB)	[60]	STL	NW	7	Sta	1	[26]
FB2 (AI_LL_TRIP_FB)	[46]	STL	NW	8	Sta	1	[12]
FB1 (AI_FB)	[60]	STL	NW	10	Sta	1	[26]
FB2 (AI_LL_TRIP_FB)	[46]	STL	NW	11	Sta	1	[12]
FB1 (AI_FB)	[60]	STL	NW	13	Sta	1	[26]
FB2 (AI_LL_TRIP_FB)	[46]	STL	NW	14	Sta	1	[12]
FB1 (AI_FB)	[60]	STL	NW	16	Sta	1	[26]
FB3 (AI_HH_TRIP_FB)	[46]	STL	NW	17	Sta	1	[12]
FB15 (SB_SELECTOR), DB103	[32]	LAD	NW	2			[6]
FB4 (IN_BCD), DB102	[34]	LAD	NW	1			[2]
DB1 (SB_DB)	[32]	LAD	NW	2			[0]
FB7 (SOOTBLOWER), DB101	[34]	LAD	NW	3			[8]
FB6 (FB_RAKE/RETRACTABLE_SB), DB1 (...	[46]	STL	NW	1	Sta	1	[12]
FB6 (FB_RAKE/RETRACTABLE_SB)	[46]	STL	NW	2	Sta	1	[12]
FB5 (FB_ROTATIVE_SOOTBLOWERS)	[46]	STL	NW	3	Sta	1	[12]
FB5 (FB_ROTATIVE_SOOTBLOWERS)	[46]	STL	NW	4	Sta	1	[12]
FB5 (FB_ROTATIVE_SOOTBLOWERS)	[46]	STL	NW	5	Sta	1	[12]
FB5 (FB_ROTATIVE_SOOTBLOWERS)	[46]	STL	NW	6	Sta	1	[12]
FB6 (FB_RAKE/RETRACTABLE_SB)	[46]	STL	NW	7	Sta	1	[12]
FB6 (FB_RAKE/RETRACTABLE_SB)	[46]	STL	NW	8	Sta	1	[12]
FB16 (SB_SEQ_STEPS), DB104	[26]	LAD	NW	4			[0]
DB1 (SB_DB)	[26]	LAD	NW	1			[0]
FB17 (LOAD_TRANSFER), DB105	[26]	LAD	NW	5			[0]
DB1 (SB_DB)	[26]	LAD	NW	1			[0]
DB1 (SB_DB)	[26]	LAD	NW	6			[0]
DB2 (TX_DB)	[26]	LAD	NW	11			[0]

Figure 5.3: S7 program structure.

To scale the raw analog inputs processed by the PLC from binary values into engineering unit values, linear interpolation can be used. Given that 0 corresponds to the low range value (4mA) and 27648 corresponds to the high range value (20mA), the corresponding engineering unit values can be derived using the following formula:

$$Engineering\ unit = \frac{Higher\ range\ limit - Lower\ range\ limit}{27648-0} \times Input(Binary\ value) + Lower\ range\ limit \quad (2)$$

The scaling process is accomplished by using a built-in block function (FC105) located inside FB1 (AI-FB), which converts the analog inputs by specifying the lower and upper-range values in engineering units. The resulting values are stored in a designated memory location, and an error signal is generated if the input exceeds the defined range. For instance, in the case of temperature transmitters, 0°C represents the lower range limit, while 300°C signifies the upper range limit.

The FB2 (AI-LL-TRIP-FB) function block is a crucial component tasked with the continuous monitoring of analog input signals representing the process variables of temperature and pressure. This function block is programmed to trigger an alarm or initiate corrective actions when the input signal falls below a predefined setpoint.

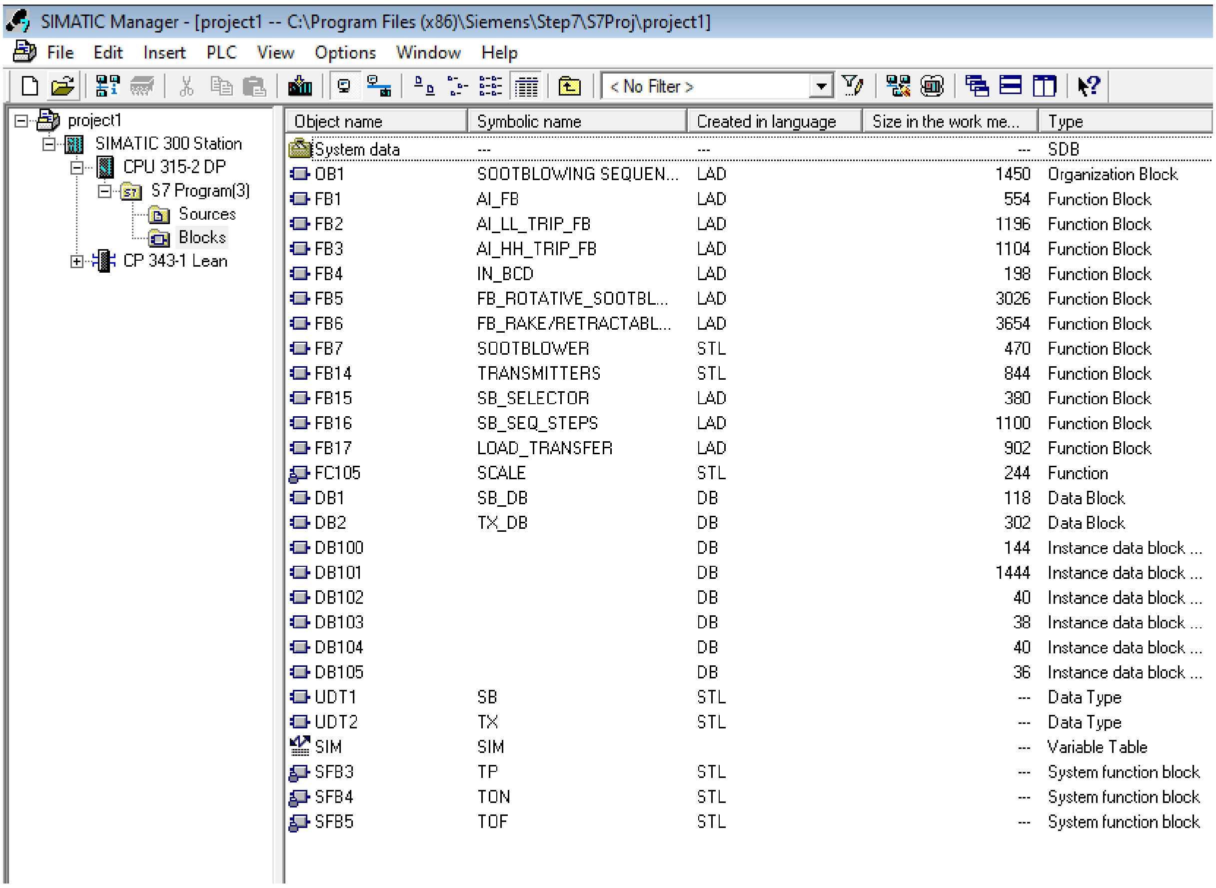
FB14 acts as a link, connecting the outputs of FB1 instances to the inputs of FB2 and FB3 instances for different transmitters. It handles all engineering unit calculations and comparisons and sends the right control signals.

In contrast, the FB3 (AI-HH-TRIP-FB) function block is designed to trigger an alarm when the input signal, representing the process variable of position, exceeds the predefined setpoint. The DB2 (TX-DB) data block stores all the important signal statuses.

The function blocks FB4 and FB15 are tasked with the conversion of incoming digital signals originating from the selector into corresponding control signals tailored for the operation of all sootblowers functioning in manual mode.

Similarly, FB5 and FB6 encapsulate the operational logic governing various types of sootblowers, with four instances of FB5 designated for rotative type sootblowers and an equal number of FB6 instances designated for two rake and two retractable sootblowers. These function blocks' data are stored within the DB1 (SB-DB) data block, with their interconnections with different storage elements configured within FB7 and FB17.

The logic sequence responsible for the automatic mode operation is encapsulated within FB16, wherein the operational sequence of the sootblowers is programmed.



Object name	Symbolic name	Created in language	Size in the work me...	Type
System data	---	---	---	SDB
OB1	SOOTBLOWING SEQUEN...	LAD	1450	Organization Block
FB1	AI_FB	LAD	554	Function Block
FB2	AI_LL_TRIP_FB	LAD	1196	Function Block
FB3	AI_HH_TRIP_FB	LAD	1104	Function Block
FB4	IN_BCD	LAD	198	Function Block
FB5	FB_ROTATIVE_SOOTBL...	LAD	3026	Function Block
FB6	FB_RAKE/RETRACTABL...	LAD	3654	Function Block
FB7	SOOTBLOWER	STL	470	Function Block
FB14	TRANSMITTERS	STL	844	Function Block
FB15	SB_SELECTOR	LAD	380	Function Block
FB16	SB_SEQ_STEPS	LAD	1100	Function Block
FB17	LOAD_TRANSFER	LAD	902	Function Block
FC105	SCALE	STL	244	Function
DB1	SB_DB	DB	118	Data Block
DB2	TX_DB	DB	302	Data Block
DB100		DB	144	Instance data block ...
DB101		DB	1444	Instance data block ...
DB102		DB	40	Instance data block ...
DB103		DB	38	Instance data block ...
DB104		DB	40	Instance data block ...
DB105		DB	36	Instance data block ...
UDT1	SB	STL	---	Data Type
UDT2	TX	STL	---	Data Type
SIM	SIM		---	Variable Table
SFB3	TP	STL	---	System function block
SFB4	TON	STL	---	System function block
SFB5	TOF	STL	---	System function block

Figure 5.4: Sootblowing system program blocks.

The figures 5.5 and 5.6 show the developed flowcharts for the sequence operations executed by this program during the preheating and automatic phases.

For the manual sootblowing sequence, the operator can select using the selector switch HS-1065 and start the sootblower from the SLP using push-button HS-1066 as mentioned in chapter 3. (Mov-1020: motorized valve, XV-1020: solenoid valve, TT-102X: temperature transmitters).

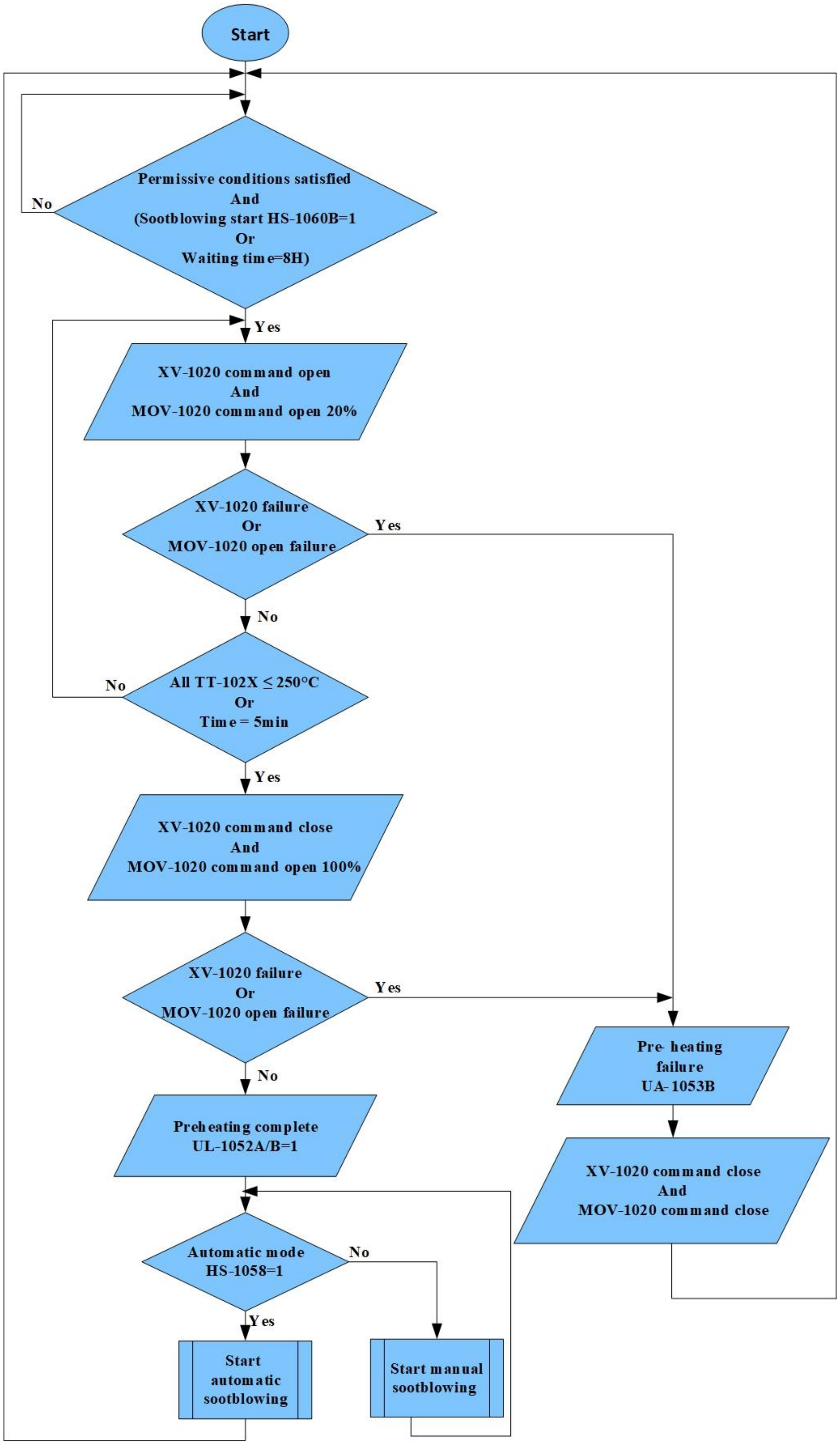


Figure 5.5: Pre-heating sequence flowchart.

Figure 5.6: Sootblowing sequence in automatic mode flowchart.

5.7 Simulation and results

After setting up the hardware and writing the structured program, performing a thorough simulation to validate its accuracy before deploying it to the physical PLC system is essential.

The simulation of the AI_FB was conducted using two analog inputs: temperature transmitter TT-1020 and position transmitter MVT-1020. As shown in Figure 5.7, the conversion of the analog input values into engineering units was successfully achieved.

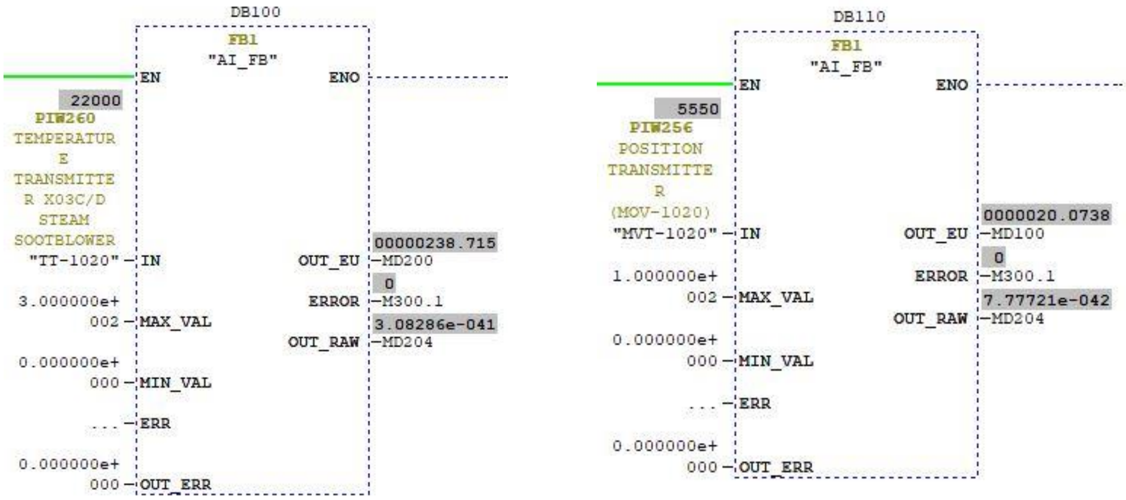


Figure 5.7: Analog Input function block simulation.

The simulation of the AI-LL-TRIP-FB was also conducted successfully, as demonstrated in the accompanying figure. An alarm was generated because the value entered was less than the trip setpoint value. Similarly, the AI-HH-TRIP-FB simulation was successful, with an alarm generated due to the value entered being greater than the trip setpoint value.

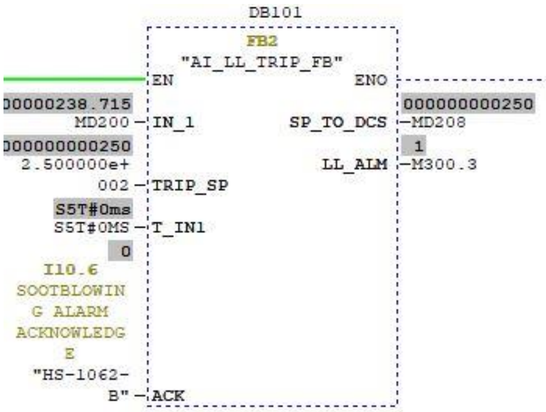


Figure 5.8: Analog input Low-Low trip function block.

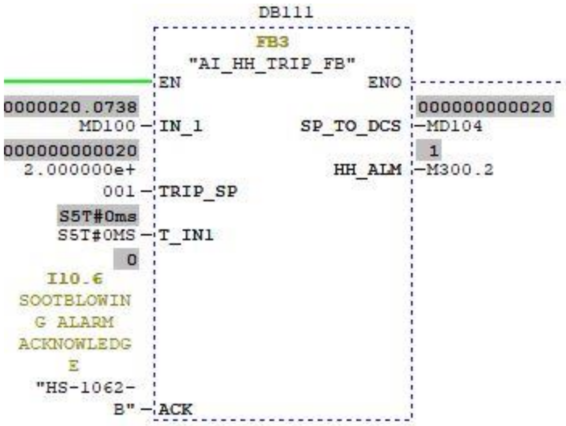


Figure 5.9: Analog input High-High trip function block.

Additionally, the rotative sootblower function block and rake/retractable function block were successfully simulated.

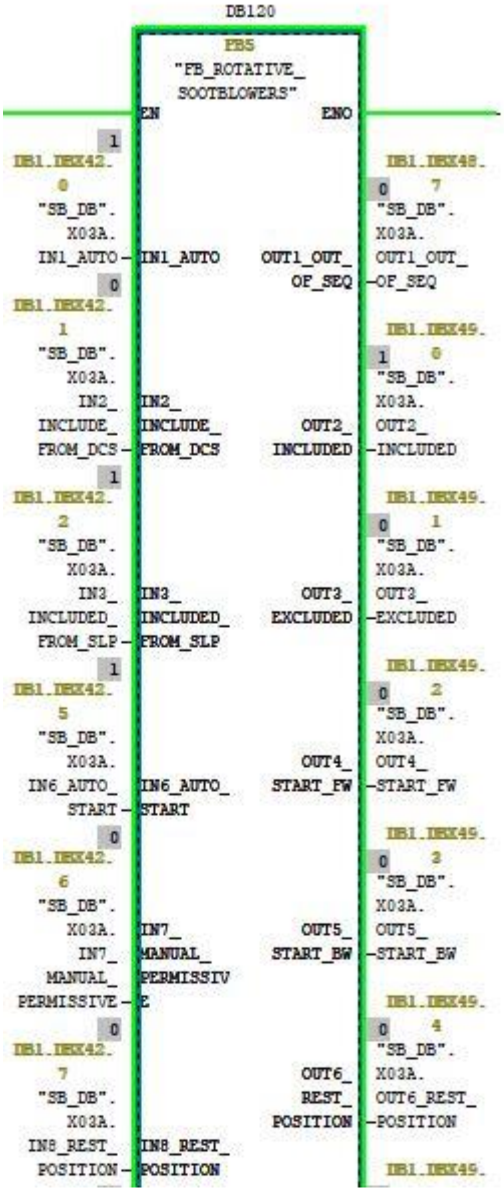


Figure 5.10: Rotative sootblower functio block simulation.

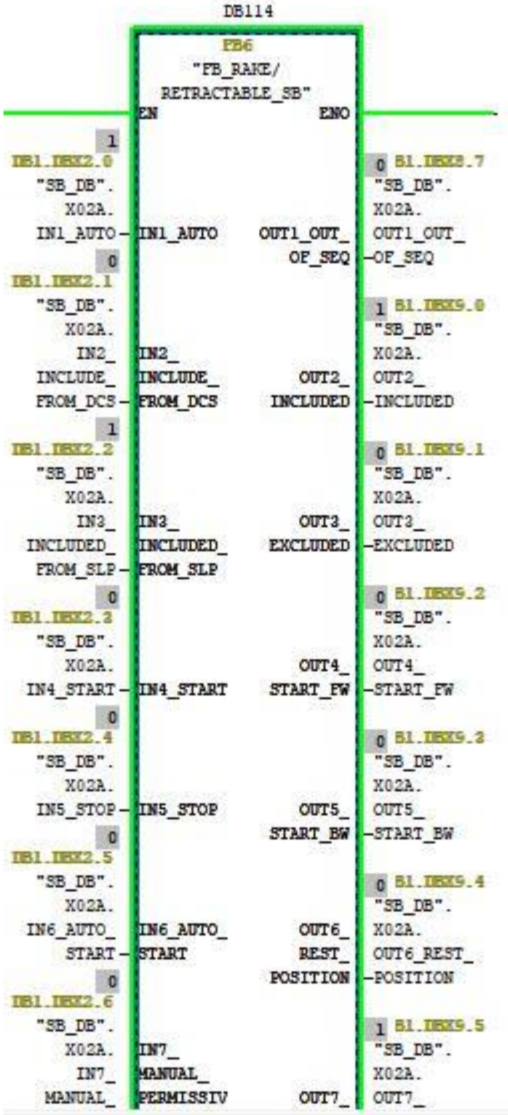


Figure 5.11: Rake/Retractable sootblower function block simulation.

The simulation of the IN_BCD FB was also successful, as shown in Figure 5.12.

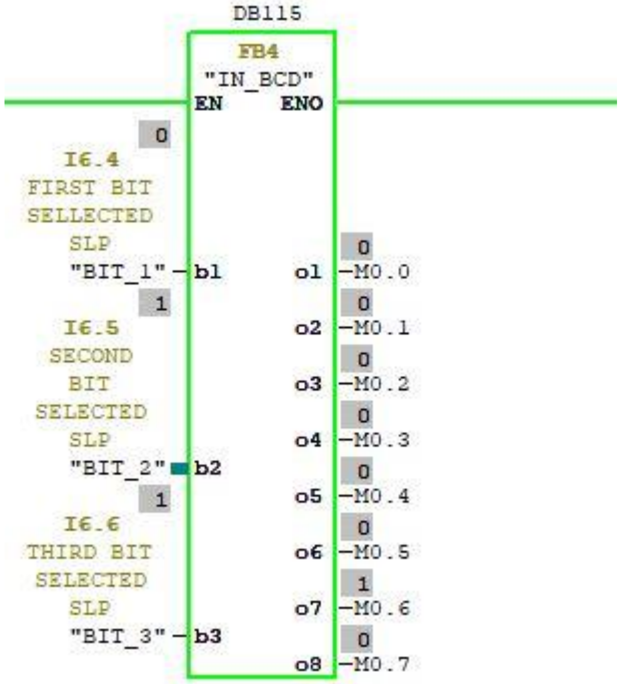


Figure 5.12: IN_BCD function block simulation.

Overall, the program's simulation was conducted successfully, covering the preheating and sootblowing sequences in both automatic and manual modes as well as motor tests.

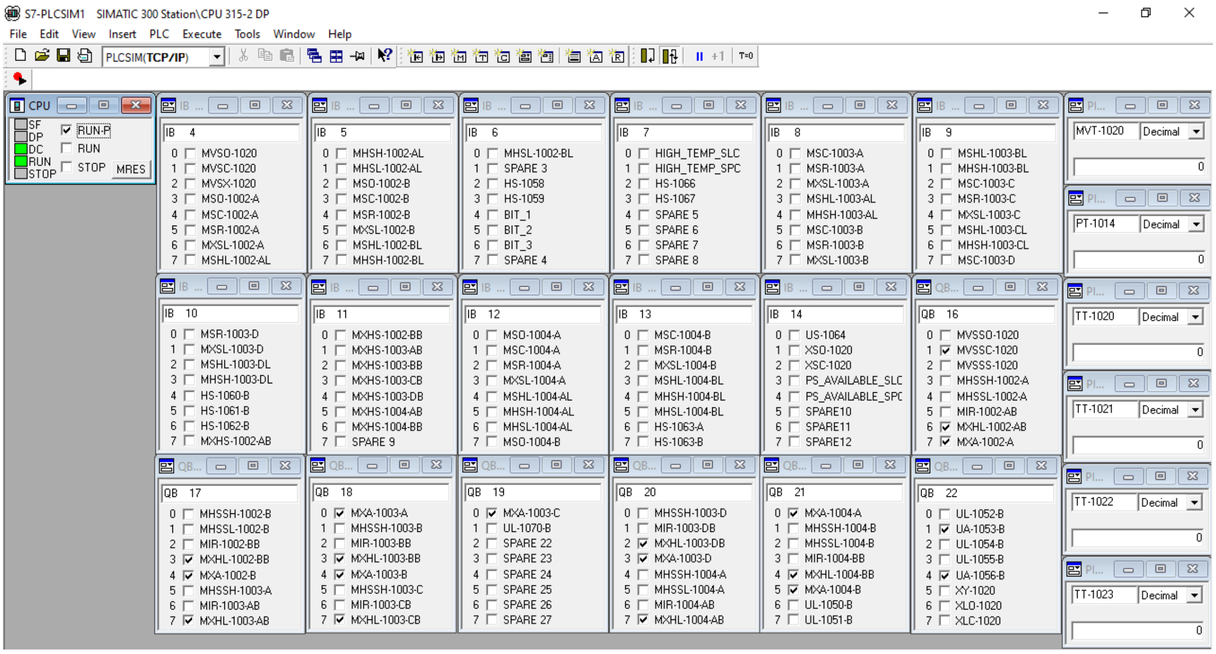


Figure 5.13: Program simulation window.

5.8 Supervision

To ensure optimal operation of the system, continuous supervision is required, which refers to the monitoring and management of processes. For this purpose, WinCC Explorer is utilized. WinCC Explorer is a powerful Human machine interface (HMI) software from Siemens, designed to provide comprehensive monitoring and control of industrial processes.

The WINCC V8.0 software was chosen to develop and design the HMI interface due to its powerful features and capabilities, and its compatibility with the programming software Step7 V5.7.

5.8.1 Integration with step 7

The integration of WinCC with STEP 7 using TCP/IP communication involves ensuring compatibility between the versions of WinCC and STEP 7 and confirming that both systems are connected to the same network. In STEP 7, hardware is configured to assign an IP address (192.168.0.1) to the PLC's Ethernet interface and specify the slot number (10) for the CP. In WinCC, a new connection (DATA) is defined with the appropriate TCP/IP driver, and the connection parameters are configured to match the PLC's IP address and slot number. Tags corresponding to the PLC data points are then created, and HMI screens are designed to display and control this data.

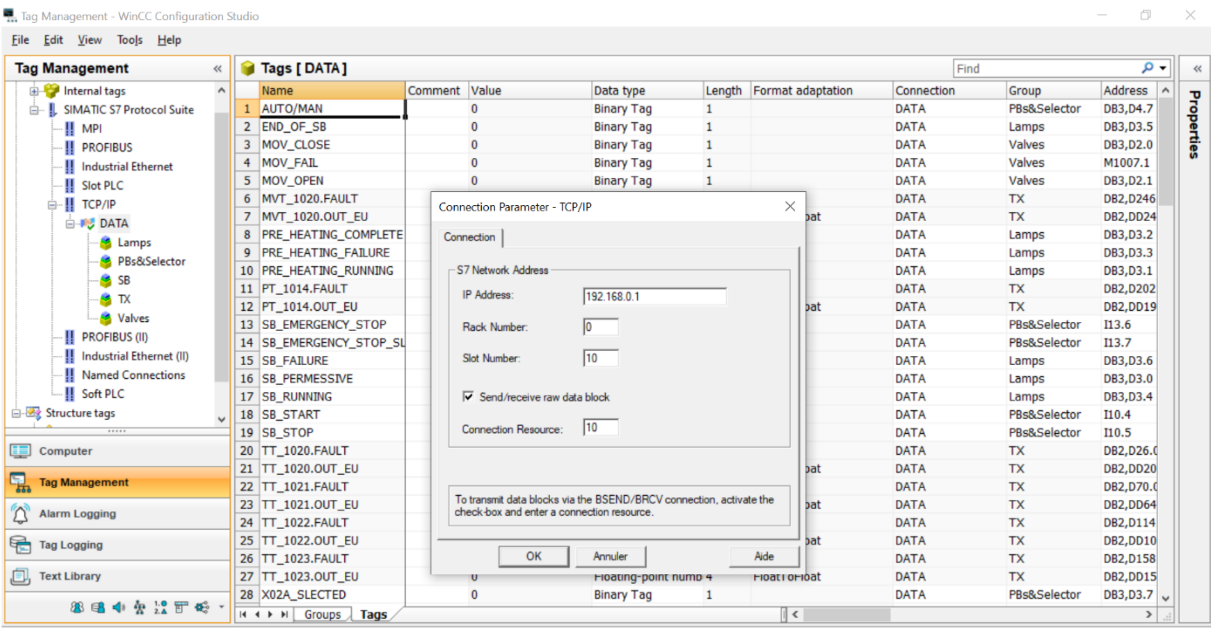


Figure 5.14: Integration of WinCC with Step 7.

5.8.2 Supervision structure

The supervision structure includes a home screen where users can enter their identifier name and password to access other screens. This central interface ensures that only authorized personnel can access the system, enhancing security and accountability. The home screen is designed to be user-friendly, providing a straightforward way for users to log in and begin their tasks.

On the right side of the home screen, shortcuts provide access to two main screens: the Sootblowing System and Lamps and Status. These shortcuts facilitate quick navigation, allowing users to efficiently move between different sections of the system.

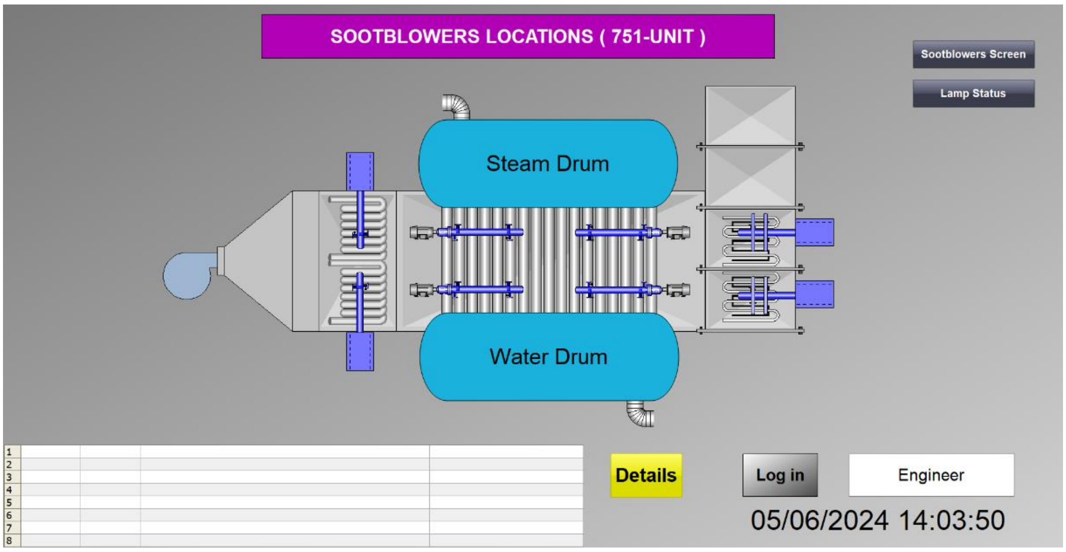


Figure 5.15: HMI home screen.

The user administrator interface is essential for managing user access and roles within the system. Administrators can add or remove users, assign permissions, and ensure that each user has the appropriate level of access based on their responsibilities. This functionality is crucial for maintaining the integrity and security of the system, ensuring that only qualified personnel can make changes or access sensitive information.

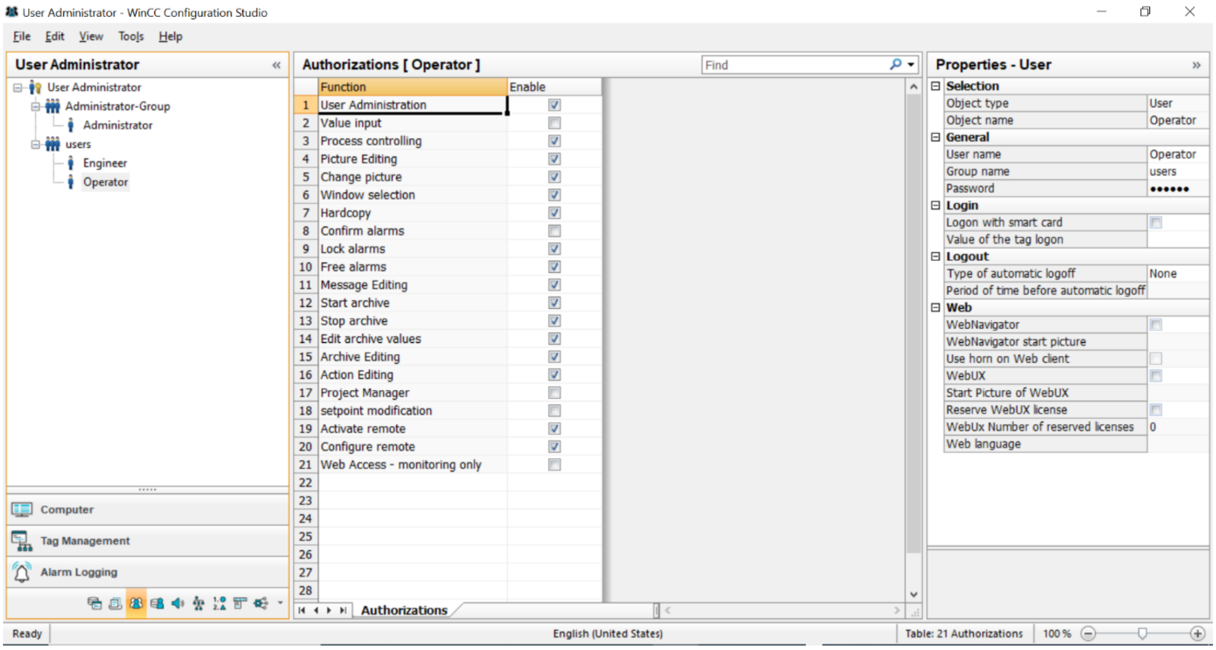


Figure 5.16: User administrator interface configuration.

The Sootblowing System screen allows users to follow the sequence of sootblowing operations, see the state of valves and sootblowers through pop-up screens, and have a full view of alarms for proactive management. This screen is crucial for monitoring the efficiency and effectiveness of the sootblowing process, ensuring optimal operation and maintenance of the system.

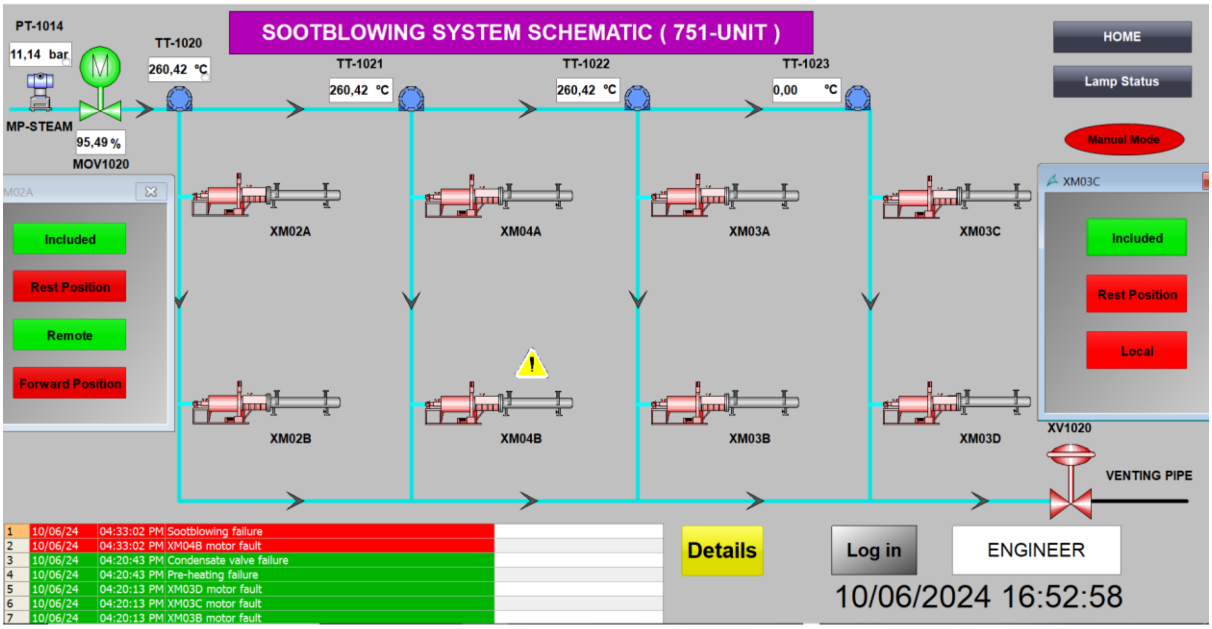


Figure 5.17: HMI Sootblowing system screen.

The Lamps and Status screen permits users to see the state of lamps and indicators (switched on/off) to better monitor the operational sequences. This screen provides a visual representation of the system's status, allowing users to quickly identify and respond to any issues.

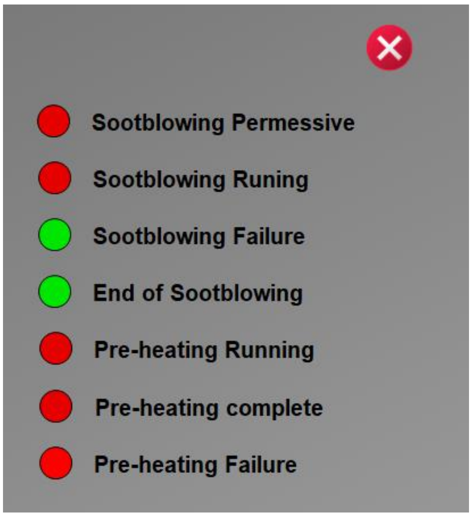


Figure 5.18: HMI lamps and status screen.

These screens are designed to ensure that users can effectively monitor and control the processes, enhancing the system's reliability and performance. By providing a structured and user-friendly interface, WinCC Explorer facilitates efficient supervision and management of industrial processes.

5.9 Conclusion

To conclude, this chapter has covered the systematic approach to programming a PLC system using Siemens Step7 v5.7 software and creating an HMI interface using WinCC v8.0. The hardware configuration section explained how to set up PLC parameters, while the symbol table emphasized the importance of user-friendly labels to improve program readability and maintainability. The program organization section demonstrated the structured coding approach using LAD, highlighting the creation and use of various function blocks for specific operational tasks. Additionally, it emphasized the importance of thorough simulation before deploying the program to the physical PLC system to ensure reliability and accuracy. Lastly, deploying an HMI device aids in visualizing processes for better monitoring and control.

GENERAL CONCLUSION

In this thesis, we have systematically explored the automation and supervision of a sootblowing system using STEP 7 and WinCC. We began with an overview of the refinery and its operations, discussed the general principles of control systems and instrumentation, and delved into the specifics of sootblowing systems and their operational importance. Our implementation involved detailed programming and simulation using both software and hardware components, with results demonstrating the efficacy of our program. Our key outcomes include improved efficiency in soot removal and enhanced operational oversight, aligning well with our original problem statement.

Throughout the project, we encountered several challenges. One significant issue was the damage of a PC, which interrupted our workflow and required swift action to resolve. Additionally, working with STEP 7 and WinCC presented compatibility problems between the two software, complicating the integration process and requiring creative solutions to ensure seamless operation. Moreover, limitations in available resources occasionally constrained our testing capabilities. Despite these challenges, we successfully developed a robust solution, demonstrating the resilience and adaptability of our approach. However, there remains room for further optimization and refinement to address these challenges more comprehensively.

Looking forward, there are numerous opportunities to enhance this project. One promising improvement is to enable sootblowers to act as sensors, detecting when sootblowing is needed and thereby optimizing the cleaning process. Additionally, integrating a Human-Machine Interface (HMI) station would give users the ability to control the system directly from a touch panel, enhancing user interaction and operational control. These advancements could significantly increase the system's efficiency and usability, ensuring its long-term viability and effectiveness.

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APPENDIX

Simulation of Program Networks

In this section, some networks of the program were presented.

Example 1

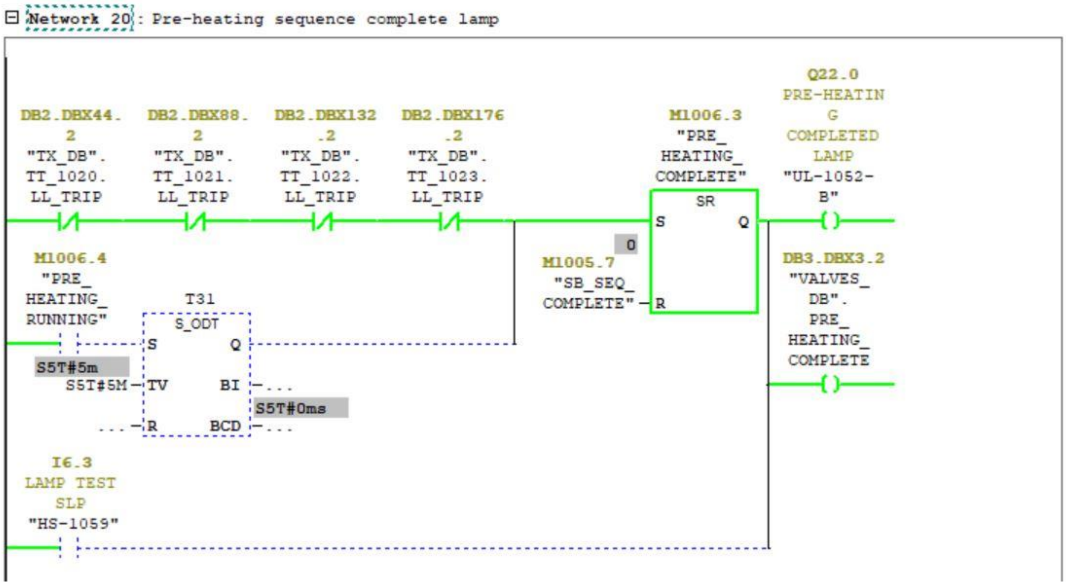

Figure 6.1: Pre-heating sequence complete lamp network.

Example 2

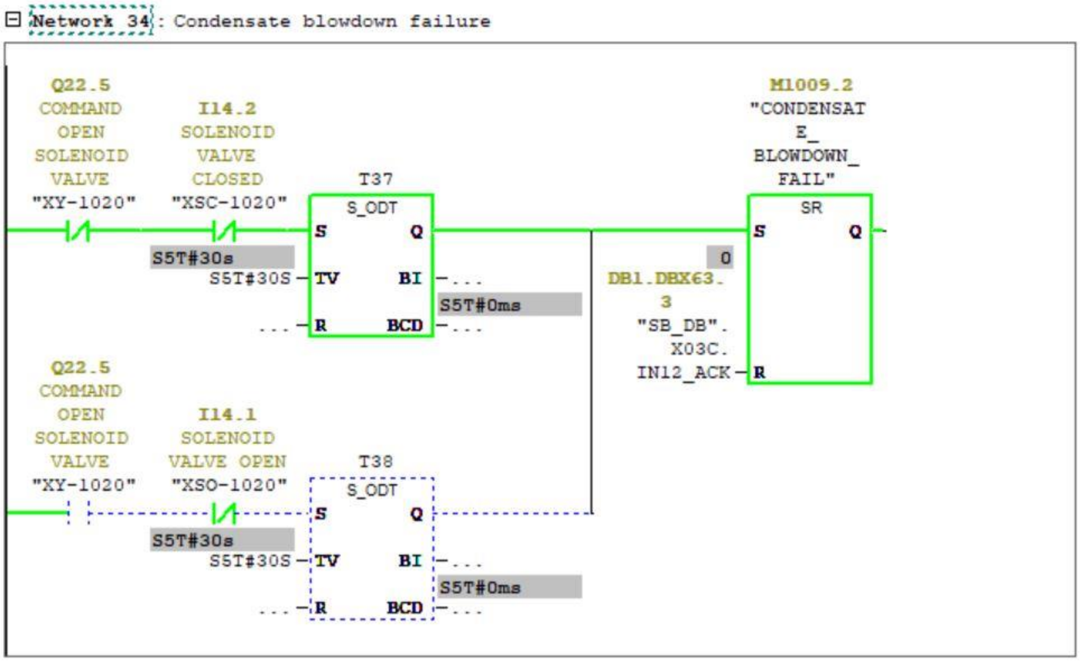

Figure 6.2: Condensate blowdown failure network.

Example 3

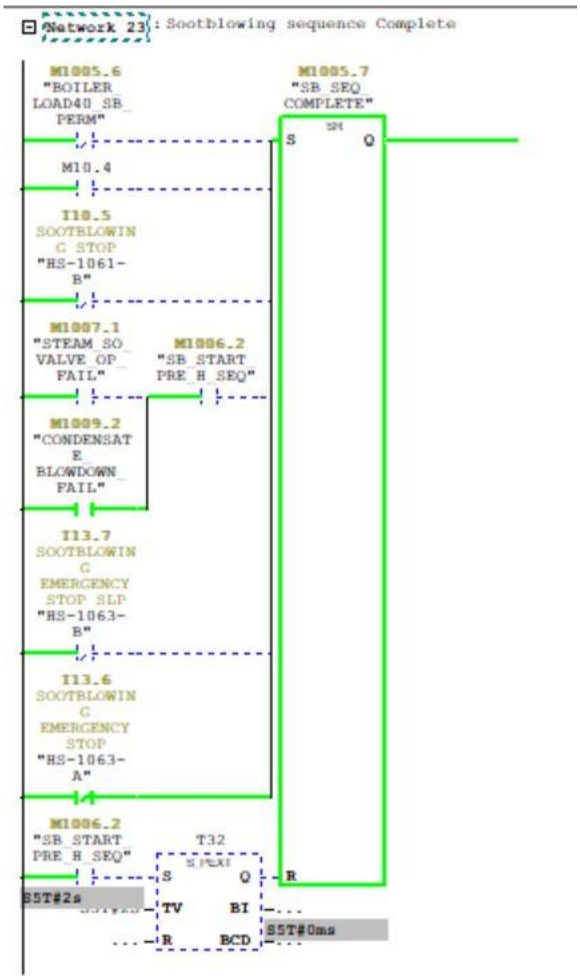

Figure 6.3: Sootblowing sequence complete network.