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MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

HIGHER SCHOOL IN APPLIED SCIENCES
--T L E M C E N--

المدرسة العليا في العلوم التطبيقية
École Supérieure en Sciences Appliquées

وزارة التعليم العالي والبحث العلمي

المدرسة العليا في العلوم التطبيقية
-تلمسان-

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Thesis Title

Water Pumping Station Automation

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Abstract

Automation is highly in demand in industrial processes because they allow full control of the plant as well as reduction of operator interaction, The work presented in this thesis focuses on the design and implementation of a PLC-based control system used to automate a water pumping station situated near the village of Hassi Ben Okba (W. Oran) and named after the latter village.

The thesis is presented in six chapters: Presentation of the host company, instrumentation, functional analysis, plc programming, simulation and a general conclusion.

Résumé

L'automatisation est très demandée dans les processus industriels car ils permettent un contrôle total de l'usine ainsi qu'une réduction de l'interaction de l'opérateur. Le travail présenté dans cette thèse se concentre sur la conception et la mise en œuvre d'un système de contrôle basé sur PLC utilisé pour automatiser une station de pompage d'eau situé près du village de Hassi Ben Okba (W. Oran) et nommé d'après le même village.

Le mémoire est divisé en six chapitres: Présentation de la société d'accueil, l'instrumentation, l'analyse fonctionnelle, la programmation API, la simulation et une conclusion générale.

ملخص

الأتمتة مطلوبة بشكل كبير في العمليات الصناعية لأنها تسمح بالتحكم الكامل في المصنع وكذلك تقليل تفاعل المشغل ، يركز العمل المقدم في هذه الأطروحة على تصميم وتنفيذ نظام تحكم قائم على PLC يستخدم لأتمتة محطة ضخ المياه تقع بالقرب من قرية حاسي بن عقبة (ولاية وهران) وسميت باسم القرية نفسها.

الأطروحة مقسمة إلى ستة فصول: عرض الشركة المضيفة، الأجهزة ، التحليل الوظيفي ، البرمجة ،المحاكاة و خلاصة عامة.

Dedication

To all my family members who have been constant source of motivation, inspiration and support.

To my beloved parents
To my brothers
To my grandparents
To my uncles

Acknowledgement

First of all, I would like to thank my supervisor Professor Sidi Mohammed Abdi El Amine for his guidance, great support and kind advice throughout my work. It was a real privilege and an honour for me to work with him.

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Table of Contents

List of Figures

List of Tables

Abbreviation

ACU	Air compressor Unit
CB	Circuit breaker
CPU	Central Processing Unit
DB	Data Block
DP	Decentralized process
DS	Downstream
FB	Function Block
FC	Function
Genset	generator set
HMI	Human Machine Interface
I/O	Input / Output
IE	Industrial Ethernet
MAO	Mostaganem-Arzew-Oran
NC	Normally Closed
NO	Normally Open
NPSH	Net positive suction head
PID	proportional integral derivative
PLC	Programmable Logic Controller
PMD	Power monitoring device
Profibus	Process field bus
PRT	Platinum Resistance Thermometers
US	Upstream
VSD	Variable Speed Drive
WHP	Water Hammer Protection
XFMR	Transformer

General Introduction

The pumping station plays a key role in the distribution of drinking water. Therefore, and adequate control is required to allow proper water management and have full control of the station. In the event of major water leaks, remote pump management allows the pump to be stopped instantly, thereby minimizing water loss and thus saving water and avoiding the damage that may result. Remote management would also allow to adjust pump speed, and thus regulate the pressure and flow of water according to the network demands.

The first chapter provides a general overview about the host company, introducing the headquarters, the technological building and the pumping station as well as describing their role in the management of public service of drinking water supply. The pumping station plan is provided in appendix F

The second chapter outlines the instrumentation being currently used in the pumping station, their principal of operation and their characteristics. Furthermore, introducing and describing the communication medium “Profibus” the networks the automation systems and field devices.

The third chapter describes the functional analysis, starting with the hardware configuration. Then the automation process areas and their units as well as the security requirements. Finally the design and configuration of operator interface that is implemented on the control panel.

The fourth and fifth chapters deals with the plc programming and simulation, providing details about the user program and describing each process unit by means of a flowchart.

Finally a general conclusion that that wraps up the work presented int this thesis, as well as the experience obtained throughout the internship.

Chapter I

Presentation of the Host Company

I.1 General overview

I.1.1 Presentation of SEOR

SEOR “Société de l’Eau et de l’Assainissement d’Oran” is a joint-stock company, whose shareholders are the Algerian Water Authority “AWE” and the National Sanitation Office “NSO”, established on April 1, 2008. The company is responsible for managing the public service of drinking water supply and sanitation of Oran province, having as key objectives the improvement of the efficiency and the quality of water services as well as the quality of life for citizens [1].

Figure I-1 SEOR Company Headquarters

I.1.2 Company missions

- Ensure the availability of water.
- Carry out preventive maintenance and upgrade sanitation infrastructure.
- Improve the technical, economic, and environmental efficiency of water services.
- Develop human and material resources and introduce new technologies by training local staff [1].

I.1.3 Water professions

Water production systems includes multiple professions, that aims to accomplish the following: [1]

- Drinking water.
- Sewerage.
- Metrology of meters.
- Water treatment.
- The operation, maintenance, and management of hydraulic structures.

I.2 Technological building

I.2.1 Presentation

Located at the Aïn El-Beïda municipality, district of Es-Senia, the SEOR technological building represents the intelligent brain of the company, capable of developing, planning, and maintaining the water supply and sewerage networks [2].

Figure I-2 Technological Building

I.2.2 Purpose of the technological building

- Managing the water supply and sewerage networks and hydraulic installations of Oran province.
- Remote monitoring and control of distribution networks, pumping, and storage infrastructures.
- Planning, study, and simulation of distribution sectors.
- Creation of a geographic information system containing archives and all types of data on Oran's hydraulic networks and infrastructure.
- Controlling & analysing the quality of water services distribution networks.

I.2.3 Departments

I.2.3.1 Cartography

Based on geographic information system "GIS" and using ARCGIS software, their goal is to update and manage a database containing the plans for urban structures, roads and sectors, resources and hydraulic installations as well as the cartographic data and the projection system UTM on WSN and sanitation networks to facilitate simulation and analysis, study, planning of these networks [2].

I.2.3.2 Sectorization

Using data from the cartography department, this department is capable of planning distribution sectors which depend on the population density, their needs, and operating criteria to improve the performance of each sector [2].

I.2.3.3 Planning

This department is responsible for the good distribution of drinking water among subscribers and sectors using MAIKEURBAN software that allows importing and exploiting GIS data (ARCGIS) and facilitate the simulation, either for WSN implementing the EPANET extension or for sanitation using SWIMM [2].

I.2.3.4 Telecontrol

The goal is to improve the quality of services offered by SEOR by speeding up intervention time, facilitating decision-making, analysing behaviour and optimizing management and drawing up periodic reports [2].

Using the Topkapi supervision software which allows to control and monitor the hydraulic stations (tanks, pumping or desalination station). Record and store measurement data (pressure and flow).

I.3 Hassi ben Okba pumping station

I.3.1 Presentation

A booster pumping station which helps to increase the flow rate based on production demands. Located at Hassi Ben Okba municipality, district of Bir El Djir. It is installed in line with the MAO supply line.

The Mostaganem-Arzew-Oran (MAO) supply line begins downstream of the water treatment station (STE) at Mostaganem and ends in the arrival chamber at the Oran reservoir. Its objective is to supply water to the most important cities located along the line (Mostaganem, Arzew and Oran) [2].

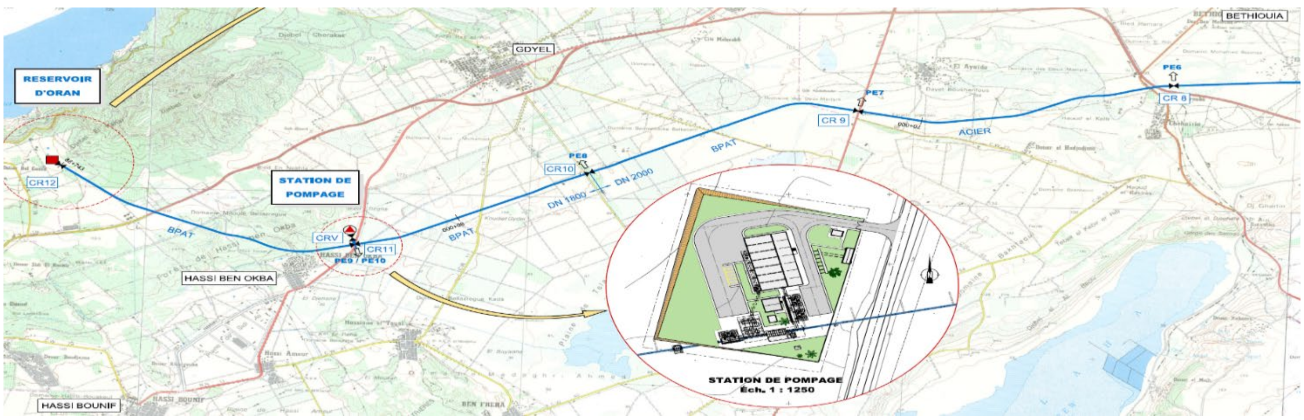

Figure I-3 Location of Hassi Ben Okba pumping station

I.3.2 Components of the pumping station

The primary constituents of the pumping station are introduced briefly in this section. Details are included later in this thesis [2].

I.3.2.1 Control room

It includes:

- Control panel: it manages the station automation algorithm, general security, measurements of both flowrate and pressure, and the alarm system.
- Human machine interface "HMI": it represents all the hydraulic components constituting the pumping station as well as the curves, notification and the alarms.

- Auxiliary electrical enclosure BT3F61: it interfaces the pressure control valves, upstream water hammer protection equipment.
- Auxiliary electrical enclosure BT3F51: it connects with the pumps' room, downstream water hammer protection equipment, instrumentation (flowmeter, pressure measurements).
- Auxiliary electrical enclosure BT3F10: it includes the power supply for direct current equipment.
- Variable speed drive for each pump.

I.3.2.2 Pumps' room

It contains electrical enclosures, each of which aims to interface with the local equipment located near the pump unit such as: discharge and suction valves, PT100 probes, etc.

Table I-1 shows the characteristics of motor-pump groups

Table I-1 Motor-pump characteristics

Number of pumps:	4 + 1
Flow rate per pump / Total flow rate (m^3/s):	1.0 / 4.0
Total head (m):	64
Pump speed (Rt/min):	993
Motor power (kw):	880

I.3.2.3 Water Hammer Protection (WHP)

The surge tanks are shock absorbers intended to dampen excess pressure variance, which occurs on the pipelines when starting or stopping the pumps. This is performed by compression/expansion of the air located at the top of the tank [2].

I.3.2.4 Pressure control room

The pressure room contains control valves which allow the adaptation of the pressure drop during the transition from the gravity water supply mode to the booster water supply mode [2].

Chapter II

Instrumentation

II.1 Measurements

II.1.1 Flowmeter

The flowmeter measures an induced voltage generated by the fluid as it flows through the pipe. The transmitter reads the voltage and converts it into flow measurements, then transmits it to the control system [3].

Figure II-1 Flow meter

Two field coils are located in each magnetic flow meter. These coils generate a constant magnetic field over the entire cross-section of the measurement tube. Two electrodes installed at a right angle can detect electrical voltage that is directly proportional to the velocity of the flow in the pipeline.

The flow meter is located downstream of the station and has the following characteristics:

- Calibration: 0 - 15,000 m^3/s
- Signal output: 4/20 ma 2-wires

II.1.2 Pressure sensor

The pressure is an expression of exerted force per unit surface. The fluid in the pipe generates an electric charge in response to stress (pressure). This is known as the Piezoelectric effect, and the pressure sensor can determine the amount of pressure by measuring the electric charge and transmits it to the control system as an analog electrical signal [4].

A redundant measurement is used as a safety procedure using two sensors. The first reading is done using an analog signal and the second one is done using two NO/NC contacts that indicate pipeline rupture or blockage.

Figure II-2 Pressure sensor

Located at:

- Main suction line.
- Main discharge line.
- Downstream of station.

The pressure sensor has the following characteristics:

- Calibration: 0 – 25 bars.
- Signal output: 4/20 ma 2-wires.

Another device is used which is the manometer, implemented as a pressure indicator, located at:

- Main suction and discharge lines.
- Downstream and Upstream water hammer protection of the station.
- Pressure control room.
- CR11.

II.1.3 Platinum resistance thermometers (PRTs)

The operation principle is to measure the resistance of a platinum element that is proportional to the temperature [5]. The PT100 sensors are used to measure the bearing and winding temperatures of each motor-pump group.

Figure II-3 Platinum resistance thermometer, PT100

II.1.4 Vibration monitoring

Vibrex provides continuous monitoring for the vibration severity and anti-friction bearing condition for both of the motor and the pump and performs automated alarm-based switching [6]. A delay interval is configured to ignore transient signal elevations (such as those during machine start-up).

Figure II-4 Vibrex

II.1.5 Level measurement

The U/S WHP surge tanks are equipped with both digital and analog level measurements instruments, as for D/S WHP surge tanks only digital level measurements instruments are implemented.

II.1.5.1 Digital measurement

- Sensor: conductive prob
- Transmitter: NIVOTESTER FTW 325

The NIVOTESTER supplies the conductive probe with an alternating current via a two-wire line and monitors the voltage of this line. If the water reaches the switch point of the probe, the voltage between the probe and NIVOTESTER is reduced and the output relay at the NIVOTESTER switches on [7].

Figure II-5 NIVOTESTER FTW 325

II.1.5.2 Analog measurement

Using a differential pressure measurement and the hydrostatic equation, the water level in surge tanks can be measured.

According to the hydrostatic equation:

$$\Delta P = \rho . g . h$$

- ΔP (N): is the differential pressure, transmitted to the control system as an electrical signal (4/20 ma - 2 wires).
- ρ is the fluid density (kg/m^3).
- g is the acceleration due to gravity (m/s^2).
- h is the height of fluid (m).

II.2 Hydraulic equipment

II.2.1 The Pump

The centrifugal pumps impart momentum to the fluid by rotating impellers that are immersed in the fluid. The momentum produces an increase in flow at the pump outlet. The amount of energy given to the liquid corresponds to the velocity at the edge or vane tip of the impeller. The faster the impeller revolves or the bigger the impeller, then the higher the velocity of the liquid at the vane tip, and the greater the energy imparted to the liquid [8].

Figure II-6 Picture of the Pump

Table II-1 shows the pump characteristics.

Table II-1 Pump characteristics

Flow rate (l/s):	1000
Total head (m):	64
Speed (rpm):	993
Efficiency:	86
Net positive suction head NPSH (m):	5.7
Absorbed power (kw):	729

II.2.2 Manual valves

Butterfly manual valves are used as shut-off valves for each WHP tank. They are equipped with “MR manual gearbox” which is a handwheel-operated mechanical reducer, and includes AMTROBOX which is limit switch box for the detection of open or closed position [2].

Figure II-7 Manual valve

II.2.3 Automatic valves

Butterfly automatic valves are used as shut-off valves and are located at:

- Suction and discharge of each pump
- Main suction and discharge lines
- Pressure control room

These valves are equipped with an ACTELEC actuator that consists of a mechanical reducer with irreversible kinematics associated with an electric multi-turn actuator supplied by AUMA (SA 07.1 servo motor). The latter is driven by an electric motor and controlled by the AUMA MATIC electronic blocks supplied with the servomotor [2].

Figure II-8 Automatic valves

AUMA actuator characteristics:

- Open/closed limit switches.
- Position indicator.
- Torque limiting system.
- Anti-condensation heater.
- Manual handwheel emergency control.
- Local/distance control mode.

II.2.4 Pressure control valves

Two pressure control valves allow the adjustment of the pressure drop according to the pump operating conditions [2].

Figure II-9 Pressure control valve

Control characteristics:

- AUMA SAR 07.1 servo motor 380v-50hz-3ph.
- Controlled by a 4/20 ma signal.
- Position signal: 4/20 ma 4-wires.
- Open/closed limit switch.
- Torque limiting system.
- Manual handwheel emergency control.
- Local/distance control mode.
- Corrosion protection.
- Condensation heater.

II.2.5 Check valves

In a silent check valve, a short linear stroke and spring return action combine to close the valve prior to flow reversal which effectively eliminates the shock and water hammer normally associated with the sudden stoppage of a reverse flow [2; 9].

The check valves are located at:

- Discharge pipe of each pump
- Main by-pass line

Figure II-10 Check valve

II.2.6 Air relief valves

A triple function air valve evacuates air during pipe filling or emptying, suppresses obstacles created by air when the pipeline works under pressure [2; 10].

Air relief valves are located at different sites of the station. Their three functions are:

- Discharging a high flow of air during the filling of the pipe.
- Automatic degassing of the air contained in the pipe under pressure.
- Admission of high airflow for the draining of the pipe.

Figure II-11 Air relief valve

II.2.7 Gate valves

Gate valves are used as draining valves and are located at various lines of the station [2].

Figure II-12 Gate valve

II.3 Mechanical equipment

II.3.1 The Motor

Squirrel-cage three-phase asynchronous motor with inner cooling air circuit used to drive the pump, characterized by its ruggedness, long service life and reliability [2].

Figure II-13 Picture of Motor

Table II-2 shows the motor characteristics.

Table II-2 Motor characteristics

Power (kW):	880
Voltage (V):	690
Frequency (Hz):	50
Current (A):	880
Nominal speed / Maximum Speed (rpm):	993 / 2200
Torque (nm):	8463
Power factor:	0.86

II.3.2 Variable Speed Drive

SINAMICS G150 drive converter cabinet units are specially designed to meet the requirements of medium performance drives with a quadratic and constant load characteristic.

Each motor is controlled by a SINAMICS G150 drive converter with the Volts/Hertz (U/F) control. This strategy intends to keep a constant flux, imposing a constant volt/hertz ratio thereby varying the pump speed to satisfy the production demand [11].

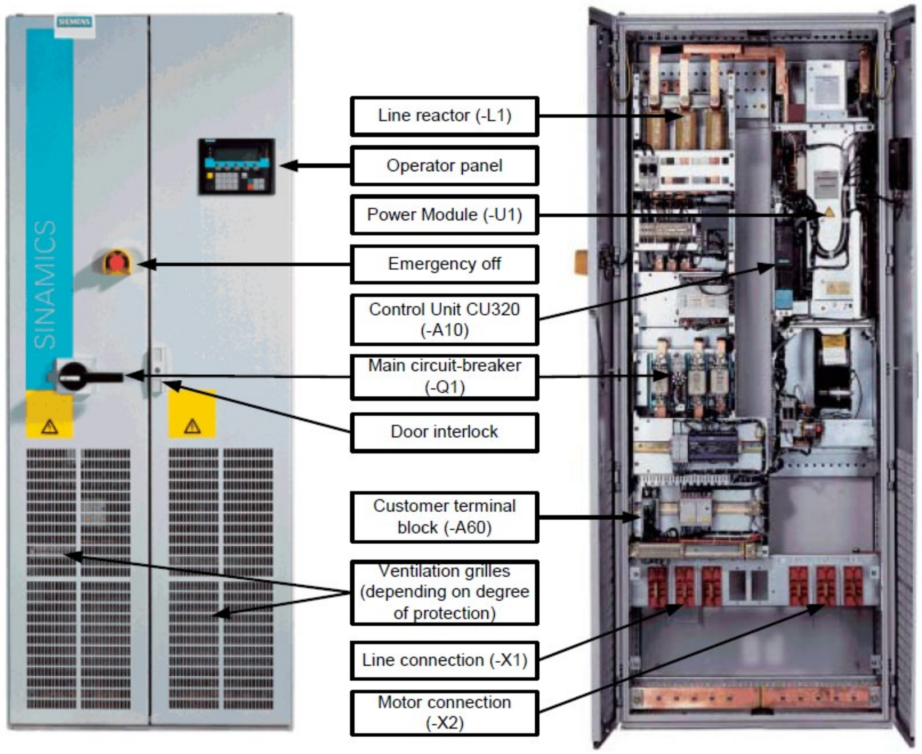

Figure II-14 Variable speed driver

II.3.3 Air compressor

A rotary vane compressor is a type of positive displacement air compressor that consists of a rotor with a number of blades inserted in radial slots within the rotor. The latter is mounted eccentric and tangential to the stator. As air enters through the inlet, it is trapped between the vanes. As the rotor turns, blades slide in and out of the slots keeping contact with the outer wall of the housing. Thus, a series of increasing and decreasing volumes is created by the rotating blades. The reduction in volume raises the pressure [2; 12].

Figure II-15 Air compressor

The sealing between moving parts, cooling and lubrication are guaranteed by injecting oil through calibrated orifices. This injection is the result of the pressure difference between the compression chamber and the oil tank.

The air compressor is equipped with an electric box that provides:

- Star/delta starter
- Motor thermal & circuit protection
- Emergency stop button
- MICROMAT: control and management system which transfer the air compressor state to the control system.

Table II-3 shows the air compressor characteristics [2; 12].

Table II-3 Air compressor characteristics

Flow rate (m3/s)	4.9
Suction pressure (bar)	1
Power (kW)	37
Voltage (V)	400
Frequency (Hz)	50
Current (A)	80
Nominal speed (rpm)	1460

II.3.4 Generator set

A complete diesel generator set including the diesel engine, alternator, control panel, automatic starting equipment, fuel tank, and all other accessories for autonomous operation. It is used as an emergency power-supply in case of grid failure [2; 13].

The generator set control panel supplies the control system with necessary information for operation requirements. Details are included in Appendix C.

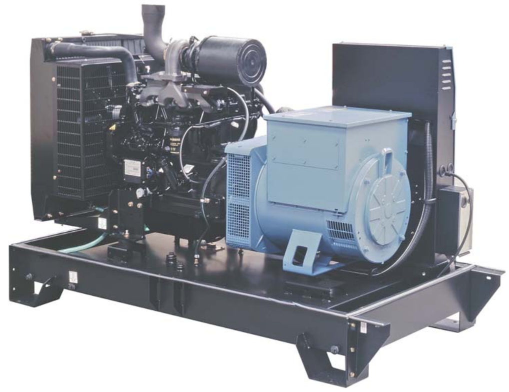

Figure II-16 Generator set

Table II-4 shows the generator set characteristics.

Table II-4 Generator set characteristics

Engine data	
Speed (rpm)	1500
Max. Stand by power (kw)	68
Alternator data	
Power factor	0.8
Exciter type	Shunt
Voltage regulator	R230

II.4 Electrical component

II.4.1 Control relay

A control relay is an electrical component that consists of a set of input terminals for a single or multiple control signals, and a set of operating contact terminals. It is used to either control a circuit by an independent low-power signal or where several circuits must be controlled by one signal [2; 14].

Figure II-17 Control relay

II.4.2 Contactors

Contactors provide the same functionality as the control relay, but are typically used in higher voltage and current environments [2; 14].

Figure II-18 Contactor

II.4.3 Changeover relays

Changeover relays are used to switch a single feed line between two active functions in a circuit. The relay is switched manually via a toggle/push switch or remotely through the circuit. In practice they allow to achieve a normally open or normally closed latching and coil suppression [2; 15].

Figure II-19 Changeover relay

II.4.4 Monitoring relays

The 3UG4 monitoring relays provide a maximum degree of protection for mobile machines or systems and unstable lines. They detect phase failure, phase sequence, phase asymmetry and under-voltage [2; 16].

Figure II-20 Monitoring relay

II.4.5 Circuit breaker

A circuit breaker is a safety device used to protect an electrical circuit from damage caused by excess current from an overload or short circuit. Whenever a fault is detected, the circuit breaker trips [2; 17].

Figure II-21 Circuit breaker

II.4.6 Motor circuit breaker

A motor circuit breaker is a device integrating low voltage circuit breakers and thermal overload relays functions. This device is capable of protecting the motor branch circuits from overload, phase-loss, and short-circuit faults [2; 18].

Figure II-22 Motor circuit breaker

II.4.7 Power supply

The SITOP UPS 24V/40A is a built-in unit for uninterruptible power supply. It helps prevent downtimes and undefined plant statuses caused by disturbances in the supply network as well as producing a constant output voltage in spite of a change in the input voltage, a change in the current load or a change in ambient temperature [2; 19].

II.4.8 Power monitoring

The DIRIS A-40 is a panel mounted power monitoring device (PMD), used for both measuring and monitoring voltage, current, power and energy [2; 20].

Figure II-23 DIRIS A-40

II.5 CPU-CPU communication

II.5.1 Profibus description

A process field bus ‘Profibus’ is a communication medium for the field level that networks automation systems and field devices which are compatible with it [21].

II.5.2 Profibus-DP

By introducing a network bus between the main controller in the control room and its I/O modules in the field area “Remote I/O”, we decentralize these modules thus allowing the different sensors and actuators to be connected directly to them which reduce the wiring cost [21].

The data transfer is done by using RS-485 cable

The benefits of Profibus-DP are:

- Independent and simultaneous commissioning of individual devices is possible
- Small and manageable programs
- Parallel processing due to distributed automation systems
- Reduced response times
- Higher-level structures can take on additional diagnostics and logging functions.
- Increased plant availability because the rest of the overall system can continue to work when a subordinate station fails.

II.5.3 Devices with Profibus-DP

The main components with Profibus-DP are listed Figure II-24 below:

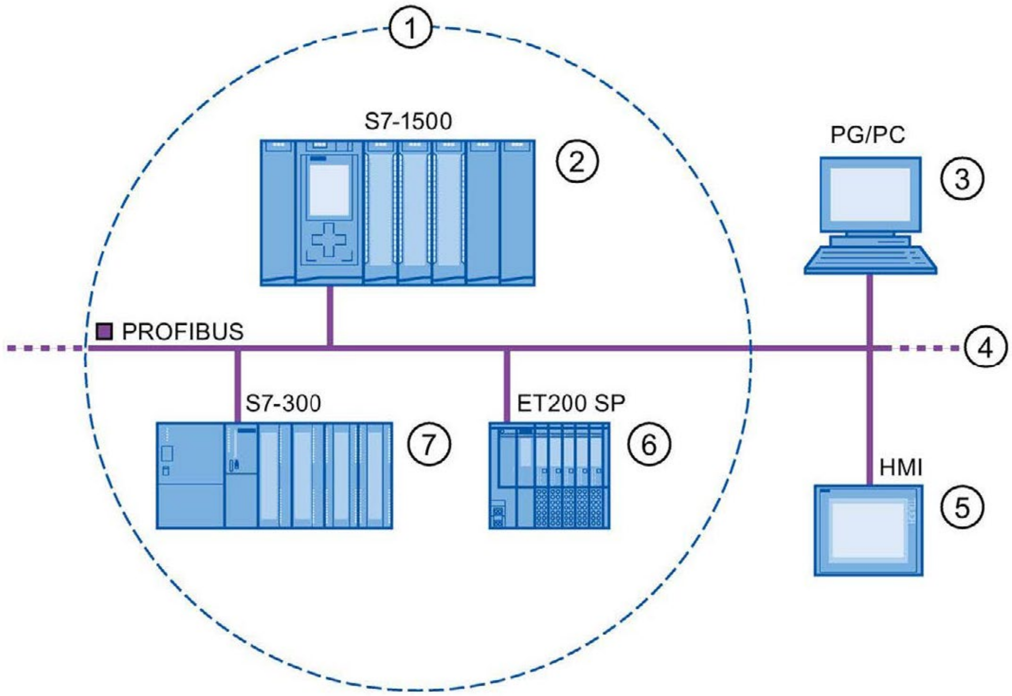

Figure II-24 Profibus network

The following nomenclature is used in figure II-24:

1- DP master system
2- DP master
3- PG/PC
4- Profibus network
5- HMI
6- DP slave
7- I-slave

II.5.4 Master-slave communication

This type of communication is based on active and passive nodes and works as follows:

- Active nodes (masters) form the logical token ring, in which they know each other and their order in the ring.
- The right to access the transfer link is passed between the active nodes according to the ring order. The passive nodes (slaves) never receive the token.
- Each active node can hold the token for a specific time ‘the token hold time’.
- If a node has the token and a master-slave connection is configured, the data transfer can be established.
- This access technique allows nodes to enter or leave the ring during operation.

II.5.5 I/O communication using Profibus-DP

Cyclic exchange of data between master I/O and slave I/O via the Profibus I/O protocol takes place as follows: [21]

- **DP master and DP slave**: the DP master reads/writes data from/to DP slaves (direct access to I/O).
- **DP master and I-slave**: the data transmission is done through transfer areas ‘configured address areas’ that can be inside or outside the process image of the I-slave CPU. If parts of the process image are used as transfer areas, these may not be used for actual I/O modules.

II.5.6 I-slave

Intelligent DP slave, the data is pre-processed by the slave’s CPU program and made available to the DP master via the I/O modules [21]. The benefits of I-slaves are:

- Simple coupling of CPUs with Profibus interface.
- Real-time communication between CPUs and Profibus interface.
- Distributed processing and Lower communication load by processing process data locally.

Chapter III

Functional analysis

III.1 Principals

III.1.1 System curve

A fluid system is characterized by a system curve, which is a parabola function of static head and the major and minor losses in the system [22]. It can be expressed as:

$$h = \Delta h + k^2 . q$$

Where:

- h is the system head (metre of water).
- Δh is the elevation (static) head difference between the inlet and outlet in the system (metre of water).
- k constant describing the total system characteristics - including all major and minor losses.
- q flow rate (m^3/s) .

Increasing or decreasing the constant, k, by either closing or opening some valves, will increase or decrease the head loss and move the system curve either upwards or downwards.

III.1.2 Pumps curve

The pump performance curve describes the relation between the flowrate and the head for the actual pump, described graphically by the manufacturer [22].

III.1.3 Operating point

The operating point is located at the intersection of the system curve and the actual pump curve [22].

III.1.4 Flow rate adjustment

III.1.4.1 Parallel pumps arrangement

The parallel pumps arrangement results in flow rate increase at the same head.
The advantages of this arrangement are both high system efficiency and high operating reliability. Whereas its disadvantage is increased construction cost [23].

III.1.4.2 Speed adjustments

The aim of this operation is to provide the system demands at the most economical possible speed. The advantages of this arrangement are both power saving and avoidance of excess pressure. Whereas its disadvantage is higher control costs [23].

III.1.4.3 Combination of parallel operation and variable speed operation

This configuration is used when: [23]

- Production demands vary.
- Cover a wide operation range.
- Power consumption must be minimized.

The advantages of this arrangement are: increased flow rate and head adjustment ranges, large variation possible in the set value range and excellent quality control. Whereas its disadvantage is higher purchase costs [23].

III.2 Pump station

III.2.1 Operation mode

The operator may switch between different operation modes through the control panel [2].

III.2.1.1 Pipe filling:

This operation is used only for either the first start-up or after pipe draining. For safety procedures the valves opening is done manually in the order listed below:

- Main suction valve.
- Suction valve for each pump.
- Discharge valve for each pump.
- Main discharge valve.
- Pressure control valves.

III.2.1.2 Idle operation

Water flows by gravity through the main by-pass valve “CR11 valve” with no pumps running [2].

III.2.1.3 Manual operation

In this mode, the operator is responsible for selecting the number of running pumps by manually turning on/off pumps. The pump selection and hour meter control functions are disabled in this mode.

The pressure and flow control functions are still active in this mode. They can be deactivated individually which leads to the full control of the station. In this case, the operator is responsible for the harm that may damage the equipment [2].

III.2.1.4 Automatic operation

The control system adjusts the pumps speed and the number of operational pumps in order to achieve the set flow introduced remotely by the telecontrol unit, or locally by the operator [2].

III.2.2 Control functions in automatic operation mode

III.2.2.1 Running pumps

A. Starting phase:

Depending on the set flow, two, three or four pumps are started up to a predefined reduced speed [2].

Table III-1 shows the number of pumps and the initial speed.

Table III-1 Starting phase data

Set flow (m^3/s)	Number of pumps	Initial speed
1.0 to 1.3	2	50%
1.3 to 1.95	3	50%
1.95 to 2.6	4	50%
2.6 to 4.75	4	60%

B. During the operation:

The number of pumps is adjusted according to the following tow operating conditions:

- If the station operates at the overflow range (the extreme right of the operating zone) for more than 60 seconds, an additional pump will be started.
- If, during a time interval greater than 1 minute, operation with one pump more or less would allow a higher efficiency for the measured flow.

In order to ensure the stability and achieve a steady-state operation point, the number of running pumps must not change for at least 20 minutes between two successive changes [2].

III.2.2.2 Hour meter control

Two hour meters are associated for each pump that count the duration in which the pump is running or stopped [2].

- When the pump is running, the “on duration” counter is incremented by a second and the “off duration” counter is reset.
- When the pump is stopped, the “off duration” counter is incremented by a second and the “on duration” counter is reset.

The control system should run a pump with the maximum “off duration” count, and stop a pump with the maximum “on duration” count.

When a pump reaches the maximum running hours count which can be adjusted by the operator, the control system should turn it off and run another one. Finally, a cyclic permutation of the pumps in automatic mode is ensured once a week [2].

III.2.3 Valve positions

All valves on the pumping station should be opened before running the station, except those on the pressure control room for the following reason:

- With a closed valve, the highest power draw is at the shutoff condition, and the driving motor will accelerate to its maximum speed. When the valve opens, the reaction time for the speed variation will be too long and the pump may run in over-flow with a risk of cavitation. In view of this, the pump must be started up with an open discharge valve thus allowing the pressure resistance in the system to build up gradually to the required operating head. The reduction of pressure spikes on start-up is guaranteed using the soft-starting by the variable frequency driver which also helps reducing the inrush current, the stress on the motor, pump, coupling and the supply network [2].

A shut-off valve should be closed for maintenance purposes only.

III.2.4 By-pass valve and CR11 room:

When water flows by gravity (pumps are idle), it passes through the CR11 valve, and the check valve is opened.

When the pressure generated by the pumps is greater than the one of gravity flow, the check valve will automatically close thus no more flow will pass through the CR11 valve.

If the pipe is broken after the CR11 room and the flow measured is exceeded, the CR11 valve should be closed [2].

III.2.5 Role of check valves

The check valves located at the individual discharge pipes of the pumps prevent the partial blockage of the fluid by passage in the opposite direction in the stopped pumps. Starting a pump in this case will cause mechanical and electrical damages [2].

III.2.6 Power-supply

A redundant power supply system is implemented, in case of a failure the back-up system takes over, and an alarm is triggered to inform the operator [2]. It is used to continuously feed low voltage equipment (plc, control panel, measuring instruments) with stabilized 24VDC even in power loss.

III.2.7 Backup power supply

The low voltage equipment supply line is fed by either the main or the backup power supply source. In case of main power supply failure, the control system is responsible for toggling between the power sources by controlling the circuit breakers [2].

Two circuit breakers are installed on the main line “XFMR CB” and “Coupling CB”, as for the backup line has one circuit breaker “Genest CB”.

The “XFMR CB” and “Coupling CB” will trip when a fault in main power supply is detected and the “Genest CB” will latch. The generator set is then turned on.

The generator set should be ready for service otherwise an alarm is triggered.

III.2.8 General security

The stopping and locking conditions which ensure the proper functioning of the pumping station are described below [2].

III.2.8.1 Emergency stop button:

This is located at the control panel and near each pump. When pressed, it stops all running pumps.

III.2.8.2 Suction pressure:

A minimum suction pressure limit is set in order to prevent the dry running of pumps.

III.2.8.3 Discharge pressure:

- **Minimum discharge pressure:** allows the detection of a broken pipe.
- **Maximum discharge pressure:** allows the detection of a pipe obstruction.

III.2.8.4 Valves

The main suction and discharge valves should be opened. In case of fault or either one is closed, the running pumps are turned off.

III.2.8.5 Temporary block:

This function prevents the starting/stopping of a pump following the starting/stopping of another as well as successive starting and maximum starts per hour for the same pump.
Table III-2 represents the interval value for each case:

Table III-2 Temporary block intervals

Case	Interval
Starting of another pump	1 min
Stopping of another pump	5 min
Starting the same pump	15 min
Maximum starts per hour	3

III.2.8.6 Thermal protection

The motor winding temperature and the bearing temperatures for both motor and pump are measured [2]; the safety procedures are defined as follows:

- When the high limit is reached, an alarm is triggered.
- When the overheating limit is reached, the pump is turned off.

III.2.8.7 Vibration

If the vibration on the pump or motor excesses the safety limit the pumps is turned off

III.2.8.8 Power supply

The power supply is continuously monitored, in case of failure, the running pumps are turned off.

III.3 Pump speed control

III.3.1 Introduction

The closed-loop control adjusts the pump speed to achieve the flow set, while ensuring the following safety requirements:

- Oran tank level.
- Mostaganem tank level.
- Minimum suction pressure.

III.3.2 Description

Figure III-1 shows a cascade control diagram block.

A cascade control strategy is implemented to improve disturbance rejection, where primary (master) controller involved in the outer loop, generates a control effort that serves as the setpoint for a secondary (slave) controller. The latter is involved in the inner loop, and in turn uses the actuator to apply its control effort directly to the secondary process. The secondary process then generates a secondary process variable that serves as the control effort for the primary process.
The primary controller tells the secondary controller how much speed it wants in terms of a desired flow rate. The secondary controller then manipulates the V/F constant in order to regulate the pump speed until the water is flowing at the requested rate.
The primary controller is implemented on the main control PLC, where the secondary is implemented on the variable speed drive [2].
The control elements are:

- Setpoint: desired flow rate
- Primary controller (master): measures flow rate and adjust pump speed

- Primary process variable flow rate
- Outer loop disturbances: fluctuations in flow rate and pressure drop
- Secondary controller (slave): measures and regulate pump speed
- Inner loop disturbances – fluctuations in pump speed power supply voltage, current and frequency
- Secondary process variable pump speed.

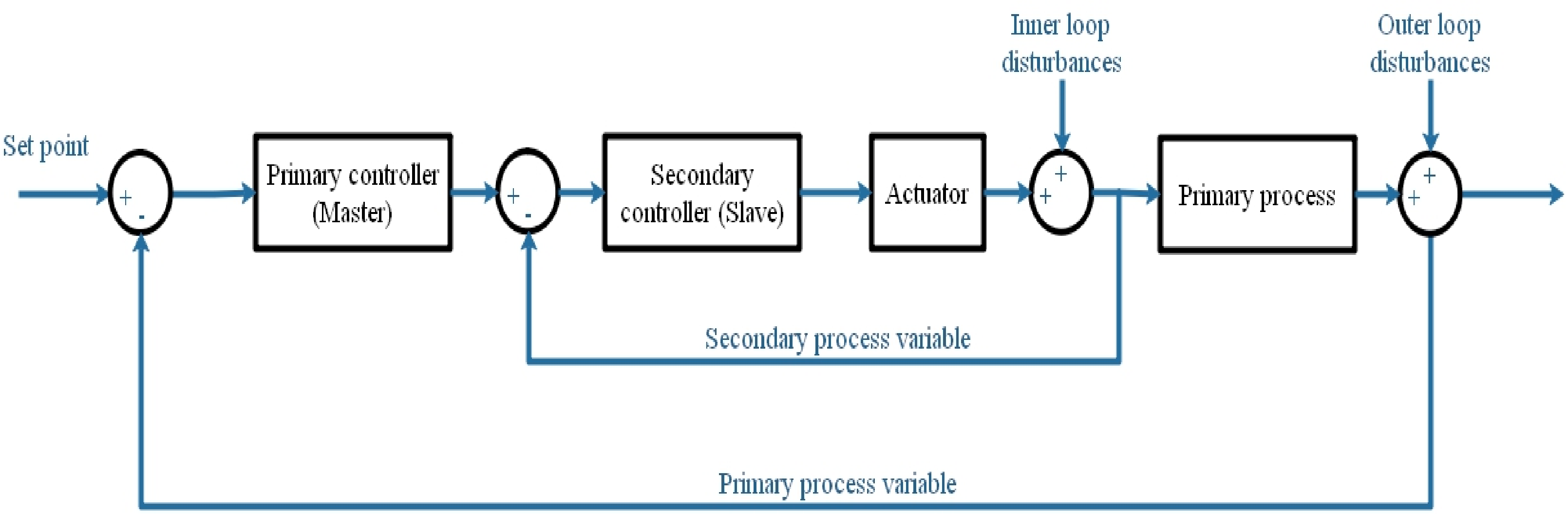

Figure III-1 Cascade control diagram block

III.3.3 Flow rate adjustment as a function of Oran tank water level

The water flow is adjusted according to the following operating conditions:

- If the level reaches high limit, the flow rate must be reduced or turn off running pumps
- If the level reaches low limit, the flow must be increased, if it continues to decrease then turn off running pumps.

The tank level, MESOran, is compared to a predefined value, Nmax1. If the result of the comparison is negative (i.e. MESOran > Nmax1) at time T_0 with the measured flow rate, Q_{T_0}, the pump speed should decrease until the decrement of the flow rate compared to Q_{T_0} is greater than a predefined parameter Q_{cor}.

If MESOran reaches Nmin1, the flow increases in a given interval. If MESOran continues to decrease and reaches Nmin2, the pumps are turned off [2].

Table III-3 Adjustments as a function of Oran tank water level

Level	Action
Nmaxmax	Close CR12 second valve
Nmax3	Close CR12first valve
Nmax2	Turn off running pumps
Nmax1	An alarm is triggered and the flow rate is decreased automatically
Nmin1	An alarm is triggered and the flow rate is decreased automatically
Nmin2	Turn off running pumps
Nmin3	Close CR12first valve
Nminmin	Close CR12second valve

(Nmaxmax>Nmax3>Nmax2>Nmax1 and *Nminmin<Nmin3<Nmin2<Nmin1)*

III.3.4 Flow rate adjustment as a function of Mostaganem tank water level

If the tank level MESMostaganem deceases and reaches Nmin1, the flow rate increases in a given interval. If it continues to decrease and reaches Nmin2 the pumps are turned off [2].

Table III-4 Adjustments as a function Mostaganem tank water level

Level	Action
Nmin1	An alarm is triggered and the flow rate is decreased automatically
Nmin2	Turn off running pumps
Nmin3	Close CR12 first valve
Nminmin	Close CR12 second valve

(Nminmin<Nmin3<Nmin2<Nmin1)

III.4 Pressure control

Figure III-2 shows the pressure control block diagram

The objective of pressure control is to limit the operation of the pumps along its characteristic curve at a reduced speed which is 50% of the nominal speed.

The measured flow provides a differential pressure value via the characteristic curve for the number of pumps in operation, Pmin, which is compared to the difference between suction pressure and discharge pressure $(DPm = Pdis - Psxn)$. The result of comparison will regulate the pressure control valves position. If DPm is less than Pmin, the pressure control valves will have to partially close to increase the pressure difference [2].

As the flow rate increases, the head decreases and the pressure control valves open gradually (or vice versa).

For the safety of the equipment, if DPm remains less than Pmin for one-minute, an alarm is triggered. If this situation extends for more than three minutes the pumps are automatically stopped.

III.4.1 By-pass valve

In order to limit the head losses that result from the pressure control valves, the by-pass valve is opened when pressure control valves are fully opened (%100) or when the approximate operation limit of the control valves is exceeded (DP <18mce and flow rate < 9.3m^3/s) [2].

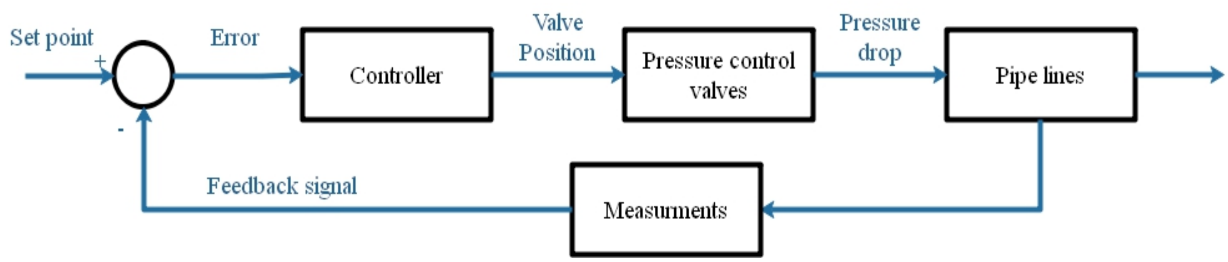

Figure III-2 Pressure control block diagram

The control elements shown in figure III-2 are:

- Setpoint: differential pressure obtained from the characteristic curve.
- Controller: PID controller implemented in PLC program.
- Actuator: pressure control valves.
- Manipulated variable: valve position.
- Disturbances: fluctuations in flow rate and pressure drop.

III.5 Water hammer protection

III.5.1 Introduction

Hydraulic shock (water hammer) is a pressure surge or wave that propagates in the pipes and may cause major problems, from noise and vibration to pipe rupture or collapse. It can occur when the water is in motion and due to suddenly closing some valves or starting and stopping the pumps.

A surge tank is a water storage device used as a pressure neutralizer in order to dampen and absorb excess pressure variance (pressure waves). This is performed by compression/expansion of the air located at the top of the tank [2; 24].

Since the water level is the same for each surge tank (hydrostatic), it may be measured in one tank only.

The air compressors are used to keep an "air / water" proportion in the tank approximately constant, and replace the amount of air that goes into solution in the water over time.

III.5.2 Operation mode

The operator may switch between the automatic and manual mode through the control panel. The automatic mode is used by default [2].

III.5.2.1 Automatic operation mode:

Based on the water level, the air compressors are turned on/off. There is an inversion between the compressors at each start-up.

III.5.2.2 Manual operation mode:

The air compressors are turned on/off and selected manually by the operator.

III.5.3 Upstream Water Hammer Protection (U/S WHP)

- Number of surge tanks: 4
- Number of air compressors: 2 + 1

The water level can be measured using two methods, the operator may select the measuring method via the control panel.

- Analog: differential pressure
- Digital: 4 limit switches

The water level limits necessary for controlling the air compressors depends on the number of running pumps.

III.5.3.1 Digital measurement:

Figure III-3 shows the limit switch arrangements on the water hammer surge tank.

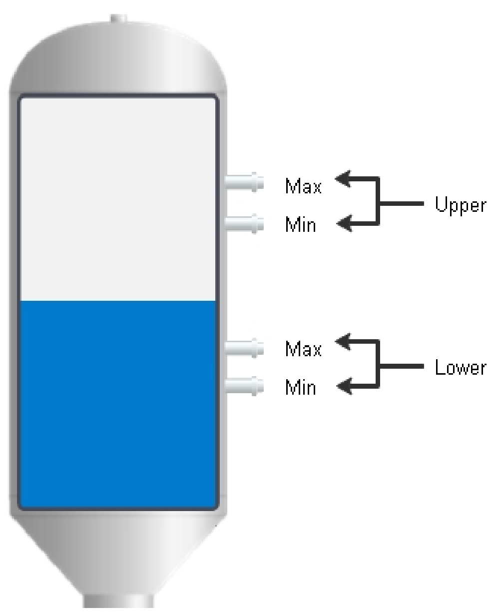

Figure III-3 U/S WHP limit switch arrangements

Table III -5 summarises the operation conditions in terms of limit switches

Table III-5 U/S WHP Air compressor operation conditions – digital measuring

Number of running pumps	Limit switches	Air compressor operation	
		Turn on	Turn off
Less than four	Upper	Max	Min
Grater or equal to four	Lower	Max	Min

III.5.3.2 Analog measurement

A differential pressure sensor measures the water level according to the Hydrostatic equation. Table III-6 summarises the operation conditions as a function of water level.

Table III-6 U/S WHP Air compressor operation conditions – analog measurement

Number of running pumps	Air compressor operation	
	Turn on	Turn off
Less than four	4,971 mm	5,171 mm
Grater or equal to four	200 mm	0 mm

III.5.4 Downstream Water Hammer Protection (D/S WHP)

- Number of surge tanks: 2.
- Number of air compressors: 1 + 1.

The water level can be measured using only the three installed limit switches. The air compressor operation conditions in terms of limit switches are listed below [2].

- Max limit: turn on the air compressor.
- Min limit: turn off the air compressor.
- Fault: an alarm is triggered indicating that there is not enough air due to air compressor mal functioning or failure.

Figure III-4 shows the limit switch arrangements on the water hammer surge tank.

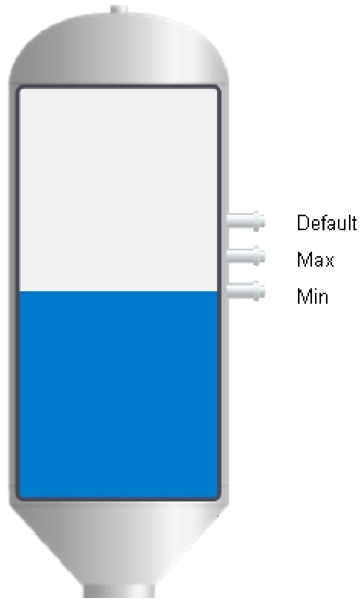

Figure III-4 D/S WHP limit switch arrangements

III.5.5 Security procedures

If the in service compressor fails, the backup compressor takes over automatically.

If the fault or max-upper limit switch is triggered for more than two minutes, the pumps are shut down. [2]

The numbers of required operational surge tanks in terms of flow rate are listed in table III-7

Note: a surge tank is operational when its corresponding valve is fully open and not in fault state.

Table III-7 Number of required surge tanks in terms of flowrate

Number of U/S surge tanks	Number of D/S surge tanks	Flow rate (m^3/s)
0	0	0.56
1	0	0.56
2	0	0.56
3	0	0.83
4	0	1.12
0	1	1.4
1	1	1.67
2	1	1.95
3	1	2.23
4	1	2.5
0	2	2.78
1	2	3.06
2	2	3.33
3	2	3.62
4	2	4

Chapter IV

PLC Programming

IV.1 Introduction

The case study of a pumping station is part of the water production system in the city of Oran. Our objective is to design and implement a PLC program in order to automate the station.
After defining the basic concepts and the fundamentals in the previous chapters, we may now deal with coding of the user program.
Both the hardware and software configurations were adjusted according to what may be achieved in simulation, for the following reasons :

- PLCSIM v15.1 maximum instances: 2
- PLCSIM v5.6 maximum instances: 8
- PROFIBUS Master/Slave communication is not supported by PLCSIM.

The automation process consists of a number of related tasks that form process areas. As each area is divided into smaller units, the process becomes less complicated.
Each Process area has a set of functions and function blocks that constitute the user program. The units are described by means of a flowchart. Further details are provided in the following sections.

IV.2 Software components

Table IV-1 lists the software used in developing, designing and simulating the PLC program and the user interface.

Table IV-1 Software component

Software	Version
STEP 7 Professional	V15.1
WinCC Professional	V15.1
PLCSim	V15.1
PLCSim	V5.6
Photoshop	CC2018

IV.3 Hardware configuration

IV.3.1 Master PLC

The Master PLC manages the control of the station including the communication between other devices, the security and alarm system, the operation modes, flow and pressure control.
The device configuration is presented figure IV-1.
Table IV-2 represents the device configuration.
The I/O addresses are included in appendix A.

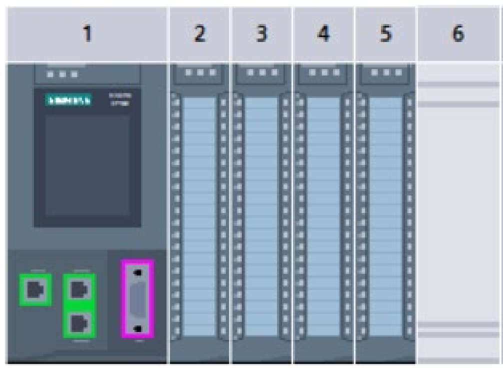

Figure IV-1 Master CPU hardware configuration

Table IV-2 Master CPU I/O modules

Module	Slot	Description
CPU 1516-3 PN/DP	1	Master PLC
DI 16x24VDC	2, 3, 4	16 bits digital input module
DQ 16x24VDC	5	8 bits digital input module

IV.3.2 Pump PLC

The Pump PLC is used for interfacing the motor and pump equipment, valve state, motor speed and temperature measurements.

The device configuration is presented figure IV-2.

Table IV-2 shows the device configuration.

The I/O addresses are included in appendix C.

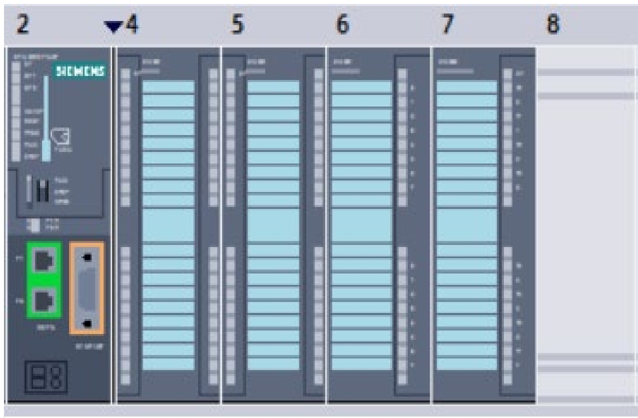

Figure IV-2 Pump CPU hardware configuration

Table IV-3 Pump CPU I/O modules

Module	Slot	Description
CPU 315-2 PN/DP	2	Pump PLC
AI 8xRTD	4 5	RTD modules enable temperatures to be measured with high precision using resistance temperature detectors
DI 16x24VDC	6	16 bits digital input module
DO 8x24VDC/0.5A	7	8 bits digital output module

IV.3.3 Field device “F51”

Field device “F51” interfaces the main discharge and suction valves, U/S WHP equipment (surge tank valves limit switches, air compressors) flowrate and pressure measuring instruments. The device configuration is presented figure IV-3.

Table IV-4 shows the device configuration.

The I/O addresses are included in appendix C.

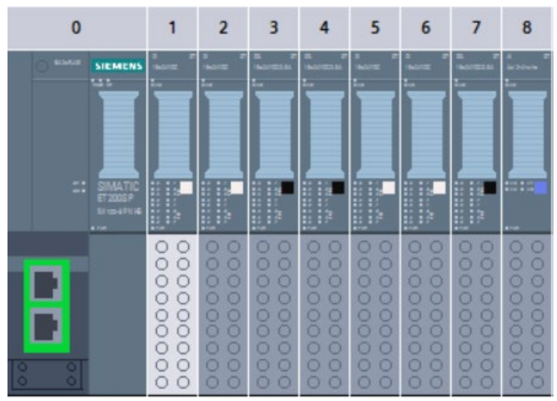

Figure IV-3 F51-DP hardware configuration

Table IV-4 Master CPU I/O modules

Module	Slot	Description
IM 155-6 PN HS	0	Interfacing module
DI 16x24VDC ST	1, 2, 5, 6	16 bits digital input module
DQ 16x24VDC ST	3, 4, 7	16 bits digital input module
AI 4xI 2-,4-wire ST	8	4 Channels Analog input module

IV.3.4 Field device "F61"

Field device "F61" interfaces the pressure control room equipment (pressure control valves position, shut-off valves), CR11 valve and D/S WHP equipment (surge tank valves limit switches, air compressors).

The device configuration is presented figure IV-4.

Table IV-5 shows the device configuration.

The I/O addresses are included in appendix D.

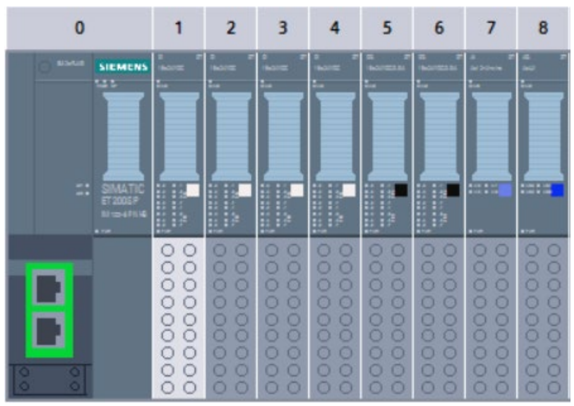

Figure IV-4 F61-DP hardware configuration

Table IV-5 Master CPU I/O modules

Module	Slot	Description
IM 155-6 PN HS	0	Interfacing module
DI 16x24VDC ST	1, 2, 3, 4	16 bits digital input module
DQ 16x24VDC ST	5, 6	16 bits digital input module
AI 4xI 2-,4-wire ST	7	4 Channels Analog input module
AQ 4xU/I ST	8	4 Channels Analog output module

IV.3.5 Summary of hardware configuration

Table IV-2 shows a summary of the entire hardware configuration,

Table IV-6 Hardware configuration

Name	Type	Function
Master	CPU 1516-3 PN/DP	Manages the control of the station including the communication between other devices, the security and alarm system, the operation modes, flow and pressure control.
Pump	CPU 315-2 PN/DP	Interfacing the motor and pumps equipment, valve state, motor speed, temperature measurements.
UPS	CPU 315-2 PN/DP	Controls the redundant power supply system.
Control Panel	TP 1200 Comfort	Human machine interface allows the operator to control and monitor the pumping station.
F51	IM 155-6 PN HS	Field device that interface the main discharge and suction valves, U/S WHP equipment (surge tank valves limit switches, air compressors ..) flowrate and pressure measuring instruments.
F61	IM 155-6 PN HS	Field device that interface the pressure control room equipment (pressure control valves position, cutoff valves…) CR11 valve and D/S WHP equipment (surge tank valves limit switches, air compressors ..).
GenSet	DIRIS A-40	Power monitoring relay.
XFMR	DIRIS A-40	Power monitoring relay.

IV.4 Network configuration

The configured industrial ethernet network is presented in figure IV-5. The IP addresses for each device are listed in table IV-7.

Table IV-7 IP addresses

Device	IP address
Master	192.168.1.1
Control Panel	192.168.1.2
F51	192.168.1.3
F61	192.168.1.4
PLC_Pump_1	192.168.1.10
PLC_Pump_2	192.168.1.11
PLC_Pump_3	192.168.1.12
PLC_Pump_4	192.168.1.13
PLC_Pump_5	192.168.1.14

IV.4.1 S7 Connections

An S7 Connection is a Siemens proprietary protocol for data exchange by means of the Industrial Ethernet network. It uses the S7 protocol for data transfer.

The parameters of active S7 connections are listed in table IV-8.

Table IV-8 Active S7 connection parameters

S7 Connection label	Type	End point	ID
S7 Connection 1	Local	Master	100
	Partner	PLC Pump 1	1
S7 Connection 2	Local	Master	101
	Partner	PLC Pump 2	1
S7 Connection 3	Local	Master	102
	Partner	PLC Pump 3	1
S7 Connection 4	Local	Master	103
	Partner	PLC Pump 4	1
S7 Connection 5	Local	Master	104
	Partner	PLC Pump 5	1

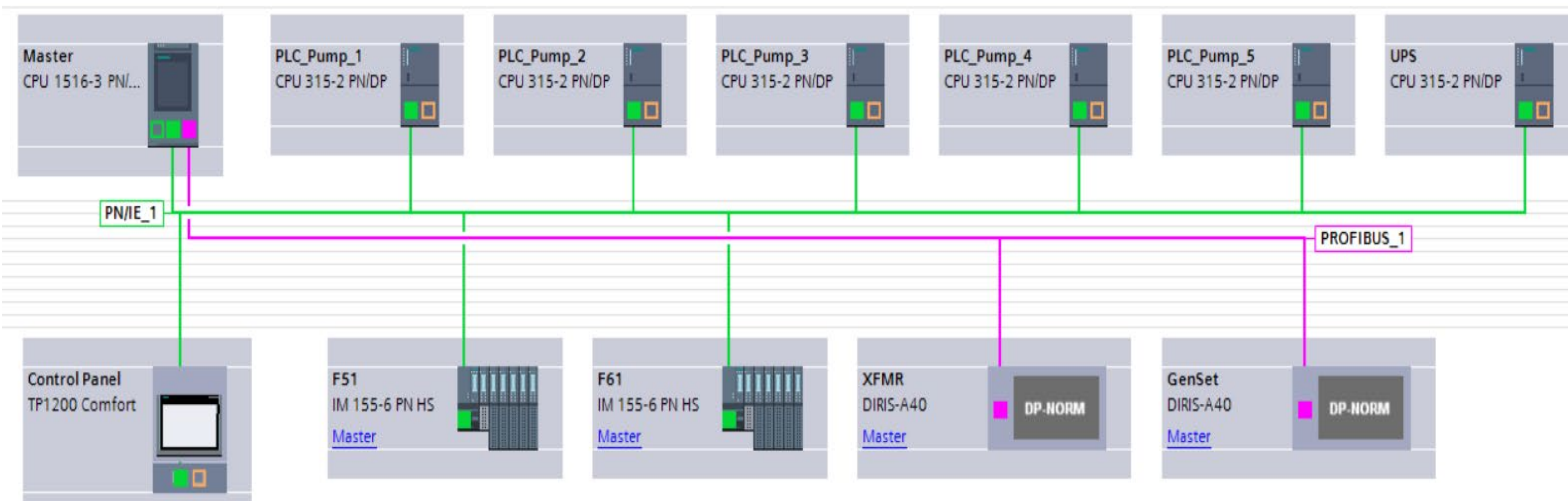

Figure IV-5 Network configuration

IV.5 CPU-CPU Communications

For simulation purposes, the CPU-CPU communication was established using the Client/Server principle. The Master CPU is configured as the client. The other CPUs are configured as Servers.

The following instructions are used :

- PUT for sending data.
- GET for receiving data.

It must be noted that the access from the remote partner via PUT/GET communication must be permitted in both S7 CPUs between which the S7 connection is configured. The "Optimized Block Access" function is also disabled for the data block containing the data to be read or written. The data is send and received in a consistent state, the reading and writing is done through the whole length of the variable, which means the transfer areas can be accessed without corrupting the current data.

IV.5.1 Client S7 CPU User Program

The user program consists of blocks that are listed and described in table IV-9.

Table IV-9 Client S7 CPU user program blocks

Block	Symbolic name	Description
OB1	Main	Calls the “Put_Get_Seq” including its instance data block cyclically
FB5	Put_Get_Seq	The instructions PUT and GET are called to transfer data via the configured S7 connection.
DB3	Put_Get_Seq_DB	Instance data block of FB1 Put_Get_Seq.
DB2	Master_Pump	The sent data is stored in the DB2 data block.
DB1	Slaves_Data	The received data is stored in the DB1 data block.

IV.5.1.1 Operational block “OB1”

The Put_Get_Seq “FB5” is called in OB1 with the instance data block DB3.

The init_com bit is first enabled in the Startup Operational block (OB100) which will reset all the communication requests, then the bit is reset after the FB5 is called.

The seq_trig bit triggers the data communication sequence every 200 ms.

IV.5.1.2 Function Block "FB5"

Since only one job at a time can be triggered by the "GET" and "PUT instructions over a configured S7 connection, a sequencer is used to call those instructions one after the other.

The PUT job is triggered by the seq_trig bit and will write six bytes for each pump CPU, and one byte for UPS CPU.

The GET job is triggered only when the PUT job is completed and will read a total of 64 bytes for each pump CPU, and one byte for UPS CPU.

Parts of the code are presented in figure IV-6.

IV.5.1.3 Data Block "DB2"

This data block holds the data to be transmitted to the pumps. It contains five variables of the "Pump_Cmd" PLC data type. The DB2 variables are presented in table IV-10.

Table IV-10 DB2 Data

Name	Type
Pump_1	Pump_Cmd
Pump_2	Pump_Cmd
Pump_3	Pump_Cmd
Pump_4	Pump_Cmd
Pump_5	Pump_Cmd

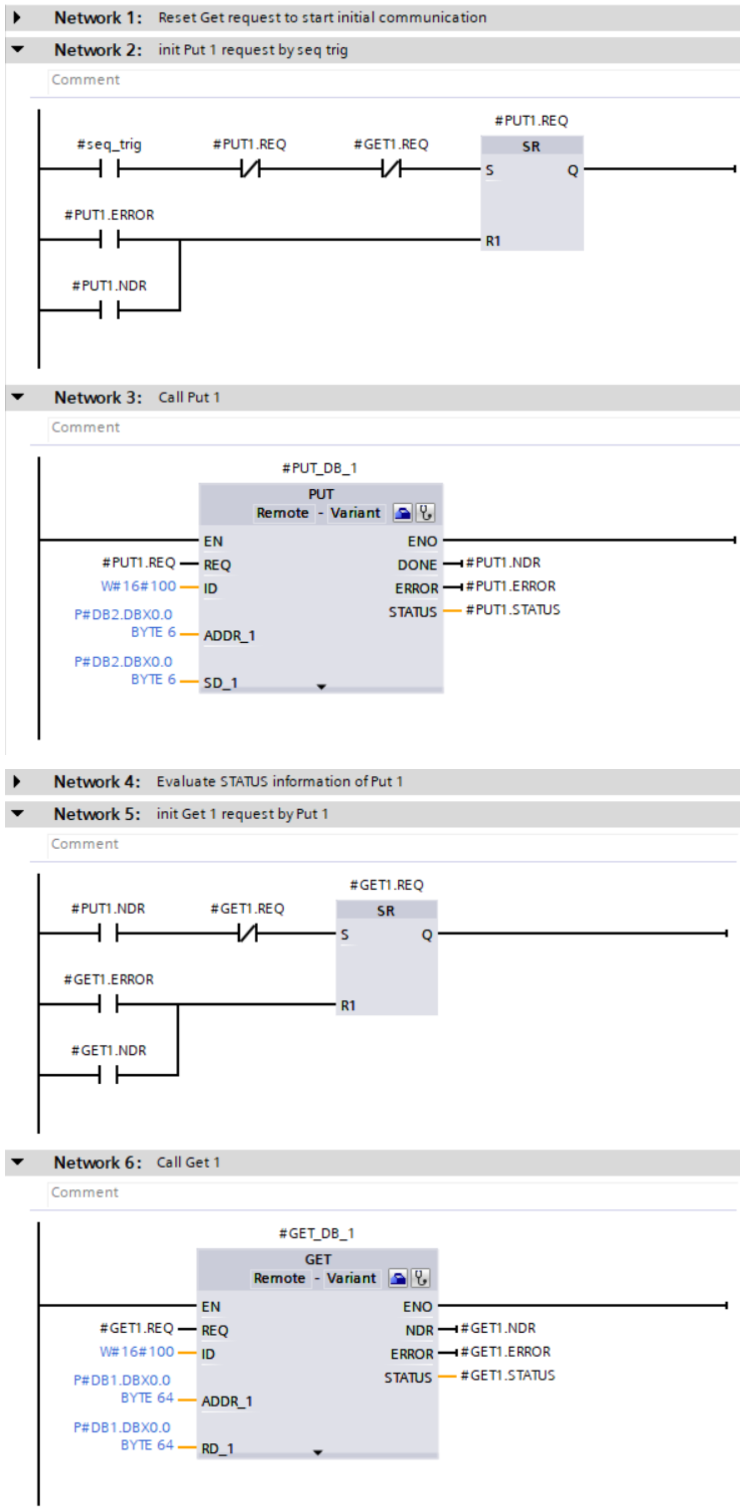

Figure IV-6 Put-Get Functions

The “Pump_Cmd” PLC data type structure is presented in table IV-11.

Table IV-11 Pump_Cmd Data type

Name	Type
Start	Bool
Stop	Bool
ACK_Master	Bool
RST_Master	Bool
Asp_Valve_Opn	Bool
Asp_Valve_Cls	Bool
Spr_Valve_Opn	Bool
Speed_SP	Real

IV.5.1.4 Data Block “DB1”

This data block holds the data to be received from the partner CPU. It contains five variables of the "Pump" PLC data type for the pumps data, and a DWord variable for the UPS notifications.

The DB1 variables are presented in table IV-12.

Table IV-12 DB1 Data

Name	Type
pump_1	Pump
pump_2	Pump
pump_3	Pump
pump_4	Pump
pump_5	Pump
UPS_Notif	DWord

The “Pump” PLC data type structure is presented in table IV-13.

Table IV-13 Pump PLC data type

Name	Type
Pump_number	Int
Pump_state	Byte
suction_valve_state	Byte
discharge_valve_state	Byte
Hour_Meter	DInt
number_of_starts	Real
duration_motor_on	Real
duration_motor_off	Real
motor_current	Real
pump_speed	Real
motor_winding_temp_1	Real
motor_winding_temp_2	Real
motor_winding_temp_3	Real
motor_bearing_temp_1	Real
motor_bearing_temp_2	Real
pump_bearing_temp_1	Real
pump_bearing_temp_2	Real
Alarms	DWord
Msg	Byte

IV.5.2 Server S7 CPU User Program

No instructions for data transfer are called in the user program of the server S7 CPU. Only data blocks in which the sent and received data is stored.

IV.5.2.1 Pumps

DB1 "Pump_Master" contains the data to be transferred to the partner CPU. The data is identical to that presented in table IV-13.

DB2 "Master_Pump" contains the data that is received from the partner CPU. The data is identical to that presented in table IV-11.

IV.5.2.2 UPS

DB1 "UPS_Master" contains the data to be transferred to the partner CPU.

DB2 "Master_UPS" contains the data that is received from the partner CPU.

IV.6 Alarm management

Alarms were configured using the dual bit alarm management which is described as follows:

- First bit triggers a notification in the control panel. It can be reset by the operator using the reset button. The notification will remain visible as long as the corresponding triggering condition is true.
- Second bit triggers the horn for once, in order to alarm the operator. It can be silenced using either the reset or acknowledge button.
- The notification and alarm bits are delayed to avoid unnecessary alarms when a signal temporarily overshoots its limit.

This configuration allows to inform and notify the operator about the current state of the station.

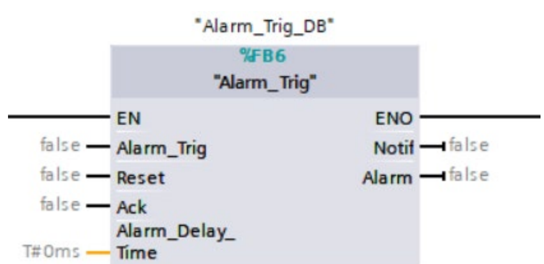

Figure IV-7 Alarm_Trig Function block

IV.7 Pumps

The user program consists of blocks that are listed and described in table IV-14.

Table IV-14 Pump CPU user program blocks

Block	Symbolic name	Description
OB1	Main	Calls the Measurements and Alarms functions, as well as the Oprt function block
FC1	Alarms	Calls the Alarm_trig function block for each pump alarm
FC2	T_measurement	Converts the analog input value to temperature value
FC3	Measurement	Calls the T_ measurement for each temperature reading
FC4	Time_To_Real	Converts the Time variable into a Real variable
FC5	Time_To_Dint	Converts the Time variable into a Double Integer variable
FB1	Alarm_trig	Handles the dual bit alarm
FB2	Valve_Cmd	Interfaces the valve I/O
FB3	Oprt	Manages the pump sequences, calls the chronometer and Valve_Cmd function blocks
FB4	Chronometer	Hour meter

IV.7.1 Hour meter

Based on the pump state, each chronometer is executed to count the total, on or off durations. The hour meter flowchart is presented in figure IV-8

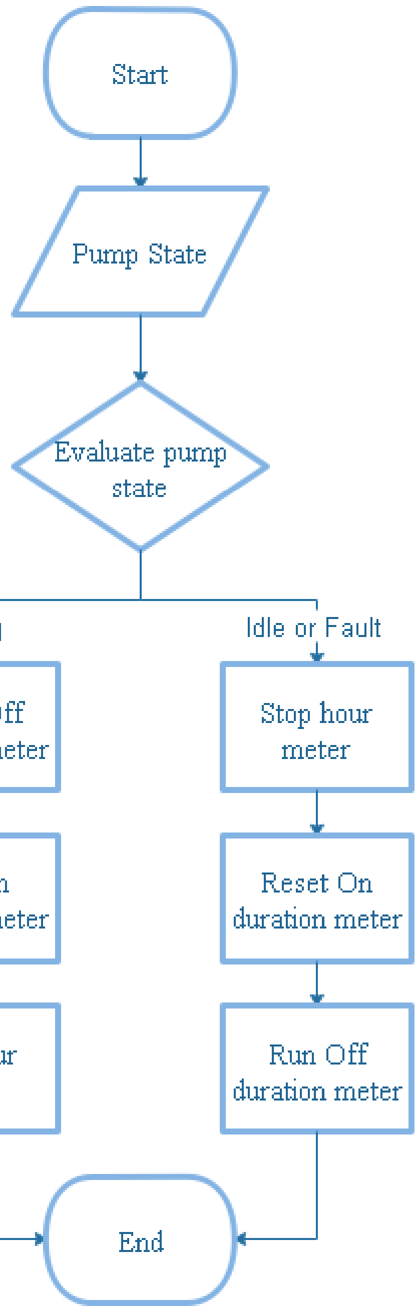

Figure IV-8 Hour meter flowchart

IV.7.2 Valve

This function allows to control the opening/closing of the valve, interface it's I/O , more over update the valve's state. The valve sequence flowchart is presented in figure IV-9.

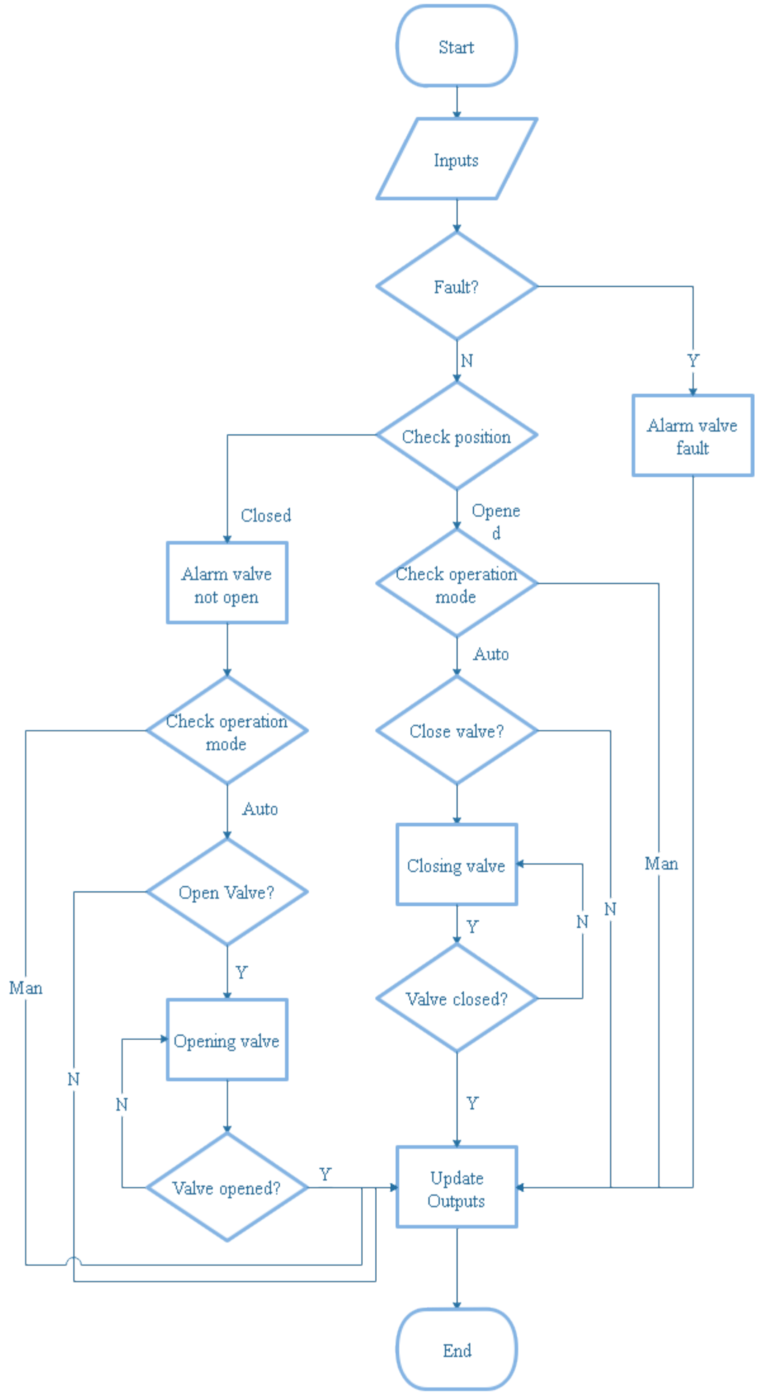

Figure IV-9 Valve sequence flowchart

IV.7.3 Pump

This function manages the pump alarms, sequence, and controls the triggering conditions for turning the pump on/off. The pump sequence flowchart is presented in figure IV-10.

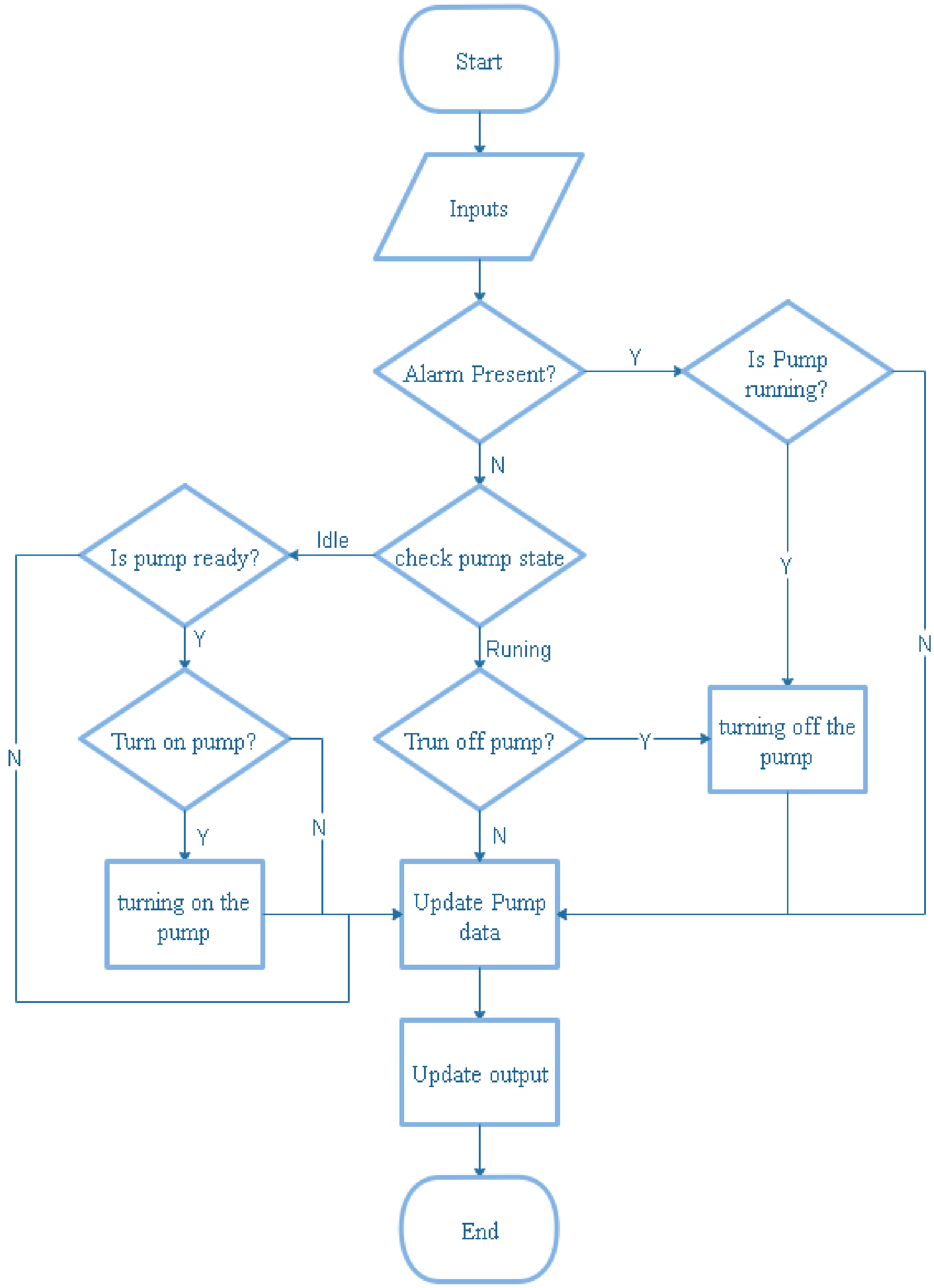

Figure IV-10 Pump sequence flowchart

IV.8 Pumps Sequence

The pumps sequence user program consists of blocks that are listed and described in table IV-15.

Table IV-15 Pump sequence user program block

Block	Symbolic name	Description
OB1	Main	Calls the Pumps_Seq function block including its instance data block
FB21	Pumps_Seq	Calls the Temp_Block and Hour_Meter_Ctrl function blocks, and Pump_trig function
FB20	Hour_Meter_Ctrl	Calls the Hourmeter_MinMax function and preforms necessary operations to turn pumps on/off based on hour meter
FB19	Temp_Block	Manages the temporary block security function
FC6	Hourmeter_MinMax	Read the pumps on/off duration and pumps state, return the pump with the maximum value (selected pump)
FC10	Pump_trig	Verify the temporary block conditions before turning on/off the pump
DB19	Pumps_Seq_DB	Instance data of FB21

IV.8.1 Hour meter control

This function ensures the selection of pump based on both the on and off durations. It calls the Hourmeter_MinMax function. The hour meter control flowchart is presented in figure IV-11.

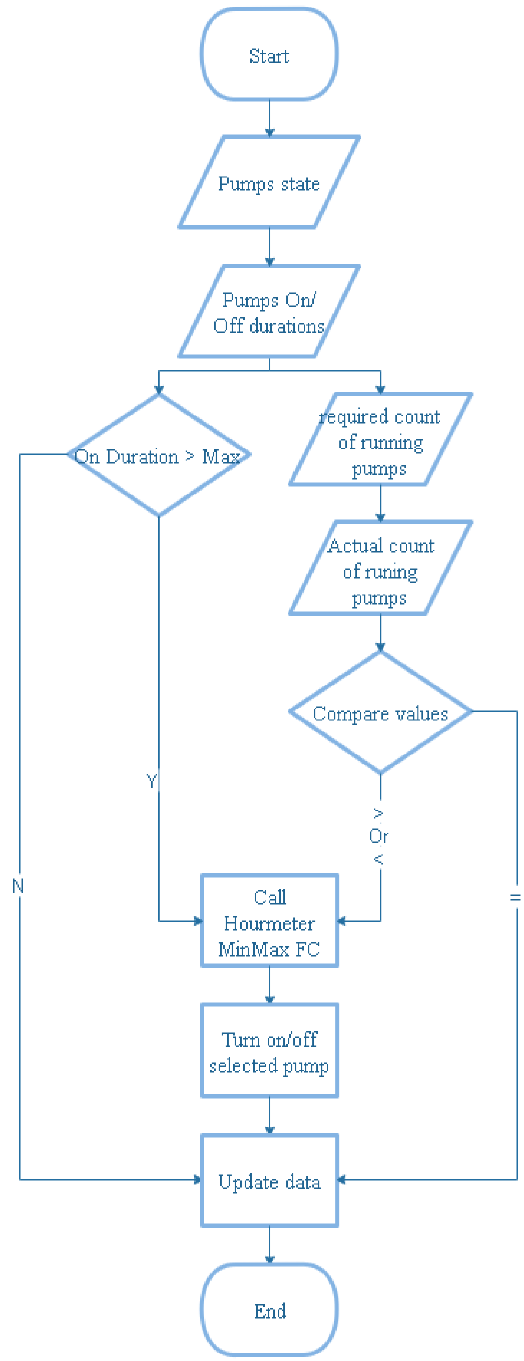

Figure IV-11 Hour meter control flowchart

IV.8.2 Hour meter Min Max function

This function reads the pumps on/off duration, verifies its state whether it is ready or not. Then, it returns the pump number with the maximum duration. The "Hour meter Min Max" flowchart is presented in figure IV-12.

IV.8.3 Temporary block

This functions triggers the temporary block security condition to prevent the successive start/stop of pumps. The "Temporary block" flowchart is presented in figure IV-13.

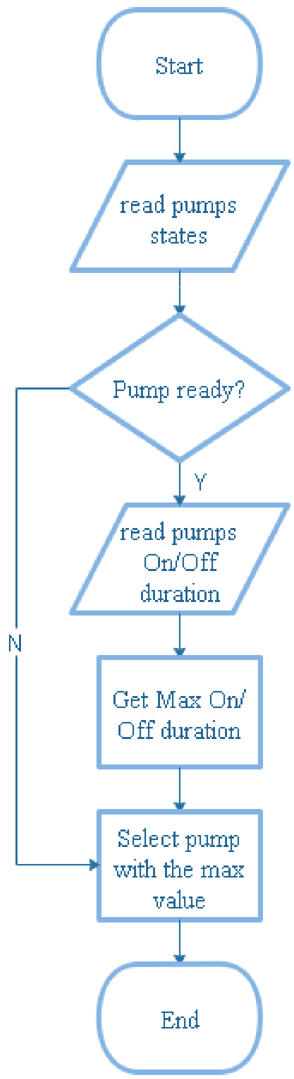

Figure IV-12 Hour meter Min Max flowchart

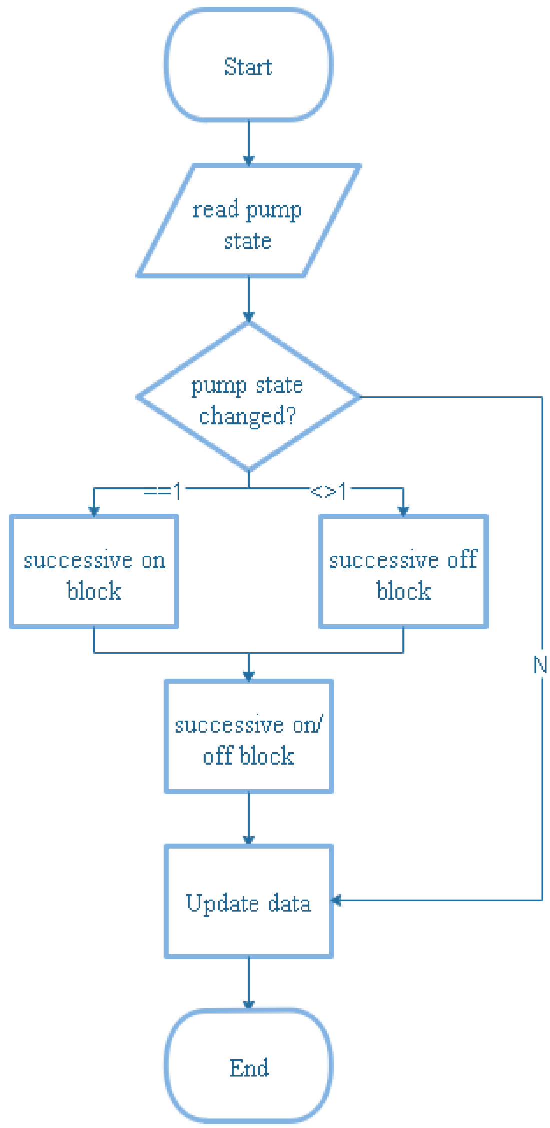

Figure IV-13 Temp block flowchart

IV.8.4 Pumps triggering "Pumps trig"

This function is called for each pump. It is used to manage the automatic and manual operations of the pumps as well as to verify the temporary block and emergency stop conditions.

The "Pump trig" flowchart is presented in figure IV-14.

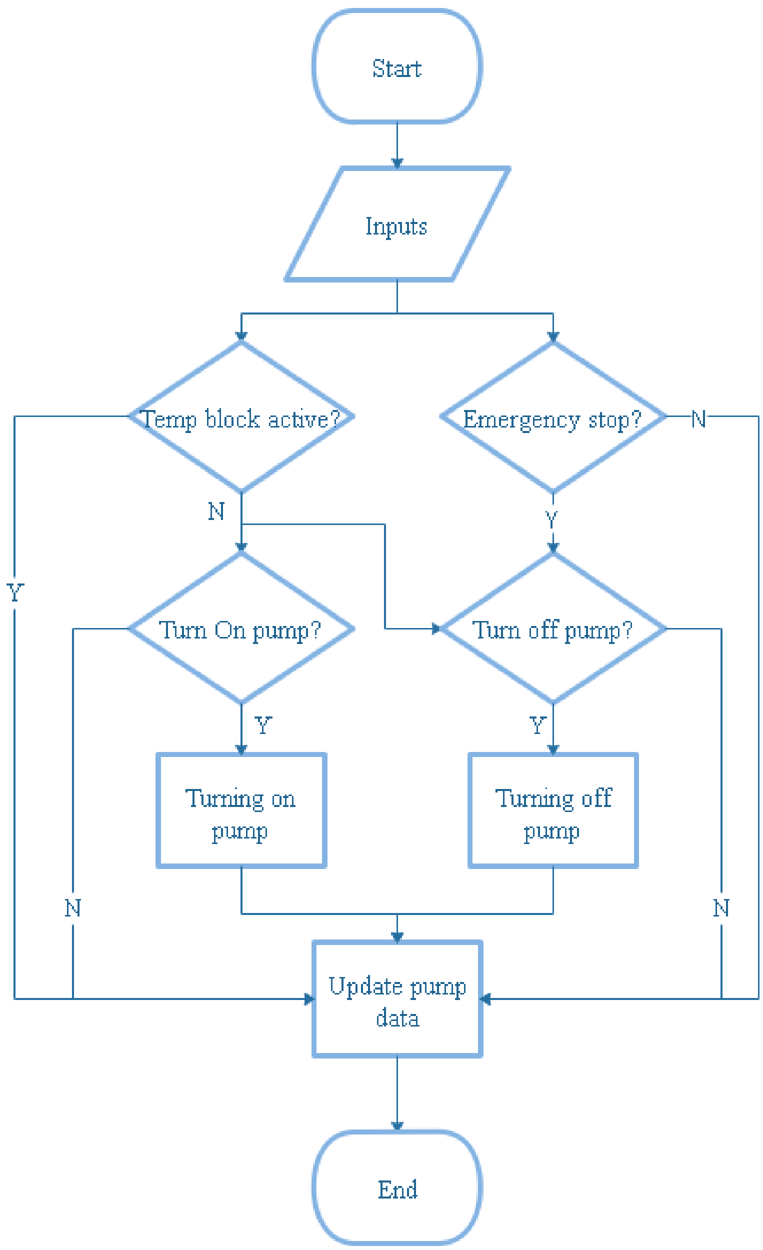

Figure IV-14 Pump trig flowchart

IV.9 Water Hammer protection

The user program for water hammer protection consists of blocks shown and described in table IV-16.

Table IV-16 Water Hammer protection user program blocks

Block	Symbolic name	Description
OB1	Main	Calls the WHP_DS_Seq, WHP_US_Seq and WHP_SC function blocks including their instances data blocks cyclically
FB1	Air_Comp	Handles the Air compressor I/O and alarms
FB3	WHP_DS_P	Controls the air compressors priorities
FB7	WHP_DS_Seq	Calls Air_Comp, WHP_DS_P function blocks, moreover manages the operation mode, program sequence and alarm system
FB8	WHP_SC	Manages the security conditions as a function of flowrate
FB16	WHP_US_P	Controls the air compressors priorities
FB15	WHP_US_Seq	Calls Air_Comp, WHP_US_P function blocks, moreover manages the operation mode, program sequence and alarm system
DB6	WHP_DS_Data	Holds the WHP DS data
DB5	WHP_US_Data	Holds the WHP US data
DB4	WHP_DS_Seq_DB	Instance data block FB7
DB16	WHP_US_Seq_DB	Instance data block of FB16

IV.9.1 Air compressor

This function is called to control each air compressor installed on the field, and verify the required conditions for turning it on/off. The air compressor sequence flowchart is presented in figure IV-15.

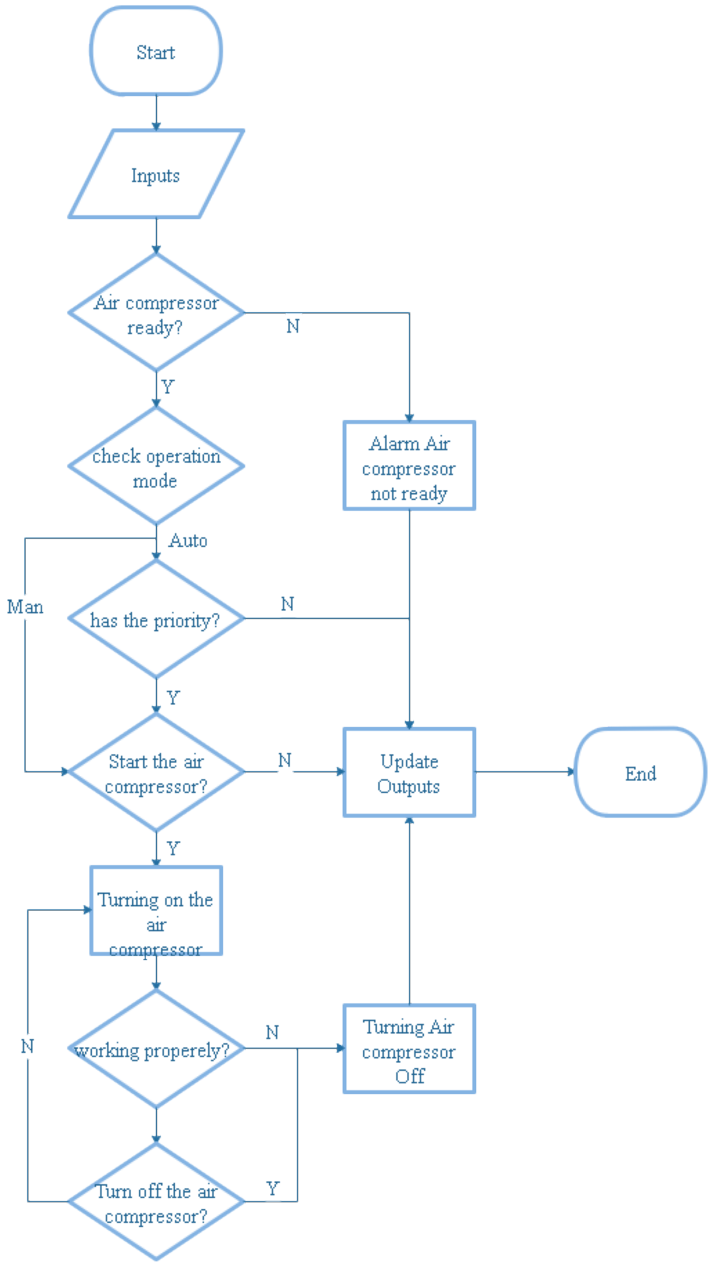

Figure IV-15 Air compressor sequence flowchart

IV.9.2 Priority

In automatic operation mode, a priority is attributed to each air compressor that ensures the inversion at each start-up. In case of failure (circuit breaker tripping or no running feedback) of any air compressor, the available ones are attributed with a higher priority. The Priority control flowchart is presented in figure IV-16.

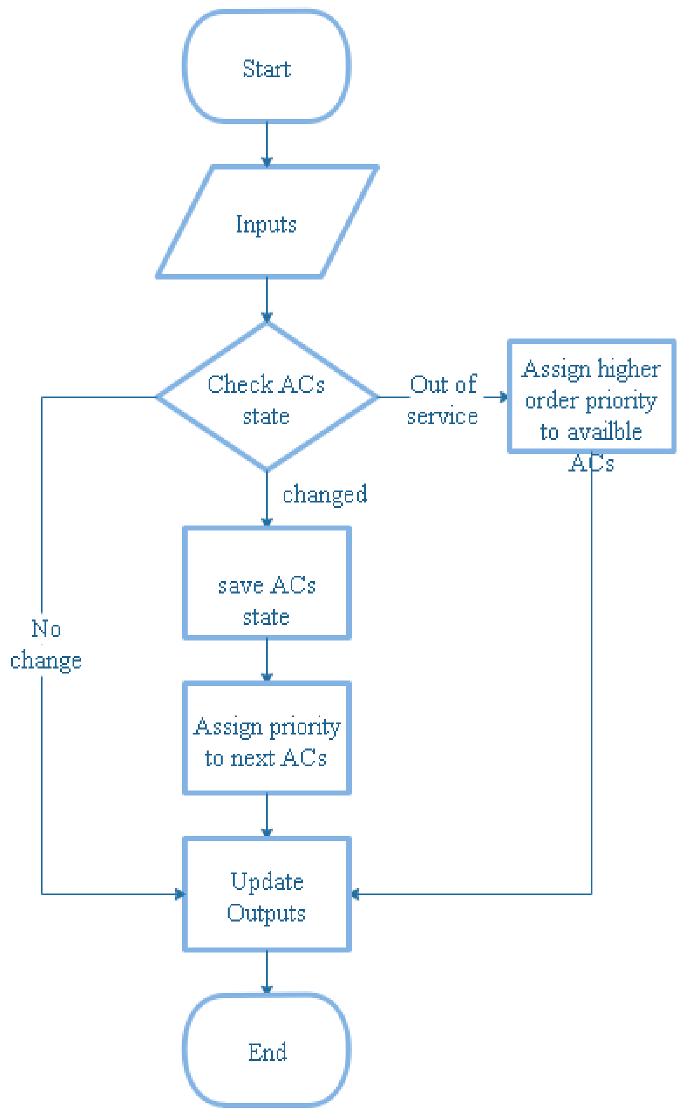

Figure IV-16 Priority control flowchart

IV.9.3 Downstream Water Hammer Protection "D/S WHP" sequence

This sequence calls both the "Air compressor sequence" and "Priority control" functions, and interfaces the surge tank valves as well as the limit switches. It also manages the operation mode. The "D/S WHP" sequence flowchart is presented in figure IV-13.

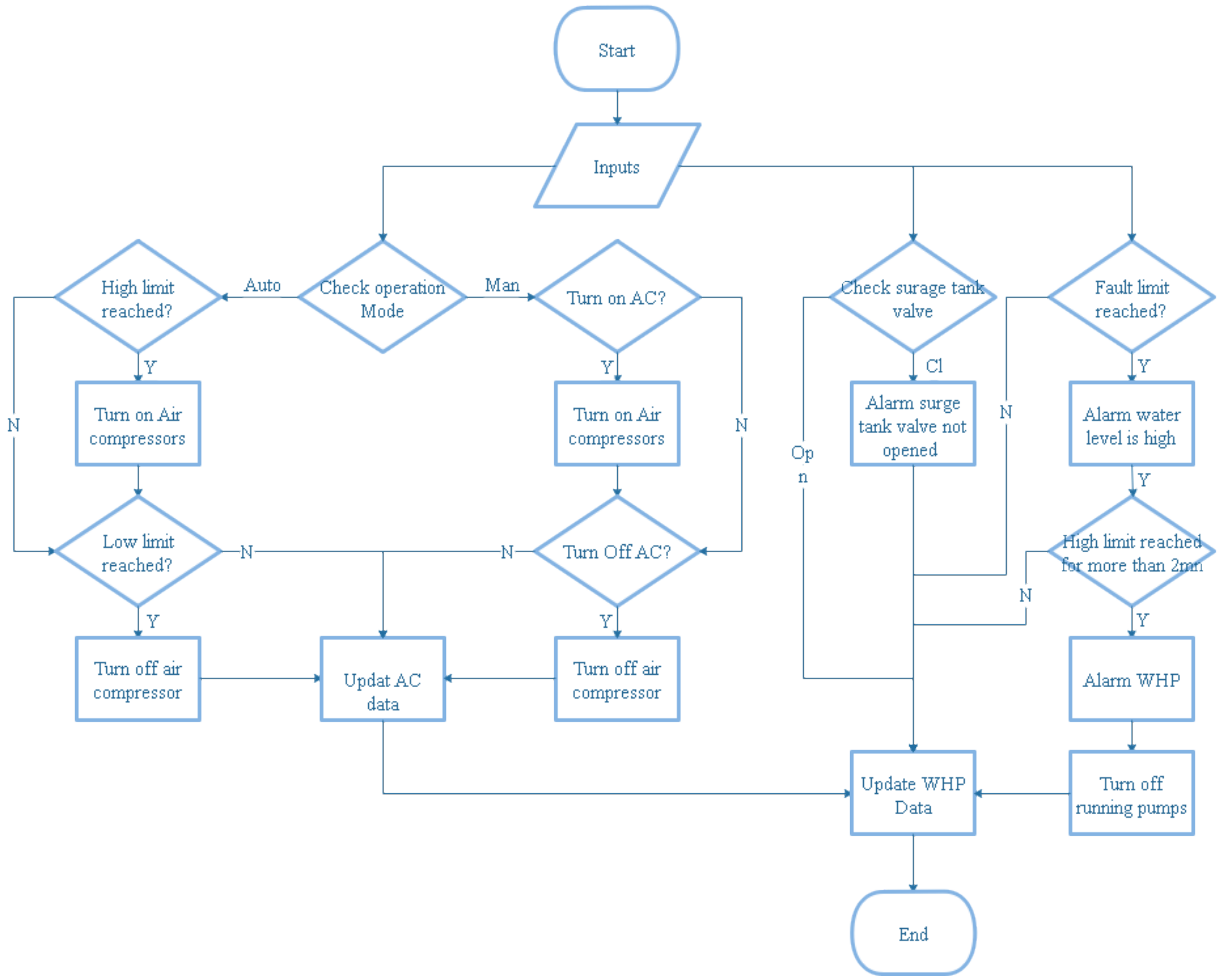

Figure IV-17 D/S WHP sequence flowchart

IV.9.4 Upstream Water Hammer Protection "U/S WHP" sequence

The "U/S WHP" sequence has the same functionalities as the "D/S WHP" sequence previously described. In addition, it manages the surge tank water level measurement mode.

The "U/S WHP" sequence flowchart is presented in both figures IV-18 and IV-19.

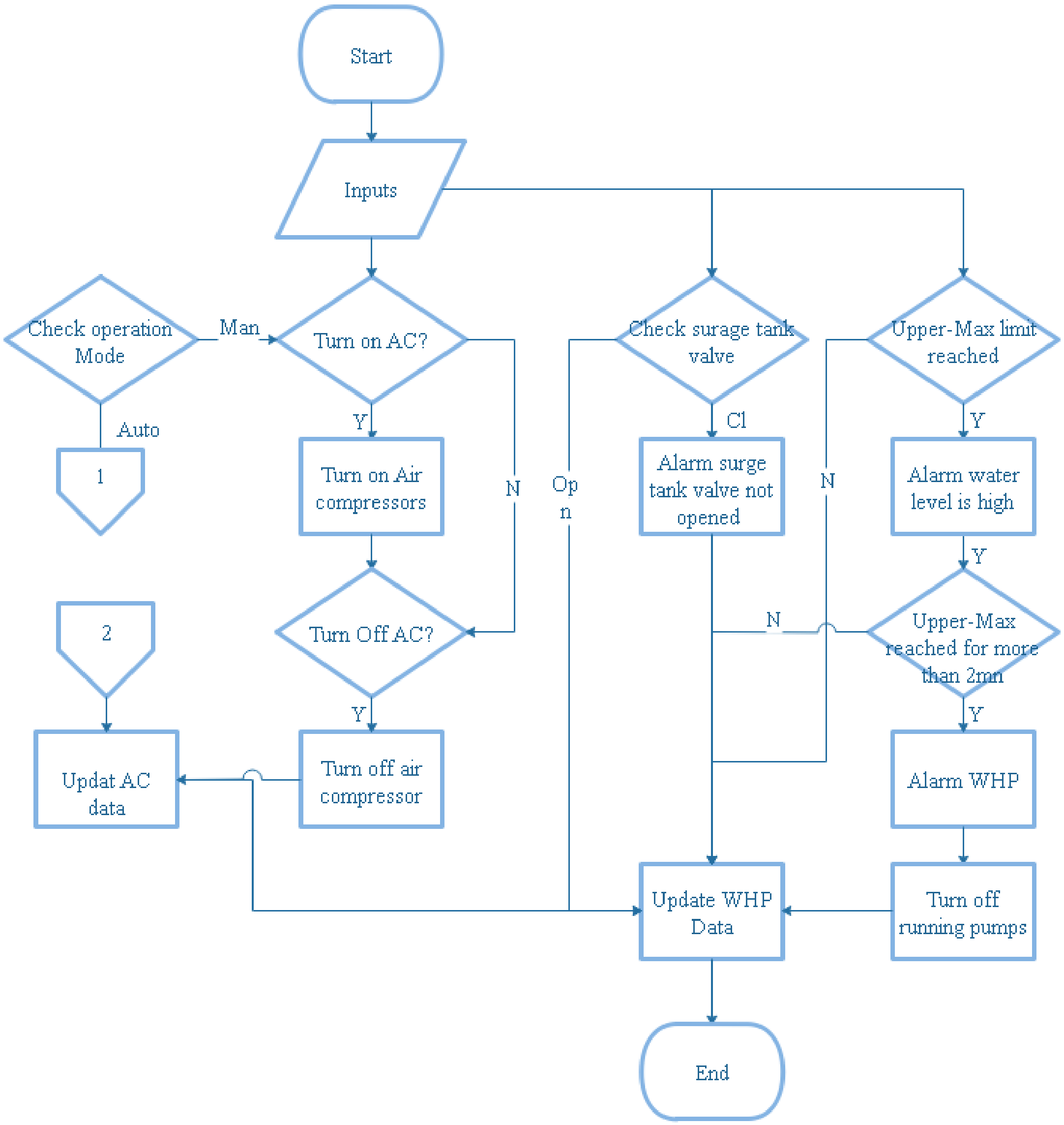

Figure IV-18 U/S WHP sequence flowchart - 1

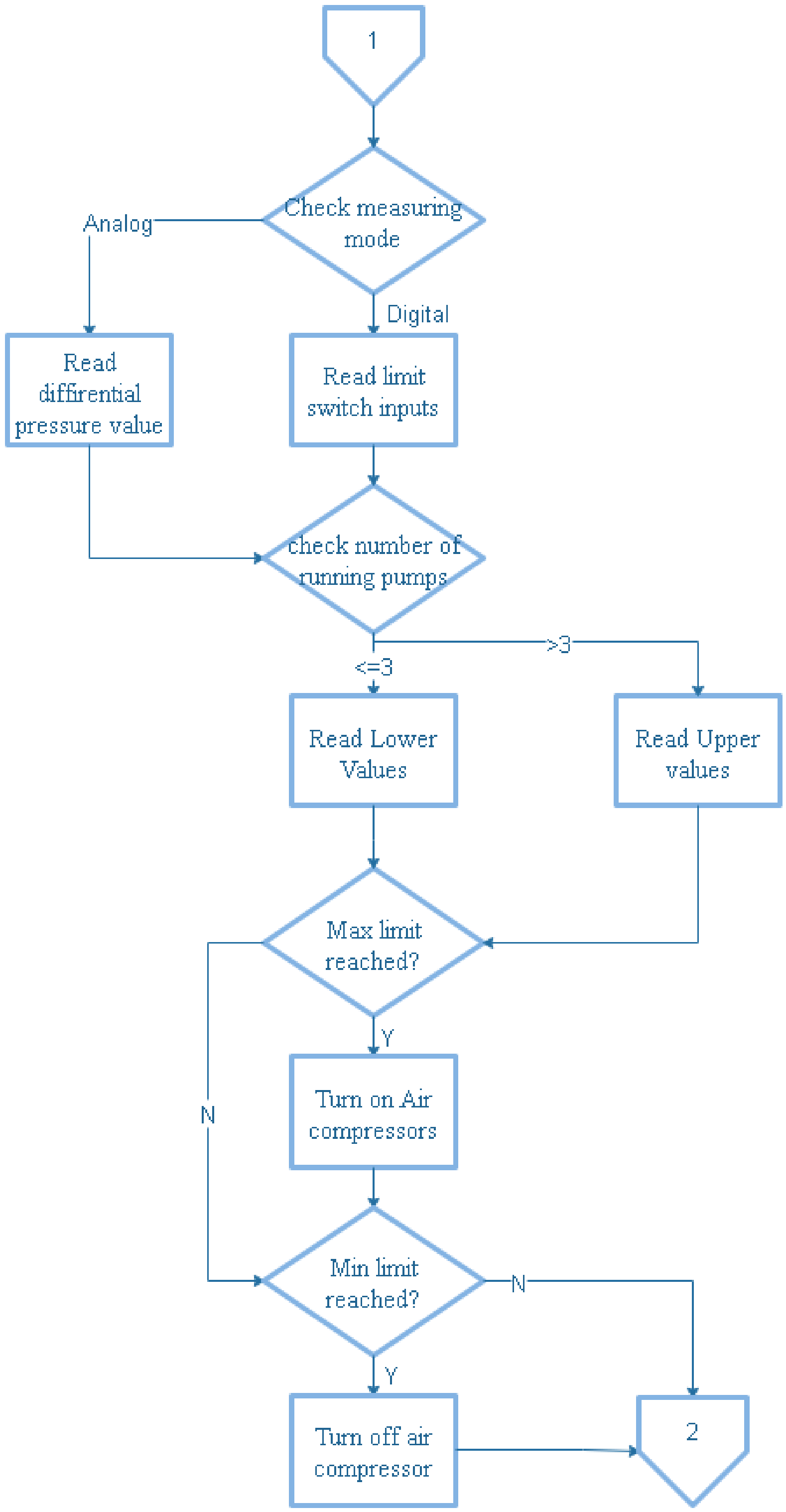

Figure IV-19 U/S WHP sequence flowchart - 2

IV.9.5 Water Hammer protection security

This function allows to ensure the safety requirements of opened surge tank valves as function of flowrate. If those requirements are not satisfied the SC bit is triggered and will turn off the running pumps.

The WHP security sequence flowchart is presented in figure IV-20.

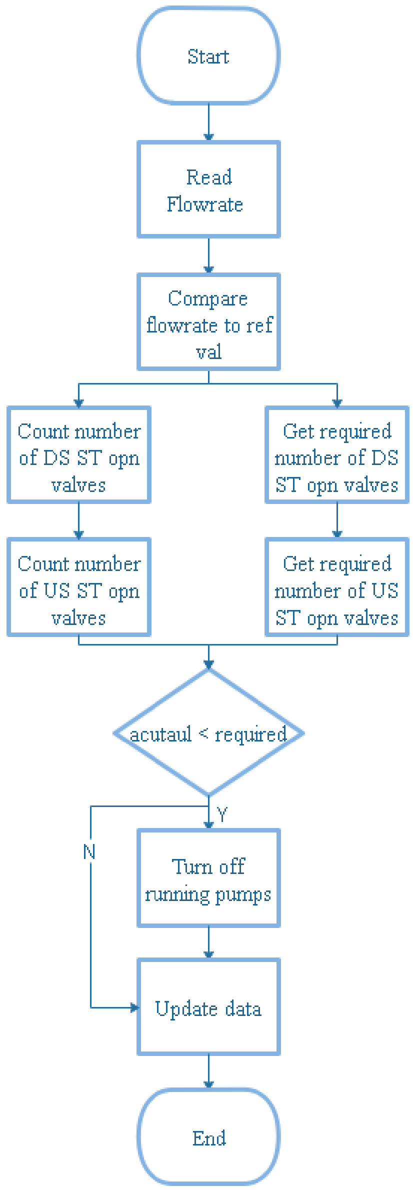

Figure IV-20 WHP security sequence flowchart

IV.10 Backup Power Supply

The user program of Backup Power Supply consists of the blocks listed and described in table IV-17.

Table IV-17 Backup power supply user program blocks

Block	Symbolic name	Description
OB1	Main	Calls the Elec_Seq function block including its instance data block
FB12	Elec_Seq	Manages the sequence of Backup power supply operation mode and conditions for switching between supply sources and controlling the circuit breakers, Calls CB function
FC5	CB	Manages the Circuit breakers inputs/outputs

IV.10.1 Operation mode

This function manages the operation mode based on the operator selection, The Backup power supply operation mode flowchart is presented in figure IV-21.

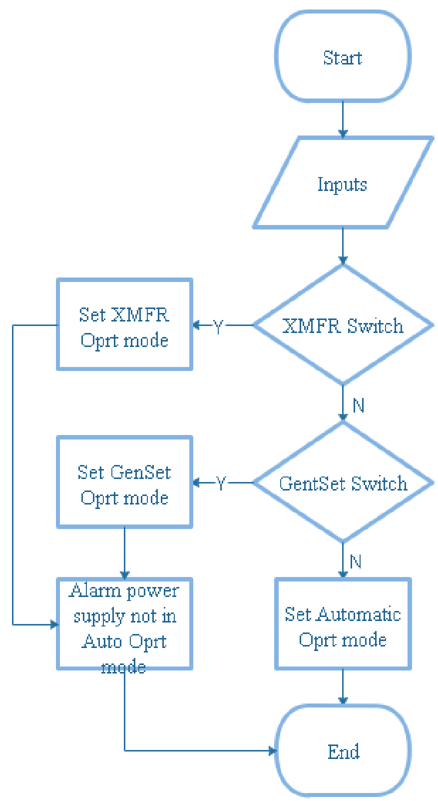

Figure IV-21 Backup power supply operation mode flowchart

IV.10.2 Transformer circuit breaker

The sequence for controlling the transformer circuit breaker is shown in figure IV-22.

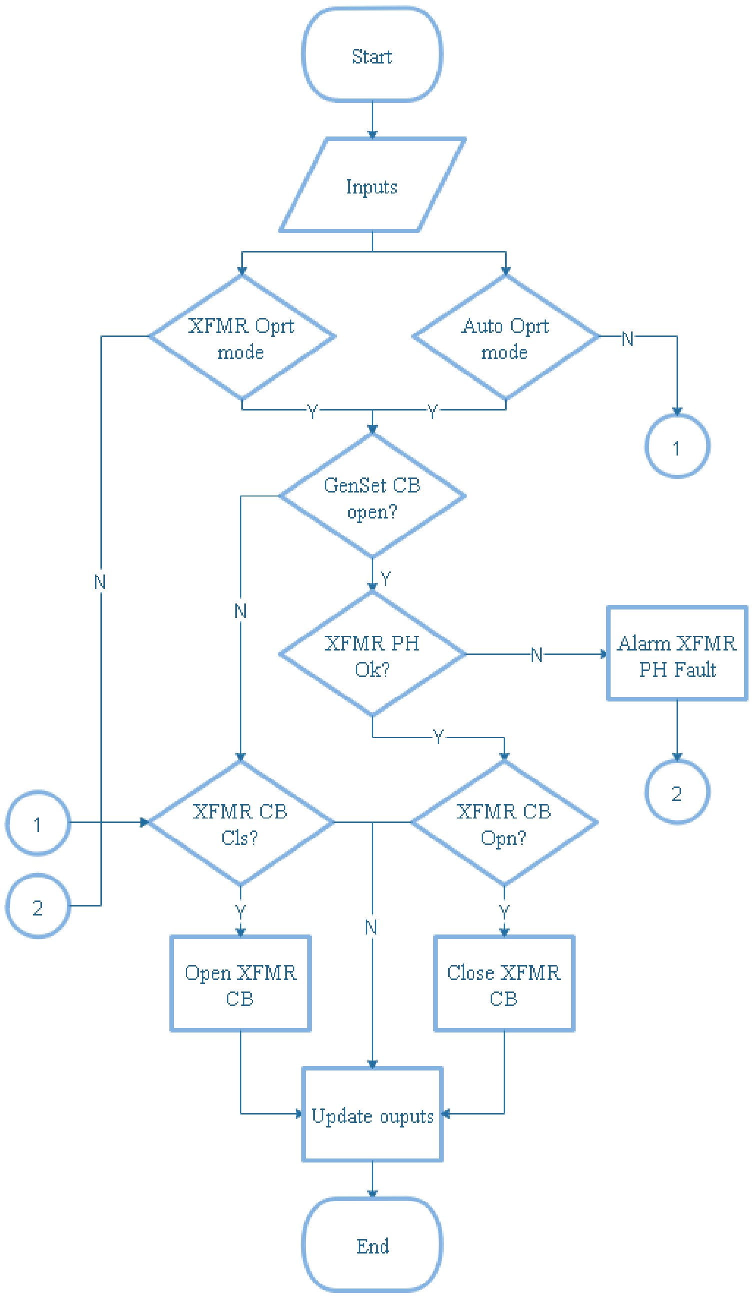

Figure IV-22 Transformer circuit breaker sequence flowchart

IV.10.3 Genset circuit breaker

The conditions for latching/unlatching the genset circuit breaker are presented in figure IV-23.

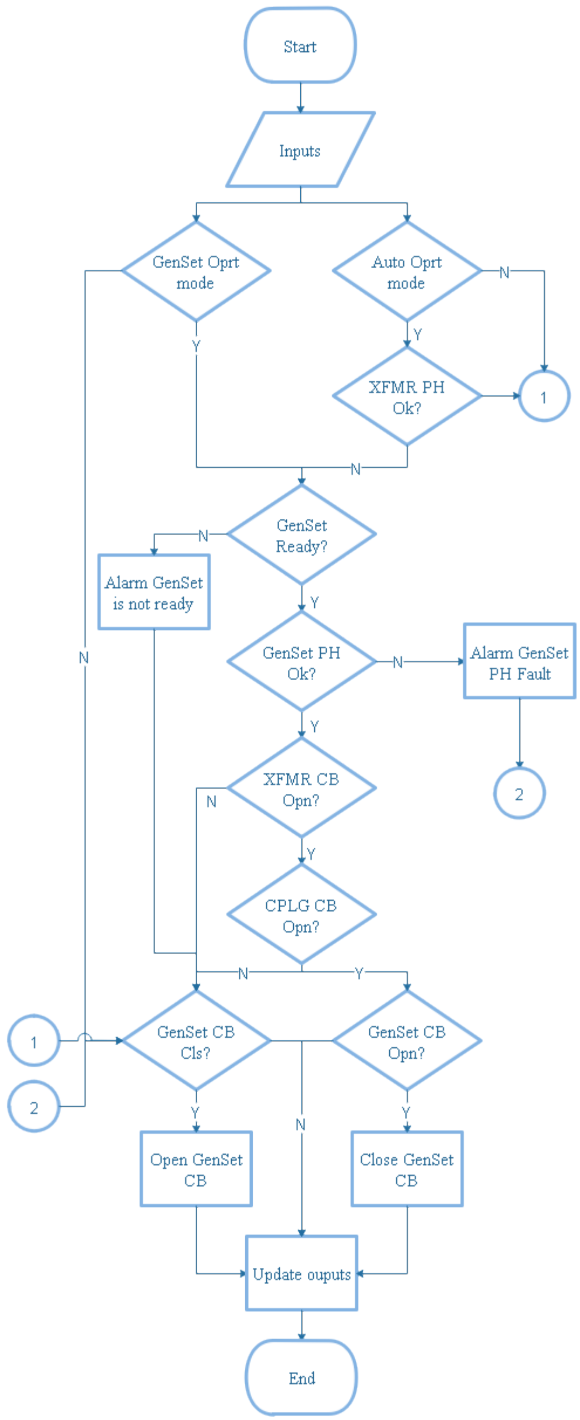

Figure IV-23 Genset circuit breaker flowchart

IV.10.4 Coupling circuit breaker

The sequence for controlling the coupling circuit breaker is shown in figure IV-24.

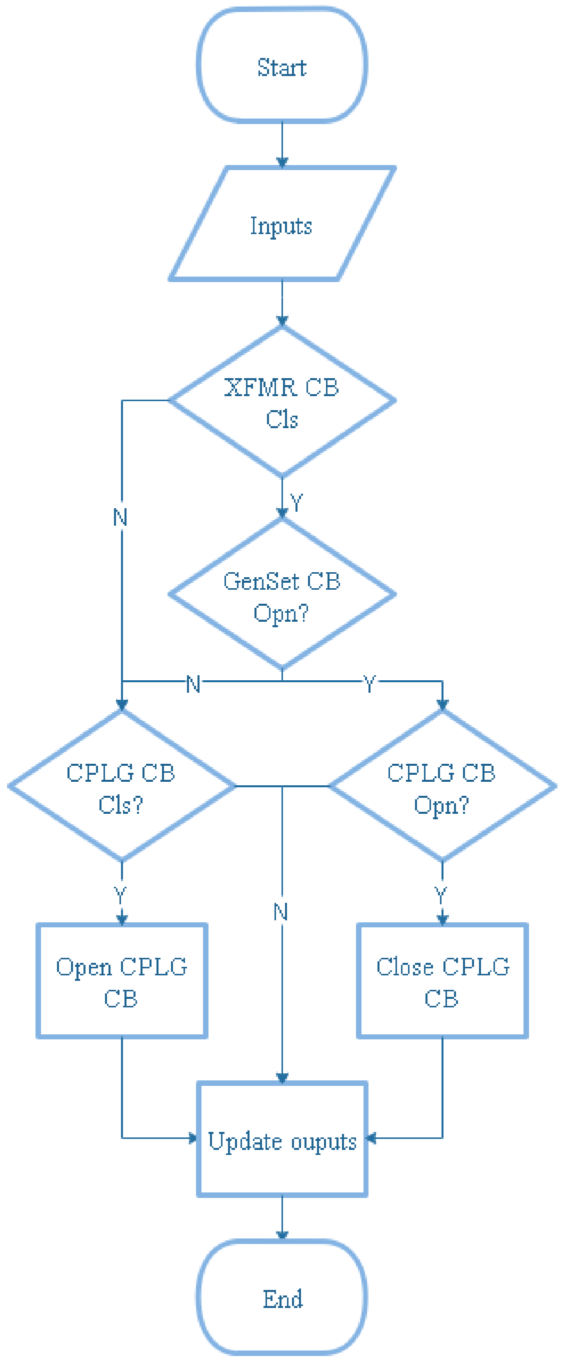

Figure IV-24 Coupling circuit breaker flowchart

IV.10.5 Generator set

Figure IV-25 shows the flowchart which describes the sequence for controlling the generator set.

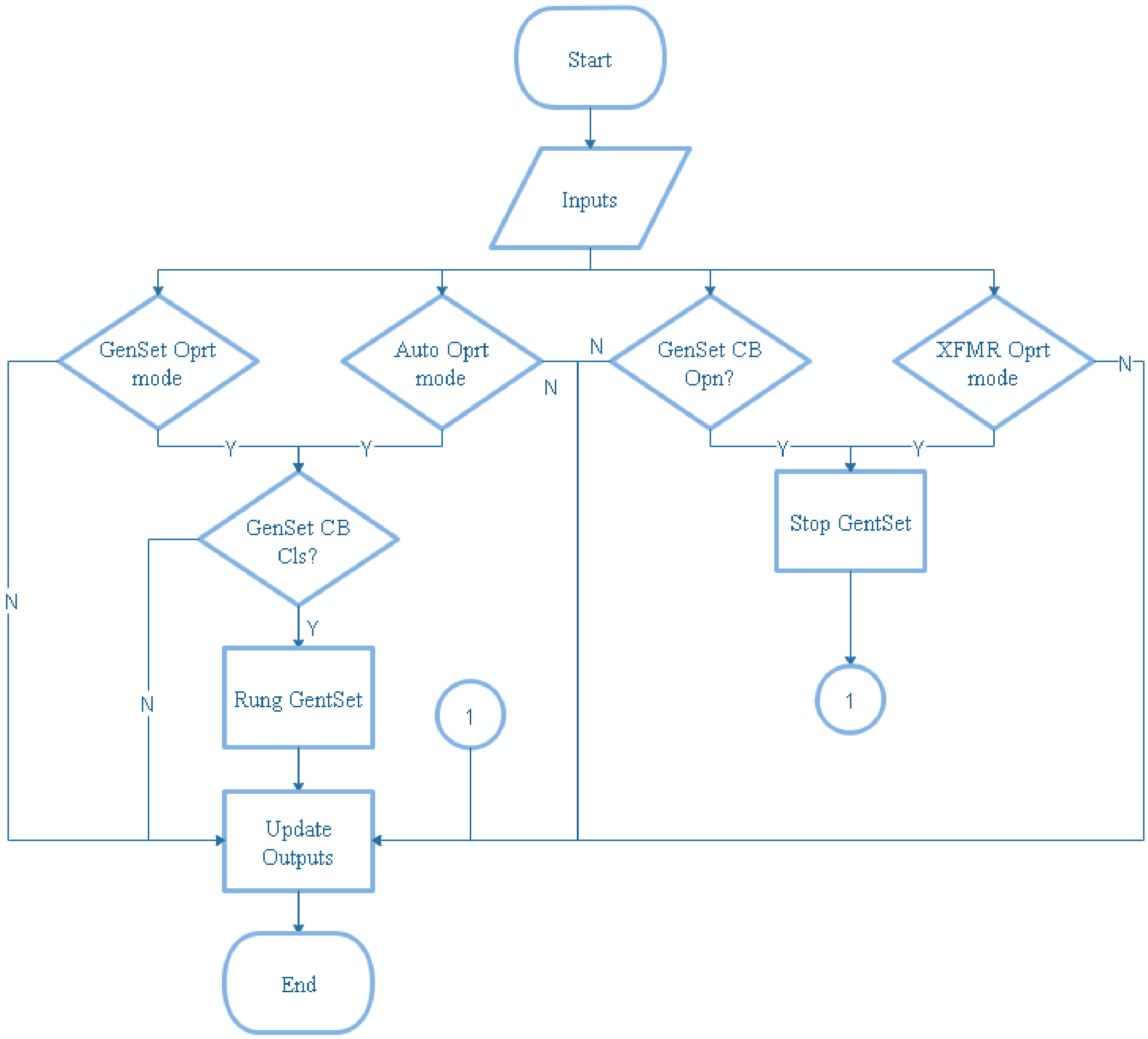

Figure IV-25 Generator set sequence flowchart

IV.11 Control functions :

A mock simulation is used to provide a general idea about the pumping station system.

IV.11.1 Flowrate Control:

Table IV-18 shows a description of the blocks that constitute the flowrate control user program.

Table IV-18 Flowrate control user program blocks

Block	Symbolic name	Description
OB30	Cyclic Interrupt	Calls the PID controller as well as the PT1 function blocks including their instance data blocks.
FB50	PT1_Sim	Simulation of a PT1-System [First Order system]
PID_Compact	PID_Compact	PID Controller

Flowrate variation as a function of pump speed is described by a first order system. The PID controller is used to regulate the pump speed. The implemented control loop represents the outer loop described previously in section III.3.

IV.11.2 Pressure control:

Table IV-19 shows a description of the blocks that constitute the pressure control user program.

Table IV-19 Pressure control user program blocks

Block	Symbolic name	Description
OB30	Cyclic Interrupt	Calls the PID_3Step, PT1_Sim and LSim_Valve function blocks including their instance data blocks.
FB50	PT1_Sim	Simulation of a PT1-System [First Order system]
FB63	LSim_Valve	Simulation of a valve with adjustable transition time
PID_3Step	PID_3Step	PID Controller

The valve position will affect the pressure on the pipes which can be simulated by both of PT1_Sim and LSim_Valve function blocks. The PID_3Step is used to control the valve position.

IV.12 Control panel

IV.12.1 Introduction

A Human-Machine Interface (HMI), sometimes referred to as Operator Interface Terminal (OIT) or Local Operator Interface (LOI), allows the operator to:

- Visually display plant data,
- Track production time, trends, and tags.
- Monitor machine inputs and outputs.

In industrial processes, the requirements for a uniform operator control and monitoring concept are high in order to guarantee short familiarization times and reduce down times during both failures and maintenance works

Using pre-programmed objects, such as Faceplates, reduces both engineering time and cost. They consist of a set of displays and operator objects which can be managed and modified centrally in a library. Thus, they enable to call and use them easily for different objects.

IV.12.2 Screen Managements

IV.12.2.1 Template

A template is a group of visible objects which can be used in different screens. In our case, only one template is configured and used for screen navigation.

Each button, when pressed, will navigate to another screen. The arrangement of buttons is shown in figure IV-26.

Figure IV-26 View of Screen Navigation

IV.12.2.2 Permanent area

In permanent area, objects which are visible in all screens, are configured. For this project, it is used to display screen name, local time and date, as well as project name. A view of the permanent area is shown in figure IV-27.

Figure IV-27 View of the permanent area

IV.12.2.3 Slide in screen

The "Slide-in screen" object provides quick navigation between the start screen and the slide-in screen containing additional configured contents.

A left slide-in screen, as shown in figure IV-28, has been configured allowing the operator to manage the operation modes of the station and the manual control of the pumps.

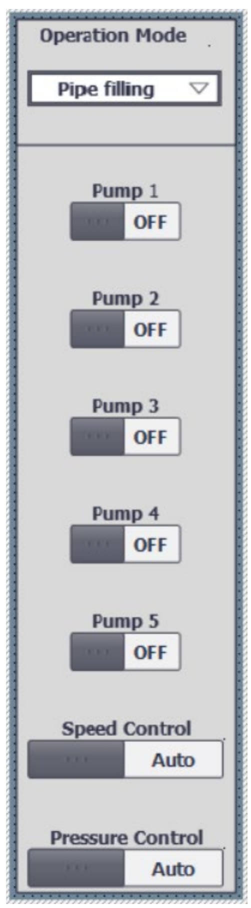

Figure IV-28 Slide-in screen

IV.12.3 Main Screen

The main screen, as shown in figure IV-29 provides details of the overall pumping station including:

- A synoptic that represent the different equipment such as: pumps valve surge tanks.
- Flow rate and pressure measurement.
- The operation mode and set points.

Table IV-20 shows the Main screen nomenclature.

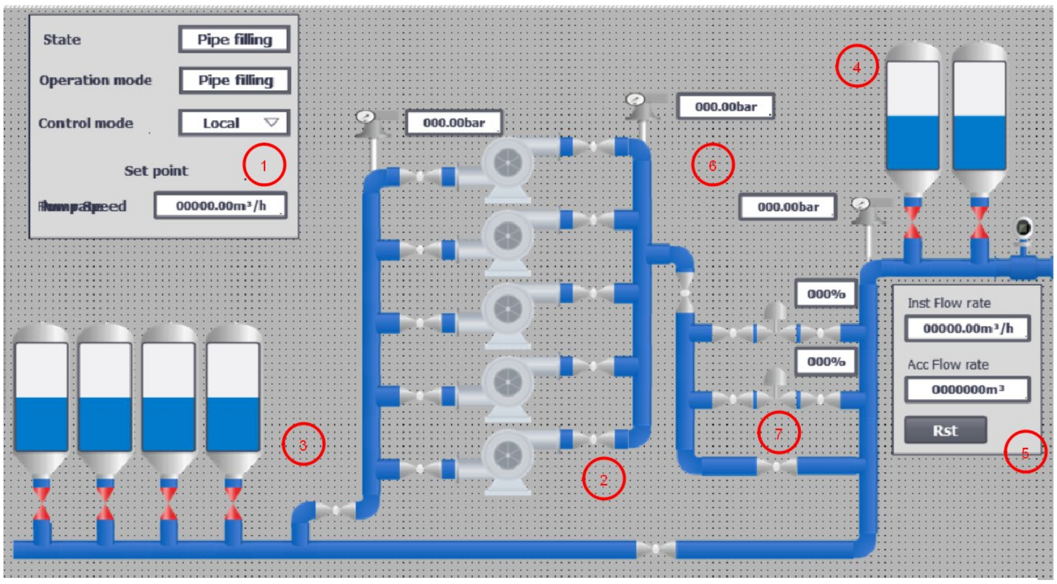

Figure IV-29 Main screen

Table IV-20 Main screen nomenclature

Number	Description
1	Pump station details: State, operation and control mode, speed or flowrate setpoint.
2	Pumps and individual suction/discharge synoptic.
3	Upstream water hammer protection.
4	Downstream water hammer protection.
5	Flow rate measurements including instantaneous and accumulated flowrate.
6	Pressure measurements including upstream, main discharge and downstream pressure.
7	Pressure control valves positions.

IV.12.4 Pump Screen

This screen provides additional details about the pump, including different temperature readings, hour meters, speed, pump and valves states.

Figure IV-30 shows the pump screen and table IV-21 lists the nomenclature used in this figure.

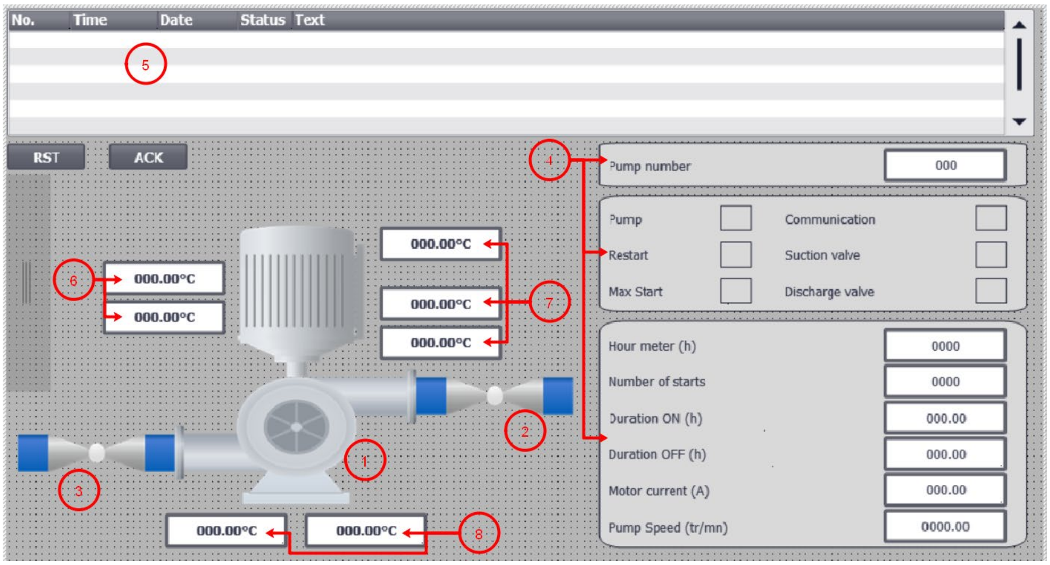

Figure IV-30 Pump Screen

Table IV-21 Pump Screen nomenclature

Number	Description
1	Pump state
2	Discharge valve state
3	Suction valve state
4	Pumps details / information
5	Alarms
6	Motor bearing temperature
7	Motor winding temperature
8	Pump bearing temperature

IV.12.5 Pumps details

This screen englobes the details of all pumps. It can be used for comparisons between pumps performances. Figure IV-31 represents the pump details screen.

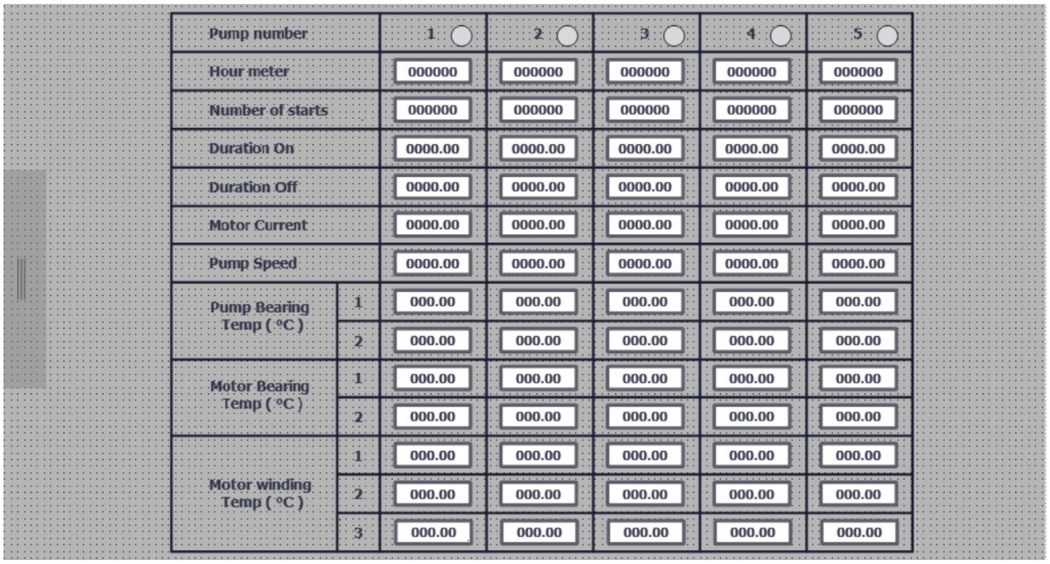

Figure IV-31 Pumps details

IV.12.6 Valves details

This screen, as presented in figure IV-32, shows details of motorized valves in the station and allows the operator to control each one individually.

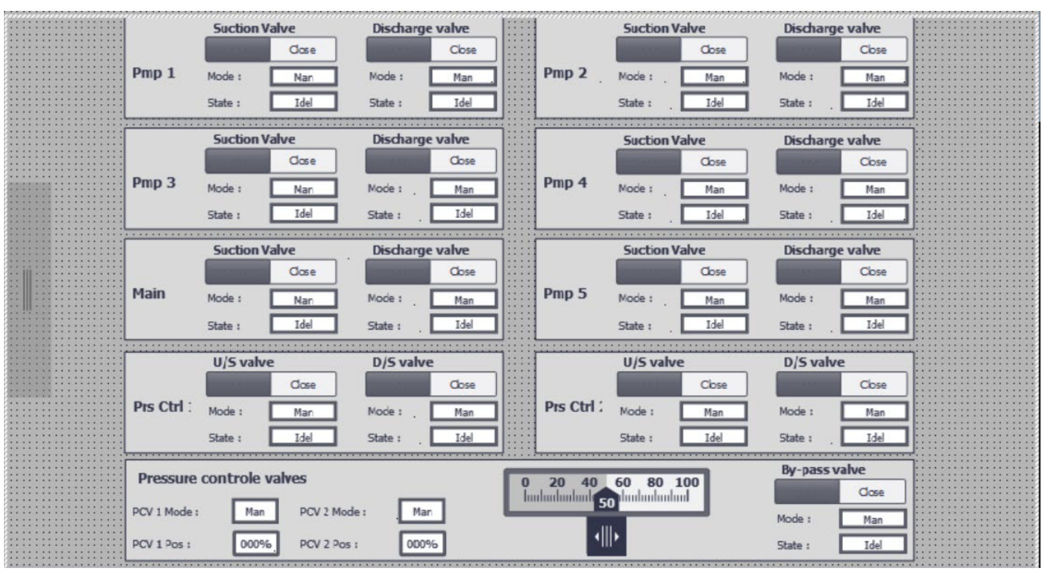

Figure IV-32 Valves details screen

IV.12.7 Upstream Water Hammer Protection

This screen provides information about the upstream water hammer protection, including the surge tanks water levels, limit switches, valve states, air compressor states and operation modes.

Figure IV-33 represents the U/S WHP screen, and table IV-22 lists the nomenclature used.

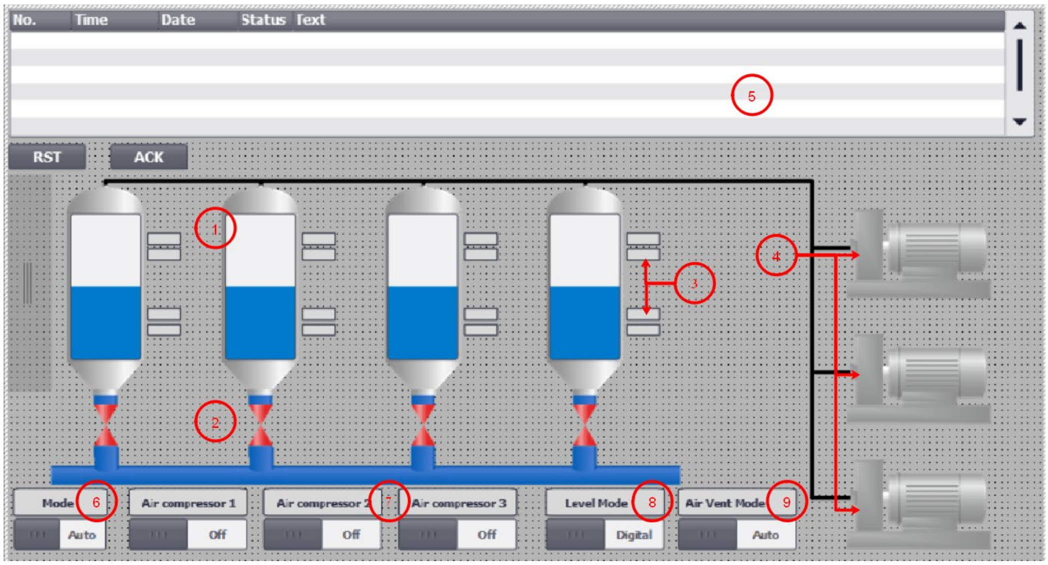

Figure IV-33 U/S WHP screen

Table IV-22 U/S WHP screen nomenclature

Number	Description
1	Surge tank water level
2	Surge tank valve state
3	Limit switches
4	Air compressor synoptic
5	Alarms
6	Operation mode (Automatic or Manual)
7	Manual operation of Air compressors (On or Off)
8	Surge tank water level reading mode (Analog or Digital)
9	Air vent operation mode (Automatic Or Manual)

IV.12.8 Downstream water hammer protection

This screen, as presented in figure IV-34, provides information about the downstream water hammer protection, including the surge tanks water levels, limit switches, valve states, air compressor states and operation modes.

Table IV-23 lists the nomenclature used in figure IV-34.

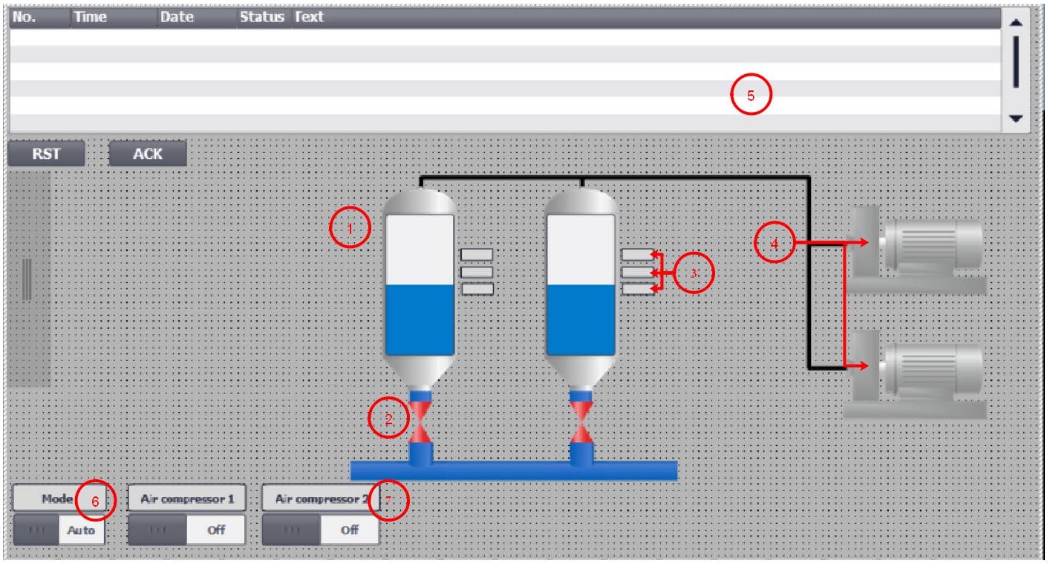

Figure IV-34 D/S WHP Screen

Table IV-23 D/S WHP screen nomenclature

Number	Description
1	Surge tank water level
2	Surge tank valve state
3	Limit switches
4	Air compressor synoptic
5	Alarms
6	Operation mode (Automatic or Manual)
7	Manual operation of Air compressors (On or Off)

IV.12.9 Trends

IV.12.9.1 General

On this screen, main suction and discharge pressures trends are displayed as well as instant flowrate. Figure IV-35 shows the general trends screen.

Table IV-24 lists the nomenclature used in figure IV-35.

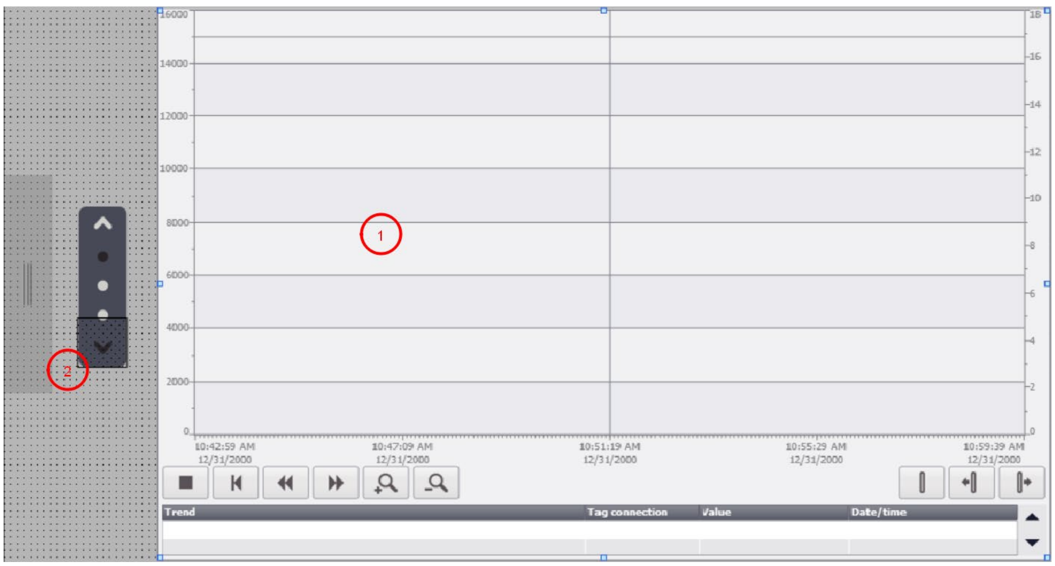

Figure IV-35 General trends screen

Table IV-24 General trends screen nomenclature

Number	Description
1	Trend view
2	Navigate to next trend screen

IV.12.9.2 Flowrate trends

This screen shows the trends related to flowrate control such as pump speed, instant flowrate, water levels of Oran and Mostaganem tanks.

Figure IV-36 shows the flowrate trends screen.

Table IV-25 lists the nomenclature used in figure IV-36.

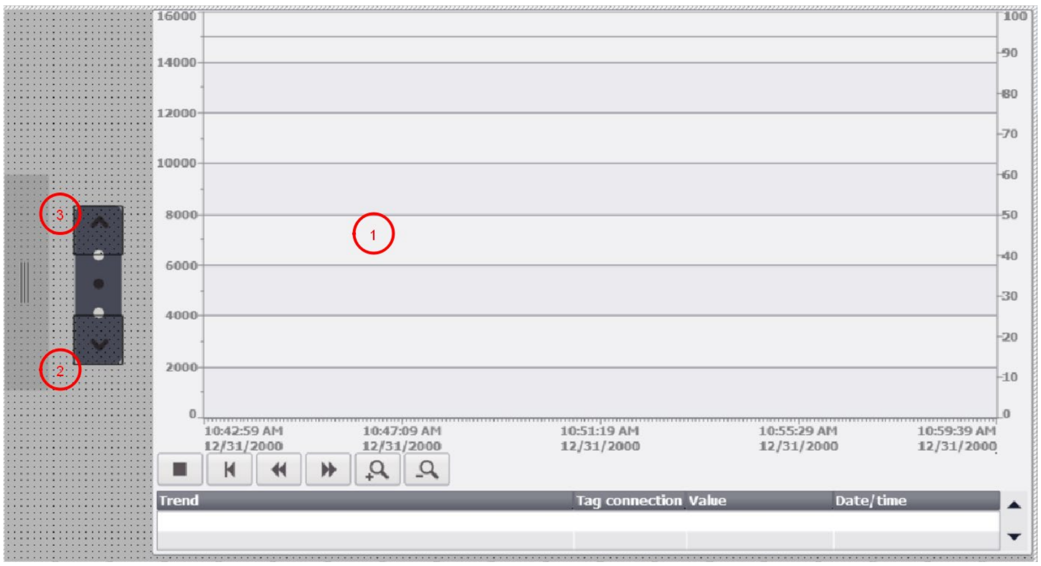

Figure IV-36 Flowrate trends screen

Table IV-25 Flowrate trends screen nomenclature

Number	Description
1	Trend view
2	Navigate to next trend screen
3	Navigate to pervious trend screen

IV.12.10 Pressure Trends

This screen shows the trends related to pressure control such as main suction, main discharge and downstream pressures and pressure control valves position.

Figure IV-37 shows the General trends screen.

Table IV-26 lists the nomenclature used in figure IV-37.

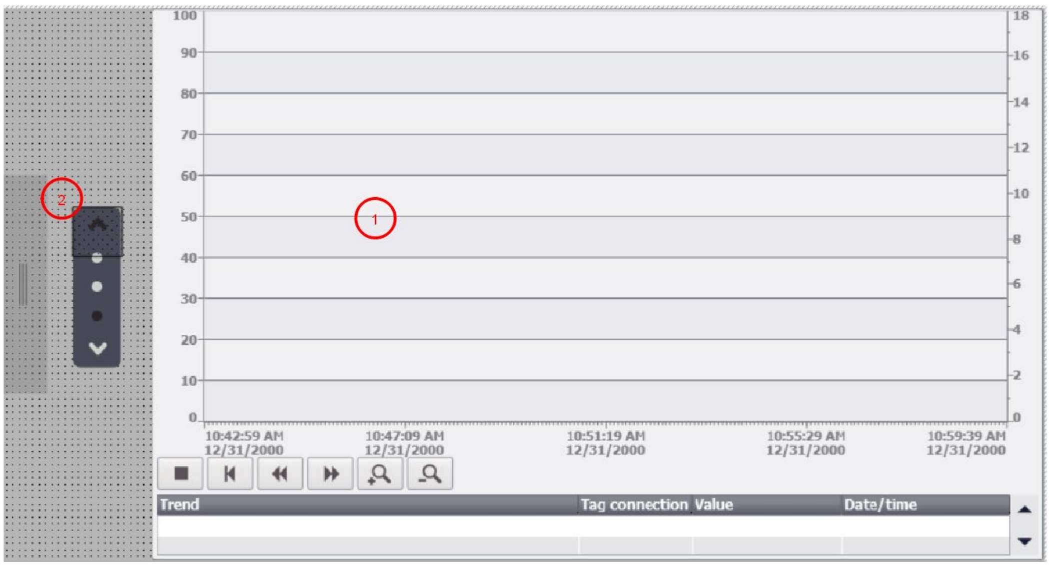

Figure IV-37 Pressure trends screen

Table IV-26 Pressure trends screen nomenclature

Number	Description
1	Trend view
2	Navigate to previous trend screen

IV.12.11 Main and backup power supply

This screen, as presented in figure IV-38, shows details of the main and backup power supplies of the station, including the generator set, transformers and circuit breakers states.
Table IV-27 lists the nomenclature used in figure IV-38.

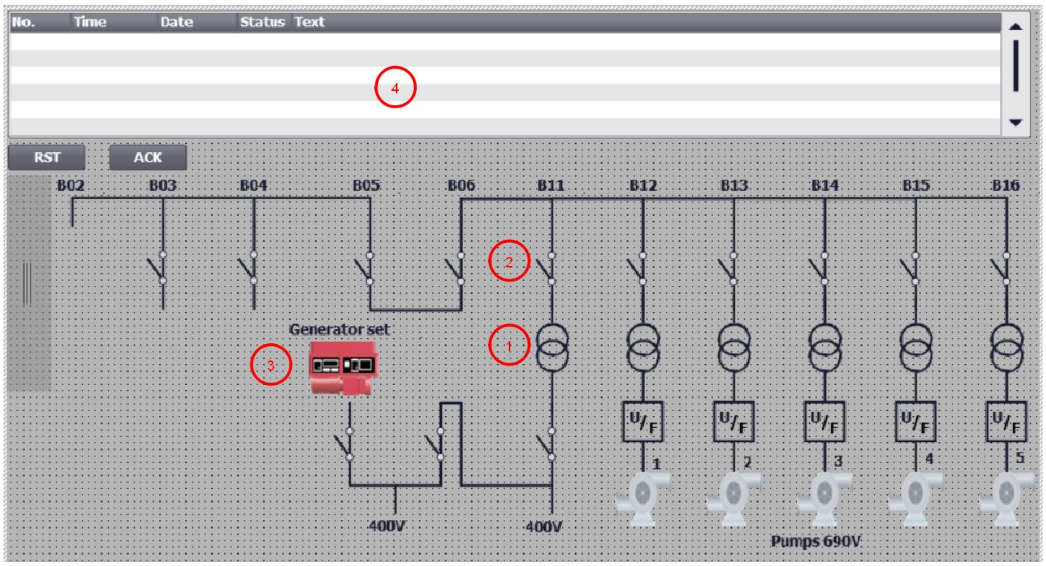

Figure IV-38 Power supply screen

Table IV-27 Power supply screen nomenclature

Number	Description
1	Transformer synoptic
2	Circuit breaker synoptic
3	Generator set synoptic
4	Alarm view

IV.12.12 Industrial Ethernet network

The network configuration is shown on this screen as presented in figure IV-39. Moreover, it provides information about communication status of each device.

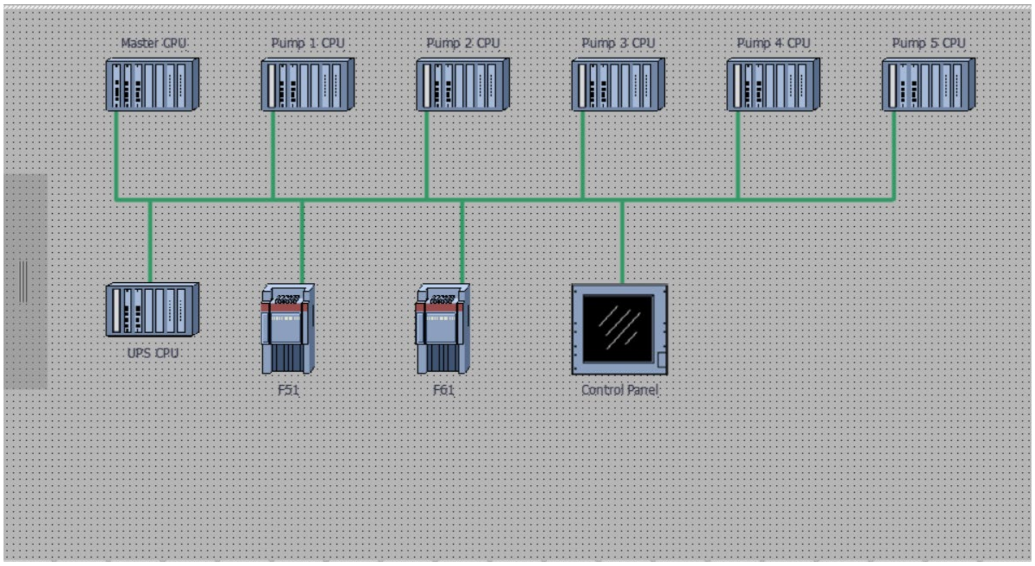

Figure IV-39 Industrial Ethernet network screen

IV.12.13 Settings screen

The operator may change the settings of the control panel on this screen, including the brightness, current time and date, as well as user administration settings.

Figure IV-40 shows the settings screen.

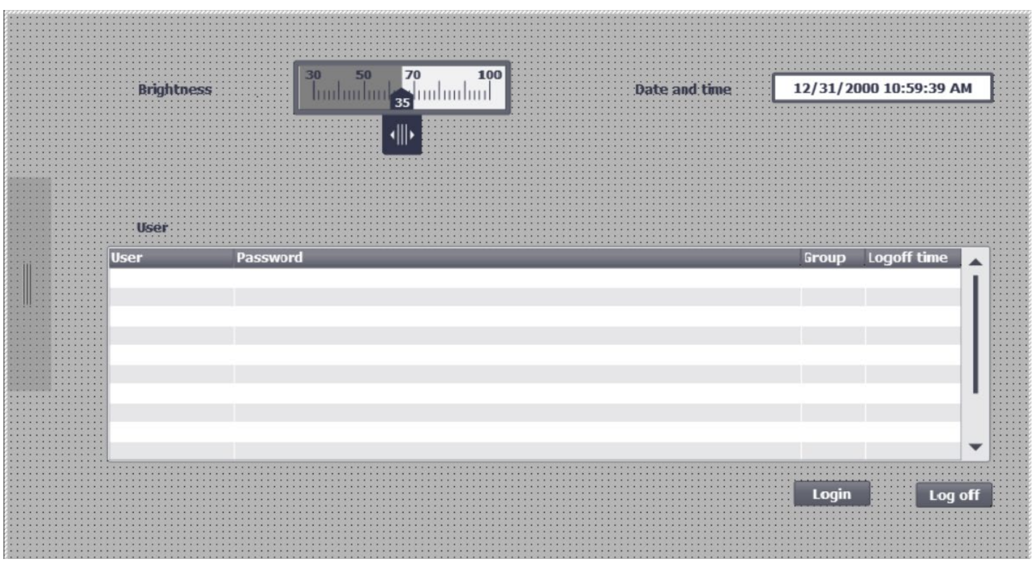

Figure IV-40 Settings screen

IV.12.14 Alarms screen

Figure IV-41 represents the Alarms Screen configuration which is used to display all active alarms of the station as well as the alarm buffer.

Table IV-28 lists the nomenclature used in figure IV-41.

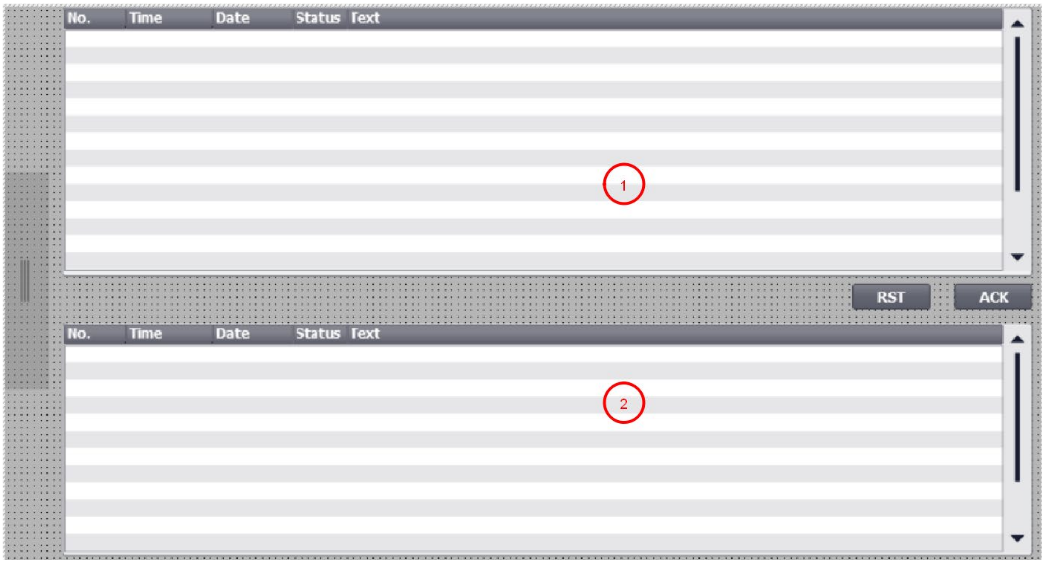

Figure IV-41 Alarms screen

Table IV-28 Alarm screen nomenclature

Number	Description
1	Active alarms
2	Alarm buffer

Chapter V

Simulation

V.1 Introduction

This section deals with the simulation of the user program that has been designed in chapter-IV. For ease of comprehension, each process area will be simulated individually, taking in consideration the safety requirements.

V.2 Pump CPU

First the pumps is turned off and both of the suction and discharge valves are closed. Two alarms are triggered warning the operator about the position of the valves and the pump is in “fault state”. The off meter will count “off duration”. The operator may open the valves locally or remotely. Details are shown in both Figures V-1 and V-2.

Once the valves are opened and alarms are acknowledged, the pump will be on “idle state” and ready for service then the pump can be turned on as shown in figure V-3.

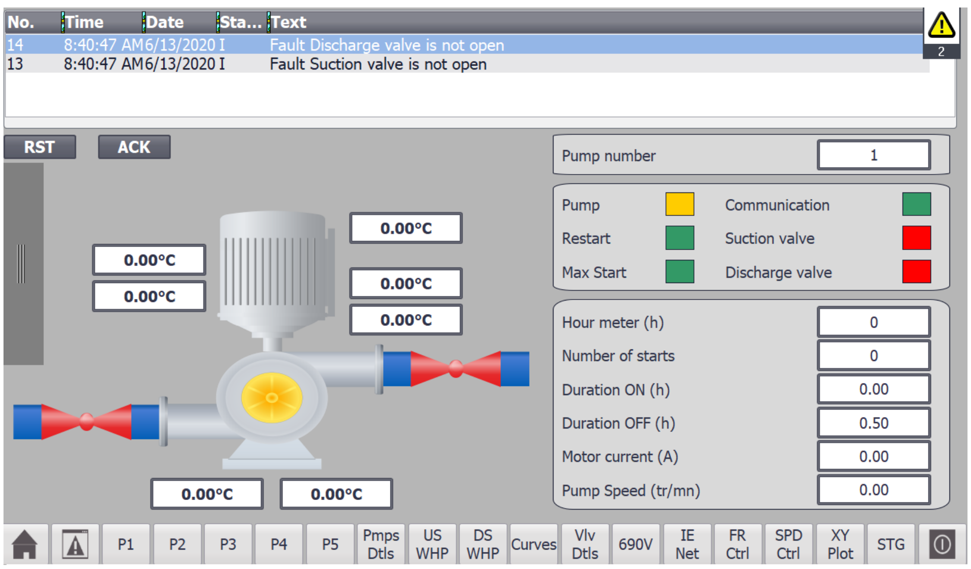

Figure V-1 Pump Simulation part 1

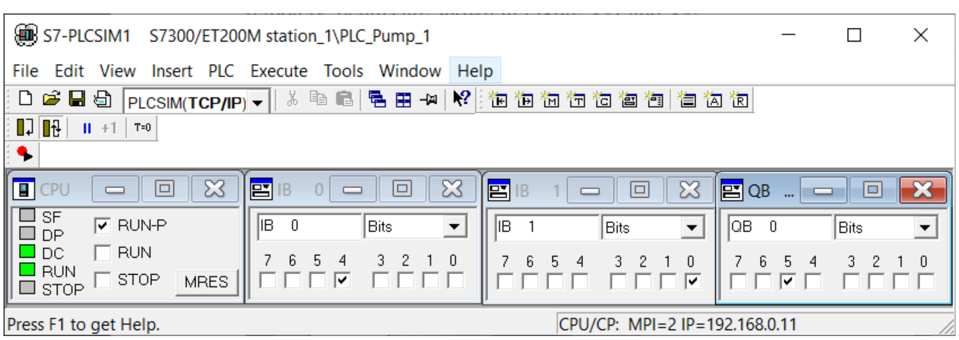

Figure V-2 Pump CPU simulation

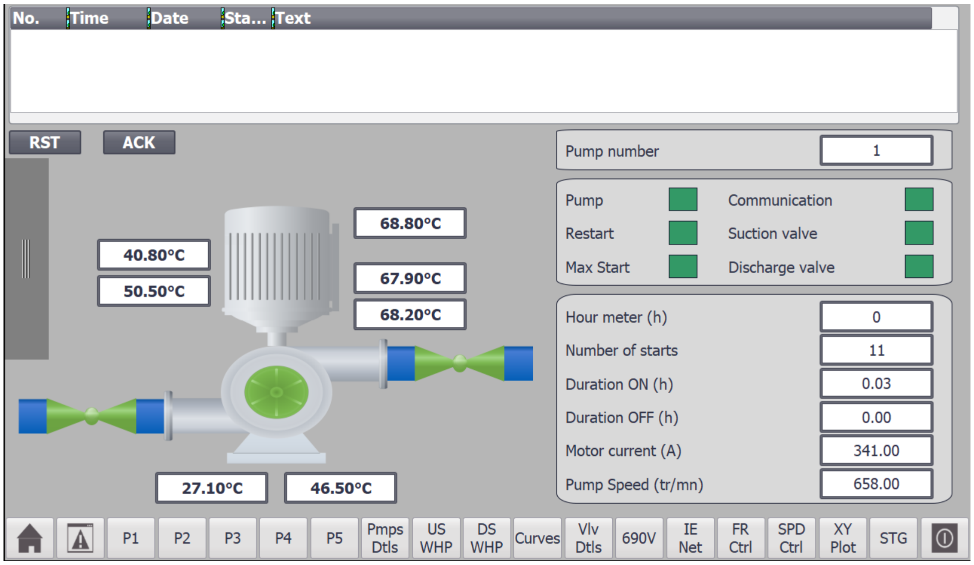

Figure V-3 Pump simulation part 2

V.3 CPU-CPU Communication

As shown in figure V-4, the left side of the screen represents the "Pump_Master" data block implemented on the pump CPU 1, whereas the right side represent the "Slaves_Data" data block implemented on the Master CPU. The data is exchanged periodically between both CPUs, and the same applies for other CPUs too.

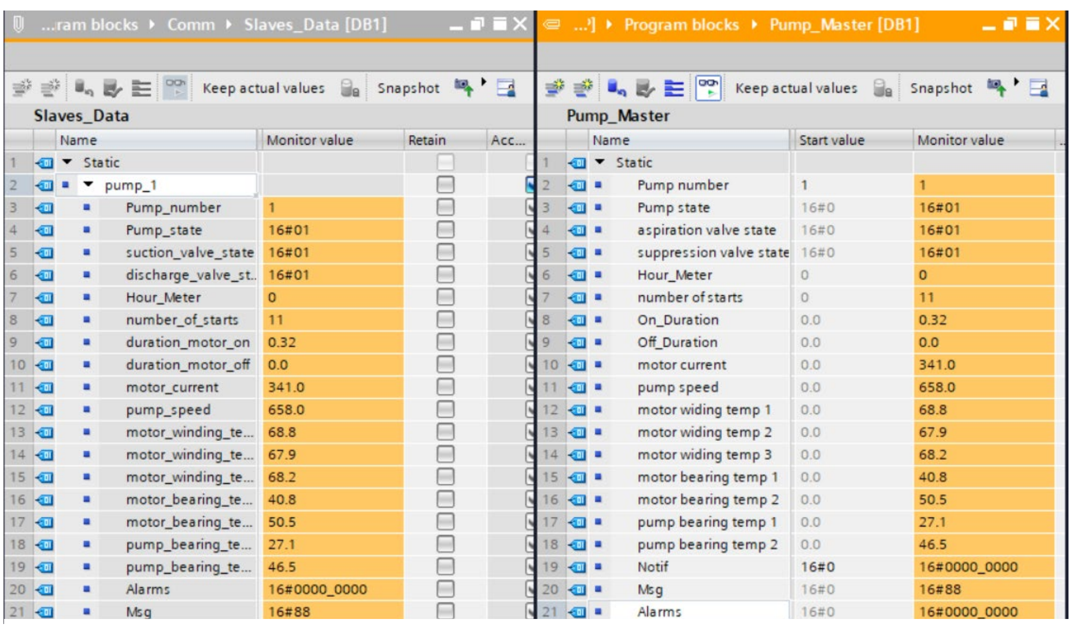

Figure V-4 CPU-CPU Communication simulation

V.4 Water Hammer Protection

V.4.1 Downstream water hammer protection

Both surge tanks valves are opened. When the water reaches the max limit switch, the number one air compressor is started, as shown in figures V-5. If it fails to start properly, then the backup air compressor is started automatically and an alarm is triggered as presented in figure V-6. The simulated variables are presented in figure V-7.

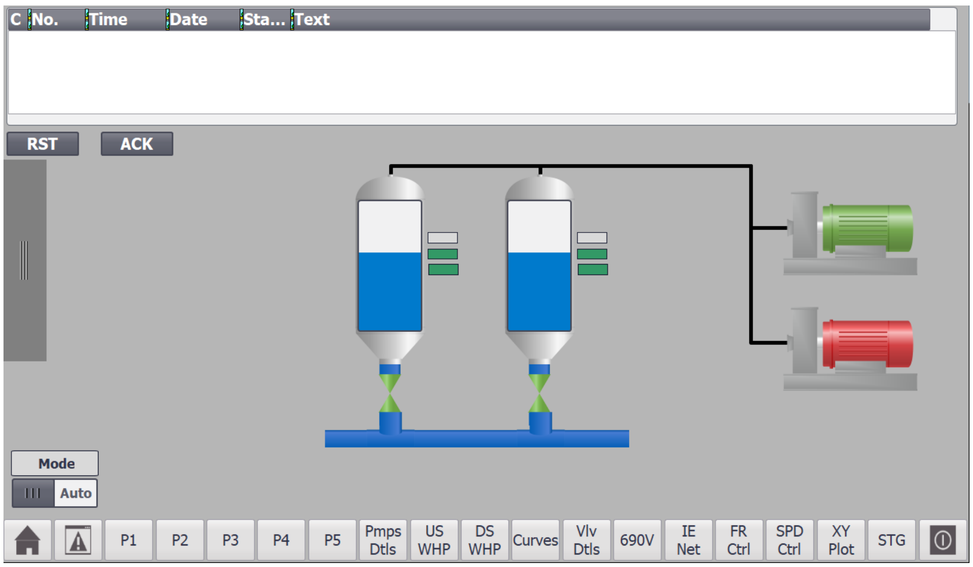

Figure V-5 D/S WHP Simulation 2

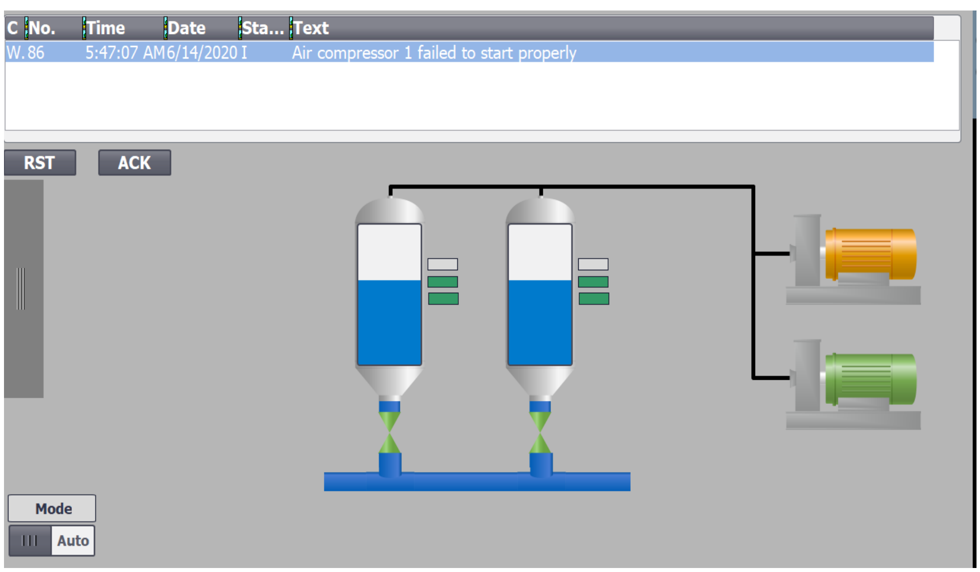

Figure V-6 D/S WHP Simulation part 2

Name	Address	Display format	Monitor/Modify value
"GNRL_DATA".RP_Count	%DB7.D...	DEC+/-	3
"GNRL_DATA".FLOW_RATE	%DB7.D...	Floating-point nu...	2500
		DEC	
"WHP_DS_Data".EMR_Stp	%DB6.D...	Bool	FALSE
		DEC	
"WHP_DS_Data".Mode	%DB6.D...	Bool	FALSE
		DEC	
▸ "WHP_DS_Data".AC_1.AC_State	%DB6.D...	Hex	16#01
▸ "WHP_DS_Data".AC_2.AC_State	%DB6.D...	Hex	16#02
		DEC	
"WHP_DS_C1_CB":P	%I20.0:P	Bool	TRUE
"WHP_DS_C1_RFB":P	%I20.1:P	Bool	TRUE
"WHP_DS_C2_CB":P	%I20.2:P	Bool	TRUE
"WHP_DS_C2_RFB":P	%I20.3:P	Bool	FALSE
		DEC	
"WHP_DS_Valve_1":P	%I21.0:P	Bool	TRUE
"WHP_DS_Valve_2":P	%I21.1:P	Bool	TRUE
		DEC	
"WHP_DS_LS_default":P	%I20.6:P	Bool	FALSE
"WHP_DS_LS_max":P	%I20.5:P	Bool	TRUE
"WHP_DS_LS_min":P	%I20.4:P	Bool	TRUE
		DEC	
▸ "WHP_DS_Data".AC_1.AC_State	%DB6.D...	Hex	16#01
▸ "WHP_DS_Data".AC_2.AC_State	%DB6.D...	Hex	16#02

Figure V-7 D/S WHP Simulated variables

V.4.2 Upstream water hammer protection

For a number of running pumps equal to four, the lower limits will be taken in consideration. Measuring mode is set to digital, and all surge tanks valves are opened.

When the water reaches the max limit switch, both of the first and second air compressors are turned on, till the water level is decreased and reaches the lower limit switch as shown in figure V-8.

As the air compressors are inverted at each start-up, the next air compressors to be turned on are the first and third ones as shown in figure V-9. The simulated variables are presented in figure V-10.

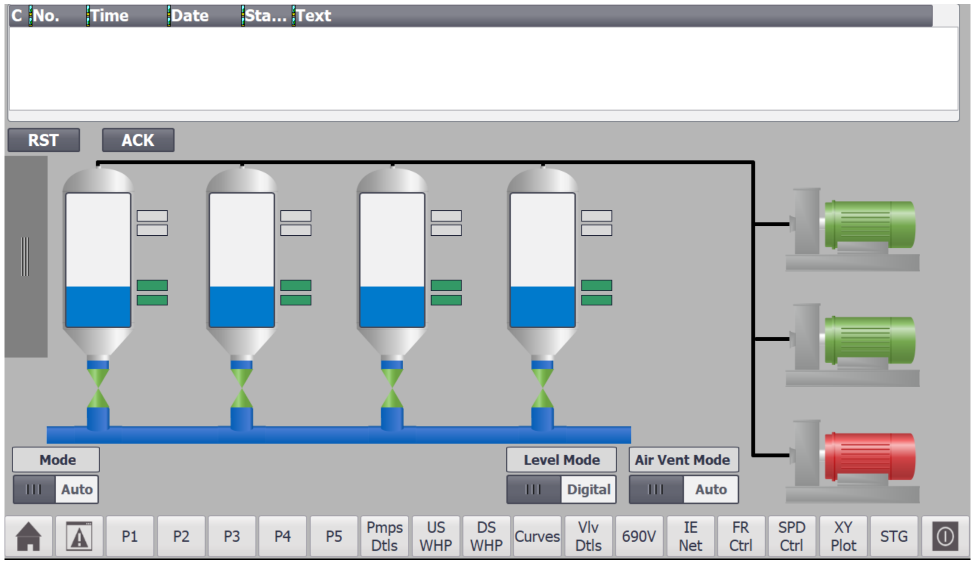

Figure V-9 U/S WHP Simulation 2

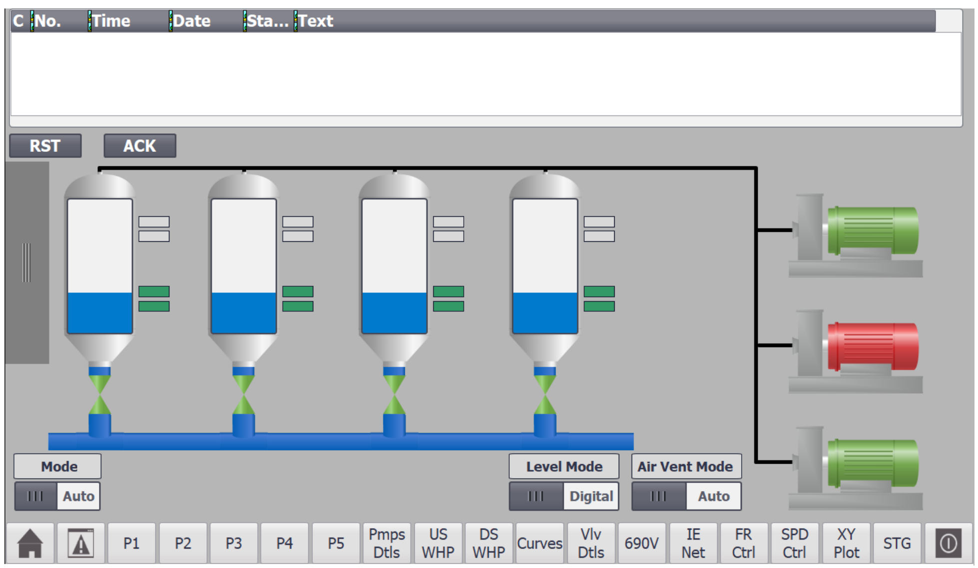

Figure V-8 U/S WHP Simulation part 2

V.4.3 Security

When the number of opened surge tank valves does not satisfy the safety requirements described previously in section III.5.5, the SC bit for both U/S and DS WHP will trigger an alarm and turn off running pumps as presented in figure V-11.

Name	Address	Display format	Monitor/Modify value
"WHP_US_Air_Vent_1_Opn"	%Q12.0	Bool	FALSE
		DEC	
"WHP_US_C1_CB":P	%I10.0:P	Bool	TRUE
"WHP_US_C1_RFB":P	%I10.1:P	Bool	FALSE
"WHP_US_C2_CB":P	%I10.2:P	Bool	TRUE
"WHP_US_C2_RFB":P	%I10.3:P	Bool	FALSE
"WHP_US_C3_CB":P	%I10.4:P	Bool	TRUE
"WHP_US_C3_RFB":P	%I10.5:P	Bool	FALSE
		DEC	
"WHP_US_Valve_1":P	%I11.4:P	Bool	TRUE
"WHP_US_Valve_2":P	%I11.5:P	Bool	TRUE
"WHP_US_Valve_3":P	%I11.6:P	Bool	TRUE
"WHP_US_Valve_4":P	%I11.7:P	Bool	TRUE
		DEC	
"WHP_US_Data".Lvl_Mode	%DB5.D...	Bool	FALSE
"WHP_US_LS_maxD":P	%I11.1:P	Bool	FALSE
"WHP_US_LS_maxU":P	%I11.3:P	Bool	FALSE
"WHP_US_LS_minD":P	%I11.0:P	Bool	TRUE
"WHP_US_LS_minU":P	%I11.2:P	Bool	FALSE
"WHP_US_PI_DP":P	%IW106...	DEC+/-	0
"WHP_US_Data".DP_Analog	%DB5.D...	Floating-point nu...	0
		DEC	
"WHP_US_Data".AC_1.AC_State	%DB5.D...	Hex	16#02
"WHP_US_Data".AC_2.AC_State	%DB5.D...	Hex	16#02
"WHP_US_Data".AC_3.AC_State	%DB5.D...	Hex	16#02

Figure V-11 U/S WHP Simulated variables

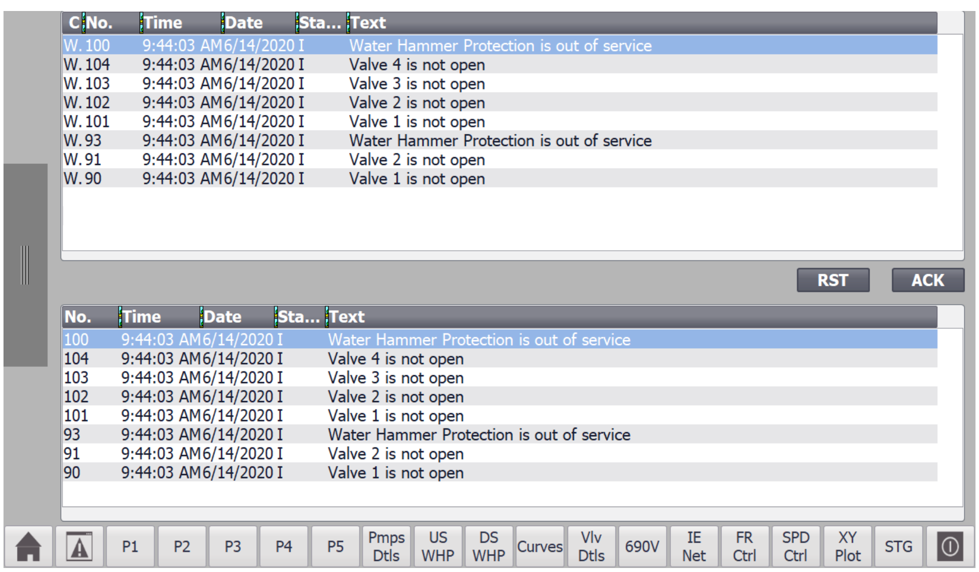

Figure V-11 WHP Security alarms

V.5 Pumps Sequence

As a function of the desired flow rate, two, three or four pumps are started up. The control system will automatically start a pump with the maximum “off meter count”. Details are shown in figures V-12 and V-13.

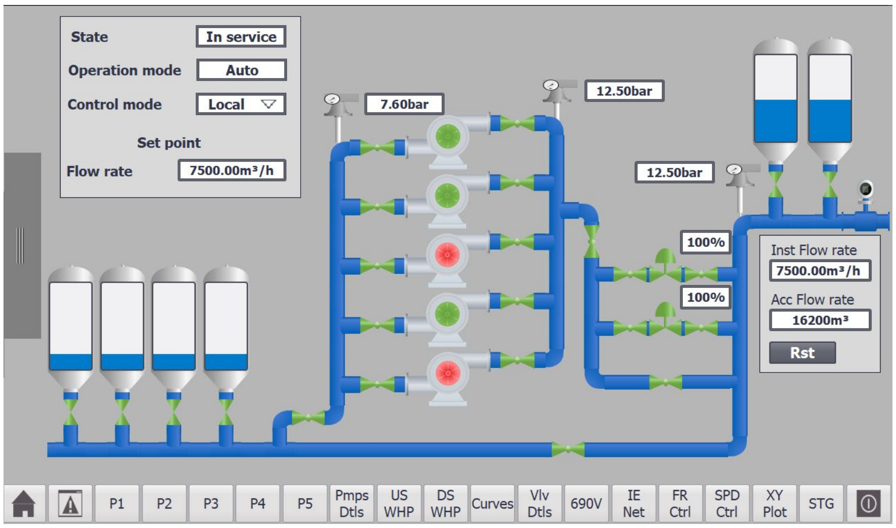

Figure V-12 Pumps sequence simulation part 1

Name	Address	Display format	Monitor value
"GNRL_DATA".SP_FR_Local	%DB7.DBD52	Floating-point nu...	0.0
"GNRL_DATA".Auto	%DB7.DBX0.5	Bool	TRUE
"GNRL_DATA".RP_Count	%DB7.DBW2	DEC	0
"Starting_Phase_DB".req		DEC	0
"GNRL_DATA".SPD_Ctrl	%DB7.DBX1.1	Bool	FALSE
"Slaves_Data".pump_1.duration_motor_on	%DB1.DBD14	Floating-point nu...	0.0
"Slaves_Data".pump_2.duration_motor_on	%DB1.DBD78	Floating-point nu...	0.0
"Slaves_Data".pump_3.duration_motor_on	%DB1.DBD142	Floating-point nu...	0.0
"Slaves_Data".pump_4.duration_motor_on	%DB1.DBD206	Floating-point nu...	0.0
"Slaves_Data".pump_5.duration_motor_on	%DB1.DBD270	Floating-point nu...	0.0
"Slaves_Data".pump_1.duration_motor_off	%DB1.DBD18	Floating-point nu...	0.03
"Slaves_Data".pump_2.duration_motor_off	%DB1.DBD82	Floating-point nu...	0.02
"Slaves_Data".pump_3.duration_motor_off	%DB1.DBD146	Floating-point nu...	0.01
"Slaves_Data".pump_4.duration_motor_off	%DB1.DBD210	Floating-point nu...	0.02
"Slaves_Data".pump_5.duration_motor_off	%DB1.DBD274	Floating-point nu...	0.0
"Pumps_Ctrl".On_Off_Block		Bool	FALSE
"Pumps_Ctrl".On_block		Bool	FALSE
"Pumps_Ctrl".Off_block		Bool	FALSE
"Pumps_Seq_DB".Temp_Block_Instance.On_block.ET		Time	T#0MS
"Pumps_Seq_DB".Temp_Block_Instance.Off_block.ET		Time	T#0MS
"Pumps_Seq_DB".Temp_Block_Instance.On_Off_Block.ET		Time	T#0MS

Figure V-13 Pumps sequence simulated variables part 1

When a pump reaches the maximum running hours limit, which is set to two minutes for simulation purposes, the control system will tun it off and start another pump as shown in figures V-14 and V-15.

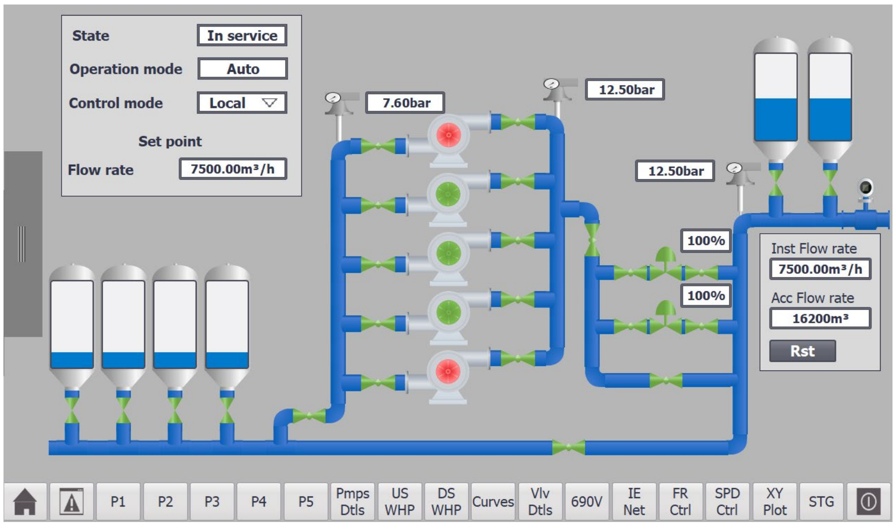

Figure V-14 Pumps sequence simulation part 2

Name	Address	Display format	Monitor value
"GNRL_DATA".SP_FR_Local	%DB7.DBD52	Floating-point nu...	7500.0
"GNRL_DATA".Auto	%DB7.DBX0.5	Bool	TRUE
"GNRL_DATA".RP_Count	%DB7.DBW2	DEC	3
"Starting_Phase_DB".req		DEC	3
"GNRL_DATA".SPD_Ctrl	%DB7.DBX1.1	Bool	FALSE
"Slaves_Data".pump_1.duration_motor_on	%DB1.DBD14	Floating-point nu...	0.0
"Slaves_Data".pump_2.duration_motor_on	%DB1.DBD78	Floating-poin...	0.01
"Slaves_Data".pump_3.duration_motor_on	%DB1.DBD142	Floating-point nu...	0.01
"Slaves_Data".pump_4.duration_motor_on	%DB1.DBD206	Floating-point nu...	0.0
"Slaves_Data".pump_5.duration_motor_on	%DB1.DBD270	Floating-point nu...	0.0
"Slaves_Data".pump_1.duration_motor_off	%DB1.DBD18	Floating-point nu...	0.0
"Slaves_Data".pump_2.duration_motor_off	%DB1.DBD82	Floating-point nu...	0.0
"Slaves_Data".pump_3.duration_motor_off	%DB1.DBD146	Floating-point nu...	0.0
"Slaves_Data".pump_4.duration_motor_off	%DB1.DBD210	Floating-point nu...	0.01
"Slaves_Data".pump_5.duration_motor_off	%DB1.DBD274	Floating-point nu...	0.0
"Pumps_Ctrl".On_Off_Block		Bool	TRUE
"Pumps_Ctrl".On_block		Bool	TRUE
"Pumps_Ctrl".Off_block		Bool	TRUE
"Pumps_Seq_DB".Temp_Block_Instance.On_block.ET		Time	T#1S_41MS
"Pumps_Seq_DB".Temp_Block_Instance.Off_block.ET		Time	T#6S_234MS
"Pumps_Seq_DB".Temp_Block_Instance.On_Off_Block.ET		Time	T#1S_41MS

Figure V-15 Pumps sequence simulated variables part 2

V.6 Back-up power supply

As soon as the main power supply fails, the generator set is turned on details are shown in figures V-16, V-17, V-18 and V-19.

Name	Address	Display format	Monitor/Modify value
"Mon_XFMR_PH":P	%I14.0:P	Bool	TRUE
"Mon_GenSet_PH":P	%I14.1:P	Bool	FALSE
"XFMR_CB_Opn_Snsr":P	%I14.2:P	Bool	FALSE
"XFMR_CB_Cls_Snsr":P	%I14.3:P	Bool	TRUE
"GenSet_CB_Opn_Snsr":P	%I14.4:P	Bool	TRUE
"GenSet_CB_Cls_Snsr":P	%I14.5:P	Bool	FALSE
"CPLG_CB_Opn_Snsr":P	%I14.6:P	Bool	FALSE
"CPLG_CB_Cls_Snsr":P	%I14.7:P	Bool	TRUE
"GenSet_Ready":P	%I15.1:P	Bool	TRUE
"XFMR_SW":P	%I15.2:P	Bool	FALSE
"GenSet_SW":P	%I15.3:P	Bool	FALSE
"Tst_Lamp":P	%I15.4:P	Bool	FALSE
"XFMR_CB_Opn_Cmd"	%Q14.0	Bool	FALSE
"XFMR_CB_Cls_Cmd"	%Q14.1	Bool	FALSE
"GenSet_CB_Opn_Cmd"	%Q14.2	Bool	FALSE
"GenSet_CB_Cls_Cmd"	%Q14.3	Bool	FALSE
"CPLG_CB_Opn_Cmd"	%Q14.4	Bool	FALSE
"CPLG_CB_Cls_Cmd"	%Q14.5	Bool	FALSE
"XFMR_On_LMP"	%Q14.6	Bool	TRUE
"XFMR_Fault_LMP"	%Q14.7	Bool	FALSE
"GenSet_On_LMP"	%Q15.0	Bool	FALSE
"GenSet_Fault_LMP"	%Q15.1	Bool	FALSE
"GenSet_On_Cmd"	%Q15.2	Bool	FALSE
"GenSet_Off_Cmd"	%Q15.3	Bool	TRUE

Figure V-16 Back-up power supply simulation part 1

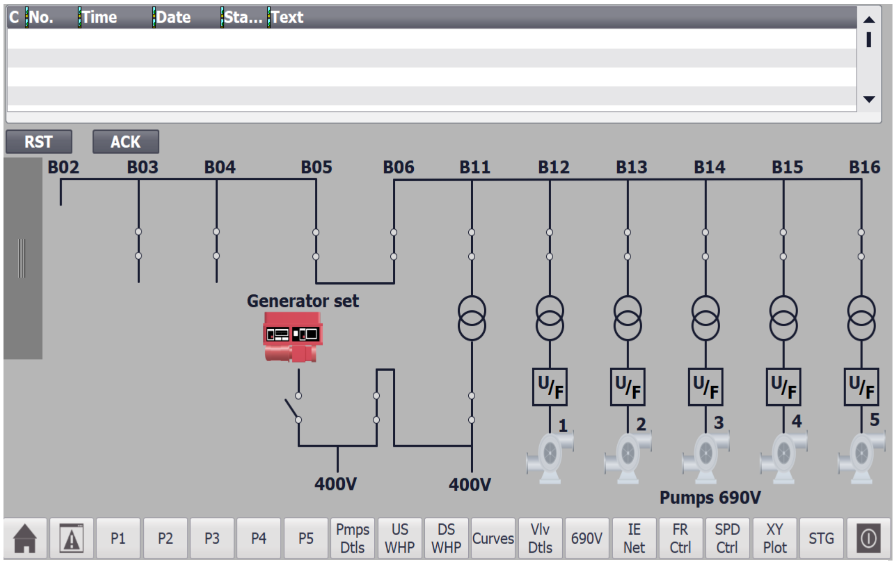

Figure V-17 Back-up power supply simulation part 2

Name	Address	Display format	Monitor/Modify value
"Mon_XFMR_PH":P	%I14.0:P	Bool	FALSE
"Mon_GenSet_PH":P	%I14.1:P	Bool	TRUE
"XFMR_CB_Opn_Snsr":P	%I14.2:P	Bool	TRUE
"XFMR_CB_Cls_Snsr":P	%I14.3:P	Bool	FALSE
"GenSet_CB_Opn_Snsr":P	%I14.4:P	Bool	FALSE
"GenSet_CB_Cls_Snsr":P	%I14.5:P	Bool	TRUE
"CPLG_CB_Opn_Snsr":P	%I14.6:P	Bool	TRUE
"CPLG_CB_Cls_Snsr":P	%I14.7:P	Bool	FALSE
"GenSet_Ready":P	%I15.1:P	Bool	TRUE
"XFMR_SW":P	%I15.2:P	Bool	FALSE
"GenSet_SW":P	%I15.3:P	Bool	FALSE
"Tst_Lamp":P	%I15.4:P	Bool	FALSE
"XFMR_CB_Opn_Cmd"	%Q14.0	Bool	FALSE
"XFMR_CB_Cls_Cmd"	%Q14.1	Bool	FALSE
"GenSet_CB_Opn_Cmd"	%Q14.2	Bool	FALSE
"GenSet_CB_Cls_Cmd"	%Q14.3	Bool	FALSE
"CPLG_CB_Opn_Cmd"	%Q14.4	Bool	FALSE
"CPLG_CB_Cls_Cmd"	%Q14.5	Bool	FALSE
"XFMR_On_LMP"	%Q14.6	Bool	FALSE
"XFMR_Fault_LMP"	%Q14.7	Bool	TRUE
"GenSet_On_LMP"	%Q15.0	Bool	TRUE
"GenSet_Fault_LMP"	%Q15.1	Bool	FALSE
"GenSet_On_Cmd"	%Q15.2	Bool	TRUE
"GenSet_Off_Cmd"	%Q15.3	Bool	FALSE

Figure V-18 Back-up power supply simulation part 3

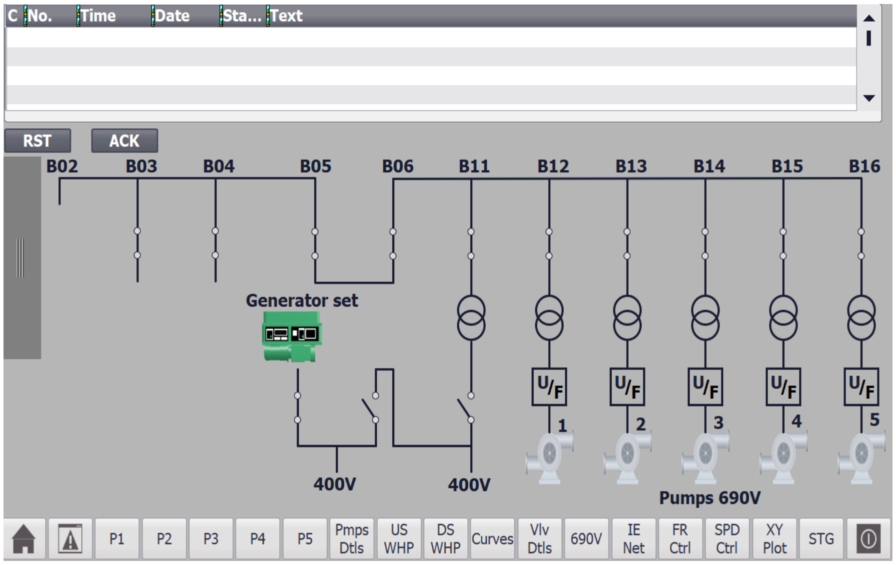

Figure V-19 Back-up power supply simulation part 4

V.7 Control simulation

V.7.1 Flowrate control

As shown in figure V-20, the PID controller will adjust the pump speed as a function of a set flowrate.

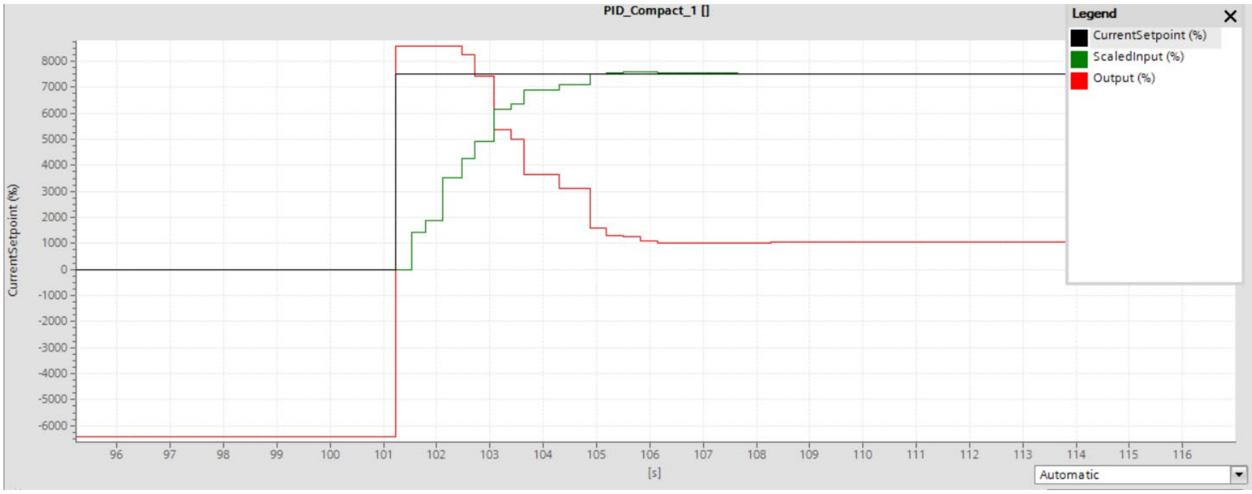

Figure V-20 Speed control simulation

V.7.2 Pressure control

As shown in figure V-16, the PID 3Step controller will adjust the valve position as a function of pressure.

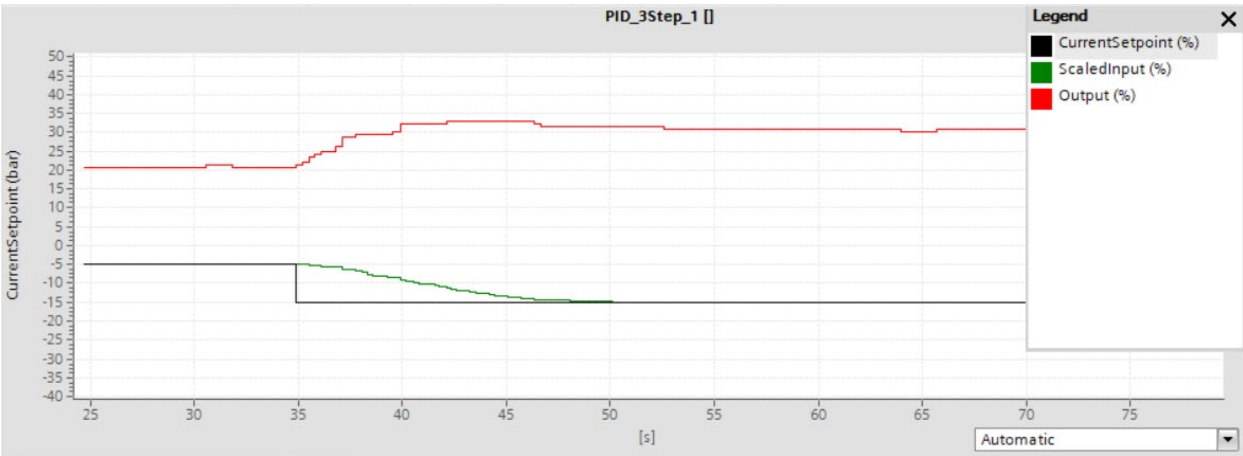

Figure V-21 Pressure control simulation

Chapter VI

Conclusion

The work presented in this thesis is part of the automation and supervision of Hassi Ben Okba water pumping station built and used by the SEOR company. It aims at designing and implementing a PLC algorithm to automate the management of the process taking into consideration the instruments and safety requirements, as well as designing a Human-machine interface for real-time monitoring.

In this work, a modeling of the operation of the station was implemented using TIA PORTAL software. A PLC program was subsequently developed to achieve the automation tasks, resolve problems related to personnel and equipment safety and provide proper management and monitoring of the overall pumping station.

The main conclusion reached from this work concerns the importance and necessity of automation control in a water supply which requires mixing knowledge from different scientific fields. Such fields are: electrical engineering, fluid mechanics, mechanical engineering, electronics, automation, IT and telecommunication.

It was also concluded that a proper modeling and understanding of the automation concept reduces both the engineering cost and time and improve the work efficiency and facilities the PLC coding for complex systems.

It is worth mentioning that this work has been very beneficial. Close contact with specialists in the field has allowed to enrich the theoretical knowledge acquired during our studies and has been a great contribution to our understanding of the overall process of operation of the pumping station.

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Appendices

Appendix A: Master PLC I/O

Name	Type	Address
EMR Stp Gnrl	Bool	%I0.0
Gnrl Fault	Bool	%I0.1
XFMR_1_24V_CMD	Bool	%I1.0
XFMR_1_OG_CB_Trip	Bool	%I1.1
XFMR_1_FLT_XFMR_Trip	Bool	%I1.2
XFMR_1_ALRM_FLT_XFMR	Bool	%I1.3
XFMR_2_24V_CMD	Bool	%I1.4
XFMR_2_OG_CB_Trip	Bool	%I1.5
XFMR_2_FLT_XFMR_Trip	Bool	%I1.6
XFMR_2_ALRM_FLT_XFMR	Bool	%I1.7
XFMR_3_24V_CMD	Bool	%I2.0
XFMR_3_OG_CB_Trip	Bool	%I2.1
XFMR_3_FLT_XFMR_Trip	Bool	%I2.2
XFMR_3_ALRM_FLT_XFMR	Bool	%I2.3
XFMR_4_24V_CMD	Bool	%I2.4
XFMR_4_OG_CB_Trip	Bool	%I2.5
XFMR_4_FLT_XFMR_Trip	Bool	%I2.6
XFMR_4_ALRM_FLT_XFMR	Bool	%I2.7
XFMR_5_24V_CMD	Bool	%I3.0
XFMR_5_OG_CB_Trip	Bool	%I3.1
XFMR_5_FLT_XFMR_Trip	Bool	%I3.2

Appendix A: Master PLC I/O (Continued)

Name	Type	Address
XFMR_5_ALRM_FLT_XFMR	Bool	%I3.3
XFMR_AUX_24V_CMD	Bool	%I3.4
XFMR_AUX_OG_CB_Trip	Bool	%I3.5
XFMR_AUX_FLT_XFMR_Trip	Bool	%I3.6
XFMR_AUX_ALRM_FLT_XFMR	Bool	%I3.7
CB_30KV_CMD	Bool	%I4.0
CB_30KV_Trip	Bool	%I4.1
CB_30KV_FLT	Bool	%I4.2
CB_30KV_AUX_V_FLT	Bool	%I4.3
GNR_DISC_V_CMD	Bool	%I4.4
Gnrl FLT	Bool	%Q0.0
Horn	Bool	%Q0.1

Appendix B: Pump PLC I/O

Name	Type	Address
Pump_Vibration_Rly_1	Bool	%I0.0
Pump_Vibration_Rly_2	Bool	%I0.1
Motor_Vibration_Rly_1	Bool	%I0.2
Motor_Vibration_Rly_2	Bool	%I0.3
Asp_valve_opn_Snsr	Bool	%I0.4
Asp_valve_close_Snsr	Bool	%I0.5
Asp_valve_fault	Bool	%I0.6
Asp_valve_OprtMode	Bool	%I0.7
Supr_valve_opn_Snsr	Bool	%I1.0
Supr_valve_close_Snsr	Bool	%I1.1
Supr_valve_fault	Bool	%I1.2
Supr_valve_OprtMode	Bool	%I1.3
Emergency_Stop	Bool	%I1.5
Motor_Heater_fault	Bool	%I1.6
I_motor widing temp 1	Int	%IW256
I_motor widing temp 2	Int	%IW258
I_motor widing temp 3	Int	%IW260
I_motor bearing temp 1	Int	%IW262
I_motor bearing temp 2	Int	%IW264
I_pump bearing temp 1	Int	%IW266
I_pump bearing temp 2	Int	%IW268
Asp_valve_opn_Cmd	Bool	%Q0.0

Appendix B: Pump PLC I/O (Continued)

Name	Type	Address
Asp_valve_close_Cmd	Bool	%Q0.1
Supr_valve_opn_Cmd	Bool	%Q0.2
Supr_valve_close_Cmd	Bool	%Q0.3
Motor_Heater_Cmd	Bool	%Q0.4
Pump_Start_Cmd	Bool	%Q0.5
Pump_Stop_Cmd	Bool	%Q0.6

Appendix C: F51 I/O

Name	Type	Address
WHP_US_LS_maxD	Bool	%I11.1
WHP_US_LS_minU	Bool	%I11.2
WHP_US_LS_maxU	Bool	%I11.3
WHP_US_Valve_1	Bool	%I11.4
WHP_US_Valve_2	Bool	%I11.5
WHP_US_Valve_3	Bool	%I11.6
WHP_US_Valve_4	Bool	%I11.7
MSV_Opn_Snsr	Bool	%I12.0
MSV_Cls_Snsr	Bool	%I12.1
MSV_Mode	Bool	%I12.2
MSV_Fault	Bool	%I12.3
MAV_Opn_Snsr	Bool	%I12.4
MAV_Cls_Snsr	Bool	%I12.5
MAV_Mode	Bool	%I12.6
MAV_Fault	Bool	%I12.7
I_Accum_FR	Bool	%I13.0
Mon_XFMR_PH	Bool	%I14.0
Mon_GenSet_PH	Bool	%I14.1
XFMR_CB_Opn_Snsr	Bool	%I14.2
XFMR_CB_Cls_Snsr	Bool	%I14.3
GenSet_CB_Opn_Snsr	Bool	%I14.4

Appendix C: F51 I/O (Continued)

Name	Type	Address
GenSet_CB_Cls_Snsr	Bool	%I14.5
CPLG_CB_Opn_Snsr	Bool	%I14.6
CPLG_CB_Cls_Snsr	Bool	%I14.7
GenSet_Ready	Bool	%I15.1
XFMR_SW	Bool	%I15.2
GenSet_SW	Bool	%I15.3
Tst_Lamp	Bool	%I15.4
PI_P_Asp	Int	%IW100
PI_P_Spr	Int	%IW102
PI_FR	Int	%IW104
WHP_US_PI_DP	Int	%IW106
WHP_US_C1_On	Bool	%Q10.0
WHP_US_C1_Off	Bool	%Q10.1
WHP_US_C2_On	Bool	%Q10.2
WHP_US_C2_Off	Bool	%Q10.3
WHP_US_C3_On	Bool	%Q10.4
WHP_US_C3_Off	Bool	%Q10.5
MSV_Opn_Cmd	Bool	%Q11.0
MSV_Cls_Cmd	Bool	%Q11.1
MAV_Opn_Cmd	Bool	%Q11.2
MAV_Cls_Cmd	Bool	%Q11.3
WHP_US_Air_Vent_1_Opn	Bool	%Q12.0

Appendix C: F51 I/O (Continued)

Name	Type	Address
WHP_US_Air_Vent_1_Cls	Bool	%Q12.1
WHP_US_Air_Vent_2_Opn	Bool	%Q12.2
WHP_US_Air_Vent_2_Cls	Bool	%Q12.3
WHP_US_Air_Vent_3_Opn	Bool	%Q12.4
WHP_US_Air_Vent_3_Cls	Bool	%Q12.5
WHP_US_Air_Vent_4_Opn	Bool	%Q12.6
WHP_US_Air_Vent_4_Cls	Bool	%Q12.7
XFMR_CB_Opn_Cmd	Bool	%Q14.0
XFMR_CB_Cls_Cmd	Bool	%Q14.1
GenSet_CB_Opn_Cmd	Bool	%Q14.2
GenSet_CB_Cls_Cmd	Bool	%Q14.3
CPLG_CB_Opn_Cmd	Bool	%Q14.4
CPLG_CB_Cls_Cmd	Bool	%Q14.5
XFMR_On_LMP	Bool	%Q14.6

Appendix D: F61 I/O.

Name	Type	Address
WHP_DS_C1_CB	Bool	%I20.0
WHP_DS_C1_RFB	Bool	%I20.1
WHP_DS_C2_CB	Bool	%I20.2
WHP_DS_C2_RFB	Bool	%I20.3
WHP_DS_LS_min	Bool	%I20.4
WHP_DS_LS_max	Bool	%I20.5
WHP_DS_LS_default	Bool	%I20.6
WHP_DS_Valve_1	Bool	%I21.0
WHP_DS_Valve_2	Bool	%I21.1
PC_USV1_Opn_Snsr	Bool	%I22.0
PC_USV1_Cls_Snsr	Bool	%I22.1
PC_USV1_Fault	Bool	%I22.2
PC_USV1_Mode	Bool	%I22.3
PC_USV2_Opn_Snsr	Bool	%I22.4
PC_USV2_Cls_Snsr	Bool	%I22.5
PC_USV2_Fault	Bool	%I22.6
PC_USV2_Mode	Bool	%I22.7
PC_DSV1_Opn_Snsr	Bool	%I23.0
PC_DSV1_Cls_Snsr	Bool	%I23.1
PC_DSV1_Fault	Bool	%I23.2
PC_DSV1_Mode	Bool	%I23.3
PC_DSV2_Opn_Snsr	Bool	%I23.4

Appendix D: F61 I/O (Continued)

Name	Type	Address
PC_DSV2_Cls_Snsr	Bool	%I23.5
PC_DSV2_Fault	Bool	%I23.6
PC_DSV2_Mode	Bool	%I23.7
PC_BPV_Opn_Snsr	Bool	%I24.0
PC_BPV_Cls_Snsr	Bool	%I24.1
PC_BPV_Fault	Bool	%I24.2
PC_BPV_Mode	Bool	%I24.3
PC_PCV1_Opn_Snsr	Bool	%I24.4
PC_PCV1_Cls_Snsr	Bool	%I24.5
PC_PCV1_Fault	Bool	%I24.6
PC_PCV1_Mode	Bool	%I24.7
PC_PCV2_Opn_Snsr	Bool	%I25.0
PC_PCV2_Cls_Snsr	Bool	%I25.1
PC_PCV2_Fault	Bool	%I25.2
PC_PCV2_Mode	Bool	%I25.3
PI_Ps_PR_1	Int	%IW200
PI_Ps_PR_2	Int	%IW202
PI_P_Out	Int	%IW204
WHP_DS_C1_On	Bool	%Q20.0
WHP_DS_C1_Off	Bool	%Q20.1
WHP_DS_C2_On	Bool	%Q20.2
WHP_DS_C2_Off	Bool	%Q20.3

Appendix D: F61 I/O (Continued)

Name	Type	Address
PC_USV1_Opn_Cmd	Bool	%Q21.0
PC_USV1_Cls_Cmd	Bool	%Q21.1
PC_USV2_Opn_Cmd	Bool	%Q21.2
PC_USV2_Cls_Cmd	Bool	%Q21.3
PC_DSV1_Opn_Cmd	Bool	%Q21.4
PC_DSV1_Cls_Cmd	Bool	%Q21.5
PC_DSV2_Opn_Cmd	Bool	%Q21.6
PC_DSV2_Cls_Cmd	Bool	%Q21.7
PC_BPV_Opn_Cmd	Bool	%Q22.0
PC_BPV_Cls_Cmd	Bool	%Q22.1
PQ_PCV1_Pos	Int	%QW200
PQ_PCV2_Pos	Int	%QW202

Appendix E: HMI tags

Name	Type	Address / PLC Tag
Tag_ScreenNumber	UInt	Local Tag
GNRL_DATA_Auto	Bool	GNRL_DATA.Auto
GNRL_DATA_Man	Bool	GNRL_DATA.Man
GNRL_DATA_Stp	Bool	GNRL_DATA.Stp
GNRL_DATA_PF	Bool	GNRL_DATA.PF
GNRL_DATA_SP_Ctrl	Bool	GNRL_DATA.SP_Ctrl
GNRL_DATA_Pr_Ctrl	Bool	GNRL_DATA.Pr_Ctrl
GNRL_DATA_Accum_FR	LInt	GNRL_DATA.Accum_FR
GNRL_DATA_RST_Accum_FR	Bool	GNRL_DATA.RST_Accum_FR
GNRL_DATA_Pumping_station_state	Byte	GNRL_DATA.Pumping_station_state
GNRL_DATA_Pumping_station_mode	Byte	GNRL_DATA.Pumping_station_mode
GNRL_DATA_SP_FR_Local	Real	GNRL_DATA.SP_FR_Local
GNRL_DATA_SP_Pmp_Spd_Man	Real	GNRL_DATA.SP_Pmp_Spd_Man
GNRL_DATA_Remote_ctrl	Bool	GNRL_DATA.Remote_ctrl
TC_Data_SP_FR_Remote	Real	TC_Data.SP_FR_Remote
GNRL_DATA_RST_Master	Bool	GNRL_DATA.RST_Master
GNRL_DATA_Notif SC	Word	%DB7.DBW36
Brightness	Int	Local Tag
TC_Data_Mosta_Tank_Lvl	Real	TC_Data.Mosta_Tank_Lvl
TC_Data_Oran_Tank_Lvl	Real	TC_Data.Oran_Tank_Lvl
GNRL_DATA_ACK_Master	Bool	GNRL_DATA.ACK_Master
ELEC_Data_L2_State	Bool	ELEC_Data.L2_State

Appendix E: HMI tags (Continued)

Name	Type	Address / PLC Tag
ELEC_Data_GNRL_DISC_State	Bool	ELEC_Data.GNRL_DISC_State
ELEC_Data_ACK	Bool	ELEC_Data.ACK
XFMR_IO_Notif_1	Word	%DB13.DBW8
XFMR_IO_Notif_2	Word	%DB13.DBW10
ELEC_Data_L1_State	Bool	ELEC_Data.L1_State
ELEC_Data_Notif	Word	ELEC_Data.Notif
ELEC_Data_XFMR_1_OG_CB_State	Bool	ELEC_Data.XFMR_1_OG_CB_State
ELEC_Data_GenSet_State	Byte	ELEC_Data.GenSet_State
ELEC_Data_XFMR_2_OG_CB_State	Bool	ELEC_Data.XFMR_2_OG_CB_State
ELEC_Data_XFMR_4_OG_CB_State	Bool	ELEC_Data.XFMR_4_OG_CB_State
ELEC_Data_XFMR_5_OG_CB_State	Bool	ELEC_Data.XFMR_5_OG_CB_State
ELEC_Data_XFMR_CB_State	Bool	ELEC_Data.XFMR_CB_State
ELEC_Data_CPLG_CB_State	Bool	ELEC_Data.CPLG_CB_State
ELEC_Data_GenSet_CB_State	Bool	ELEC_Data.GenSet_CB_State
ELEC_Data_CB_30KV_State	Bool	ELEC_Data.CB_30KV_State
ELEC_Data_XFMR_Aux_OG_CB_State	Bool	ELEC_Data.XFMR_Aux_OG_CB_State
ELEC_Data_XFMR_3_OG_CB_State	Bool	ELEC_Data.XFMR_3_OG_CB_State
ELEC_Data_RST	Bool	ELEC_Data.RST
FR	Real	GNRL_DATA.FLOW_RATE
P_out	Real	GNRL_DATA.P_out
P_ref	Real	GNRL_DATA.P_Spr
P_asp	Real	GNRL_DATA.P_Asp

Appendix E: HMI tags (Continued)

Name	Type	Address / PLC Tag
Pumps_Ctrl_P1_Man_trig	Bool	Pumps_Ctrl.P1.Man_trig
Pump 1 Alarm 2	Word	%DB1.DBW60
Pump 1 RST	Bool	Master_Pump.Pump_1.RST_Master
Pump 1 ACK	Bool	Master_Pump.Pump_1.ACK_Master
Pump 1 Alarm 1	Word	%DB1.DBW58
Pump_Master_pump_1	Pump	Slaves_Data.pump_1
Pump 2 ACK	Bool	Master_Pump.Pump_2.ACK_Master
Pumps_Ctrl_P2_Man_trig	Bool	Pumps_Ctrl.P2.Man_trig
Pump 2 Alarm 1	Word	%DB1.DBW122
Pump 2 Alarm 2	Word	%DB1.DBW124
Pump_Master_pump_2	Pump	Slaves_Data.pump_2
Pump 2 RST	Bool	Master_Pump.Pump_2.RST_Master
Pumps_Ctrl_P3_Man_trig	Bool	Pumps_Ctrl.P3.Man_trig
Pump_Master_pump_3	Pump	Slaves_Data.pump_3
Pump 3 Alarm 1	Word	%DB1.DBW186
Pump 3 ACK	Bool	Master_Pump.Pump_3.ACK_Master
Pump 3 RST	Bool	Master_Pump.Pump_3.RST_Master
Pump 3 Alarm 2	Word	%DB1.DBW188
Pump 4 ACK	Bool	Master_Pump.Pump_4.ACK_Master
Pump 4 Alarm 1	Word	%DB1.DBW250
Pump 4 RST	Bool	Master_Pump.Pump_4.RST_Master
Pump 4 Alarm 2	Word	%DB1.DBW252

Appendix E: HMI tags (Continued)

Name	Type	Address / PLC Tag
Pump_Master_pump_4	Pump	Slaves_Data.pump_4
Pumps_Ctrl_P4_Man_trig	Bool	Pumps_Ctrl.P4.Man_trig
Pump 5 Alarm 1	Word	%DB1.DBW314
Pumps_Ctrl_P5_Man_trig	Bool	Pumps_Ctrl.P5.Man_trig
Pump 5 RST	Bool	Master_Pump.Pump_5.RST_Master
Pump 5 ACK	Bool	Master_Pump.Pump_5.ACK_Master
Pump_Master_pump_5	Pump	Slaves_Data.pump_5
Pump 5 Alarm 2	Word	%DB1.DBW316
Valves_State_PC_DSV1	Valve	Valves_State.PC_DSV1
Valves_State_PC_USV1	Valve	Valves_State.PC_USV1
Valves_State_PC_DSV2	Valve	Valves_State.PC_DSV2
Valves_State_PC_BPV	Valve	Valves_State.PC_BPV
Valves_State_MDV	Valve	Valves_State.MDV
Valves_State_PC_USV2	Valve	Valves_State.PC_USV2
Valves_State_P5_Sxn_V	Valve	Valves_State.P5_Sxn_V
Valves_State_MSV	Valve	Valves_State.MSV
Valves_State_P4_Sxn_V	Valve	Valves_State.P4_Sxn_V
Valves_State_PC_PCV1	Valve_PC	Valves_State.PC_PCV1
Valves_State_P5_Dis_V	Valve	Valves_State.P5_Dis_V
Valves_State_P1_Dis_V	Valve	Valves_State.P1_Dis_V
Valves_State_P2_Dis_V	Valve	Valves_State.P2_Dis_V
Valves_State_PC_PCV2	Valve_PC	Valves_State.PC_PCV2

Appendix E: HMI tags (Continued)

Name	Type	Address / PLC Tag
Valves_State_P3_Dis_V	Valve	Valves_State.P3_Dis_V
Valves_State_P2_Sxn_V	Valve	Valves_State.P2_Sxn_V
Valves_State_P4_Dis_V	Valve	Valves_State.P4_Dis_V
Valves_State_P1_Sxn_V	Valve	Valves_State.P1_Sxn_V
Valves_State_P3_Sxn_V	Valve	Valves_State.P3_Sxn_V
WHP_DS_Data_C1_Man	Bool	WHP_DS_Data.C1_Man
WHP_DS_Data_RST	Bool	WHP_DS_Data.RST
WHP_DS_Data_Default	Bool	WHP_DS_Data.Default
WHP_DS_Data_Max	Bool	WHP_DS_Data.Max
WHP_DS_Data_Min	Bool	WHP_DS_Data.Min
WHP_DS_Data_Mode	Bool	WHP_DS_Data.Mode
WHP_DS_Data_Visual_Lvl	Real	WHP_DS_Data.Visual_Lvl
WHP_DS_Data_Valve_State_1	Bool	WHP_DS_Data.Valve_State_1
WHP_DS_Data_AC_2	Air_Compr_State	WHP_DS_Data.AC_2
WHP_DS_Notif	Word	WHP_DS_Data.NOTIF
WHP_DS_Data_ACK	Bool	WHP_DS_Data.ACK
WHP_DS_Data_C2_Man	Bool	WHP_DS_Data.C2_Man
WHP_DS_Data_AC_1	Air_Compr_State	WHP_DS_Data.AC_1
WHP_DS_Data_Valve_State_2	Bool	WHP_DS_Data.Valve_State_2
WHP_US_Data_Mode	Bool	WHP_US_Data.Mode
WHP_US_Data_ACK	Bool	WHP_US_Data.ACK
WHP_US_Data_RST	Bool	WHP_US_Data.RST

Appendix E: HMI tags (Continued)

Name	Type	Address / PLC Tag
WHP_US_Data_C1_Man	Bool	WHP_US_Data.C1_Man
WHP_US_Data_min_U	Bool	WHP_US_Data.min_U
WHP_US_Data_C3_Man	Bool	WHP_US_Data.C3_Man
WHP_US_Data_AC_1	Air_Compr_State	WHP_US_Data.AC_1
WHP_US_Data_AC_2	Air_Compr_State	WHP_US_Data.AC_2
WHP_US_Data_AC_3	Air_Compr_State	WHP_US_Data.AC_3
WHP_US_Data_min_D	Bool	WHP_US_Data.min_D
WHP_US_Data_Air_Vent_Mode	Bool	WHP_US_Data.Air_Vent_Mode
WHP_US_Data_max_D	Bool	WHP_US_Data.max_D
WHP_US_Data_max_U	Bool	WHP_US_Data.max_U
WHP_US_Notif	Word	%DB5.DBW12
WHP_US_Data_Valve_State_4	Bool	WHP_US_Data.Valve_State_4
WHP_US_Data_Valve_State_3	Bool	WHP_US_Data.Valve_State_3
WHP_US_Data_Valve_State_2	Bool	WHP_US_Data.Valve_State_2
WHP_US_Data_Visual_Lvl	Real	WHP_US_Data.Visual_Lvl
WHP_US_Data_Valve_State_1	Bool	WHP_US_Data.Valve_State_1
WHP_US_Data_C2_Man	Bool	WHP_US_Data.C2_Man
WHP_US_Data_Lvl_Mode	Bool	WHP_US_Data.Lvl_Mode

Appendix F: Pumping station plans

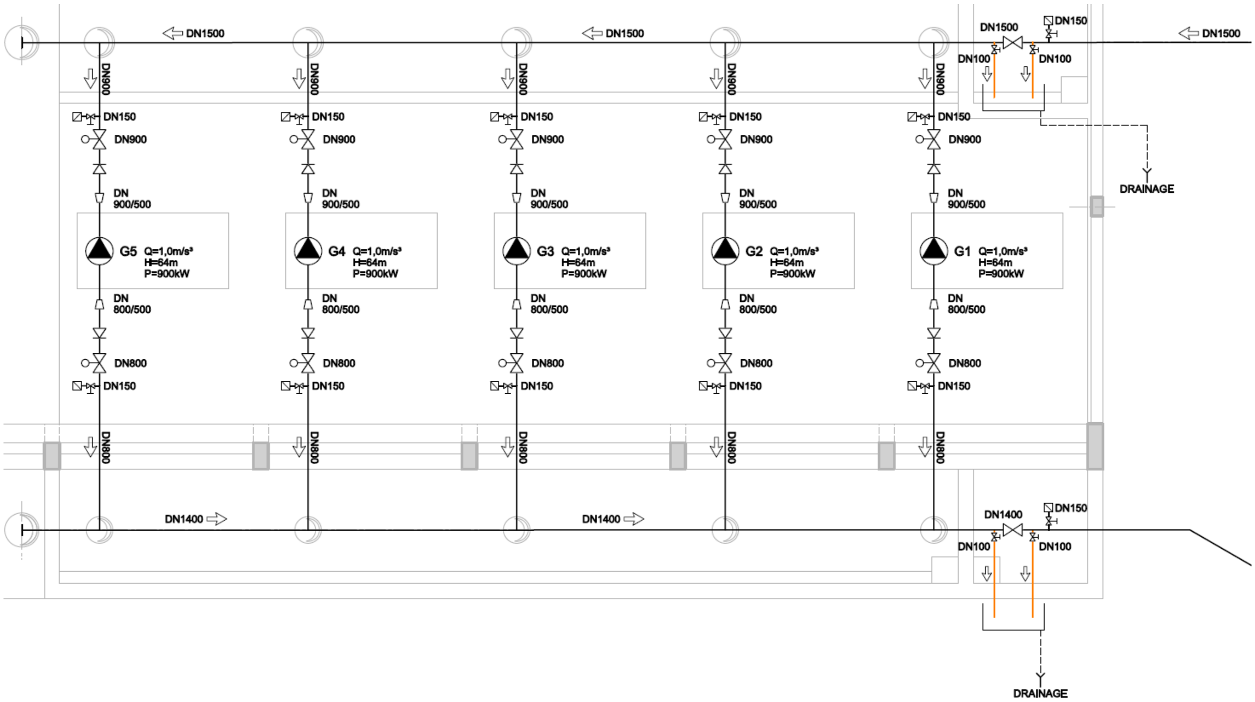

Figure A pumps room plan

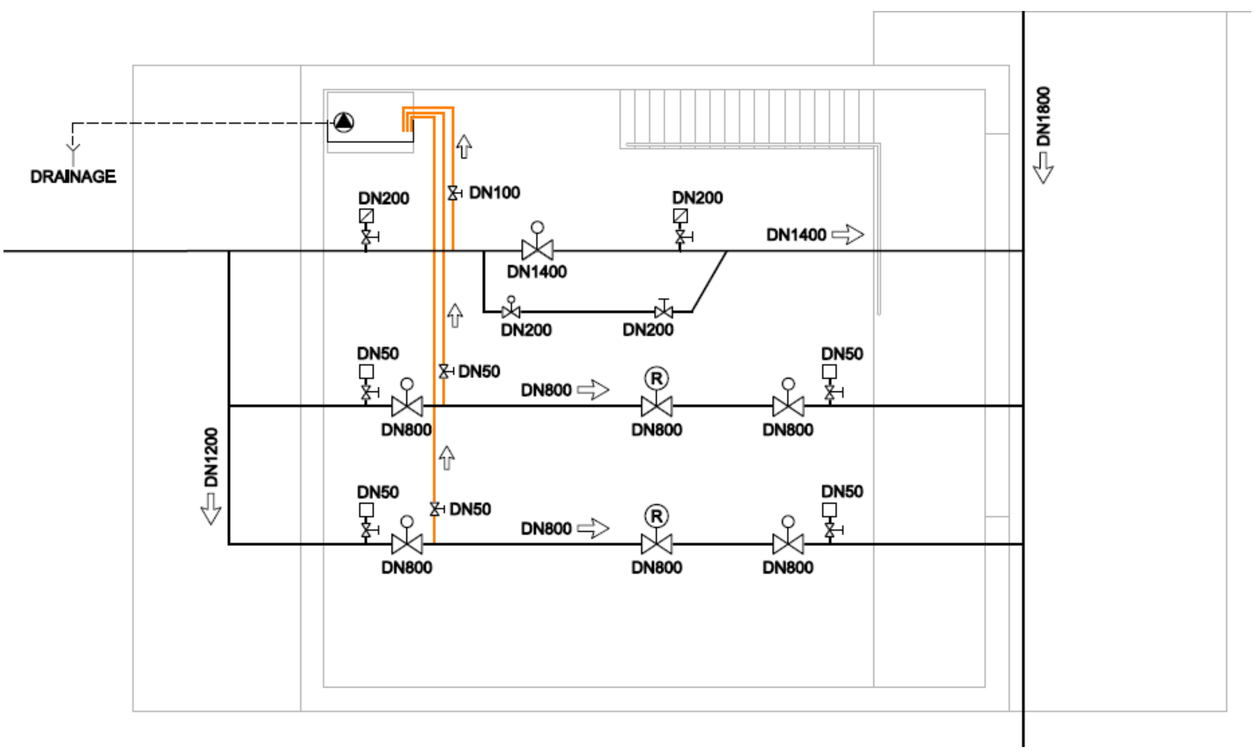

Figure B Pressure control room plan

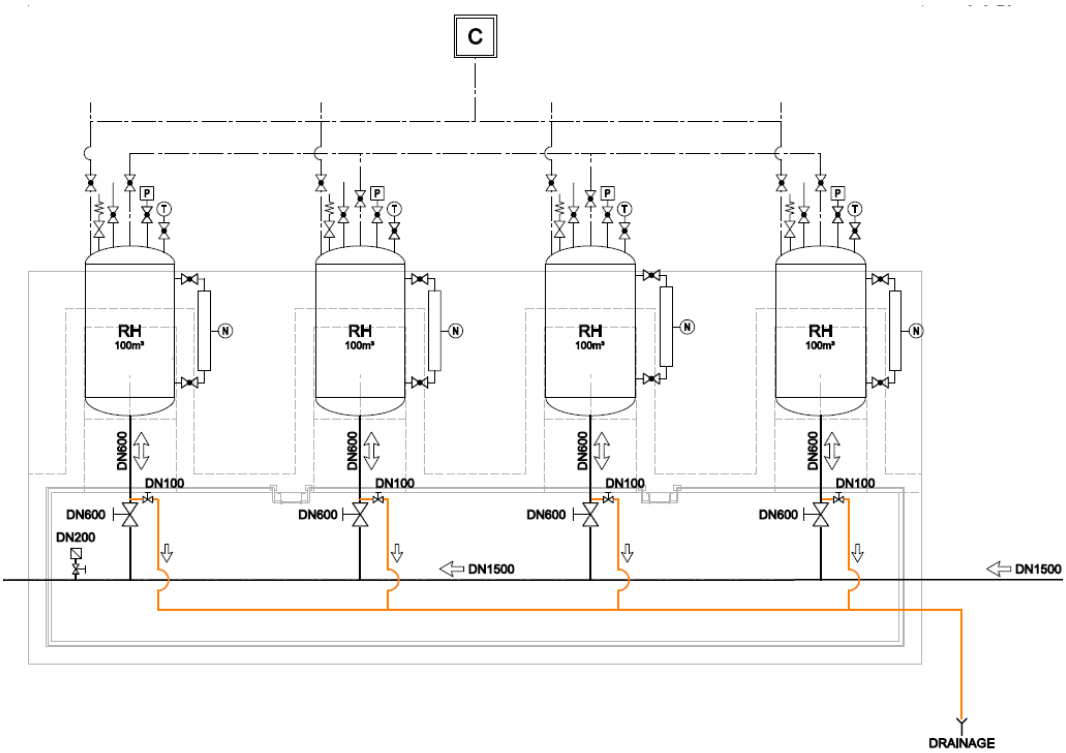

Figure C U/S WHP plan

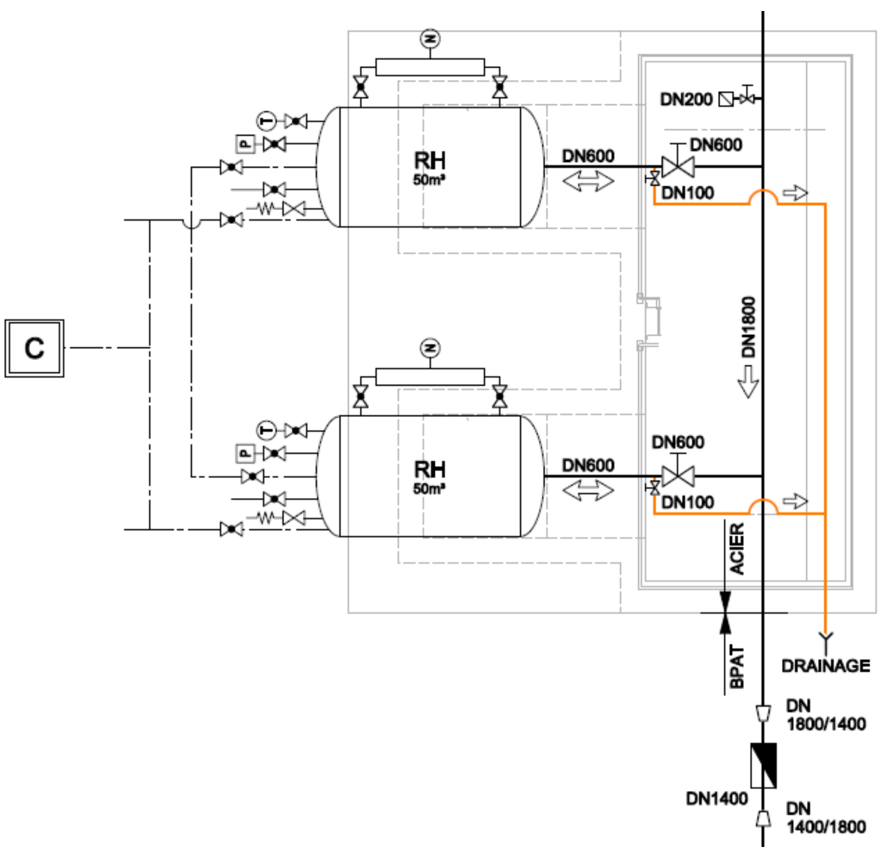

Figure D D/S WHP

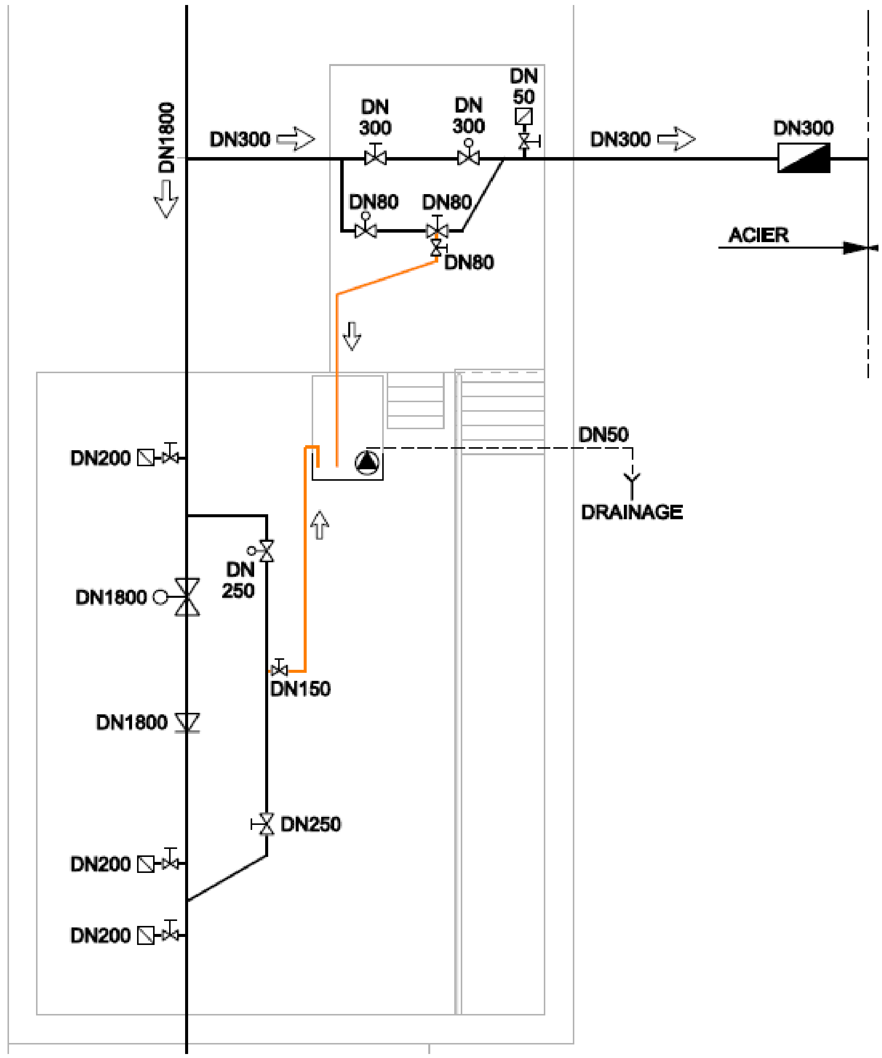

Figure E CR11 room plan