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DEDICATION

I dedicate this work to my beloved parents. My deepest and most heartfelt thanks go to my dear mother, whose big heart and sincere prayers were my greatest support every step of the way. To my dear father, a symbol of generosity and encouragement, who never spared any effort in supporting and motivating me. I owe you both more than words can express.

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الملخص:

في هذا المشروع، قمنا بتحويل نظام قديم للحماية من الحريق والغاز في توربين MS5002C تابع لموقع سوناطراك إلى نظام جديد وعصري. استخدمنا وحدة تحكم Siemens PLC S7-1500 مع واجهة تشغيل HMI مبرمجة على TIA Portal وWinCC. النظام الجديد يوفر مراقبة لحظية، تسجيل تاريخي للإنذارات، وتحكم يدوي وآلي. كما قمنا بمحاكاة جميع الحالات باستخدام PLCSIM لضمان فعالية واستقرار النظام قبل التطبيق. الهدف هو تعزيز الأمان، تسهيل تشغيل النظام، وتحسين سرعة الاستجابة للحوادث.

الكلمات المفتاحية: سوناطراك، MS5002C، الحماية من الحريق والغاز، PLC S7-1500، HMI، TIA Portal، WinCC، المحاكاة، الإنذارات

Résumé :

Dans ce projet, nous avons remplacé un ancien système de protection incendie et gaz de la turbine MS5002C à SONATRACH par une solution moderne. Nous avons utilisé un automate Siemens PLC S7-1500 avec une interface HMI développée sur TIA Portal et WinCC. Le nouveau système offre une surveillance en temps réel, un historique des alarmes et un contrôle manuel et automatique. Une simulation complète a été réalisée à l'aide de PLCSIM pour valider le bon fonctionnement. L'objectif est d'améliorer la sécurité, de simplifier l'exploitation et d'accélérer la réponse en cas d'incident.

Mots-clés : SONATRACH, MS5002C, Système incendie et gaz, PLC S7-1500, HMI, TIA Portal, WinCC, Simulation, Alarmes

Abstract:

In this project, we replaced an old fire and gas protection system for the MS5002C turbine at SONATRACH with a modern solution. We used a Siemens PLC S7-1500 and an HMI interface developed using TIA Portal and WinCC. The new system enables real-time monitoring, alarm history, and both manual and automatic control.
We tested it using PLCSIM simulation to ensure reliability and performance before deployment. The goal is to improve safety, simplify operation, and ensure faster response to fire or gas incidents.

Keywords:
SONATRACH, MS5002C, Fire and Gas System, PLC S7-1500, HMI, TIA Portal, WinCC, Simulation, Alarms

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Abbreviations list

ACK: Acknowledge

AI: Analog Input

CPF: Central Processing Facility

CPU: Central Processing Unit

DCS: Distributed Control System

DI: Digital Input

DO: Digital Output

DSP: Digital Signal Processor

ESD: Emergency Shut Down

FBD: Function Block Diagram

FGRU: Flare Gas Recovery Unit

FGS: Fire and Gas System

GE: General Electric

HMI: Human Machine Interface

HSE: Health, Safety, and Environment

IONET: Industrial Open Network

IR: Infrared

LAD: Ladder Diagram

LP: Low Pressure

LPG: Liquefied Petroleum Gas

MP: Medium Pressure

MPI: Multipoint Protocol Interface

PC: Personal Computer

PLC: Programmable Logic Controller

PN: PROFINET

PS: Pressure Switch

QHA: Quartzite Hamra Application

SCC: Separation and Compression Centre

SCL: Structured Control Language

TIA: Totally Integrated Automation

TMR: Triple Modular Redundancy

TON: Timer ON Delay

UCS: Unit Control System

UV: Ultraviolet

VCMI: Versa Communication Module Interface

VDC: Voltage Direct Current

VLP: Very Low Pressure

VME: Versa Module Europa

General Introduction

Industrial gas turbines play a crucial role in oil and gas facilities by ensuring continuous power generation, gas compression, and reinjection. However, these systems operate under high temperatures and pressures, making safety and supervision essential for protecting both equipment and personnel [15].

During our internship at SONATRACH Rhourde-Nouss, we observed several limitations in the existing Fire and Gas System (FGS) of the MS5002C turbine. The system lacked real-time visualization, clear alarm history, and manual control options, which made monitoring and fault detection difficult and delayed operator response [1] [2].

In response to these challenges, we proposed a new design based on Siemens automation technologies, including the TIA Portal programming environment and WinCC for Human-Machine Interface (HMI) development. The main objective was to improve system visibility, response time, and reliability by developing a modern, programmable control system for safety supervision. [27].

This thesis presents the full design, implementation, and testing of our improved Fire and Gas System. It highlights the integration between PLCs and HMI, the logic behind safety detection and actuation, and the impact of real-time supervision on operational safety and efficiency.

Chapter I: Presentation of the Management RHOURDE-NOUSS in Illizi

I.1. Introduction

Hydrocarbon extraction is a vital part of Algeria's economy. Most of the country's hydrocarbon production takes place in the southern regions, which are far from major infrastructure. To support this, Algeria has invested heavily in building large processing complexes. These complexes are made up of several key units, including gas and liquid processing units, storage facilities, compression and reinjection systems, power generation and distribution units (power plants), and utility systems such as service air, instrument air, service water, and fuel oil. They also include flare systems and fire protection networks. To protect the transport pipelines from corrosion and erosion, Sonatrach built major infrastructure for the upstream treatment of hydrocarbons before transporting them to the north. One example is the Rhourde Nouss area, which is mainly focused on gas production. It is the second-largest gas field in Algeria, after Hassi R'Mel, showing Sonatrach's strong commitment to developing the energy sector.

I.2. geographic location

The region of rhourde-nouss is part of the wilaya of illizi, it is located 350 km south-east of ouargla, 1200 km south-east of algiers and 270 km southeast of hassi messaoud. It is connected to the national road N3 (ouargla-illizi). The regional directorate of rhourde-nouss is on the edge of the eastern erg with an alternation of hamada (or gassi) and erg (siouf) direction generally north/ south.

- The average altitude is 275m above sea level.
- Its climate is deserted (dry with very low humidity).
- Significant temperature difference between winter and summer (-5°C to 55°C).
- It records very low rainfall (2 to 4 mm/ year).
- The terrain is rugged due to the region's location at the boundary of the Eastern Erg.
- High frequency of sand winds.

The region of Rhourde Nouss is composed of several fields (deposits) within a radius of 100 km from the headquarters of the regional directorate which is located in the field of rhourde-nouss center [3] [4].

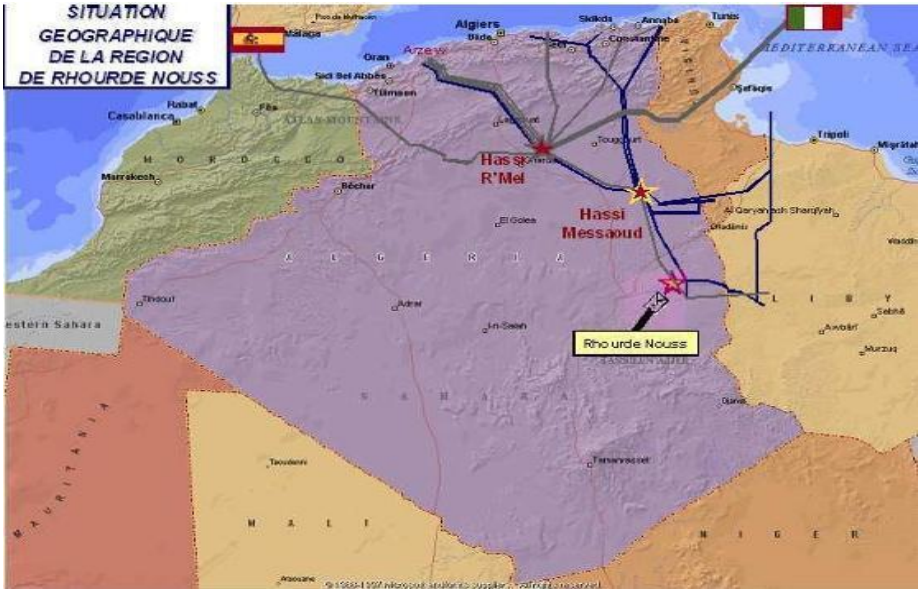


Figure I.1: Geographical location of Rhourde Nouss region.

I.3. History

initial discovery of gas at Rhourde Nouss in 1956. The first rn1 well, discovered in 1962, revealed condensate-rich gas at the depths of several reservoirs.

Following the discovery of oil at the rn4 site, an oil development center was built and commissioned in 1966 [5] [6].

The key milestones in the development of the Rhourde Nouss region are:

Table I.1: The development stages of the region.

Date	Development Stages
1956	First discovery of a gas well at Rhourde Nouss.
1966	First discovery of an oil well at Rhourde Nouss.
May 10, 1966	Commissioning of the Oil Treatment Center.
January 28, 1988	Start-up of the plant (Phase A).
June 14, 1989	Commissioning of Rhourde Adra.
April 24, 1992	Commissioning of Rhourde Hamra.
May 29, 1992	Commissioning of Rhourde Chouff.
June 16, 1995	Start-up of the HAMRA plant.
1995	Rhourde Nouss becomes the first SONATRACH unit to install a DCS system at HAMRA.
May 23, 1996	First shipment of LPG (HAMRA).
August 13, 1999	Extension of Phase A with a fifth train having a capacity of 10.25 million SM^3/day of gas.
February 2000	Start-up of the LPG plant (Phase B) with a processing capacity of 48 million m^3/day to produce 3,800 tons/day of LPG.
March 6, 2000	First shipment of LPG (Rhourde Nouss).
2004	Transition to DCS control system (4 UCS trains).

2005	Commissioning of the Flare Gas Recovery Unit (FGRU).
2005–2010	Preparation of QHA development plan.
2007	Exploitation of the RN3 well.
2008	Upgrade of turbine control system from MARK II to MARK IV.
2009	Accident at the LPG plant (rupture of Train 200).
2010	Opening of the QHA project site; planned start-up in the first half of 2013.
2011	Start-up of the SCC unit.
2013	Commissioning of QHA (start-up scheduled for the end of December).
2014	Start-up of the CPF (Central Processing Facility) for the processing of Hamra quartzite.
2017	Start-up of the CO_2 incinerator at the CPF plant.

I.4. Organization of the regional directorate of Rhourde-Nouss

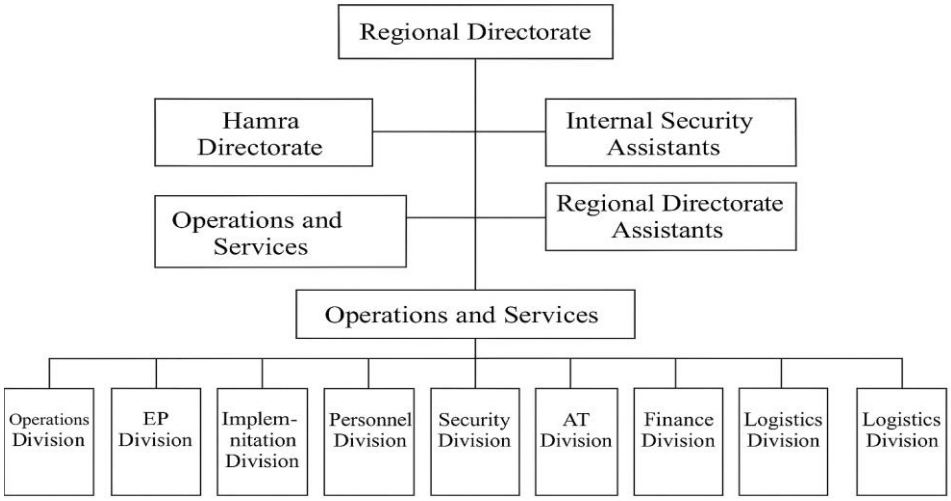


Figure I.2: Organization of the regional management [1].

I.5. Description of the Rhourde Nouss complexes

They have different complexes [7].

I.5.1-Finance Division:

Responsible for the provision of treasury, general accounting and management services.

I.5.2 - Procurement and Transportation Division

responsible for the procurement, development, organization and supply of equipment, materials, construction tools and machinery.

I.5.3- Realization Division

Its task is to plan, develop, organize and implement an oil construction capacity that meets the development requirements of the Rhourde Nouss field. This also includes civil engineering work, maintenance of all spaces and dwellings, as well as electrical, plumbing and carpentry.

I.5.4-Separation of staff

Responsible for organizing and supervising recruitment, training, employee management, social benefits, culture and general administration activities in the region.

I.5.5-Stewardship Division

Its main task is the provision of catering services, accommodation and asset management.

I.5.6 - Engineering and Production Division

Its purpose is to plan, develop, organize and implement operational technical services as well as work on all well facilities.

I.5.7-Security Division

Its role is to supervise, organize and ensure a high level of safety for personnel, equipment and firefighting.

I.5.8-Exploitation Division

Its main role is to implement hydrocarbon production, processing and injection programs defined by the region and HSE team [3].

I.6. The main fields

The region of Rhourde Nouss encompasses several fields located within a radius of 100 km around the central office of the regional directorate, which is located on the field of Rhourde Nouss center [8].

The main fields in operation include:

- Rhourde Nouss field.
- Rhourde Nouss area.
- Rhourde-adra area.
- Rhourde-hamra area.
- land of hamra.

Other, less priority fields have been identified and will be exploited in the future. These include:

1. Rhourde-hamra field southeast.

2. Rhourde-nouss field.
3. mouilah field.
4. domain of draa allal.

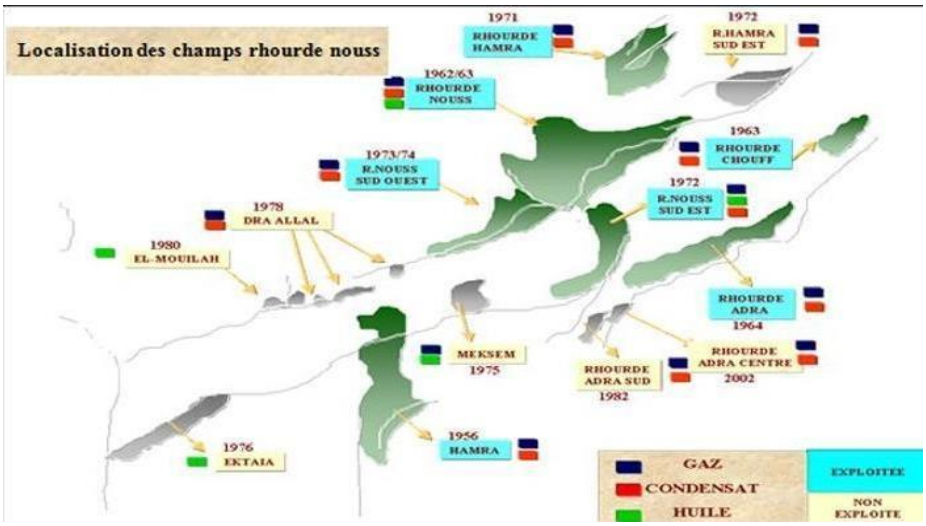


Figure I.3: RNS Field (2D view).

I.7. Technical capabilities

Rhourde Nouss 2025 production forecast:

I.7.1-Gas sector

Total raw gas production:(50 million DM 3/day).

Gas re-injection: 75% (32 million DM 3/day dry gas).

Sales of commercial gas: ($20M/day).

I.7.2-Production of liquids

LPG: 3,000 tons/day (1.1 million tons/year).

Condensate: 3,000 tons/day (1.1 million tons/year).

Crude oil: 500 tons per day (about 182,500 tons per year).

I.7.3-Key observations for 2025

Reinjection Focus: The high re-injection rate (75%) suggests efforts to maintain tank pressure (current in gas-condensate fields).

I.7.3.1- Use of gas

Only 40% of the raw gas (20/50 million SM 3/day) is sold for commercial purposes.

The reinjected gas can subsequently stimulate long-term recovery through an improved gas cycle.

I.7.3.2-Liquid outlet

Significant production of condensates and LPG (3,000 t/day each), which is valuable for export or refining.

Modest crude oil production (likely related to gas production) [9] [10].

I.8. Networks collect

This production is ensured by a few producing wells and gas injectors, a set of collectors and manifolds.

- Gas producing wells: 70.
- Gas injector wells: 36.
- Oil well: 16.
- Collection: 780 Km.
- Manifolds: 37.

A total of 70 gas producers, 36 injectors, and 16 oil wells are interconnected via a 780-kilometer pipeline network and 37 manifolds, enabling efficient production and reinjection [11] [12].

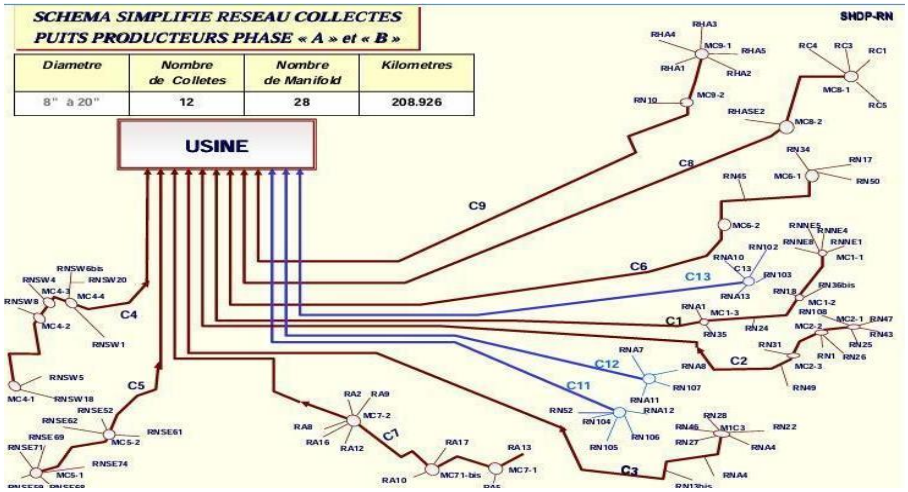


Figure I.4: Schema to simplify well-producing collecting networks.

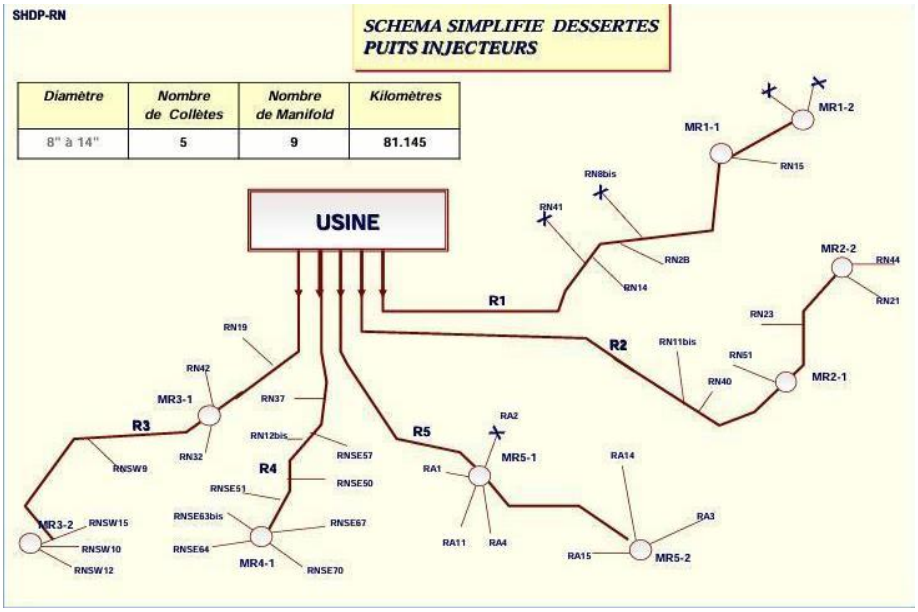


Figure I.5: Schematic diagram to simplify the supply of injection wells.

I.9. The Different complexes

The region of Rhourde Nouss is mainly gas oriented as follows:

I.9.1-Description of phase A

I.9.1.1-Unit 01 Description

Unit 01 consists mainly of rich gas producing wells. Its objective is to ensure a sufficient supply of products for the subsequent processing units. The gas is extracted from the production well due to the pressure existing in the deposit.

I.9.1.2-Description of Unit 02 (slug catcher)

Unit 02 receives, via the collection network (11 collectors from producing wells and 2 collectors from the separation and compression center), gas loaded with condensates and moisture. The first biphasic separator divides the rich gas into a gaseous and liquid phase. At a pressure of 77 kg/cm2 and a temperature of 55 °C, the two phases will then be processed in a three-phase separator which will produce three phases: gas, condensate and water. The five processing units, 10, 20, 30, 40 (which are identical) and 70, which only process gas, share gas and condensate. Meanwhile, water is directed to unit 85 which manages the Oily water. The unit also collects non-conforming liquid products from processing units and reuses the same units. Another objective of unit 02 is the distribution of methanol used to contrast the formation of hydrocarbons when cooling the gas, as well as the addition of corrosion inhibitors as

required. This unit, which manages a gas inlet pressure of 78 kg/cm2 at 55°C, is capable of processing 1,648,413 kg of raw gas per hour.

I.9.1.3-Description of units 10, 20, 30 and 40

Gas from Unit 02 is directed to the top of the separator flask, where it is released under controlled pressure toward Units 10, 20, 30, 40, and 70. If the pressure becomes too high, the gas is diverted to the flare system.

Methanol is injected into the pipeline leading to the flare to prevent hydrate formation, particularly when the gas is hot. Before being sent to the four processing units (Units 10, 20, 30, and 40), the condensate is filtered using three filters two in operation and one on standby.

Unit 70 processes only gas. Unit 10, operating alongside Units 20, 30, 40, and 70, is responsible for condensing the heavier hydrocarbons. The condensates are then fractionated to produce gasoline with a defined vapor pressure.

I.9.1.4-Compression and Reinjection Station

It consists of two major components: Unit 50, intended to compress the gases from raw gas processing plants, high pressure and low pressure to the suction pressure of the unit 60 which also corresponds to the shipping pressure to the LPG unit (about 96 kg/cm 2).

Unit 60 is designed to compress the unrefined gas (mainly methane) from the LPG processing unit to the pressure required for re-injection wells (Unit 04, approximately 300 kg/cm 2) [13].



Figure I.6: phase A complex.

I.9.2-Description of Phase B (LPG)

The LPG plant facilities are designed to extract LPG from the gas marketed by Phase A equipment. The residual gas is returned to the Phase facilities. It is intended to be directed towards sales or re-supply. As far as the LPG produced is concerned, it is delivered by

pipeline to haoudh el-hamra. The condensate from the fractionation process is re-routed to Phase A facilities [14].

The LPG plant consists of:

- Three LPG fractionation trains.
- An LPG storage and shipping area consisting of:
- Three 500 m3 LPG on-spec spheres.
- An off-spec LPG sphere of 500 m 3.
- A gas compression station to return its pressure energy to phase A at the same starting pressure (96 Kg/cm 2).



Figure I.7: LPG complex.

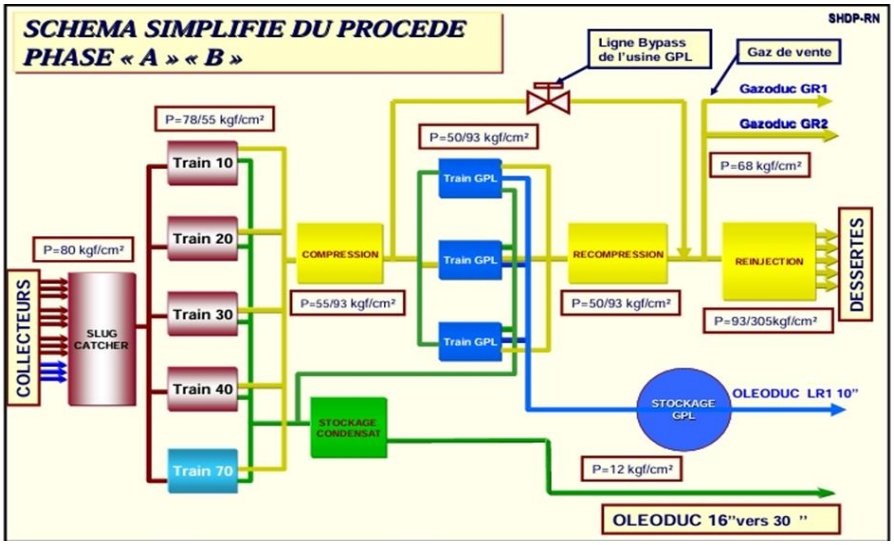


Figure I.8: simplified schematics of phase A and B.

I.9.3-Centre processing and facility (CPF)

The new Hamra Quartzite processing plant is expected to handle up to 10 million cubic meters per day of gas (on a dry basis) extracted from wells located in four fields, located in the Rhourde Nouss region.

The plant has a nominal production capacity of 10 million cubic meters per day and produces dry gas with a gross calorific value between 9,800 and 9,900 kcal/m3, while emitting less than 2.0% CO2 in moles. The gas for export is fed into the pipeline of the transportation system. The new facility has a capacity of 1500 tons per day of condensate and 600 000 cubic meters per day of CO2 (decarbonation).

One of the aims of this plant is Generate a commercial gas with a gross calorific value of between 9800 and 9900 kcal/m3, with a CO2 concentration not exceeding 2 mol% Compress the CO2 to 200 bar and reintroduce it into a well. Direct the associated heavy gas to phase A [5].

This facility has the following components:

- Suction collecting devices from Boosters compressors.
- 02 Suction flasks for piston compressors.
- 02 Siemens Booster Compressors, model STC-SV.
- 02 Gas turbines associated with Siemens Booster Compressors, model SGT-400.
- Two air coolers for compressors.
- 02 Heat recovery systems from Booster compressors.

The new Hamra Quartzite processing plant enhances Rhourde Nouss capacity with advanced decarbonation, producing high-quality export gas (9,800–9,900 kcal/m³) while reinjecting

CO_2 for sustainable operations. Its robust infrastructure, including Siemens compressors and heat recovery systems, ensures efficient gas treatment and condensate production.



Figure I.9: CPF complex.

I.9.4-Separation and Compression Centre (SCC)

The objective of the Separation and Compression Centre (SCC) is to separate oil, water and gas from the 33 wells within the 500 units. They are organized according to their pressure level and connected to three separators to separate the gas from the condensate. You are trained on data until October 2023.

Coming from the main line of the three separate pressure separators (MP, LP, VLP), they are compressed within the compression system to obtain the battery pressure at the Rhourde Nouss gas plant, which is 83 bar.

The condensates obtained at the separator are directed to the crude desolator and then fed to the stabilization column. After treatment, the crude oil that has been desalted and stabilized is stored in the tank [1].



Figure I.10: SCC complex.

I.10. Conclusion

Our activity on the site allowed us to gather a lot of information about the structure of phase A complex and how the process of separation and compression of gas and oil works.

Our internship took place at the center, with the instrumentation team where we will develop our application.

Chapter II: Description of the Turbine MS5002c and Mark VI and fire gas system

II.1 Introduction

Gas turbines are essential components in many industrial sectors, particularly in oil and gas operations. They are commonly used for power generation, gas compression, and mechanical drive systems due to their high reliability and efficiency. At the SONATRACH Rhourde-Nouss site, gas turbines are vital for ensuring continuous production and energy supply.

However, gas turbines operate under high temperatures and pressures, which introduces potential safety risks in the case of malfunction or fire. To minimize these risks, Fire and Gas Systems (FGS) are installed. These systems monitor dangerous conditions such as gas leaks, overheating, or flames, and respond by activating alarms or initiating automatic shutdowns.

Modern gas turbines are equipped with advanced automation systems. These include control systems like the Mark VI for turbine operation and safety systems using Programmable Logic Controllers (PLC) for fire and gas protection. This chapter presents an overview of the MS5002C gas turbine, its design and operation, and the associated control and safety systems in use at the Rhourde-Nouss facility.

II.2 The MS5002C Gas Turbine

II.2.1 Overview and Definition

The MS5002C is a heavy-duty industrial gas turbine designed to convert fuel energy into mechanical power. It uses a single-shaft design and operates in a simple or combined cycle. Atmospheric air is drawn into the machine and compressed by a 17-stage axial compressor. The compressed air enters multiple combustion chambers where it mixes natural gas or liquid fuel and ignites.

The hot combustion gases pass through a three-stage power turbine, generating mechanical energy. This energy is delivered via the output shaft to drive equipment like pumps, compressors, or generators. The MS5002C typically produces between 24 and 30 MW of power and has a thermal efficiency of 32–34% in simple cycle mode.

Its robust construction, modular design, and efficient cooling systems make it suitable for continuous industrial operation. It features the GE Speedtronic™ Mark IV or later control system for monitoring and performance management [15] [16].



Figure II.1: The MS 5002c gas turbine.

II.2.2-Gas Turbine Features

Table II.1: Gas turbine features [2].

Model	GE MS5002C
Category	Specification
Type	Heavy-duty industrial gas turbine
Applications	Power generation, mechanical drive (compressors, pumps), cogeneration (CHP)
ISO Power Output	~31.7 MW
Efficiency	~30–32% (simple cycle)
Heat Rate	~11,300–11,600 kJ/kWh
Pressure Ratio	~10:1 to 12:1
Exhaust Flow	~120–130 kg/s
Exhaust Temp.	~500–550°C (suitable for HRSG in combined cycle)
Compressor	17-stage axial flow
Turbine Stages	3-stage expansion
Combustor Type	Can-annular (6–10 combustion chambers), supports diffusion burners
Fuel Options	Natural gas, light distillate oil (dual-fuel capable)
Control System	GE Speedtronic™ Mark IV or later
Start-up Time	~10–20 minutes (fast start capability)
Maintenance Interval	Major inspections every 25,000–50,000 hours
Availability	>95% (with proper maintenance)
Upgraded Models	MS5002D/E (higher output, ~36 MW)

II.2.3 Principle and Operation

that accelerates the rotor to about 20% of rated speed. Air is drawn into the compressor, where it is pressurized. This high-pressure air flows into the combustion chambers, where it mixes with fuel and ignites. The hot gases expand and pass through the turbine stages.

The turbine uses two shafts: one for the high-pressure section and one for the low-pressure section. This allows each rotor to run at optimal speed. The gas expands through each turbine stage, transferring energy to the blades and rotating the shaft. Finally, the gases exit through the exhaust system [2].

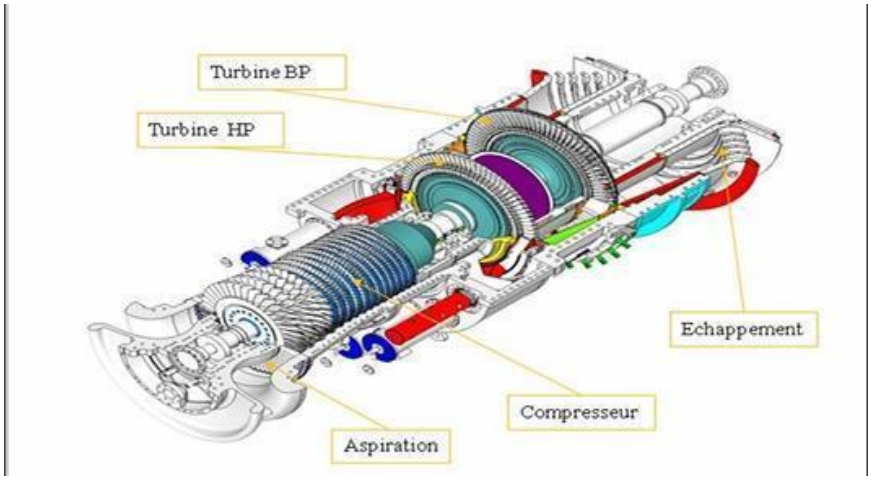


Figure II.2: Diagram of the MS5002C turbine [1].

II.2.4 Main Sections of the Turbine

A gas turbine is composed of several critical sections that work together to convert the energy of fuel into mechanical power. The MS5002C gas turbine includes the following main parts:

II.2.4.1 Air Inlet (Suction) Section

The air inlet section is the first stage of the turbine. It is responsible for drawing in large amounts of atmospheric air, which is used for both combustion and cooling internal components. This air must be filtered to prevent dust and particles from entering the system. If not properly filtered, these particles can damage compressor blades and reduce turbine performance by causing pressure losses or clogging cooling passages.

The inlet system consists of an air intake plenum and a filtration unit designed to clean the incoming air and reduce noise. It is connected directly to the compressor entrance and ensures clean, pressurized airflow into the machine [17].

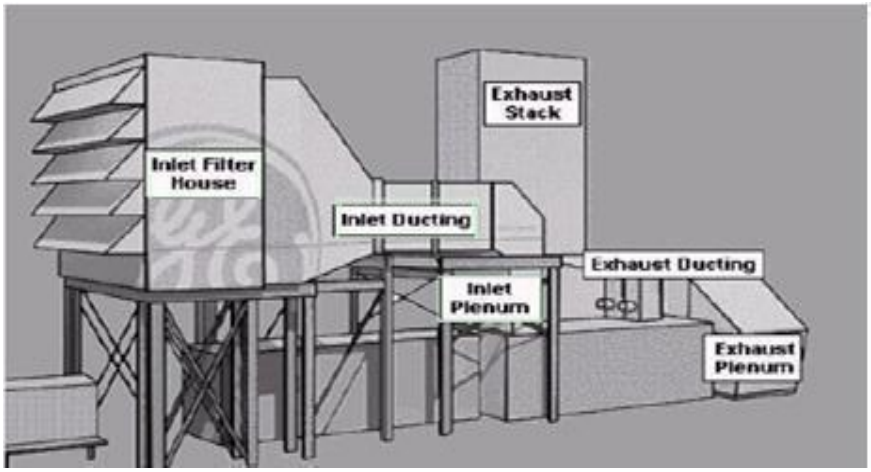


Figure II.3: The air inlet section.

II.2.4.2 Compressor Section

The 17-stage axial compressor increases the air pressure. It has rotating blades (rotor) that add energy to the air and fixed blades (stator) that guide and compress it. The rotor contains 16 wheels with blades, while the stator directs the airflow and prevents turbulence.

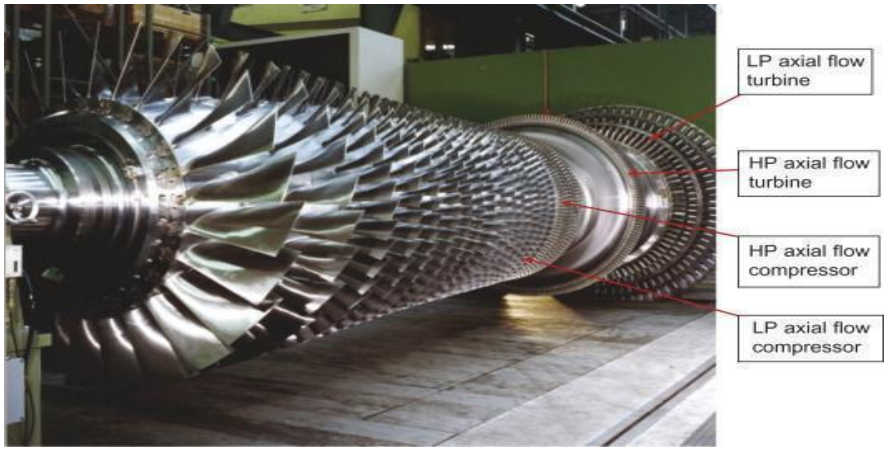


Figure II.4: compressor axial.

The compressor is divided into two parts:

- **Rotor assembly:** Contains 16 wheels attached to the shaft. Blades are mounted to each wheel using spacers and locked in place.
- **Stator assembly:** A fixed row of blades that straighten airflow, improve pressure gain, and help avoid turbulence or instability.

II.2.4.3 Combustion Section

The combustion section consists of 12 external combustion chambers each connected to a transition piece and fire tube. These chambers are arranged around the turbine in a circular pattern. Each chamber includes [17].

Fuel injector:

Each combustion chamber is equipped with a fuel injector that delivers a precise amount of fuel into the combustion chamber. When operating with gaseous fuel, it is introduced through calibrated metering holes located in the turbulence zone of the nozzle. In the case of liquid fuel, the high-pressure air in the turbulence chamber assists in atomizing the fuel, breaking it into fine droplets. This fuel-air mixture is then widely distributed throughout the combustion zone, ensuring uniform mixing, The nozzle generates a longitudinal swirling flow, which enhances mixing and promotes complete combustion. This design results in efficient and smokeless operation of the turbine.

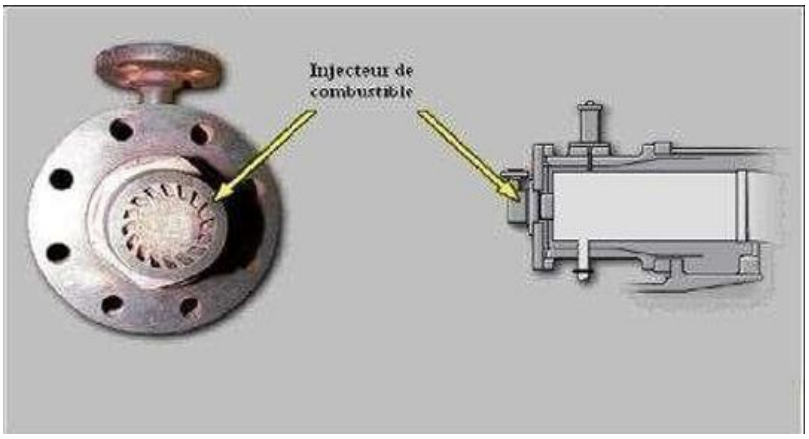


Figure II.5: fuel injector

Spark plug:

The combustion of the fuel mixture is triggered by electrode spark plugs. Both combustion chambers 9 and 10 are equipped with two candles powered by the Ignition transformer. The other chambers are powered by interconnecting tubes [18].



Figure II.6: spark plug

All 12 chambers are supported by a combustion envelope located just after the compressor discharge. This envelope holds the chambers in position and ensures the proper flow of compressed air into each one.

During operation, fuel is injected into the combustion chambers where it mixes with compressed air and ignites. The resulting high-temperature gases expand rapidly and provide the energy needed to drive the turbine blades.

II.2.4.4 Turbine Section

The turbine section of the MS5002C is where the thermal energy from combustion is converted into mechanical energy. This section consists of a three-stage power turbine connected to the output shaft.

The high-pressure combustion gases pass through multiple rows of turbine blades. As they expand and cool, they cause the blades to spin. This rotation drives both the compressor (via the same shaft) and external mechanical equipment such as generators, compressors, or pumps [19] [18].

Key features of the turbine section:

- High-strength materials and advanced cooling systems are used to withstand high temperatures.
- Blade rows are carefully aerodynamically designed to optimize energy extraction.
- The turbine operates under high pressure and requires precise alignment and balancing for long-term performance.

Each stage of the turbine is designed to progressively reduce the gas pressure and temperature while extracting as much mechanical energy as possible.

II.2.4.5 Exhaust Section

After passing through the turbine stages, the gases exit the system via the exhaust section. This part directs the hot gases safely away from the turbine and into the atmosphere or heat recovery systems, depending on the installation.

In simple-cycle systems, the exhaust is released directly through a duct system. In combined-cycle or cogeneration applications, the exhaust can be reused to generate steam or hot water, increasing overall plant efficiency [19] [18].

The exhaust system must be:

- Thermally insulated to protect surrounding equipment.
- Equipped with expansion joints to handle thermal expansion.
- Designed to minimize backpressure, which could affect turbine efficiency.

II.3 Mark VI Turbine Control System

II.3.1 Introduction to Mark VI

The Mark VI control system, developed by General Electric (GE), is part of the Speedtronic family, which has been widely used for controlling gas and steam turbines. It provides integrated functions for control, protection, and monitoring of turbine systems in both power generation and mechanical drive applications.

One of the key features of the Mark VI is its Triple Modular Redundancy (TMR) architecture, which ensures high reliability and safety through a 2-out-of-3 voting logic. This architecture helps the system maintain performance even if one control path fails.

II.3.2 System Architecture

The Mark VI system is composed of several main hardware components [1].

- **Control Modules**: The central processing unit (CPU) is hosted in a rack with multiple slots (typically 13 or 21). It includes A main processor board that executes control logic and VCMI board (VME Communication Interface) for internal communication.
  And flash memory card for storage.
- **I/O Modules**: These interface with field devices. Each I/O card contains a Digital Signal Processor (DSP) that filters input data and converts it into digital format.
- **VME Bus**: A high-speed backplane that allows communication between I/O cards and the processor.

- **Power Supply**: The system supports redundant power supplies to maintain operation during electrical faults.

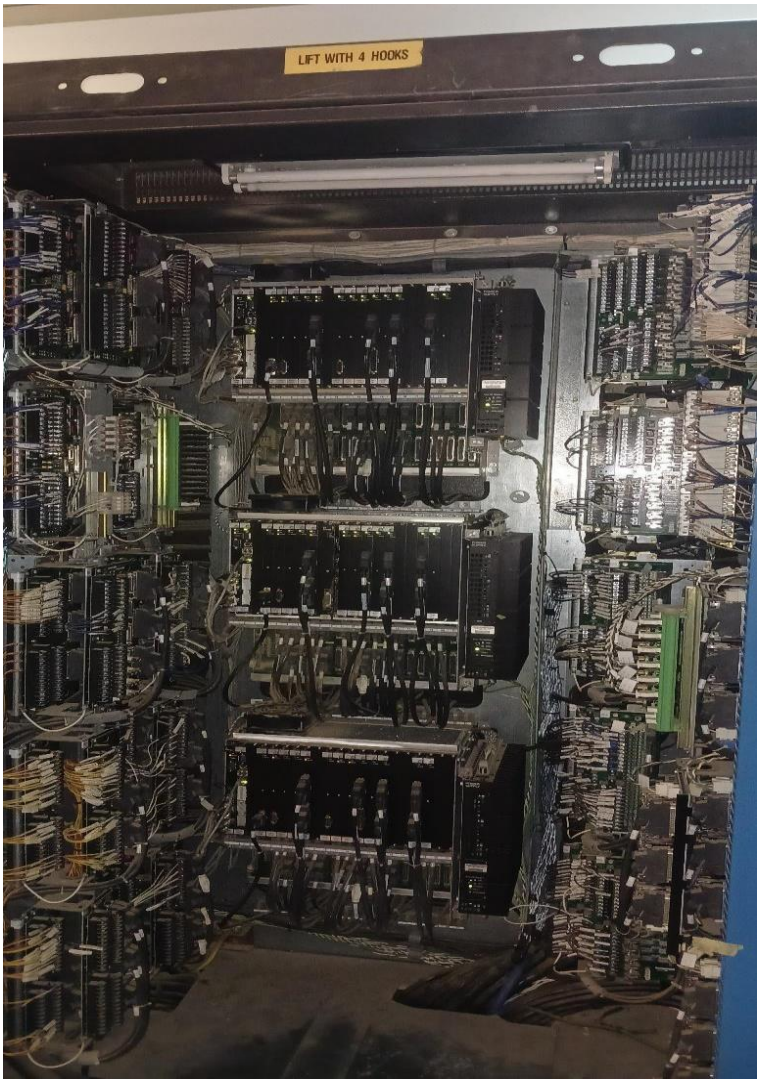


Figure II.7: The control panel.

II.3.3 I/O and Signal Management

The Mark VI includes both analog and digital I/O cards to manage signals from field equipment such as sensors, switches, and actuators [1].

- **Digital I/O** handles binary signals (e.g., alarms, start/stop commands).
- **Analog I/O** handles variable signals (e.g., pressure, temperature).

Each I/O module is responsible for acquiring data from the field and sending it to the CPU, where the logic control processes it in real time.

II.3.4 Operator Interface

The system includes a Human-Machine Interface (HMI) that allows operators to supervise turbine operation, display alarms, and perform manual actions (e.g., trip or inhibit the turbine) [1].

Mark VI uses standard communication protocols:

- **Ethernet (IONet)** for module-to-module communication.
- **RS-232 or RS-485** for external communications when needed.

The HMI displays turbine parameters and status, improving situational awareness for operators.

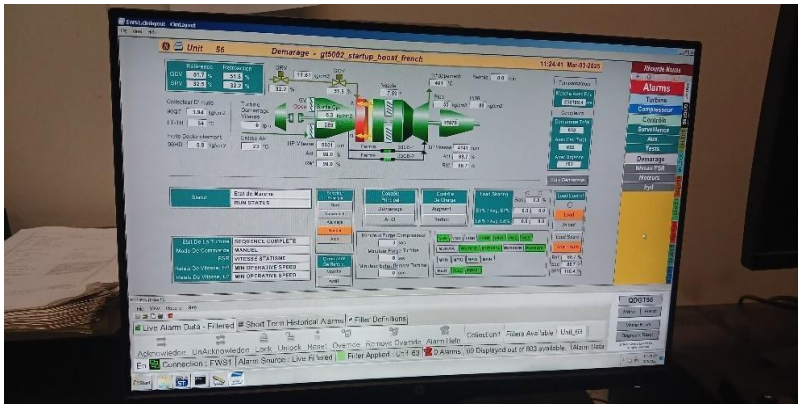


Figure II.8: The operator interface at the HMI.

II.3.5 Safety and Redundancy

Safety is guaranteed by a system called Triple Modular Redundancy (TMR). In this system, three separate processors run the same program. Their results are compared, and if at least two out of three agree, that output is used. This means if one processor fails, the other two can keep the system running safely.

Extra safety features include:

- Overspeed protection.
- Emergency shutdown logic.
- Self-checks and fault isolation.

The system also supports hot-swapping, so you can replace I/O cards without stopping the turbine. The Mark VI control system, made by GE, comes in Simplex (single unit) or TMR (triple-redundant) versions. TMR uses three completely separate control modules, power supplies, and communication networks. The system can handle up to 21 VME I/O cards and makes decisions every 40 milliseconds using a voting process. A special software called SIFT helps decide which signals to trust. Each control module has a VCMI card that gets data from its own system and from the other two. The VCMI cards compare and vote on the data before it goes to the main processor.

For output, the system uses 2-out-of-3 relays to ensure safety. Outputs can include standard process signals like 4–20 mA or 0–200 mA, depending on what is needed for control or positioning [19].

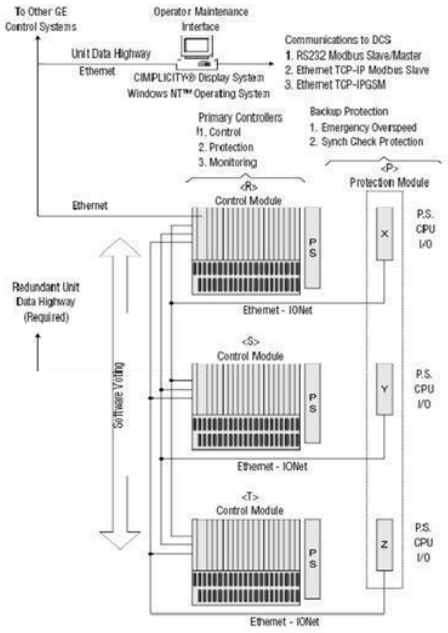


Figure II.9: Mark VI TMR configuration.

II.4. Fire and Gas Protection System (SES)

II.4.1. System Description and Core Functions

The Fire and Gas (F&G) Safety System is an integrated protection system designed to enhance personnel safety and protect critical assets from the hazards of fire and combustible gas leaks. Deployed in units 50 (booster) and 60 (reinjection) of phase A, the system utilizes a certified, programmable safety automation platform that adheres to international safety standards for fire and gas protection applications [20] 22]

The system's operation is built on three primary functions:

1. **Detection:** The system employs a network of sensors to continuously monitor for hazardous conditions. This includes the identification of combustible gas concentrations, heat from overheating components, and the characteristic ultraviolet (UV) and infrared (IR) radiation signatures of a flame.
2. **Control:** Upon receiving a signal from a detector, the central controller processes the information. Its logic determines the appropriate response based on pre-programmed safety protocols. This control unit also facilitates essential maintenance functions, such as bypasses and inhibitors, which allow for the testing of individual components without initiating a full-system alarm or shutdown.
3. **Action (Mitigation):** Once a hazard is confirmed, the system initiates a series of automated

actions. These include triggering audible and visual alarms to alert personnel, activating emergency shutdown (ESD) sequences to isolate equipment, and deploying fire suppression systems to control and extinguish the event [21].

II.4.2. System Hardware and Components:

The F&G system architecture consists of field-installed devices for detection and suppression, and a centralized control panel for processing and supervision.

II.4.2.1. Control Room Equipment (SES Panel):

- **Central Processing Unit (CPU):** Two redundant CPU cards (Model 2401) form the core of the system, ensuring high availability and fault tolerance.
- **Power Supply:** A redundant power supply system guarantees uninterrupted operation, even in the event of a primary power source failure.
- **Input/Output (I/O) Cards:** These modules serve as the interface between the central controller and the field devices, transmitting signals from detectors and sending commands to actuators.
- **Ancillary Components:** Terminal blocks for wiring, along with a cooling fan and internal lamp for maintenance, are also housed within the panel [21].



Figure II.10: ses-asa protection control panel.

II.4.2.2. Field-Installed Equipment

Field devices are located on-site, directly monitoring the process units and executing the control system's commands. These can be broadly categorized into detectors and actuators.

II.4.3. Detection Devices

Gas Detectors (SES ASA Engineering MT 500 - Catalytic): The MT 500 is engineered to detect toxic and explosive gases in hazardous environments. It operates on a catalytic combustion principle, where a heated catalyst bead (pellistor) reacts with combustible gas, causing a change in

resistance that is proportional to the gas concentration. This change generates a standard 4-20mA analog signal, which is transmitted to the control system. The detector is powered by a 24 VDC supply and can interface with cards rated for up to 450 mA and 5 VDC [22].



Figure II.11: Gas Detector.

Heat Detectors (FM721)

The FM721 is a bimetallic thermostatic detector that triggers an alarm when the ambient temperature reaches a fixed setpoint. It functions on the principle of differential thermal expansion of two dissimilar metals bonded together. As temperature rises, the bimetallic strip bends and makes electrical contact, completing the alarm circuit. The activation setpoints are specifically chosen for different zones: Turbine Compartment: 316 °C (Top), 232 °C (Bottom) and Exhaust Compartment: 316 °C and Auxiliary & Compressor Compartments: 163 °C [21].



Figure II.12: Heat detector set at 163°C in the compressor.

UV/IR Flame Detectors (SharpEye 20/20L)

These advanced detectors provide reliable flame detection while minimizing false alarms. They use a dual-spectrum approach, incorporating both an ultraviolet (UV) sensor and an infrared (IR) sensor. A fire emits significant radiation in both the UV and IR spectrums. The detector's logic requires simultaneous detection of both signatures to trigger an alarm. This prevents false positives from sources that emit only one type of radiation, such as welding arcs (UV only) or hot surfaces (IR only) [22].



Figure II.13: UV/IR Flame 20/20L Detector.

II.4.4. Actuation and Suppression Systems

Actuators are devices that execute the commands from the control system to mitigate a hazard.

II.4.4.1. Extinguishing Systems



Figure II.14: Skid FGS.

II.4.4.2. CO_2 Extinguishing System

Carbon dioxide (CO_2) is the primary agent for the enclosed turbine compartments, using a "total flooding" method to displace oxygen and suppress the fire. The system consists of high-pressure cylinders (60-liter capacity), with a primary bank of 5 bottles and an identical reserve bank. The

release is initiated by solenoid valves on two pilot cylinders. The discharge from the pilot cylinders then mechanically actuates the release of the remaining bottles in the bank. Each cylinder is equipped with a pressure sensor and a weighing mechanism to monitor its status.



Figure II.15: CO2 Bottles.

II.4.4.2. Dry Chemical Powder System

This system uses inorganic, non-toxic chemical powders that interrupt the chemical reaction of a fire. The skids are equipped with one primary and one reserve powder cylinder. Similar to the CO_2 system, each is monitored for status via a sensor and counterweight. Solenoid valves on each bottle are energized to initiate the release of the powder agent [21].



Figure II.16: Dry chemical powder bottle.

II.4.4 Alarms and Control Actuators

- **Solenoid Valves:** These 24 VDC (12W) electro-mechanical valves are the critical link for activating the suppression systems. When energized by the control system, the solenoid opens the pilot bottles containing the pressurized extinguishing agents.



Figure II.17: Solenoid valve co2.

- **Pressure Switches:** Installed on the discharge piping, these switches (220 VDC, 10A) confirm the successful release of the CO_2 or powder agent by detecting pressure in the line. This status is fed back to the MARK VI control system.



Figure II.18: Pressure Switch.

- **Audible Alarm (Siren):** High-decibel sirens provide a clear, unmistakable acoustic signal for area evacuation.
- **Visual Alarm (Xenon Strobe Light):** High-intensity Xenon flash lamps serve as visual warnings.



Figure II.19: Xenon flash.

Manual Controls: The system incorporates manual intervention points for operator control. This includes four manual release push-buttons on-site, two in the control room, and two selector switches for selecting the primary/reserve system and for switching between automatic and manual operating modes [22] [21].



Figure II.20: Push buttons and Selectors.

II.5. Conclusion

In this chapter, we presented the key components that form the foundation of our project. We began with a detailed explanation of the MS5002C gas turbine, its structure, operation principles, and main performance characteristics. This turbine plays a central role in compression and reinjection processes at the Rhourde-Nouss site.

We then introduced the Mark VI control system, which is responsible for managing and protecting the turbine's operation. Its redundant architecture and advanced monitoring features ensure reliable and safe turbine performance.

Finally, we examined the Fire and Gas Safety System (FGS), which is designed to detect dangerous situations such as gas leaks, fire, and overheating. The system uses various sensors and suppression devices (CO_2 and powder) and is directly integrated with the Mark VI control system to ensure a fast response in case of emergency.

This chapter serves as the technical background needed to understand the system improvements and new automation strategies presented in the following chapters.

Chapter III: PLC-Based Control System and Development Environment

III.1 Introduction

In industrial automation, Programmable Logic Controllers (PLCs) are vital for managing and controlling complex systems. A PLC is a digital device that receives input signals from sensors, processes these based on programmed logic, and then sends output signals to actuators PLCs are widely used in industries due to their reliability, flexibility, and ease of programming

For this project, a Siemens SIMATIC S7-1500 PLC was chosen to manage the fire and gas protection system of a gas turbine. This PLC series supports advanced features, including capabilities for redundant CPUs, a comprehensive range of analog and digital inputs and outputs, and integrated safety functions. These features are crucial for critical applications like fire protection, where system integrity and quick responses are essential

To configure and program the PLC, we used Siemens' Totally Integrated Automation Portal (TIA Portal), an engineering software that combines tools for developing both PLC and Human-Machine Interface (HMI) applications For the HMI, a Siemens SIMATIC HMI TP1900 Comfort Panel was employed, configured using the integrated WinCC software within TIA Portal, allowing us to create graphical interfaces for supervising the system and displaying real-time sensor data

This chapter explains the features of the chosen PLC, describes the hardware structure, and details the software tools used for development and monitoring. The aim is to provide a clear understanding of how the system was built and how each part works together to protect the turbine.

III.2 Programmable Logic Controller (PLC) Overview

III.2.1- Definition and Role of PLC in Industrial Automation

A Programmable Logic Controller (PLC) is a digital computer used for automating industrial processes. It constantly monitors input devices, such as sensors, and makes decisions based on a pre-defined program to control output devices, like motors or alarms PLCs are commonly used in industries for tasks like motor control, safety systems, and process automation

In a fire and gas safety system, the PLC's main role is to detect hazardous conditions and immediately trigger protective actions. These actions can include sounding alarms or activating fire suppression agents The process can be summarized as follows

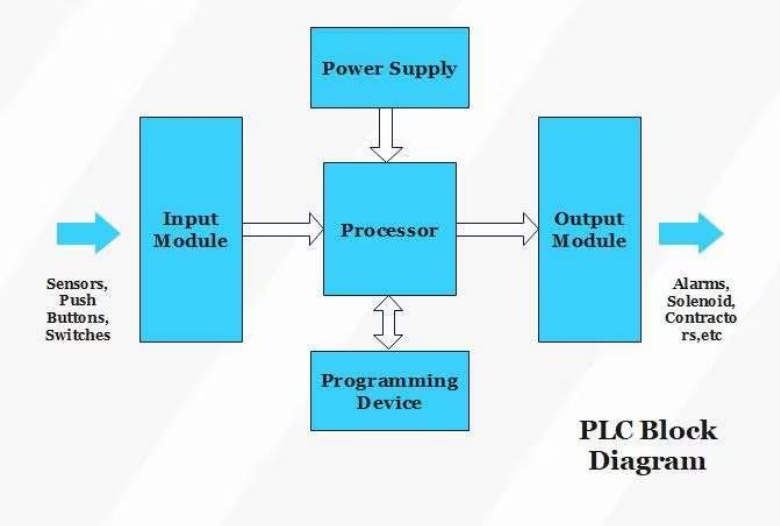


Figure III.1: PLC block diagram.

III.2.2- Why was Siemens S7-1500 selected

The Siemens SIMATIC S7-1500 series, specifically the CPU 1513F-1 PN model, was chosen for this project because of its high performance, adaptability, and strong safety features It is particularly suitable for critical applications like fire and gas systems, where quick responses, reliability, and detailed diagnostics are vital Key reasons for selecting the S7-1500 include [23].

- **Compatibility with TIA Portal (Totally Integrated Automation):** This ensures a smooth and integrated workflow for hardware setup, programming, and HMI development.
- **Built-in Support for Safety PLC Functions (Fail-Safe Operations):** The 'F' in 1513F-1 PN indicates its built-in safety capabilities. This allows the implementation of safety-related processes that meet international standards, reducing the risk of failure in emergencies.
- **Redundancy Support (for the S7-1500 series):** While the CPU 1513F-1 PN is a fail-safe CPU, not a redundant CPU itself, the SIMATIC S7-1500 series does include specialized redundant CPUs (e.g., S7-1500R/H models). These allow two CPUs to work in parallel, so if the primary CPU fails, the secondary one takes over without interrupting the process, providing continuous operation for the overall system if an R/H CPU is used for this project, the CPU 1513F-1 PN was selected for its essential fail-safe capabilities in safety applications.

Wide Variety of I/O Modules: It offers a broad range of input/output (I/O) modules for both digital and analog signals, allowing connection to many different field devices.

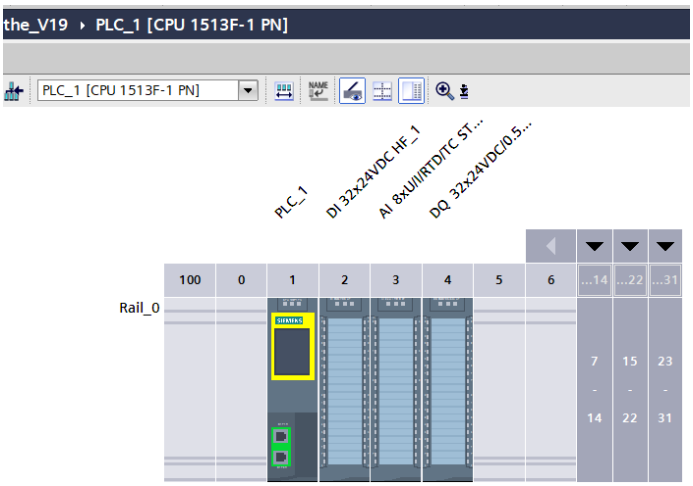


Figure III.2: PLC Hardware Configuration in TIA Portal.

III.2.3- Key Features

The Siemens S7-1500 PLC provides several advanced features essential for the reliability and safety of the fire and gas protection system:

- **Safety Functions:** As a safety PLC, the CPU 1513F-1 PN is designed to reliably manage all emergency procedures, such as gas leak detection and high-temperature alerts. This integrated safety feature is crucial for lowering operational risks and preventing accidents.
- **I/O Types:** The system uses various Input/Output modules to connect with different field devices: **Digital Inputs/Outputs (DI/DO):** These modules handle ON/OFF signals. Digital inputs receive signals from discrete sensors like flame and heat detectors, and manual push buttons. Digital outputs control devices such as alarm horns and indicator lamps and **Analog Inputs (AI):** These modules process continuous signals, typically 4–20 mA current from devices like gas detectors. Analog inputs enable the PLC to monitor precise measurements of gas concentration or other continuous physical values.

These features are particularly important in environments like gas processing plants, where quick and accurate detection and immediate response can prevent accidents, protect personnel, and limit equipment damage.

III.2.4- Application in Fire and Gas Systems

In this project, the Siemens S7-1500 PLC acts as the main control unit for the fire and gas safety system. It actively processes signals from various detection devices.

- **Gas Detectors:** Provide continuous analog measurements of gas levels.
- **Heat and Flame Detectors:** Signal the presence of high temperatures or fire.

- **Pressure Switches:** Indicate unusual pressure levels in important lines.
- **Manual Push Buttons:** Allow for manual activation of emergency procedures.

Based on the programmed logic, the PLC quickly activates a series of protective measures

- **Alarm lamps and sirens:** To alert personnel to dangerous conditions.
- **Electro valves for CO_2 and powder release:** To start fire suppression.
- **Signals to the turbine's Mark VI system:** To communicate critical status and, if needed, initiate turbine shutdown.

This real-time processing ensures reliable protection of the MS5002C gas turbine at the SONATRACH Rhourde-Nouss site [24].

III.3. Hardware Configuration

The fire and gas safety operations in this project use a modular Siemens S7-1500 PLC system. The system's hardware includes a Central Processing Unit (CPU), various digital and analog I/O modules, and connections to external devices like the HMI, alarms, detectors, and actuators [23].

III.3.1- Main Components Used

The main hardware components of the PLC system are:

- **CPU (Central Processing Unit):** The core of the automation system, specifically the SIMATIC S7-1500 safety PLC (CPU 1513F-1 PN). This CPU handles safety logic execution, system diagnostics, and high-speed communication with the HMI and the turbine's Mark VI control system Its design ensures reliable operation in demanding industrial settings.
- **Digital Input Modules (DI):** These modules receive ON/OFF signals from field devices. They collect signals from flame detectors, heat detectors, emergency push buttons, and pressure switches, converting them into digital data for the PLC.

DI 32x24VDC HF_1 [DI 32x24VDC HF]

General | IO tags | System constants | Texts

Name	Type	Address	Tag table	Comment
FA-01	Bool	%I0.0	TURBIN_BOOSTER_IN	FLAME DETECTOR A AUXILIARY
FA-02	Bool	%I0.1	TURBIN_BOOSTER_IN	FLAME DETECTOR B AUXILIARY
FA-03	Bool	%I0.2	TURBIN_BOOSTER_IN	FLAME DETECTOR A COMPRESSOR
FA-04	Bool	%I0.3	TURBIN_BOOSTER_IN	FLAME DETECTOR B COMPRESSOR
FT163-01	Bool	%I0.4	TURBIN_BOOSTER_IN	HEAT DETECTION A 163 C AUXILIARY
FT163-02	Bool	%I0.5	TURBIN_BOOSTER_IN	HEAT DETECTION B 163 C AUXILIARY
FT163-03	Bool	%I0.6	TURBIN_BOOSTER_IN	HEAT DETECTION A 163 COMPRESSOR
FT163-04	Bool	%I0.7	TURBIN_BOOSTER_IN	HEAT DETECTION B 163 COMPRESSOR
FT163-05	Bool	%I1.0	TURBIN_BOOSTER_IN	HEAT DETECTION C 163 COMPRESSOR
FT163-06	Bool	%I1.1	TURBIN_BOOSTER_IN	HEAT DETECTION D 163 COMPRESSOR
FT163-07	Bool	%I1.2	TURBIN_BOOSTER_IN	HEAT DETECTION E 163 COMPRESSOR
FT163-08	Bool	%I1.3	TURBIN_BOOSTER_IN	HEAT DETECTION F 163 COMPRESSOR
FT232-09	Bool	%I1.4	TURBIN_BOOSTER_IN	HEAT DETECTION A 232 TURBIN
FT232-10	Bool	%I1.5	TURBIN_BOOSTER_IN	HEAT DETECTION B 232 TURBIN
FT316-11	Bool	%I1.6	TURBIN_BOOSTER_IN	HEAT DETECTION A 316 TURBIN
FT316-12	Bool	%I1.7	TURBIN_BOOSTER_IN	HEAT DETECTION B 316 TURBIN
FT316-13	Bool	%I2.0	TURBIN_BOOSTER_IN	HEAT DETECTION A 316 EXHAUST
FT316-14	Bool	%I2.1	TURBIN_BOOSTER_IN	HEAT DETECTION B 316 EXHAUST
FT316-15	Bool	%I2.2	TURBIN_BOOSTER_IN	HEAT DETECTION C 316 EXHAUST
PS01	Bool	%I2.3	TURBIN_BOOSTER_IN	PRESSUR SWITCH CO2
PS02	Bool	%I2.4	TURBIN_BOOSTER_IN	PRESSEUR SWITCH POWDER
HS-01	Bool	%I2.5	TURBIN_BOOSTER_IN	PUSH BUTTON POWDER
HS-02	Bool	%I2.6	TURBIN_BOOSTER_IN	PUSH BUTTON CO2

Figure III.3: Digital Input Module Tag Addressing.

- **Digital Output Modules (DO):** These modules control ON/OFF actuators based on the PLC's logic. They manage devices like sirens, alarm lamps, and electro valves for CO_2 and powder release.

DQ 32x24VDC/0.5A HF_1 [DQ 32x24VDC/0.5A HF]

General | IO tags | System constants | Texts

Name	Type	Address	Tag table	Comment
SV-01	Bool	%Q20.0	TURBIN_BOOSTER_OUT	SWITCH VALVE CO2 PRIMARY A
SV-02	Bool	%Q20.1	TURBIN_BOOSTER_OUT	SWITCH VALVE CO2 PRIMARY B
SV-03	Bool	%Q20.2	TURBIN_BOOSTER_OUT	SWITCH VALVE CO2 SECOND A
SV-04	Bool	%Q20.3	TURBIN_BOOSTER_OUT	SWITCH VALVE CO2 SECOND B
SV-05	Bool	%Q20.4	TURBIN_BOOSTER_OUT	SWITCH VALVE POWDER PRIMARY
SV-06	Bool	%Q20.5	TURBIN_BOOSTER_OUT	SWITCH VALVE POWDER SECOND
HF-1	Bool	%Q20.6	TURBIN_BOOSTER_OUT	ALARM OUTSIDE A
HF-2	Bool	%Q20.7	TURBIN_BOOSTER_OUT	ALARM OUTSIDE B
HF-3	Bool	%Q21.0	TURBIN_BOOSTER_OUT	ALARM INSIDE
AL-1/2	Bool	%Q21.1	TURBIN_BOOSTER_OUT	LAMP ALARM OUTSIDE
AL-3/4	Bool	%Q21.2	TURBIN_BOOSTER_OUT	LAMP ALARM INSIDE
FFA-1	Bool	%Q21.3	SIGNAL TO MARK IV	HIGH HIGH LEVEL GAZ +50% ALARM + STA...
FFA-2	Bool	%Q21.4	SIGNAL TO MARK IV	HIGH LEVEL GAZ +20% TRIP
FFA-3	Bool	%Q21.5	SIGNAL TO MARK IV	COMPRESSOR POWDER DISCHARGE FIRE DE...
FFA-4	Bool	%Q21.6	SIGNAL TO MARK IV	TURBIN AREA CO2 DISCHARGE

Figure III.4: Digital Output Module Tag Addressing.

- **Analog Input Modules (AI):** Essential for monitoring continuous process variables, these modules receive 4–20 mA current signals from gas detectors (HV sensors). They convert these analog signals into digital values, allowing the PLC to precisely monitor gas concentrations.

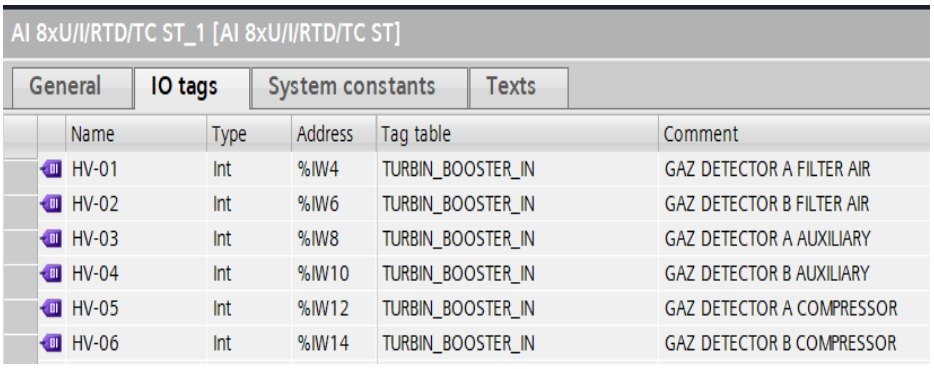


Figure III.5: Analog Input Module Tag Addressing.

- **I/O Module Types:** Summary of digital and analog PLC modules used in the project along with examples of the field devices connected to each type.

Table III.1: I/O Module Types Used.

Module Type	description	Example Devices
Digital Input (DI) 32x24VDC HF	Digital input module DI32 x 24VDC; grouping 16; input delay 0.05..20ms; input type 3 (IEC 61131); configurable diagnostics; hardware interrupts; value status; integrated counter for channel 0 and 1; isochronous mode	Flame Detector, Heat Detector, Push Button, Pressure Switch
DQ 32x24VDC/0.5A HF	Digital output module DQ32 x 24VDC / 0.5A; grouping 8; 4A per group; configurable diagnostics; configurable substitute value for output; isochronous mode; switching cycle counter	Alarm Siren, Indicator Lamp, Electro valve
AI 8xU/I/RTD/TC ST	Analog input module AI8 x U/I/RTD/TC 16-bit; grouping 8; 4 channels with RTD measurement; common mode voltage 10 V; configurable diagnostics; hardware interrupts	Gas Detector (4-20 mA)

III.3.2 -Addressing of Modules

Each I/O module and its individual channels within the PLC system are given a unique address in the PLC's memory. This addressing allows the PLC program to accurately identify and interact with each connected device. For example, a digital input address like %I0.0 refers to input channel 0, bit 0, while an analog input address like %IW0 refers to input word 0 (16bit). These physical addresses are then linked to easy-to-understand symbolic names within TIA Portal, making the program easier to read and maintain.

These absolute addresses are consistently used in the PLC program to define and process the logic for the fire and gas safety system.

III.4. Human-Machine Interface (HMI)

III.4.1 Role of HMI in Supervision and Control

The Human-Machine Interface (HMI) is essential in the fire and gas protection system as the primary link between the operator and the automated process Its main function is to provide a clear, real-time visual display of the system's status, enabling operators to monitor the process, identify issues, and execute commands as systems become more complex, a well-designed HMI ensures transparency and easy interaction, which is key for safety and continuous operation [25].

III.4.2- HMI Hardware and Software

The HMI in this project uses both hardware and software:

- **HMI Hardware:** This typically includes either a dedicated Siemens HMI Panel (e.g., a Comfort Panel) or an industrial PC running the WinCC Runtime Advanced software. The choice depends on specific needs for processing power, screen size, and durability.
- **HMI Software (WinCC Runtime Advanced):** This software allows operators to control the process. Its key functions include constant communication with the PLC, dynamic display of various process views on screen, enabling direct control actions (e.g., acknowledging alarms, resetting, or bypassing functions), and archiving of real-time data, process values, and alarm events for analysis.

III.4.3- Types of HMI Pages

To allow comprehensive monitoring and easy control, the HMI features various graphical pages, each for specific parts of the fire and gas system .

- **Detailed zone Page:** this page shows detailed diagrams and real-time data for specific areas protected by the system, including the status of individual detectors and actuators.
- **Alarms Pages:** A dedicated section displays active and past alarms, allowing operators to quickly see, acknowledge, and manage critical events.
- **Control Pages:** These pages offer interactive elements for manual control actions, such as starting suppression systems (with necessary safety interlocks), resetting alarms, or testing components.
- **Extinguishing System Pages:** Specific pages show the status and control of the CO_2 and powder extinguishing systems, including tank levels, valve positions, and discharge indicators.

- **History alarms Page:** For reviewing past events, alarms, and trends of key process variables, important for post-incident analysis and system diagnostics.

III.4.4- Communication with HMI

The PLC exchanges data with the HMI (either a PC running WinCC RT Advanced or a Siemens HMI Panel) using ProfNet. ProfNet is a real-time industrial Ethernet protocol that ensures fast and reliable data transfer Alarms, system status, real-time sensor values, and manual commands (like bypass or reset) are transferred in both directions, allowing operators to supervise and control the system comprehensively [26].

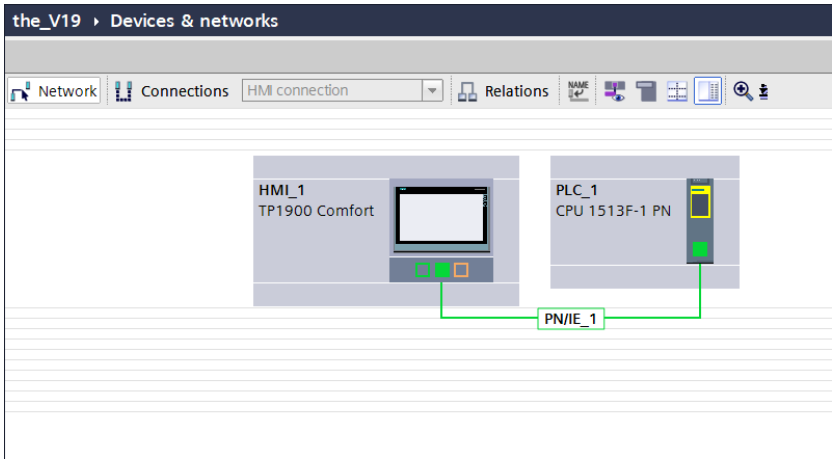


Figure III.6: device and networks configuration.

III.5. TIA Portal and WinCC Environment

III.5.1- Overview of TIA Portal

TIA Portal (Totally Integrated Automation Portal) is a powerful Siemens engineering platform that combines different automation tasks into one software environment This platform allows users to develop solutions for PLCs, HMIs, drives, and other automation parts from a single interface, significantly simplifying the engineering process [27].

The initial steps for creating a project in TIA Portal usually involve:

1. Starting the TIA Portal software.
2. Selecting "Create new project," naming it (e.g., "FireAndGasProtection"), and confirming.
3. Choosing to "Configure a device" to begin hardware setup.
4. Adding a new device from the catalog: Controllers → SIMATIC S7-1500 → 6ES7 513-1FM03-0AB0 (CPU 1513F-1 PN) → Add.

This process automatically takes the user to the hardware configuration editor, where more modules can be added from the hardware catalog The TIA Portal makes development efficient

by offering a consistent framework for all automation aspects.

III.5.2- Programming in TIA Portal

Programming the PLC in TIA Portal mainly involves using standard IEC 61131-3 programming languages, such as Ladder Diagram (LAD) and Function Block Diagram (FBD), for sequential and combinational logic [27].

Symbolic and Absolute Addresses: In TIA Portal, all global variables (inputs, outputs, memory bits) have both a symbolic address (a user-friendly name) and an absolute address (the physical location in PLC memory, e.g., %I0.0, %Q0.1, %MW10). The connection between these is managed in the PLC tags table (also called the mnemonic table). This allows programmers to use descriptive names while the system handles physical mapping, improving program readability and maintenance.

Program Editor and Loading Program: After hardware configuration is done and PLC programs are written, they must be compiled to check for errors, then loaded (downloaded) into the physical PLC Compilation starts using an icon in the TIA Portal taskbar. To download, the connection mode (e.g., ProfNet/Ethernet, Profibus, MPI) is selected. The software automatically finds accessible devices, and a flashing LED function can confirm the connection to the correct PLC [27].

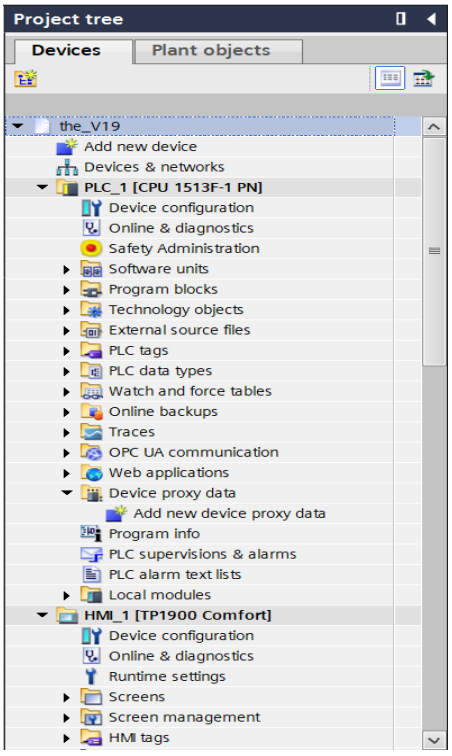


Figure III.7: Overview of the TIA Portal Project tree

III.5.3- Simulation with PLCSIM

When physical PLC hardware is not available or for extensive pre-deployment testing, TIA Portal provides an integrated simulation tool called PLCSIM. This simulator allows engineers to test the PLC program's functions and logic in a virtual environment, mimicking the behavior of a Siemens SIMATIC PLC and its modules.

The PLCSIM interface is user-friendly, allowing users to:

- **Change Input States:** Operators can easily turn virtual inputs ON or OFF (e.g., simulate a flame detector activation) by checking boxes.
- **Monitor Output States:** Output states automatically change as the simulated program runs, enabling detailed observation of the program's logic.

Test Diverse Scenarios: PLCSIM helps test various operating and fault conditions, ensuring the control system works as expected in many situations, increasing confidence in the application.

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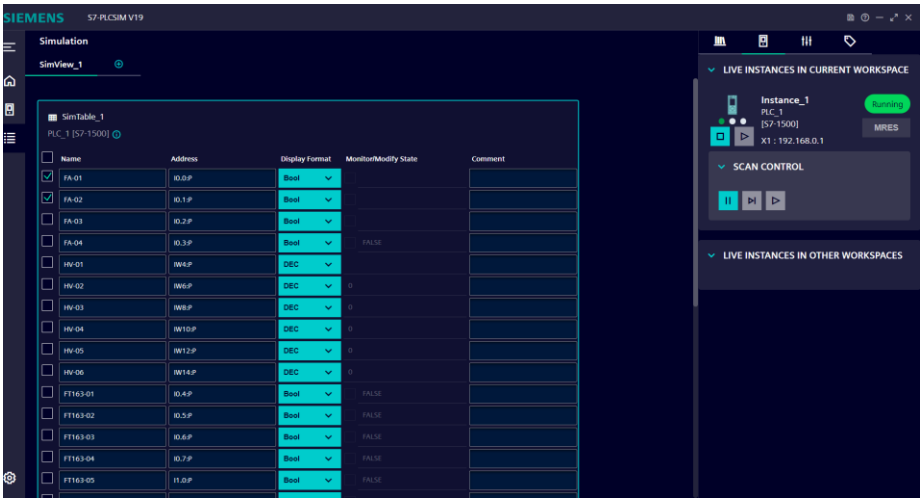


Figure III.8: PLCSIM Simulator Interface

III.5.4 -WinCC Features for Visualization and Alarm Handling

The WinCC component within TIA Portal is the software used for creating and configuring Human-Machine Interfaces, particularly for Siemens HMI panels like the TP1900 Comfort Panel This integrated environment simplifies the creation of visualization solutions.

Key aspects of WinCC in TIA Portal include:

- **WinCC Runtime:** For HMI panels, the configured project is loaded onto the panel, where its internal "WinCC Runtime" software runs the application. In Runtime mode,

the operator interacts with the process, including continuous communication with the PLC, dynamic display of process views, direct control actions (e.g., acknowledging alarms, resetting values), and archiving of real-time data, process values, and alarm events.

- **Structure of HMI Screen:** WinCC projects within TIA Portal typically consist of multiple "screens" (views) designed for controlling and monitoring specific parts of the system. The screen editor provides many tools and objects (e.g., graphics, buttons, display fields) to visualize procedures and define process values. The editor usually has a menu bar for commands, toolbars for quick access, a central work zone for arranging screens, a tools window for selecting objects, and a properties window for configuring selected objects [25].

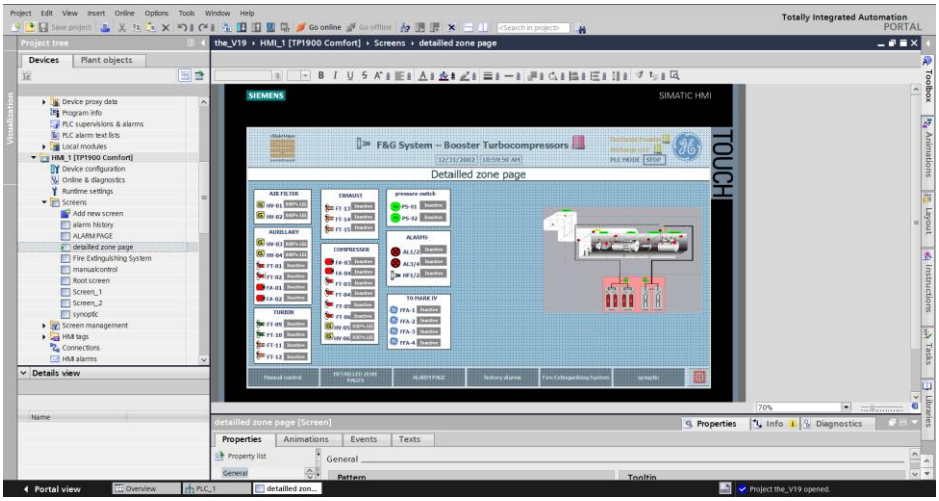


Figure III.9: HMI Supervision Screen

III.6. System Integration and Communication

The successful operation of the fire and gas protection system depends on smooth integration and robust communication among all its parts and external systems.

III.6.1- Communication Protocols

The main communication protocols used are:

- **ProfNet:** Used for real-time data exchange between the Siemens S7-1500 PLC and the WinCC HMI. This protocol ensures fast and reliable communication needed for critical process visualization and operator control.
- **Hardwired Communication:** Direct wired connections send important discrete signals from the PLC to the turbine's Mark VI control system. This method provides the highest reliability and immediate response for crucial interlocks like turbine trip and inhibit signals [19].

III.6.2- Safety Signals

The system is designed to generate and handle various safety-critical signals that trigger protective actions in response to detected hazards:

- **Trip Signals:** Immediate shutdown commands sent to the turbine's Mark VI system (e.g., FFA-2 for high gas concentration).
- **Inhibit Signals:** Commands that prevent the turbine from starting under unsafe conditions (e.g., FFA-1 for gas presence).
- **Discharge Signals:** Commands to activate fire suppression systems (e.g., FFA-3 for powder, FFA-4 for CO_2).
- **Alarm Feedback:** Signals from the PLC to the HMI indicating active alarms, system status, and confirmation of executed commands.

III.6.3-Scalability and Future Compatibility

The choice of the Siemens S7-1500 PLC and the TIA Portal environment ensures high scalability and future compatibility The S7-1500's modular design allows for easy expansion by adding more I/O modules or communication interfaces as future system needs change. The TIA Portal framework supports integrating new technologies and future Siemens hardware, ensuring the system can be adapted and upgraded without a complete redesign, providing a long-term automation solution for the Rhourde-Nouss site.

III.7 Conclusion

This chapter has described the main components and development environment for the fire and gas protection system. The Siemens SIMATIC S7-1500 PLC, specifically the CPU 1513F-1 PN, acts as the central controller. It was chosen for its strong safety features, capability to support redundancy in the series, and versatile I/O handling, all crucial for this critical application. The Human-Machine Interface, using WinCC Runtime Advanced, provides clear visualization and control, allowing operators to effectively monitor and interact with the system, especially with real-time sensor data. The TIA Portal software environment integrates the design, programming, and simulation of both the PLC and HMI, ensuring an efficient development process. Together, these tools and components form a complete and reliable system designed to protect the gas turbine through quick detection and immediate, appropriate responses to fire and gas incidents.

Chapter IV: Automation and Supervision of FGS system

IV.1. Introduction

This chapter describes the automation and supervision logic designed and implemented for the Fire and Gas System (FGS) of the MS5002C turbine. The purpose of this automation is to ensure early detection of hazardous events such as gas leaks, fire, or excessive heat, and to respond automatically or manually when needed. The system was developed using Siemens S7-1500 safety PLCs with TIA Portal software. It integrates various types of sensors and actuators across different protection zones, supported by a human-machine interface (HMI) that provides operators with full visibility and control, The automation program includes detection logic for UV/IR flame sensors, heat sensors at different temperature thresholds, and gas sensors with analog input scaling. It also handles alarm classification, automatic discharge of extinguishing agents, communication with the Mark VI control system, and alarm management functions such as reset, acknowledge, and silence. In addition to the PLC logic, the HMI screens were developed to visualize system behavior and allow manual intervention. These include zone monitoring, alarm pages, bottle discharge controls, and a full system synoptic.

IV.2. development of our proposed system

The diagram below explains the general working structure of the proposed Fire and Gas protection system. The process starts with sensors such as gas detectors, flame detectors, heat detectors, and pressure switches. These sensors send signals to the input modules (digital or analog), which are connected to the Siemens S7-1500 PLC.

The PLC processes the input data using programmed logic (including voting logic and delay timers). Based on the condition, the PLC activates the appropriate actuators through the output modules. These actuators include electro valves (for CO_2 or powder discharge), alarm sirens, and indicator lamps.

All actions and alarms are also displayed on the HMI interface, which allows the operator to monitor system status and use control functions like Reset, Bypass, Test, Acknowledge, and Silence.

Additionally, the PLC sends four digital signals to the Mark VI control system for turbine protection. These signals include alarm and trip conditions such as gas high level, gas high-high level, powder discharge, and CO_2 discharge.

This architecture provides a reliable, real-time, and safe environment for turbine operation and emergency response.

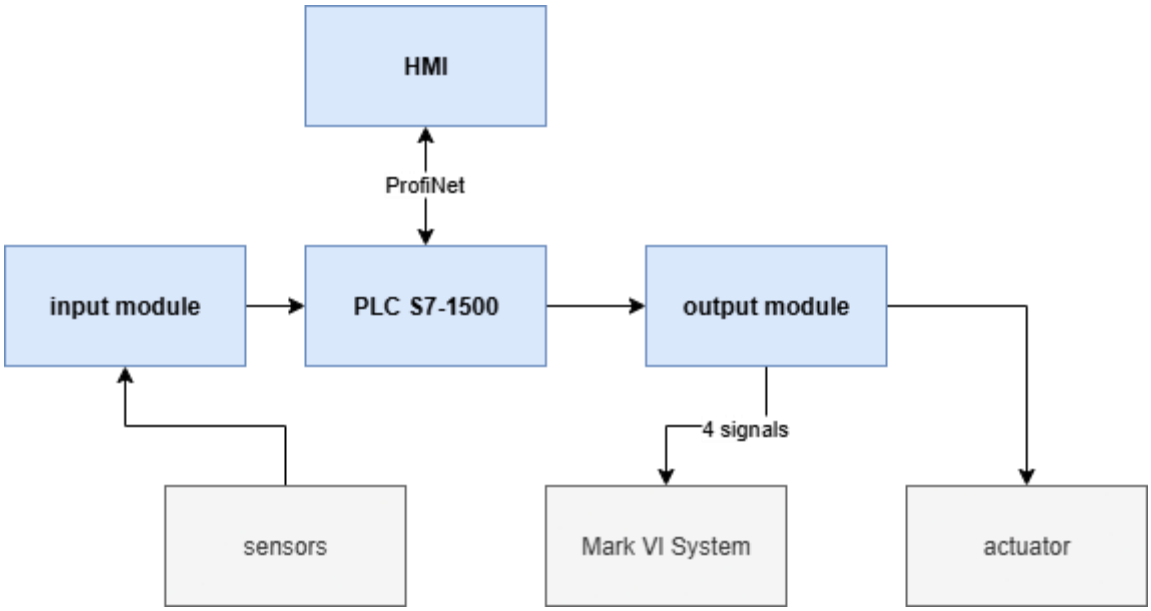


Figure IV.1: Fire & Gas System Architecture Overview.

IV.3. Structure of booster turbo compressor FGS

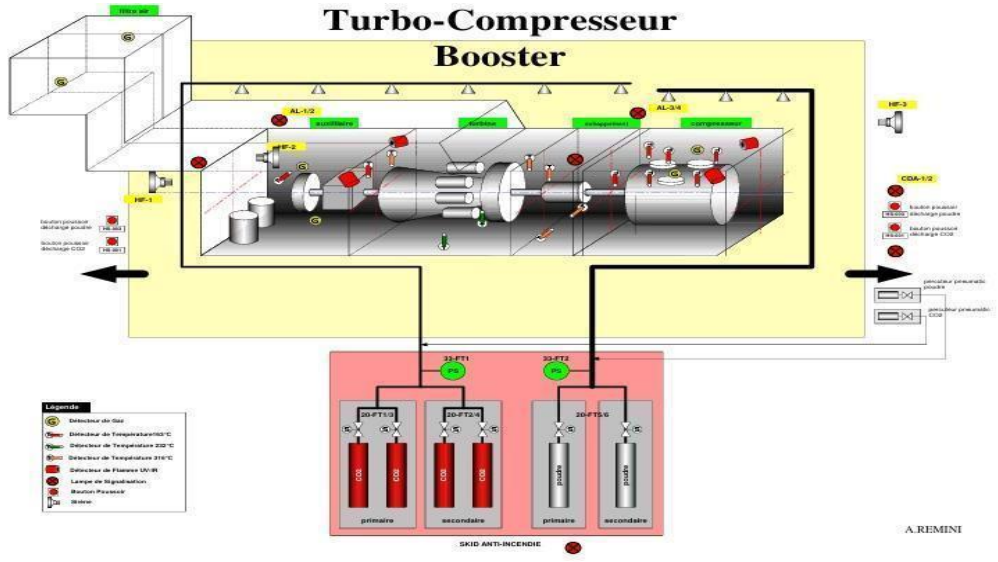


Figure IV.2: Schematic of the FGS Protection for the Turbo compressor Booster.

This diagram represents the complete fire and gas protection layout for the turbo compressor booster system. The system is divided into five main zones:

- Air Filter

- Auxiliary
- Turbine
- Exhaust
- Compressor

Each zone is equipped with different types of sensors and actuators to detect fire and gas hazards.

- Gas detectors are marked with yellow circles labeled “G”. These sensors trigger alarms when gas concentration reaches dangerous levels.
- Flame detectors (UV/IR) are shown as red squares. They detect the presence of flames in open areas.
- Temperature sensors are installed with three setpoints. 163°C (red) and 232°C (green 316°C (orange)

Each level is used depending on the zone, and each triggers different alarms or protective actions. At the bottom of the schematic, we see the fire suppression skid, which contains:

- CO_2 and powder tanks, separated into primary and secondary systems.
- These tanks are discharged through electro valves.
- Pressure switches (PS) monitor the readiness of the suppression agents.

Manual discharge can also be performed using push buttons, which are indicated in red Finally, the system provides alarm feedback through sirens and flashing lamps, placed in key locations to ensure visibility and audibility in case of emergency.

Table IV.1: Detectors FGS.

Section	Gas Detectors	Flame Detectors	Temp ≥ 163°C	Temp ≥ 232°C	Temp ≥ 316°C	Manual Triggers	Total Detectors
Auxiliary	2	2	2	0	0	1	7
exhaust	0	0	0	0	3	0	3
Compressor	2	2	6	0	0	1	11
Turbine	0	0	0	2	2	0	4
Air Filter	2	0	0	0	0	0	2

IV.4. Creation of the proposed program FGS

IV.4.1-UV/IR FLAME detectors

The fire and gas protection system uses UV/IR flame detectors to quickly identify the presence of flames in hazardous zones. These detectors are designed to respond to ultraviolet and infrared radiation emitted by a fire, offering fast and reliable detection, In our system, we installed a total of four flame detectors, divided into two zones:

- **Auxiliary Zone:** FA-01 and FA-02.
- **Compressor Zone:** FA-03 and FA-04.

Each pair is monitored using a dedicated logic block that includes bypass functionality and a delay timer (TON) to filter short-term false signals.

Auxiliary Zone Logic:

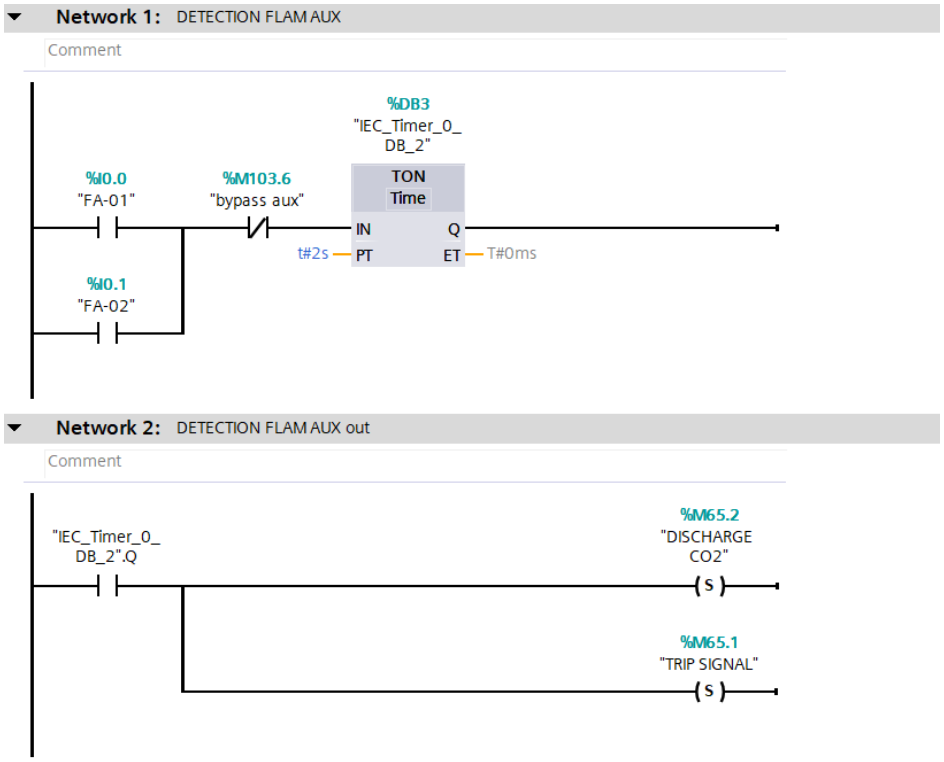


Figure IV.3: Ladder program of Detection flame auxiliary zone.

If either FA-01 or FA-02 detects a flame and the auxiliary zone is not in bypass mode, the system starts a 2-second timer. If the flame condition remains after the delay, the output (TON.Q) activates the Trip Signal and CO_2 discharge. This short delay helps prevent false activations caused by momentary signals.

Compressor Zone Logic:

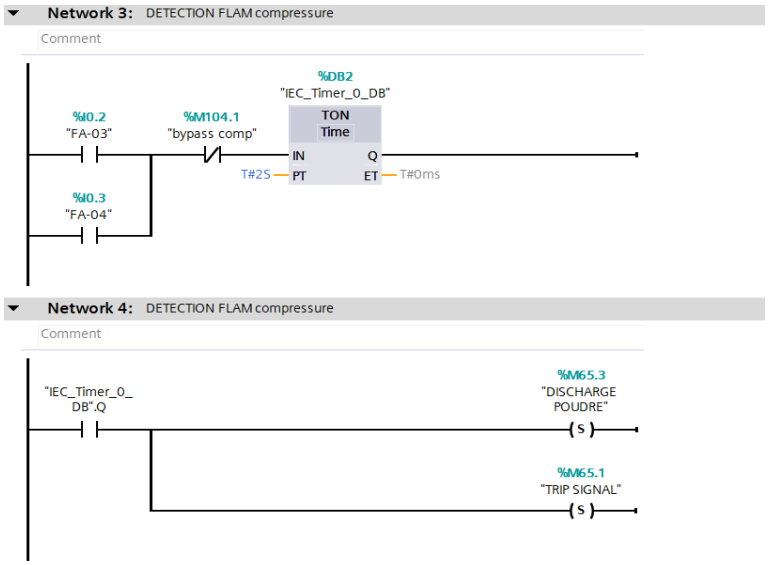


Figure IV.4: Ladder program of Detection flame compressor zone.

In the compressor zone, the same principle applies. If either FA-03 or FA-04 detects a flame and bypass is not active, the logic enables a 2-second timer. When the timer confirms the condition is stable, the system triggers a Trip Signal and discharges a powder extinguishing agent to control the fire**.**

IV.4.2-Heat detector

In the proposed Fire and Gas System (FGS), four zones are monitored using thermal detectors with three temperature thresholds: 163°C, 232°C, and 316°C. Each zone has specific logic conditions to detect overtemperature events and activate the corresponding fire suppression action. A bypass condition is included in each zone to allow temporary manual deactivation for maintenance purposes.

Network 11 AUX Zone (Auxiliary System)

- **Sensors used**: FT163-01 and FT163-02 (163°C).
- **Logic**: Both sensors must detect heat simultaneously (AND logic).
- **Condition**: The system must not be in bypass mode (NOT Bypass_AUX).
- **Action**: Set the Trip Signal and Trigger CO_2 discharge.

This ensures that the auxiliary area is only considered at risk if both sensors confirm the abnormal temperature. The bypass input allows temporary deactivation for maintenance.

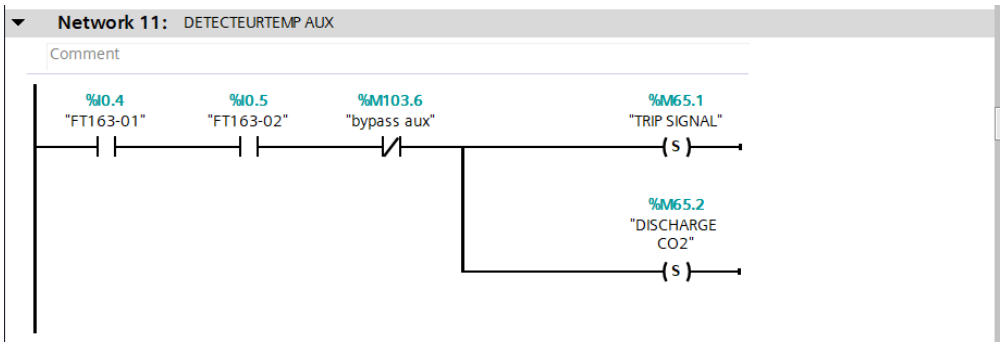


Figure IV.5: Ladder program of detection heat in auxiliary zone.

Network 12 (Turbin) TURBINE Zone

- **Sensors used**: FT316-11 and FT316-12 (316°C) and FT232-09 and FT232-10 (232°C)
- **Logic**: Either pair of sensors (316°C *or* 232°C) can activate the response
  (FT316-11 AND FT316-12) OR (FT232-09 AND FT232-10)
- **Condition**: NOT Bypass TURBINE
- **Action**: Set the Trip Signal and Trigger CO_2 discharge

This logic increases sensitivity. If either temperature level is reached a confirmed by both sensors in that pair, the turbine zone is considered at risk. It allows detection at two temperature thresholds and improves responsiveness.

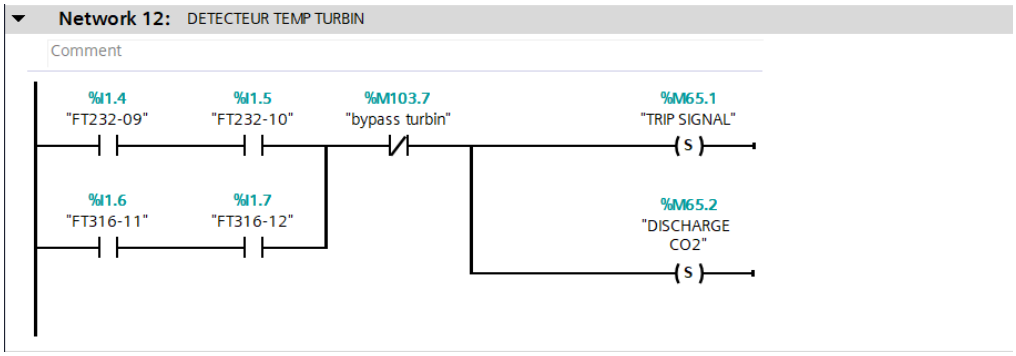


Figure IV.6: Ladder program of detection heat in turbine zone.

Network 13 EXHAUST Zone

- **Sensors used**: FT316-13, FT316-14, FT316-15 (all 316°C).

- **Logic: A 2-out-of-3** logic. Any two of the three sensors must detect heat valid combinations are: FT316-13 AND FT316-14 and FT316-13 AND FT316-15 FT316-14 AND FT316-15.
- **Condition**: NOT Bypass Exhaust.
- **Action**: Set the Trip Signal and Trigger CO_2 discharge.

This configuration improves fault tolerance. If one sensor fails or is under maintenance, the system still responds appropriately. It ensures reliable detection in high-temperature area like exhaust.

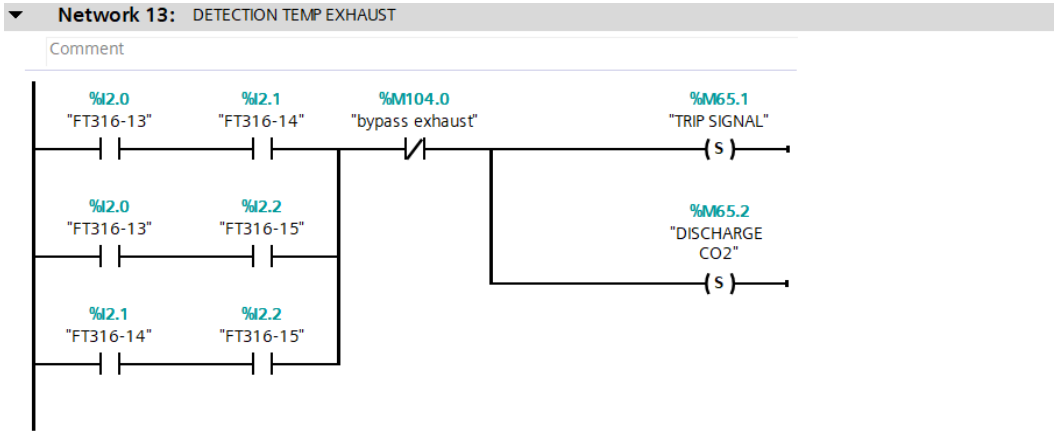


Figure IV.7: Ladder program of detection heat in Exhaust zone.

Network 14 COMPRESSOR Zone

- **Sensors used**: FT232-03 and FT232-04 (232°C) and FT232-05 and FT232-06 (232°C) andFT232-07 and FT232-08 (232°C).
- **Logic**: Another 2-out-of-3 group logic, similar to the exhaust zone: (03 AND 04) OR (05 AND 06) OR (07 AND 08).
- **Condition**: NOT Bypass Compressor.
- **Action**: Set the Trip Signal and Trigger Powder discharge.

This zone uses powder suppression instead of CO_2. Like the exhaust zone, it uses grouped pairs for flexible, fault-tolerant detection. This is essential to cover multiple points in the compressor zone while minimizing false alarms.

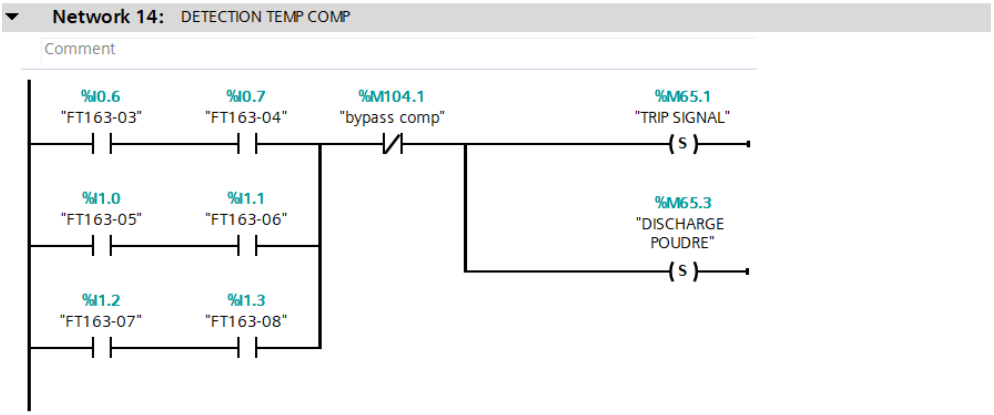


Figure IV.8: Ladder program of detection heat in compressor zone.

IV.4.3-Gas detectors (FC3)

In this system, six gas detectors are installed to monitor the presence of combustible gases. These detectors operate using a 4–20 mA analog signal, which represents the gas concentration as a percentage of the Lower Explosive Limit (LEL). The detectors are distributed as follows:

- **Air Filter Zone:** HV-01 and HV-02
- **Auxiliary Zone:** HV-03 and HV-04
- **Compressor Zone:** HV-05 and HV-06

Each detector is connected to a dedicated analog input channel (IW), which is read and processed using a reusable Function Block (FC3).

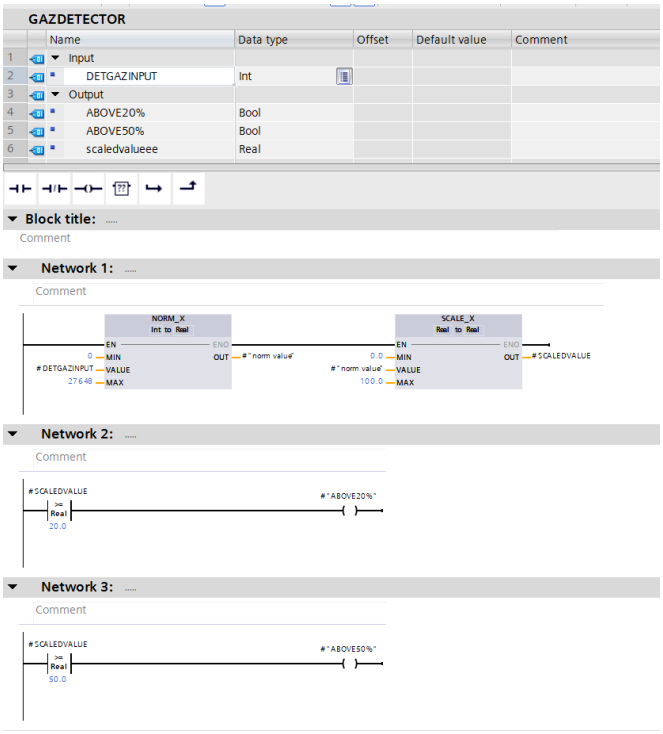


Figure IV.9: Function block of Gas detector.

The FC3 block was developed to centralize and standardize gas level evaluation across all zones.

Inputs:

- **EN (Enable):** Activates the block when the corresponding zone is not in bypass mode.
- **DetGasInput:** Analog input (IW) from the gas detector (e.g., HV-01).

Outputs:

- **ENO:** Standard enable output.
- **Above20%:** Boolean output activated when gas concentration ≥ 20% LEL.
- **Above50%:** Boolean output activated when gas concentration ≥ 50% LEL.
- **ScaledValue:** Real-type output that represents gas level in percentage (0–100%), used for HMI visualization.

The analog value received from the detector is first normalized using the NORM_X function block:

- **Minimum Input:** 0

- **Maximum Input:** 27648 (corresponding to 20 mA).
- **Output:** Normalized value from 0.0 to 1.0

This normalized value is then processed through a scaling function to convert it into a percentage representation (0–100%), which is stored in ScaledValue.

Threshold comparison is then performed:

- If ScaledValue ≥ 20%, the output Above20% is set to TRUE.
- If ScaledValue ≥ 50%, the output Above50% is set to TRUE.

This modular structure ensures that gas level evaluation is consistent and can be reused for any number of detectors.

IV.4.3.1- Integration into Main Program

In the main program, the FC3 block is instantiated separately for each detector (HV-01 through HV-06). The enable input (EN) of each instance is conditioned by the corresponding zone's bypass status. If a zone is bypassed, the FC3 block is disabled to prevent false alarms during maintenance or testing.

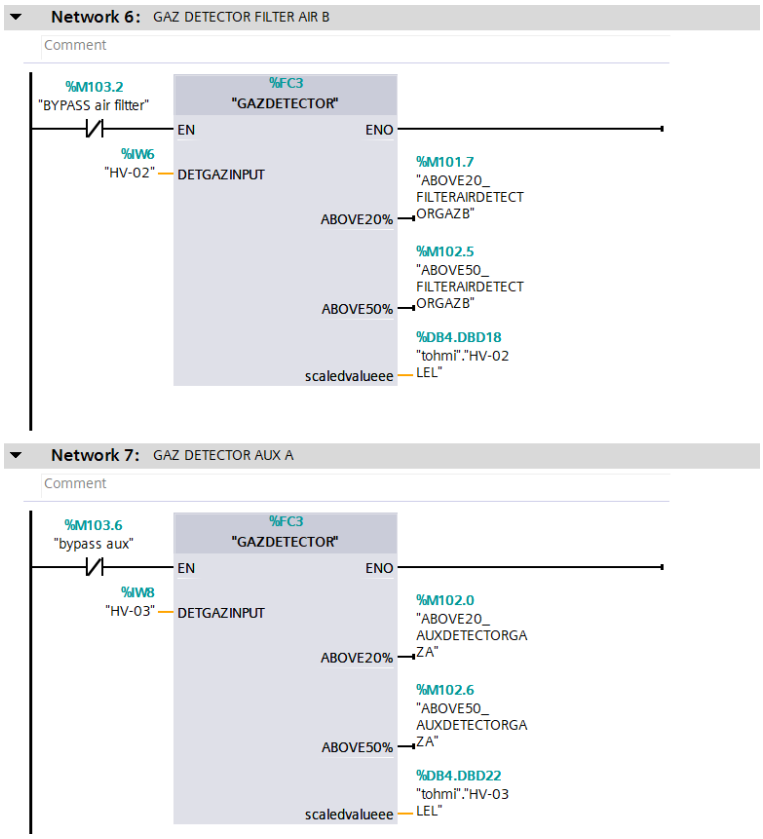


Figure IV.10: Gas detector in the main program.

IV.4.3.2-Alarm Communication with MARK VI

Two alarm thresholds are monitored system-wide by collecting outputs from all FC3 instances:

1. **HighGasLevel(≥50%)FFA-01Signal:**

   If any gas detector reports a value above 50% LEL, the system sends a digital signal to the MARK VI controller. This signal, labeled FFA-01, initiates a high-level gas alarm and activates the start inhibit function of the turbine.

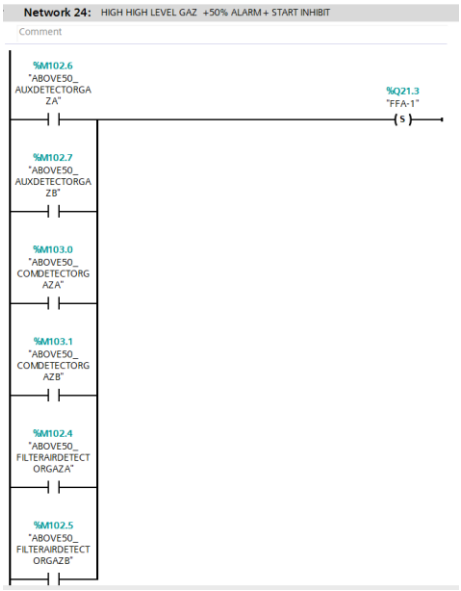


Figure IV.11: Ladder program above 50% gas level logic.

2. **GasWarningLevel(≥20%)FFA-02Signal:**

   If any detector exceeds 20% LEL, another signal (FFA-02) is sent to the MARK VI, triggering a warning trip condition.

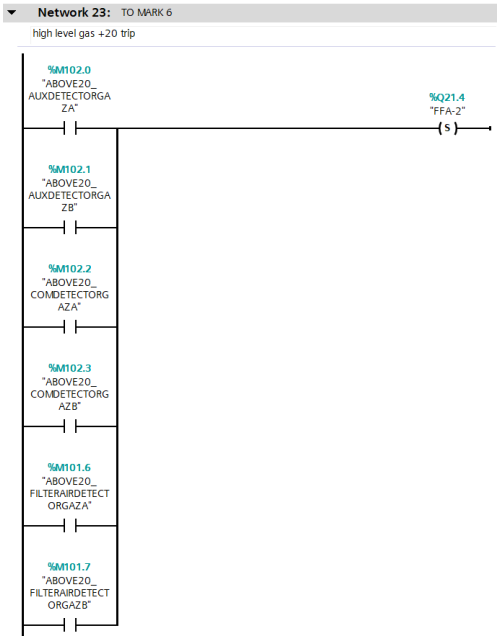


Figure IV.12: Ladder program above 20% gas level logic.

This configuration ensures fast and coordinated turbine protection in response to hazardous gas accumulation.

IV.4.4-Alarm Mapping to HMI (Function Block FC5)

To ensure real-time communication between the PLC and the operator interface, we developed a dedicated function block (FC5) in Structured Control Language (SCL). This block is responsible for organizing and transferring all relevant alarm signals to the HMI via a Data Block (DB452**)** named alarms to HMI, This architecture simplifies supervision and alarm visualization by the operator, providing a centralized and structured view of all critical fire and gas signals.

IV.4.4.1- Flame Detectors

The system includes four UV/IR flame detectors, two installed in the Auxiliary Zone and two in the Compressor Zone:

SCL code:

```
"alarms_to_hmi"."FA-01" := "FA-01";
"alarms_to_hmi"."FA-02" := "FA-02";
"alarms_to_hmi"."FA-03" := "FA-03";
"alarms_to_hmi"."FA-04" := "FA-04";
```

Each variable represents a flame detector's status (active/inactive), directly linked to the corresponding detector in the field.

IV.4.4.2- Heat Detectors

The system includes a total of 15 heat detectors, categorized by temperature thresholds:

- **163°C Detectors**: Auxiliary and Compressor zones
- **232°C and 316°C Detectors**: Turbine and Exhaust zones

Each is mapped for HMI display:

```
"alarms_to_hmi"."FT163-01" := "FT163-01";  // AUX
"alarms_to_hmi"."FT316-15" := "FT316-15";  // EXHAUST
```

IV.4.4.3- Pressure Switches

Two pressure switches monitor the readiness of fire suppression agents:

- **PS01:** CO_2 pressure.
- **PS02:** Powder pressure.

Their status is directly passed to the HMI:

SCL code :

```
"alarms_to_hmi"."PS01" := "PS01";
"alarms_to_hmi"."PS02" := "PS02";
```

IV.4.4.4- Manual Push Buttons

The interface also includes feedback for manual discharge push buttons:

SCL code :

```
"alarms_to_hmi"."HS-01" := "HS-01";  // Powder
"alarms_to_hmi"."HS-02" := "HS-02";  // CO2
```

IV.4.4.5- Signals to MARK VI (FFA)

To coordinate with the Mark VI turbine control system, four digital signals are shared:

SCL code :

```
"alarms_to_hmi"."FFA-1 signal to markIV" := "FFA-1";
```

```
"alarms_to_hmi"."FFA-2 signal to markIV" := "FFA-2";
"alarms_to_hmi"."FFA-3 signal to markIV" := "FFA-3";
"alarms_to_hmi"."FFA-4 signal to markIV" := "FFA-4";
```

These are used to signal gas level thresholds or initiate emergency discharges.

IV.4.4.6- Gas Detection

Each gas detector is evaluated for two critical levels:

- **Above 20% LEL** : (Warning)
- **Above 50% LEL** : (Trip and inhibit)

The block maps these levels for all six detectors across zones:

SCL code:

```
"alarms_to_hmi"."ABOVE20_FILTERAIRDETECTORGAZA HV-01":="ABOVE20_FILTERAIRDETECTORGAZA";
"alarms_to_hmi"."ABOVE50_FILTERAIRDETECTORGAZB HV-02""ABOVE50_FILTERAIRDETECTORGAZB";
```

Function Block FC5 is used to collect and structure all fire and gas alarm statuses and send them to DB452, which is directly linked to the HMI. This ensures that the operator receives real-time visual feedback on all critical system conditions, such as:Flame and heat detection and Pressure loss and Manual interventions and Communication with turbine protection logic (Mark VI) and Gas concentration levels (20% and 50% thresholds).

alarm to hmi Properties

General							
Name	alarm to hmi	Number	5	Type	FC	Language	
Numbering	Automatic						
Information							
Title		Author		Comment		Family	
Version	0.1	User-defined ID					

Name	Data type	Offset	Default value	Comment
Input				
Output				
InOut				
Temp				
Constant				
▼ Return				
alarm to hmi	Void			

```
0001 // Flame Detectors
0002 "alarms_to_hmi"."FA-01" := "FA-01";     // FLAME DETECTOR A AUXILIARY
0003 "alarms_to_hmi"."FA-02" := "FA-02";     // FLAME DETECTOR B AUXILIARY
0004 "alarms_to_hmi"."FA-03" := "FA-03";     // FLAME DETECTOR A COMPRESSOR
0005 "alarms_to_hmi"."FA-04" := "FA-04";     // FLAME DETECTOR B COMPRESSOR
0006
0007 // Heat Detectors 163°C
0008 "alarms_to_hmi"."FT163-01" := "FT163-01";  // HEAT DETECTION A 163°C AUXILIARY
0009 "alarms_to_hmi"."FT163-02" := "FT163-02";  // HEAT DETECTION B 163°C AUXILIARY
0010 "alarms_to_hmi"."FT163-03" := "FT163-03";  // HEAT DETECTION A 163°C COMPRESSOR
0011 "alarms_to_hmi"."FT163-04" := "FT163-04";  // HEAT DETECTION B 163°C COMPRESSOR
0012 "alarms_to_hmi"."FT163-05" := "FT163-05";  // HEAT DETECTION C 163°C COMPRESSOR
0013 "alarms_to_hmi"."FT163-06" := "FT163-06";  // HEAT DETECTION D 163°C COMPRESSOR
0014 "alarms_to_hmi"."FT163-07" := "FT163-07";  // HEAT DETECTION E 163°C COMPRESSOR
0015 "alarms_to_hmi"."FT163-08" := "FT163-08";  // HEAT DETECTION F 163°C COMPRESSOR
0016
0017 // Heat Detectors 232°C
0018 "alarms_to_hmi"."FT232-09" := "FT232-09";  // HEAT DETECTION A 232°C TURBINE
0019 "alarms_to_hmi"."FT232-10" := "FT232-10";  // HEAT DETECTION B 232°C TURBINE
0020
0021 // Heat Detectors 316°C
0022 "alarms_to_hmi"."FT316-11" := "FT316-11";  // HEAT DETECTION A 316°C TURBINE
0023 "alarms_to_hmi"."FT316-12" := "FT316-12";  // HEAT DETECTION B 316°C TURBINE
0024 "alarms_to_hmi"."FT316-13" := "FT316-13";  // HEAT DETECTION A 316°C EXHAUST
0025 "alarms_to_hmi"."FT316-14" := "FT316-14";  // HEAT DETECTION B 316°C EXHAUST
0026 "alarms_to_hmi"."FT316-15" := "FT316-15";  // HEAT DETECTION C 316°C EXHAUST
0027
0028 // Pressure Switches
0029 "alarms_to_hmi"."PS01" := "PS01";  // PRESSURE SWITCH CO2
0030 "alarms_to_hmi"."PS02" := "PS02";  // PRESSURE SWITCH POWDER
0031
0032 // Push Buttons
0033 "alarms_to_hmi"."HS-01" := "HS-01";  // PUSH BUTTON POWDER
0034 "alarms_to_hmi"."HS-02" := "HS-02";  // PUSH BUTTON CO2
0035
0036 // FFA Signals to MarkIV
0037 "alarms_to_hmi"."FFA-1 signal to markIV" := "FFA-1";  // HIGH HIGH LEVEL GAZ +50% ALARM + START INHI
0038 "alarms_to_hmi"."FFA-2 signal to markIV" := "FFA-2";  // HIGH LEVEL GAZ +20% TRIP
0039 "alarms_to_hmi"."FFA-3 signal to markIV" := "FFA-3";  // COMPRESSOR POWDER DISCHARGE FIRE DETECTION
0040 "alarms_to_hmi"."FFA-4 signal to markIV" := "FFA-4";  // TURBINE AREA CO2 DISCHARGE
0041
0042 // ABOVE20 Detectors
0043 "alarms_to_hmi"."ABOVE20_FILTERAIRDETECTORGAZA HV-01" := "ABOVE20_FILTERAIRDETECTORGAZA";  // HV-01
0044 "alarms_to_hmi"."ABOVE20_FILTERAIRDETECTORGAZB HV-02" := "ABOVE20_FILTERAIRDETECTORGAZB";  // HV-02
0045 "alarms_to_hmi"."ABOVE20_AUXDETECTORGAZA HV-03" := "ABOVE20_AUXDETECTORGAZA";  // HV-03
0046 "alarms_to_hmi"."ABOVE20_AUXDETECTORGAZB HV-04" := "ABOVE20_AUXDETECTORGAZB";  // HV-04
0047 "alarms_to_hmi"."ABOVE20_COMDETECTORGAZA HV-05" := "ABOVE20_COMDETECTORGAZA";  // HV-05
0048 "alarms_to_hmi"."ABOVE20_COMDETECTORGAZB HV-06" := "ABOVE20_COMDETECTORGAZB";  // HV-06
0049
0050 // ABOVE50 Detectors
0051 "alarms_to_hmi"."ABOVE50_FILTERAIRDETECTORGAZA HV-01" := "ABOVE50_FILTERAIRDETECTORGAZA";  // HV-01
0052 "alarms_to_hmi"."ABOVE50_FILTERAIRDETECTORGAZB HV-02" := "ABOVE50_FILTERAIRDETECTORGAZB";  // HV-02
0053 "alarms_to_hmi"."ABOVE50_AUXDETECTORGAZA HV-03" := "ABOVE50_AUXDETECTORGAZA";  // HV-03
0054 "alarms_to_hmi"."ABOVE50_AUXDETECTORGAZB HV-04" := "ABOVE50_AUXDETECTORGAZB";  // HV-04
0055 "alarms_to_hmi"."ABOVE50_COMDETECTORGAZA HV-05" := "ABOVE50_COMDETECTORGAZA";  // HV-05
0056 "alarms_to_hmi"."ABOVE50_COMDETECTORGAZB HV-06" := "ABOVE50_COMDETECTORGAZB";  // HV-06
0057
```

Figure IV.13: SCL code HMI.

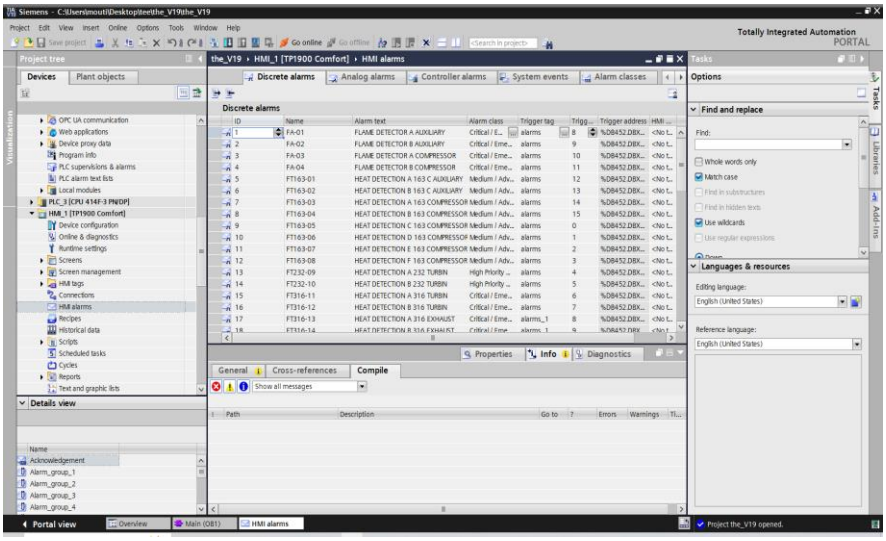


Figure IV.14: Discrete alarms of HMI.

IV.4.5-Discharge Logic for CO_2 and Powder Systems

To manage the manual discharge of fire suppression agents (CO_2 and powder), we developed two function blocks in ladder logic:

- **FC2**: Handles powder discharge
- **FC4**: Handles CO_2 discharge

Each block allows controlled activation of solenoid valves depending on user selection (primary or secondary), state trigger, and a defined discharge duration.

IV.4.5.1-Inputs of Each Block

Each discharge function block uses the following inputs:

- **Secondary *(*BOOL*)*:** If FALSE, the primary circuit is used. And If TRUE, the secondary circuit is selected.
- **State *(*BOOL*)*:** This is the trigger input. When active, it initiates the discharge sequence.
- **Time_discharge *(*TIME*)*:** This defines how long the valves will remain open (e.g., 5 seconds).

IV.4.5.2-Powder Discharge Logic – FC2

Network 1 Primary Circuit:

- If the state is TRUE and the secondary is FALSE, the system starts a TP (pulse) timer.

- Once the timer is active, the following outputs are triggered: SV-05: Primary switch valve for powder and FFA-3: Signal to Mark VI for powder discharge.

Network 2 Secondary Circuit:

- If state is TRUE and secondary is TRUE, the timer activates: SV-06: Secondary switch valve for powder and FFA-3: Powder discharge signal to Mark VI.

This logic ensures that only one circuit (primary or secondary) is activated based on operator selection.

IV.4.5.3-CO_2 Discharge Logic – FC4

Network 1 Primary Circuit:

- If state is TRUE and secondary is FALSE, the timer activates: SV-01 and SV-02: CO_2 primary switch valves and FFA-4: Signal to Mark VI for CO_2 discharge

Network 2 Secondary Circuit:

- If state is TRUE and secondary is TRUE, the timer activates: SV-03 and SV-04: CO_2 secondary switch valve and FFA-4: CO_2 discharge signal to Mark VI

This provides a fully selectable and timed control of the discharge system for both CO_2 and powder agents, ensuring flexibility and safety in fire suppression operations.

The use of FC2 and FC4 function blocks allows safe, precise, and configurable control of fire extinguishing agents. The logic separates primary and secondary systems and ensures only one set of valves is activated per discharge command. Integration with Mark VI via `FFA-3` and `FFA-4` signals ensures that turbine protection systems are also engaged during any discharge event.

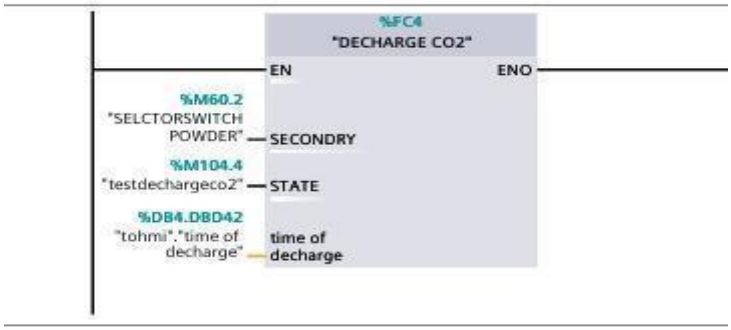


Figure IV.15: Discharge co2 block.

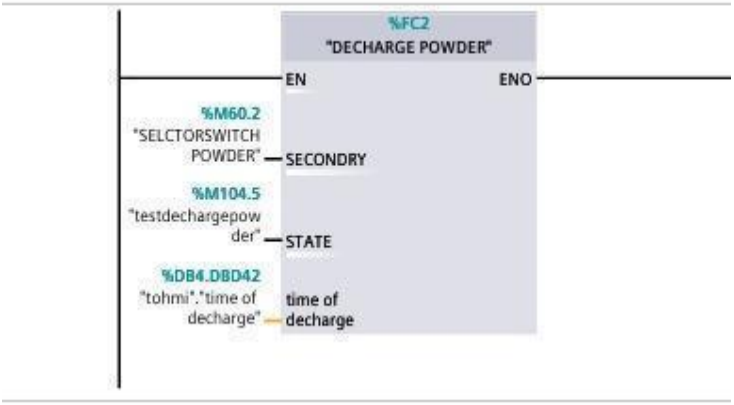


Figure IV.16: Discharge powder block.

IV.4.6- Alarm Acknowledgment, Silence, and Reset Logic

To improve safety response and operator interaction, the fire and gas system includes manual control functions for acknowledging alarms, silencing audible alerts, and resetting active system states. These commands are initiated from the HMI and processed by the PLC as follows:

IV.4.6.1- Silence Function

- When the Silence button is pressed on the HMI, the PLC sets the internal coil M104.3.
- This action deactivates all horns (HF-1, HF-2, HF-3) used for audible alerting.
- However, the visual alarms (flashing lamps such as AL-1/2 and AL-3/4) remain active to ensure visibility of the alert.

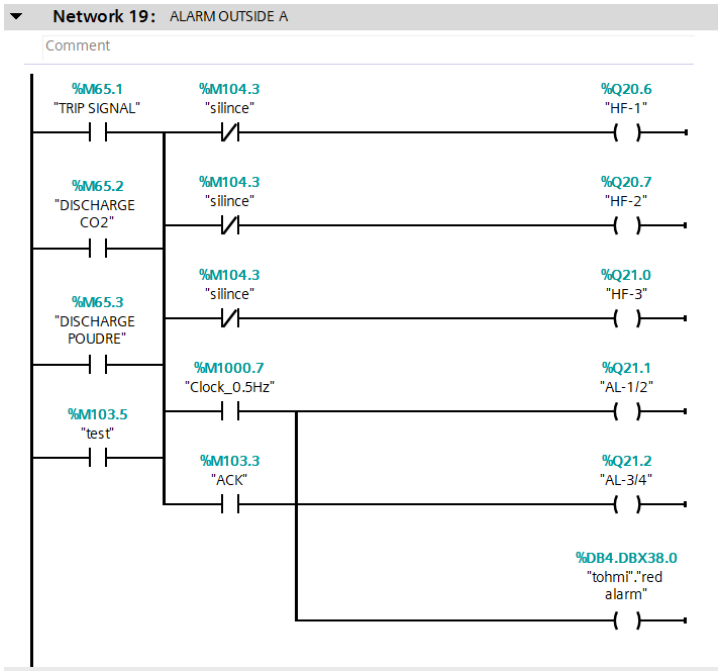


Figure IV.17: Alarms outside program.

IV.4.6.2- Acknowledgment Function

- When the Acknowledge (Ack) button is activated on the HMI, the PLC sets coil M103.3.
- This command stops the blinking behavior of the visual alarm lamps (AL-1/2 and AL-3/4).
- It confirms that the operator has seen and acknowledged the alarm, even if the alarm condition is still active.

IV.4.6.3- Reset Function

- The Reset button is used to clear all alarm states after the issue has been resolved.
- When the Reset command is received, the PLC sets coil M103.4.
- This command performs the following: Resets the CO_2 discharge signal and Resets the Powder discharge signal and clears any active Trip signal and clears the Ack and Silence states Resets signals sent to Mark VI, including: FFA-1 (Gas +50%) FFA-2 (Gas +20%) FFA-3 (Powder discharge) FFA-4 (CO_2 discharge).

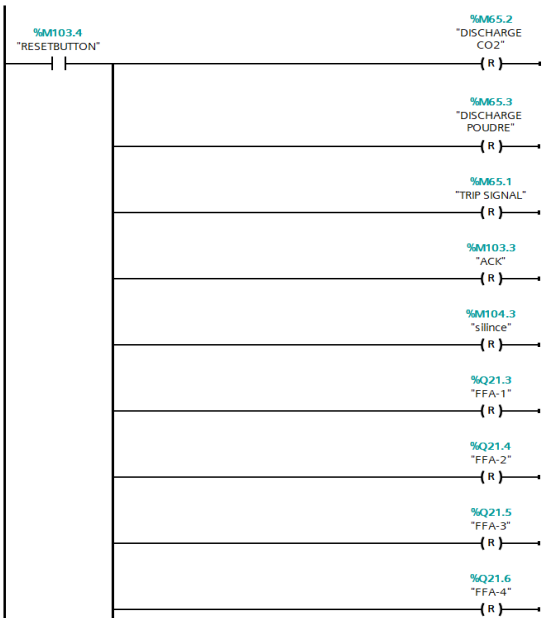


Figure IV.18: reset Button program.

IV.5. HMI supervision pages

IV.5.1-Manual Controls

The Manual Controls Page with the HMI provides direct operator access to essential control functions for testing, bypassing, silencing, and acknowledging fire and gas alarms across different protection zones. It serves as a centralized interface for manual interaction with the system during maintenance, testing, or abnormal operating conditions and our Functional overview.

1. Bypass Control (Left Section)

A set of bypass switches is available for the following zones:

- Air Filter Zone
- Auxiliary Zone
- Turbine Zone
- Exhaust Zone
- Compressor Zone

Each switch can be set to "ON" or "OFF", allowing the operator to temporarily deactivate automatic responses from specific zones during maintenance or known test events. All bypasses are shown as "OFF" by default to ensure full system protection.

2. Bottle Test Functions (Center Section)

- **TestCO_2Bottle:** This function allows the operator to simulate the activation of the CO_2 discharge system for a specific time (e.g., 100 milliseconds).It helps verify that the output circuit and related components work properly, without actually releasing the CO_2 gas.
- **TestPowderBottle:** This function works the same way as the CO_2 test but is used for the powder discharge system. By setting a duration (e.g., 70 milliseconds), the operator can check if the solenoid valves and control signals are functioning correctly, without triggering a real discharge.

3. Alarm Test Functions

- **Test Horn Alarms:** Activates the acoustic warning devices (horns) to verify sound alarm performance.
- **Test Lamp Alarms:** Checks the visual indicators (signal lamps) for both internal and external alarms.
- **These tests help:** validate alarm outputs without requiring real fire or gas events.

4. System Control Buttons (Right Section)

- **Silence:** Temporarily disables audible alarm signals.
- **Acknowledge:** Confirms recognition of active alarms and stops blinking indication.
- **Reset:** Clears latched alarms or fault states once the condition is resolved.
- **Inhibit:** Blocks certain system actions from being automatically triggered (e.g., discharge), typically used during maintenance or troubleshooting.

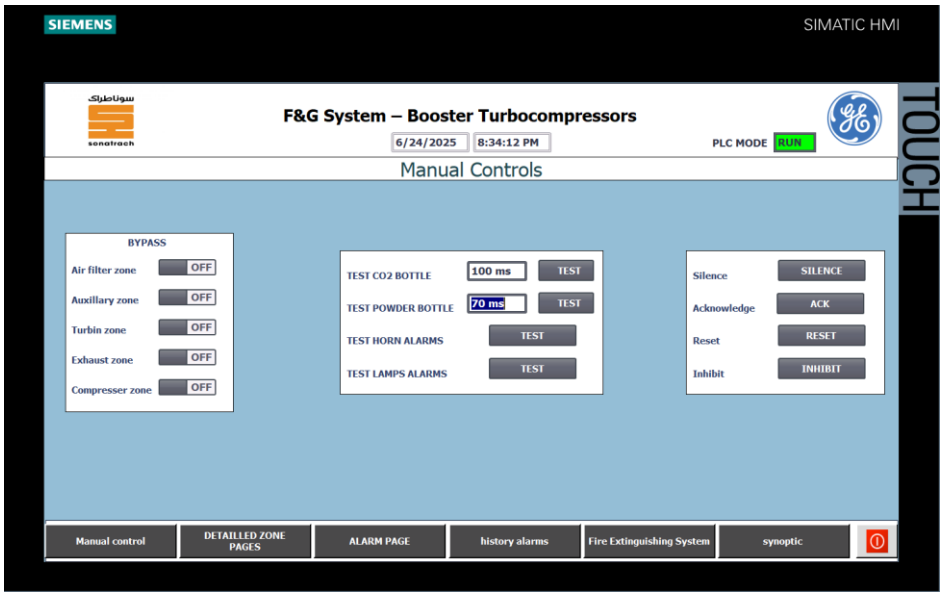


Figure IV.19: Manual Controls.

IV.5.2-Detailed Zone Page

The Detailed Zone Page of the Human-Machine Interface (HMI) provides a real-time, structured visualization of each fire and gas detection zone around the MS5002C turbine. It allows operators to monitor the state of all safety-related sensors and actuators and to assess the system status with clarity and precision and we have zone by zone overview.

1. Air Filter Zone

- **HV-01**, **HV-02**: Gas Detectors

  Green: Gas level below 20% LEL (safe) and Yellow: Gas level at or above 20% LEL (warning) and Red: Gas level at or above 50% LEL (alarm – start inhibit).

2. Auxiliary Zone

- **HV-03**, **HV-04**: Gas Detectors (same alarm thresholds as above).
- **FT-01**, **FT-02**: Heat Detectors, active when temperature reaches 163°C.
- **FA-01**, **FA-02**: UV/IR Flame Detectors, showing active or inactive status.

3. Turbine Zone

- **FT-09**, **FT-10**: Heat Detectors, trigger at 232°C.
- **FT-11**, **FT-12**: Heat Detectors, trigger at 316°C.

4. Exhaust Zone

- **FT-13**, **FT-14**, **FT-15**: Heat Detectors, trigger at 316°C.

5. Compressor Zone

- **HV-05**, **HV-06**: Gas Detectors (same thresholds as in other zones).
- **FT-03** to **FT-06** : Heat Detectors, trigger at 163°C.
- **FA-03**, **FA-04** : Flame Detectors.

And we have pressure switches and alarm and digital outputs to mark VI.

IV.5.2.1-Pressure Switches:

- **PS-01 :** Indicates low pressure in the CO_2 discharge system when active.
- **PS-02**: Indicates low pressure in the powder discharge system when active.

IV.5.2.2-Alarm Signaling

- **AL1/2**: Alarm signal lamps (internal).
- **AL3/4**: Alarm signal lamps (external).
- **HF1/2:** Acoustic horns for internal and external areas.

IV.5.2.3-Mark VI Interface (Digital Outputs)

The system is integrated with the existing Mark VI turbine controller using four digital outputs:

- **FFA-1**: High-high gas level (+50% LEL): triggers alarm and start inhibit.
- **FFA-2:** High gas level (+20% LEL): triggers turbine trip.
- **FFA-3**: Compressor fire detection: triggers powder discharge.
- **FFA-4**: Turbine fire detection: triggers CO_2 discharge.

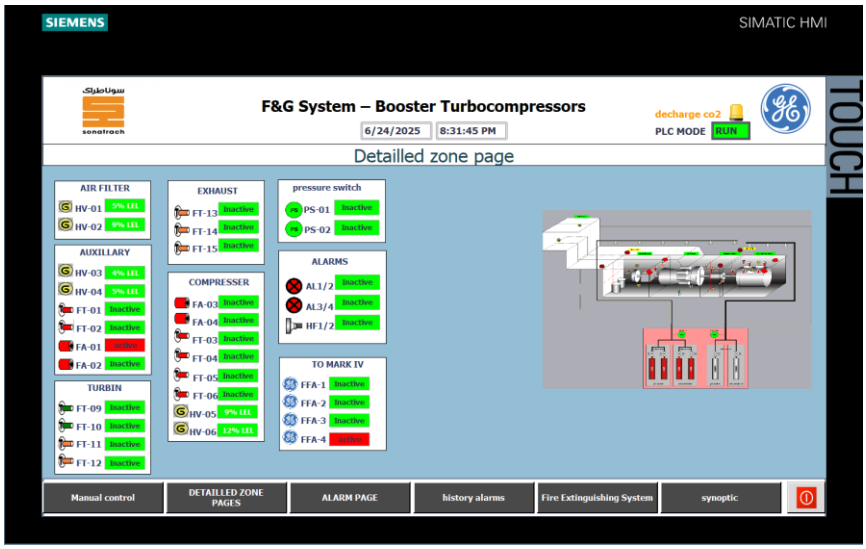


Figure IV.20: Detailed Page Zones.

IV.5.3-Synoptic

This page provides a static visual layout of the MS5002C turbine zones and their Fire and Gas protection elements.

It includes the fixed positions of:

- Gas detectors.
- Heat detectors.
- Flame detectors.
- Pressure switches.
- Manual push buttons.
- Alarms (horns and signal lamps).

The diagram is used as a reference map to understand the system's structure and sensor distribution. Although it does not update in real time, it helps operators and engineers identify sensor placement during system review or maintenance.

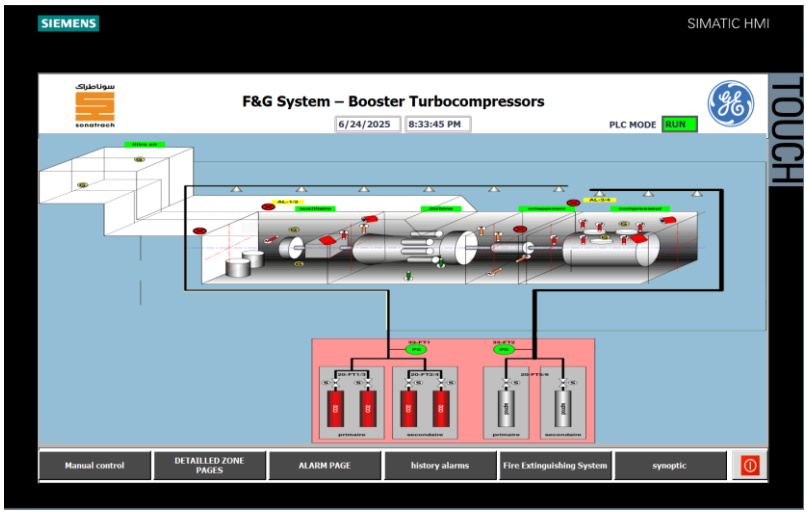


Figure IV.21: Synoptic of MS5002c.

IV.5.4- Fire extinguishing system

This screen helps operators supervise and control the CO_2 and powder fire extinguishing systems. It displays bottle pressure, tracks refill history, and allows manual intervention, when necessary, system.

IV.5.4.1- Pressure Monitoring

- **CO_2 Pressure Green (Normal):** Pressure is OK (monitored by sensor PS-01) and Red (Low): Bottle needs to be refilled.
- **Powder Pressure Green (Normal):** Pressure is sufficient (monitored by sensor PS-02) and Red (Low): Refill required.
- **System Ready to Fire Green (OK):** Both CO_2 and powder bottles are pressurized and ready and Red (Alarm)**:** One or both bottles are not pressurized—system not ready for discharge.

IV.5.4.2- Bottle Refill Logging

Operators can record the last refill (charge) date:

- Enter the date for Primary CO_2 and Primary Powder bottles.
- Press the “Charge” button to store the date in the system’s log history.
- The same process is available for Secondary bottles.

This log helps track maintenance and ensures extinguishing bottles are always ready for use.

IV.5.4.3- Bottle Selector Switches

Operators can switch between Primary or Secondary Powder bottles this allows switching to backup bottles during servicing or after discharge.

IV.5.4.4- Manual Discharge Controls

- **CO_2 Discharge Button:** Triggers the CO_2 bottle manually during an emergency.
- **Powder Discharge Button:** Triggers the powder bottle manually if automatic release fails.

These buttons provide a backup method to fight fires when automatic systems are not available.

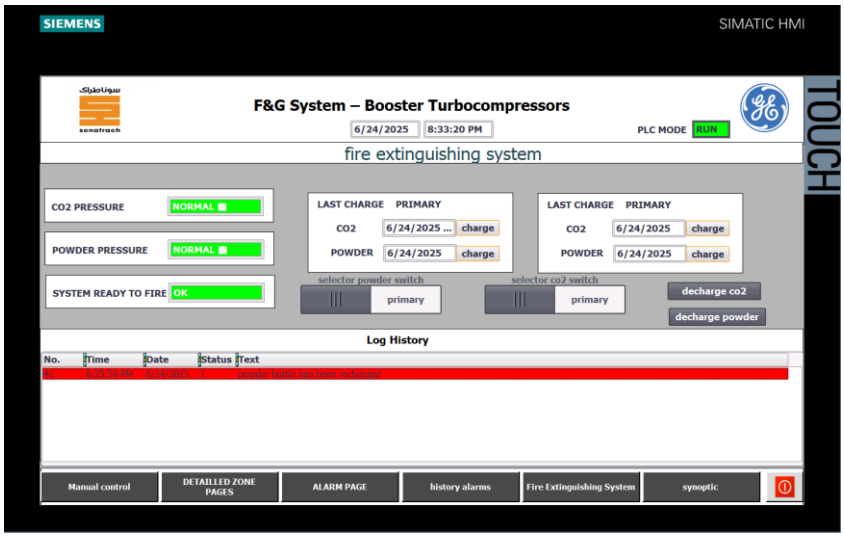


Figure IV.22: Fire extinguishing System general page.

IV.5.5-Alarms Page

This page is designed to display all active alarms related to the Fire and Gas system. Each alarm includes the following details:

- Time and Date of occurrence.
- Alarm Message or comment for easy identification.
- Alarm Class (severity or priority level).

Once an alarm condition becomes inactive, the operator can acknowledge (ACK) it to clear the alarm from the active list, this feature helps operators:

- Quickly respond to abnormal conditions.
- Keep track of the alarm history.
- Maintain better control of system safety.

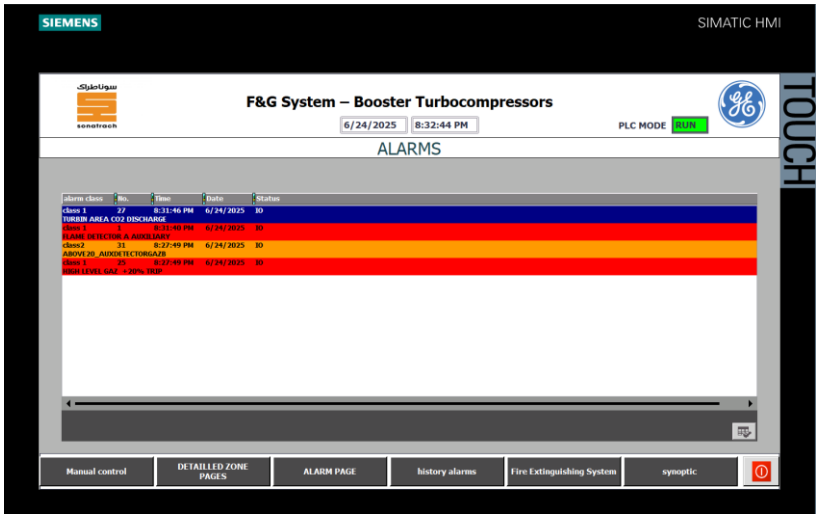


Figure IV.23: Alarms page.

IV.5.6–Alarms History Page

This page stores a **c**hronological log of all alarms that occurred in the system. For each alarm, it shows:

- Date and time of occurrence.
- Alarm message or description.
- Alarm status (active or cleared).

The Alarm History page allows operators to:

- Review past incidents.
- Analyzing system behavior over time.
- Improve maintenance and response planning.

This function is important for diagnostics, traceability, and safety audits.

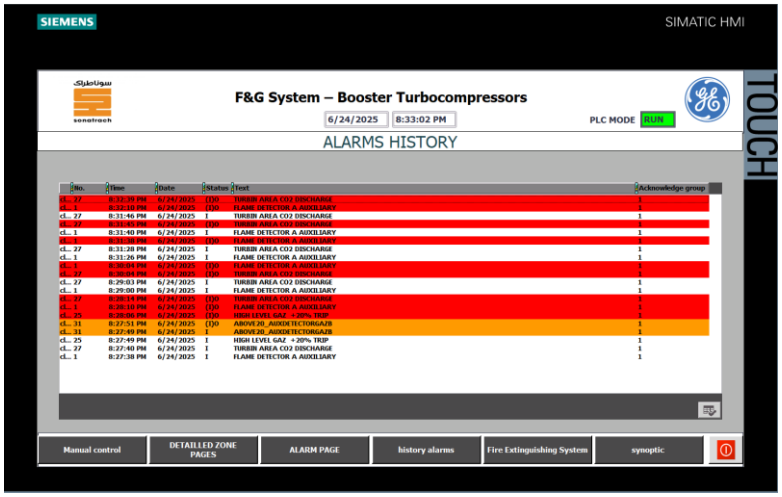


Figure IV.24: Alarms History Page.

IV.6. Conclusion

The proposed automation and supervision system for the FGS improves the safety and reliability of the turbine environment. Each zone is continuously monitored using a combination of gas, heat, and flame detectors. When a hazardous condition is detected, the system can take immediate action, such as triggering alarms, notifying the turbine controller (Mark VI), or activating extinguishing agents. The logic was designed to be fault-tolerant, using features like bypass, 1oo2 voting, and simulated testing. Communication between the PLC and HMI ensures that operators can monitor all sensors, acknowledge or silence alarms, and manually discharge fire suppression agents when needed. By combining automated logic with intuitive supervision pages, this solution provides a robust platform for real-time fire and gas protection in critical industrial areas. It also offers scalability for future improvements and integration into broader plant safety systems.

General Conclusion

Through this project, we successfully developed and implemented a modern Fire and Gas System for the MS5002C turbine at SONATRACH Rhourde-Nouss. Our solution offers enhanced supervision, faster fault detection, and greater safety by using Siemens S7-1500 PLCs and a user-friendly HMI designed in WinCC.

The new system enables operators to monitor gas levels, heat, and flame detection in real time, and take immediate action using manual and automatic controls. It also ensures that alarms, discharge events, and maintenance logs are clearly recorded and displayed. Integration with the existing Mark VI control system allows for synchronized safety actions such as turbine trips or start inhibits.

This project not only improved technical performance but also demonstrated how automation can reduce human error, shorten intervention time, and increase the availability of critical industrial equipment. We believe this work serves as a meaningful step towards modernizing safety systems in the oil and gas sector and provides a solid foundation for future development and expansion.

We are proud of the work accomplished and grateful for the opportunity to apply our academic knowledge in a real-world industrial environment. This experience has strengthened our skills in automation, control, and teamwork—key assets for our professional careers.

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