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Analysis and Design of a SCADA System

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Abstract

Supervisory Control And Data Acquisition (SCADA) systems are essential for improving industrial and automation systems. Moreover they provide complete control of the plant, better communication and efficiency for the system.

The aim of this study is to plan and design a modern SCADA System for the purpose of Hassi Ben Okba pumping station. To do so, an optimum SCADA system is suggested taking into account all the necessary parameters.

Résumer

Les systèmes de contrôle et d'acquisition de données (SCADA) sont essentiels pour améliorer les systèmes industriels et d'automatisation. De plus, ils fournissent un contrôle complet de l'installation, une meilleure communication et une meilleure efficacité du système.

Le but de cette étude est de planifier et de concevoir un système SCADA moderne pour la station de pompage Hassi Ben Okba. Pour ce faire, un système SCADA optimal est suggéré en tenant compte de tous les paramètres nécessaires.

ملخص

تعد أنظمة التحكم الإشرافي والحصول على البيانات (سكادا) ضرورية لتحسين الأنظمة الصناعية وأنظمة الأتمتة. علاوة على ذلك ، فإنها توفر التحكم الكامل في المصنع ، وتحسين الاتصال والكفاءة للنظام.

الهدف من هذه الدراسة هو تخطيط وتصميم نظام (سكادا) الحديث لغرض محطة ضخ حاسي بن عقبة. للقيام بذلك ، تم قترح نظام يسمح بمراعاة جميع المعلمات الضرورية.

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

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Abbreviation

AE	Alarms & Events
D/S	Downstream
DA	Data Access
DNP	Distributed Network Protocol
DX	Data eXchange
eWON	European Work Organization Network
HAD	Historical Data Access
HDLC	High Level Data Link Control
HMI	Human Machine Interface
IEC	International Electrotechnical Commission
ISO	International Standards Organization
LAN	Local Area Network
MTU	Master Terminal Unit
OPC	Open Platform Communications
OSI	Open Systems Interconnection
PLC	Programmable logic controller
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SQL	Structured Query Language
U/S	Upstream
UA	Unified Architecture
VPN	Virtual Private Network
WAN	Wide Area Network
WHP	Water Hammer Protection
XML	Extensible Markup Language

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 & analyzing 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, analyzing behavior 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].

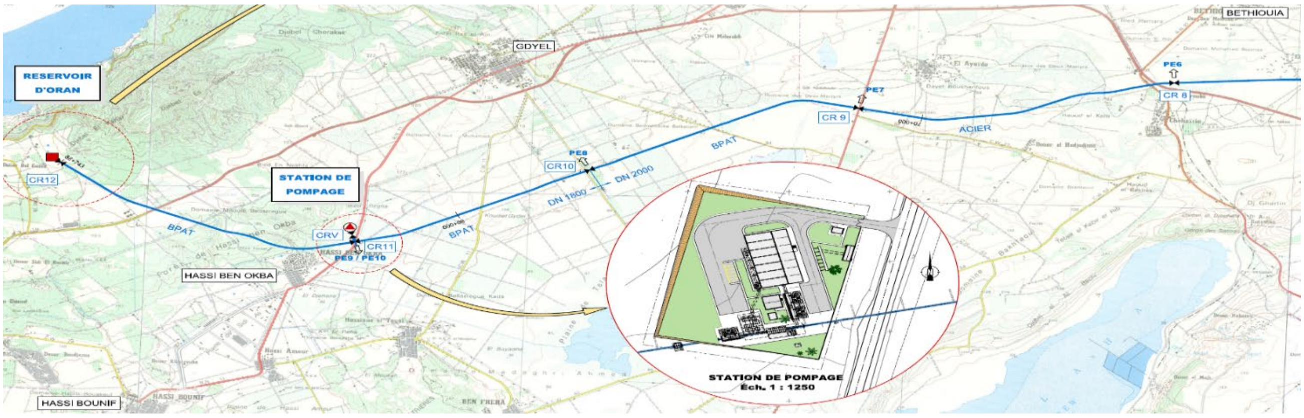


Figure I-3 Location of Hassi Ben Okba pumping station

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

Supervision and monitoring system

II.1 Introduction

A supervision and monitoring system aims at performing, in the best conditions, production planning. It means that it has to recognize abnormal situations. Then, the origin of this situation must be found ‘diagnosis problem’. When the problem is well identified, a curative solution must be elaborated. Actions on the control system and on the controlled process have to be performed.

This chapter describes the main aspects, concepts, functionalities and methodologies for supervision and monitoring system.

II.2 Basics concepts

Generic terms related to supervision and monitoring systems are defined in this section,

- **Fault**: action, voluntary or not, that does not take all the specifications into account.
- **Defect**: difference between the actual value of a parameter and its nominal value.
- **Error**: part of a model isn't exactly matching the specifications of the physical system. Logically, an error is a consequence of a fault.
- **Latent error:** the error is qualified of latent as long as the erroneous part of the model has not been used. After uses of the erroneous part, the error becomes effective.
- **Malfunction**: execution of a process operation that does not give the expected results.
- **Failure**: event characterizing a situation in which an operation is not executed by a resource because its state does not correspond any more to the nominal specifications.
- **Breakdown state**: state from which the system cannot provide the specified service. This state follows from a failure.
- **Symptom:** event or data through which the detection system identifies an abnormal operation of the process. The symptom is the only information the monitoring system knows at the detection step.
- **Exception**: predefined corrective treatment executed when a specific symptom is recognized.
- Mechanism reserved for well-known failures needing no heavy corrective means.
- **Recovery point:** state reachable from the breakdown state in which the system must be driven to return to the normal operation.
- **Recovery sequence:** set of ordered actions executed in order to make the process evolve from the breakdown state to the recovery point [3].

II.3 Monitoring

A monitoring system features a hardware device and a purpose-developed software program, this system is used to collect data from the process and from the controller, determine the actual state of the controlled system and makes the inferences needed to produce additional data (historic, diagnosis, etc.). In this case, the status of the system being monitored can only be checked, this means no direct actions either on the models or on the process are performed.

This system is most advantageous when associated with an alarm signaling system. In this case, the values are compared against a series of preset standard or ideal values, or against a range of values that the monitored parameters must stay within. If the values read do not coincide with the preset parameters, the alarm system signals a fault, allowing the user to take action to restore optimum operating conditions. [3; 4]

II.4 Remote management

The user can set the system control parameters remotely, such as the operating times, set points and alarm thresholds. The centralized management of systems that may be installed even large distances apart simplifies troubleshooting operations, as the actions can be carried out in real time [4].

II.5 Supervision

Computes and parameterizes the control sequence to be executed according to the state of the control system and of the process, providing for the system itself to make decisions, when certain situations arise, so as to ensure correct operation, resolve problems and optimize energy consumption. It includes normal and abnormal operation [3; 4].

- During normal operation, the supervision takes the decisions to raise the indecision in the control system (real-time scheduling, optimization, control parameterization and switching from a control law to another one).
- When a process failure occurs, supervision takes all the decision necessary to put the system back: in its normal operation (rescheduling, recovery actions, emergency procedures, ...)

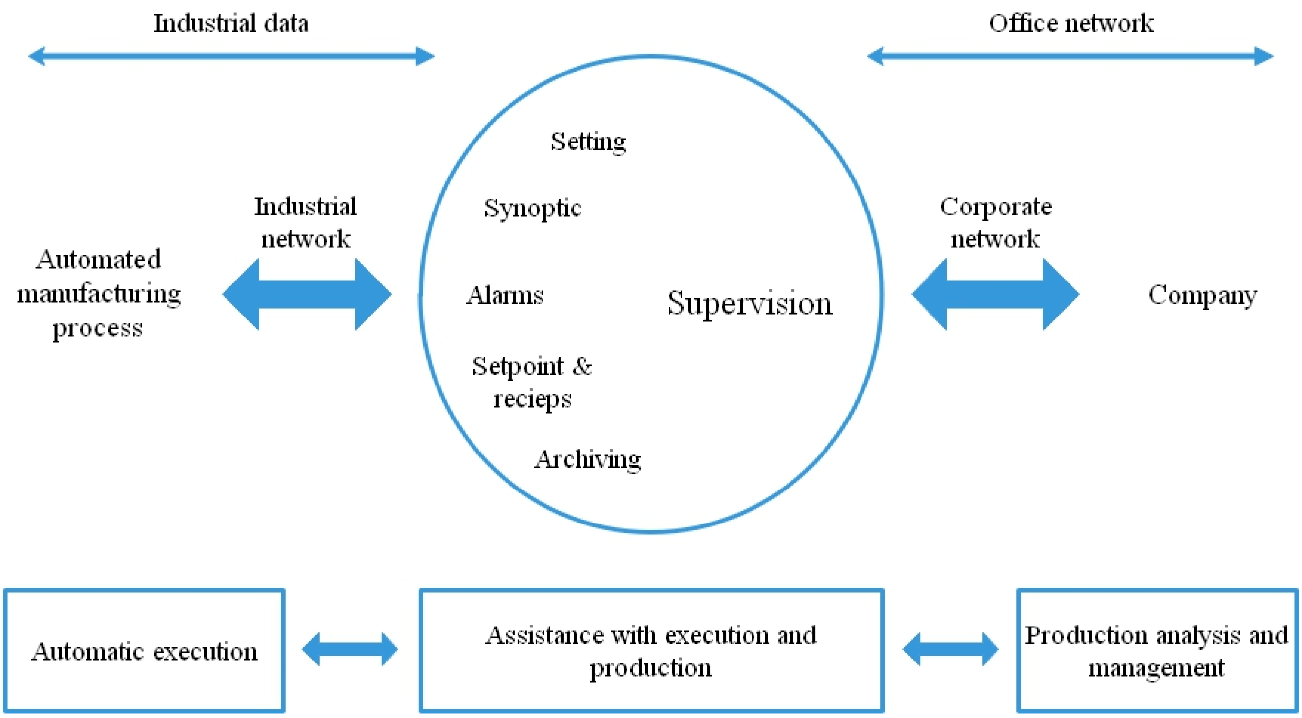


Figure II-1 Supervision chart

II.6 Supervision methodology

It simply provides the answer to the following questions:

- What to supervise?
- How to supervise?
- When to supervise?

The what describes the application domain in which we want to obtain information about or have control over, monitor and interact with its equipment and devices.

The How corresponds to the methods used in order to supervise such as: the observation, the analysis, the detection… etc.

The when is how frequent we want to supervise [5].

II.7 Active and Passive supervision

Two main methods of supervision are passive and active, described briefly bellow [5].

II.7.1 Active supervision

It's the most widely used method, it has the advantage of being reliable, the checks for supervised data are carried out regularly and in question-answer mode. It consists of steps listed below:

- The server sends a request to the supervised resource.
- The resource responds to the server request.
- The server analyzes the information and determines a state for the resource.

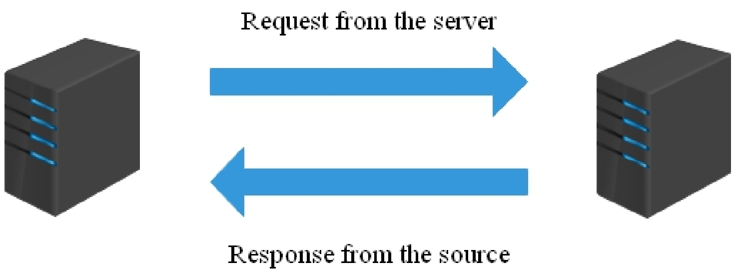


Figure II-2 Active supervision

II.7.2 Passive supervision

The supervised data are checked in the remote units, and the results are transmitted to the server, the server receives the alerts and processes it. The data exchange is unidirectional. It has the advantage of reduced communication costs, yet a major disadvantage concerns the update of information, there is no guarantee that the supervised resource is in a correct state if no data are received.

Figure II-3 Passive supervision

II.8 Elementary functions of a supervision and monitoring system

Several features have been developed and implemented in supervision and monitoring systems, in general they are dived into two categories described as follow: [3]

II.8.1 Monitoring functions:

a. **Data acquisition**: collect technical data coming from the process sensors and the controller.

b. **Perception**: extracts indicators from technical data. Other monitoring functions to determine if the process evolutions are normal ones uses these indicators or not.

c. **Detection:** determine the normality or abnormality of the system functioning. Two classes of abnormal operations are considered:
   - The first one includes situations in which basic operating constraints of the process are violated (collisions for instance).
   - The second one groups together situations in which the part routing (control law) is not respected (fabrication delays for instance).

d. **Filtering:** forbid requests sending if the process is not in a state compatible with the corresponding evolution.

e. **Follow**: maintain a history of treatments executed by and a trace of events observed by the Control supervision system.

f. **Classification:** evaluate the degree of severity of the failure in order to adapt the treatment to the criticity of the situation (emergency shutdown, diagnosis, ...). A failure can be:
   - Critical, needing an emergency processing,
   - Significant, needing a specific treatment,
   - Minor or without global consequences,
   - Tolerable (by the controller), not requiring a corrective treatment.

g. **Diagnosis:** look for a causality link between the observed symptom, the failure and its origin. Classically, three sub-functions are distinguished:
   - Localization determines the subsystem responsible for the failure.
   - Identification identifies the causes of the failure.
   - Explanation justifies the conclusions.

h. **Prognosis:** foresee the consequences of a failure on the future operation of the system. The consequences can be immediate ones (resource unavailable) or induced ones (faulty parts in the workshop).

Figure II-4 shows a summary of monitoring functions.

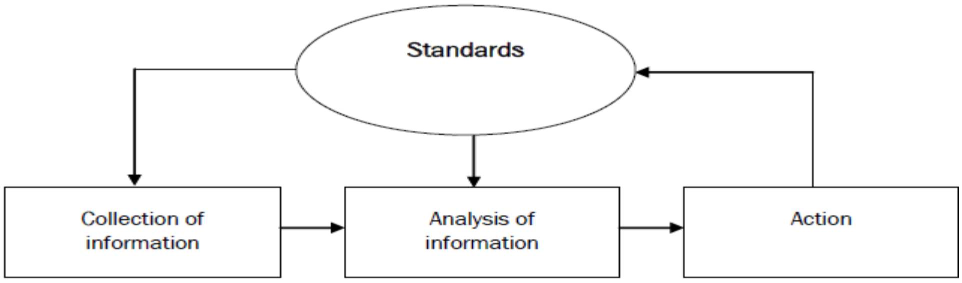


Figure II-4 Monitoring functions

II.8.2 Supervision and control

- **a. Safety and emergency mechanism:** processing with a high level of priority applied in order to avoid dangerous evolutions for the machines or the shop workers.
- **b. Compensation:** guarantee the service continuity when a failure occurs. This term does not distinguish between a temporary and a complete process repairing.
- **c. Reconfiguration**: acts on the process by changing the resources states or equipment and on the control system by changing the control laws, the part routing, etc. Three classes can be defined:
  - Minor, only the control law is adapted,
  - Significant, other resources are re-allocated,
  - Major, re-allocated resources need to be prepared to execute the recovery.
- **d. Decision:** determine the state that must be reached to return to the normal operation, then determines the sequence of corrective actions to be performed to reach this state.
- **e. Resumption**: execute the corrective actions needed to return to a normal operation [3].

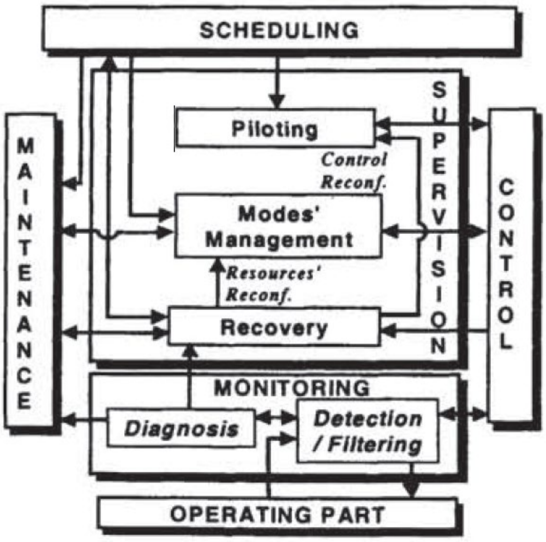


Figure II-5 Structure of monitoring and supervision

II.9 Supervision Standards (ISO 7498/4)

The concept of supervision has been standardized by ISO. The defined functions are:

II.9.1 Performance management

The performance and efficiency of resources that constitute the system must be evaluated, it includes procedures for data collection and statistics, dashboard establishment, and plan developments in the network.

Network performance is evaluated based on four parameters:

- Response time
- The flow
- The error rate per bit
- Availability

II.9.2 Configuration management

Configuration management allows you to identify, configure and control the various network objects. The procedures required to manage a configuration are:

- Information gathering
- State control
- Historical backup of system state configurations.

II.9.3 Accounting management

Its role is to know the charges of the managed objects as well as their communication costs. Usage quotas can be set temporarily or not on each of the network resources. In addition, accounting management authorizes the implementation of billing systems according to the use for each user. Therefore, it allows the establishment of user costs as well as invoicing for the use of resources.

II.9.4 Fault management

Fault management allows the detection, localization and correction of transient or persistent anomalies.

II.9.5 Security Management

Security management controls access to resources based on established usage rights policies. It ensures that unauthorized users cannot access certain protected resources.
It also has the role of implementing security policies.

Chapter III

Scada system

III.1 History

Before SCADA, plant personnel had to be maintained on site, during production, in order to control the processes via selector switches, push buttons, and dials for analog signals.

Relays and timers were used to provide some level of supervisory control and limited automation functionality yet they were difficult to reconfigure and troubleshoot. As manufacturing grew and remote sites began to scale out in size, solutions were needed to control equipment over long distances.

Controlling industrial plants via processors became a reality in the early 1950s. Where computers were first developed and used for industrial control purposes, thanks to the telemetry establishments in the 60s the measurement data could be transmitted from remote to monitoring units. Another decade later the term SCADA was used to describe systems with PLC's and microprocessors that were being used for the monitoring and control of automated processes on an even greater scale yet each SCADA system stood on its own because Networks were not available "referred to as monolithic SCADA systems." In the next couple of decades, the '80s and 90s, with the advent of Local Area Networking (LAN), and HMI software, SCADA systems were able to connect to related systems. Unfortunately, these were incapable of communicating with systems from other vendors. These systems were called distributed SCADA systems Later in the '90s and 2000s, SCADA began to implement open system architectures with communication protocols that were not vendors specific.

With the adoption of modern IT standards such as SQL and web-based applications, software has greatly improved the efficiency, security, productivity, and reliability of SCADA systems [6].

III.2 Definition

The SCADA acronym stands for Supervisory Control and Data Acquisition, it is a collection of both software and hardware components that allows to:

- Gathering and analyzing real-time data.
- Interact with devices such as sensors, valves, pumps, motors locally or remotely.
- Record events into a log file.

This collection begins with real-time data collected from plant floor devices, then passed to the processors such as PLCs. From the processor, the data are distributed to a remote-control center where a graphical representation of the operations exists for operator interactions that help to maintain efficiency, process data for smarter decisions, and communicate system issues as well as enabling a high-level process supervisory management and control [6; 7].

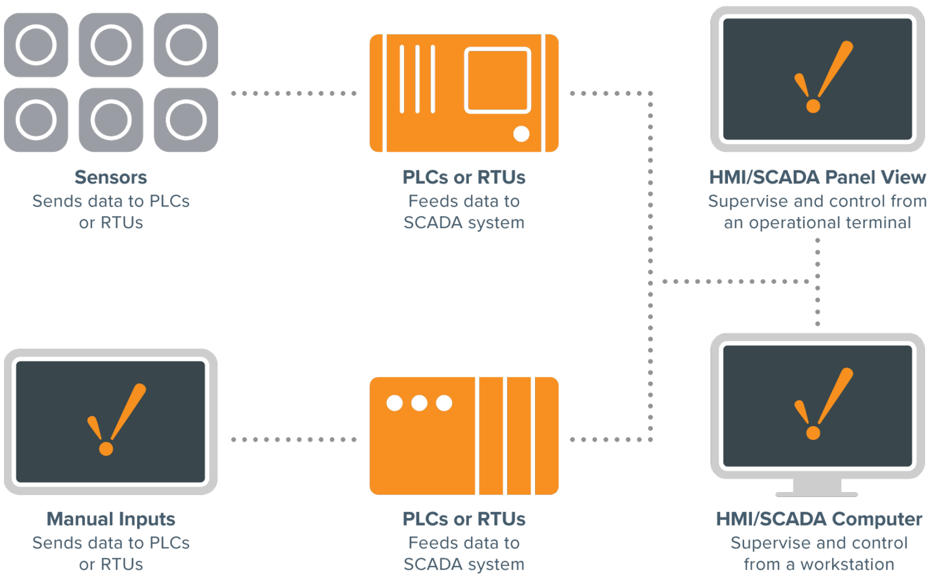


Figure III-1 A Basic SCADA Diagram

III.2.1 Objectives of SCADA

SCADA systems work well in many different types of enterprises because they can range from simple configurations to large, complex installations. In view of this, Scada systems aims to: [6]

- Monitor: continuously monitoring the physical parameters.
- Measure: measuring the processing parameters.
- Data Acquisition: Archiving & retrieving It acquires data from RTU, data loggers, etc., and then store it in the data center.
- Data Communication: provide a communication and transmission medium for data between different remote sites and central unit.
- Controlling: it allows interact with field devices and control stations remotely or locally.
- Automation: It helps for automatic transmission and functionality.
- Reports valued tool for tracking and analyzing performance and overall production health.

III.2.2 Benefits of Scada

Effective SCADA systems can result in significant savings of time and money. Numerous case studies have been published highlighting the benefits using a modern SCADA software solution, some of these benefits are:

- Improved overall System efficiency and performance.
- Improved reliability and quality of service.
- Reduce operation and maintenance cost.
- Reduced labor costs required for troubleshooting or service.
- Reduce system implementation costs.
- Facilitates engineering decision.
- Provide immediate knowledge of overall system health.
- High value service providers.

III.2.3 Features of Scada

SCADA systems perform several functions that allow for proper management of remote facilities. The following are the core functions of SCADA system [8].

- Alarm handling
- Trend curves patterns
- Data access and retrieval
- Computer networking and processing
- Substation parameter monitoring
- Safety tagging
- High-resolution time stamping
- Sequence of events reporting for post event analysis
- Demand side management
- Volt/VAR control
- Preventive maintenance
- Fault detection isolation and restoration

III.3 Applications of Scada

SCADA is widely used in different industrial organizations and companies in the public and private sectors the list of applications of SCADA can be listed as follows: [9]

a) **Electric power generation, transmission and distribution**: Electric utilities use SCADA systems to detect current flow and line voltage, to monitor the operation of circuit breakers and to take sections of the power grid online or offline.

b) **Water, Waste Water Utilities and Sewage:** State and municipal water utilities use SCADA to monitor and regulate water flow, reservoir levels, pipe pressure and other factors.

c) **Buildings, facilities and environments:** Facility managers use SCADA to control HVAC, refrigeration units, lighting and entry systems.

d) **Manufacturing**: Manage parts lists for just-in-time manufacturing, regulate industrial automation and robots, and monitor quality and process control.

e) **Mass transit**: Transit authorities use SCADA protocols to regulate electricity in remote locations. They also use it to automate traffic signals, to track and locate trains and buses, and to control railroad crossing gates.

f) **Traffic signals** SCADA regulates traffic lights, controls traffic flow, and detects out-of-order signals

III.4 Functional Units of SCADA

The major components of SCADA system include: [5; 7]

- Master Terminal Unit (MTU).
- Remote Terminal Unit (RTU).
- Communication Network.

III.4.1 Master Terminal Unit (MTU)

A central host computer server or servers (sometimes called SCADA Center, master station, Master Terminal Unit (MTU) or Main Control Room (MCR)). It’s responsible for communication establishments, collecting and saving data, interfacing with operators and to communicate data to other systems [5; 7].

III.4.2 Remote Terminal Unit (RTU)

One or more field data interface devices, which interface field sensing devices and actuators. Collect data and send it to the MTU when requested, modern technology such as PLCs are used as RTUs. This helps for direct transfer and control of data without any signal from MTU [5; 7].

III.4.3 Communication Network

A communications system used to transfer data between RTU and MTU, the communication mediums can be wired or wireless channels, fiber optic cables, twisted pair cables [5; 7].

III.5 Architecture of SCADA

SCADA architecture may be divided in two categories: [10]

- Hardware Architecture
- Software Architecture

III.5.1 Hardware architecture

This architecture of the system englobes two main parts:

- **Client Layer**: For human machine interface
- **Data Server Layer**: For data processing

The SCADA station refers to the servers, and it is composed of a single PC which process controllers like PLCs or RTUs in the field can communicate with directly or indirectly via WAN or LAN networks.

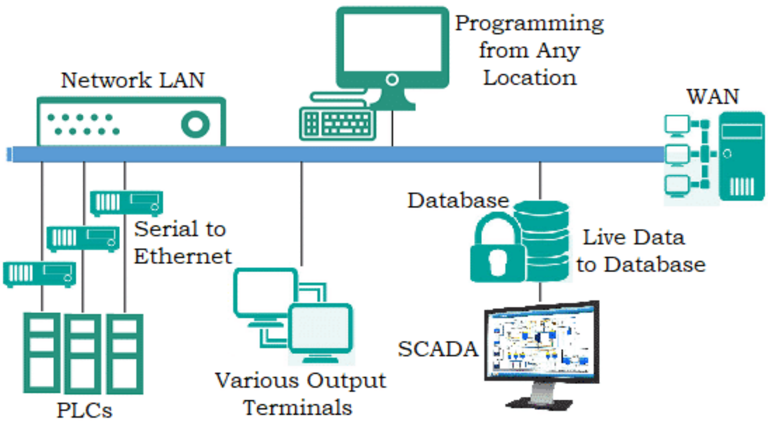


Figure III-2 Scada Hardware architecture

III.5.2 Software Architecture:

The software architecture consists of:

- Server which is used mainly for a real-time database and multitasking and are responsible for handling and gathering of data.
- Set of programs that provides the main functionalities of SCADA system such as trending, diagnostic and troubleshooting information, more over a graphical representation of the plant.

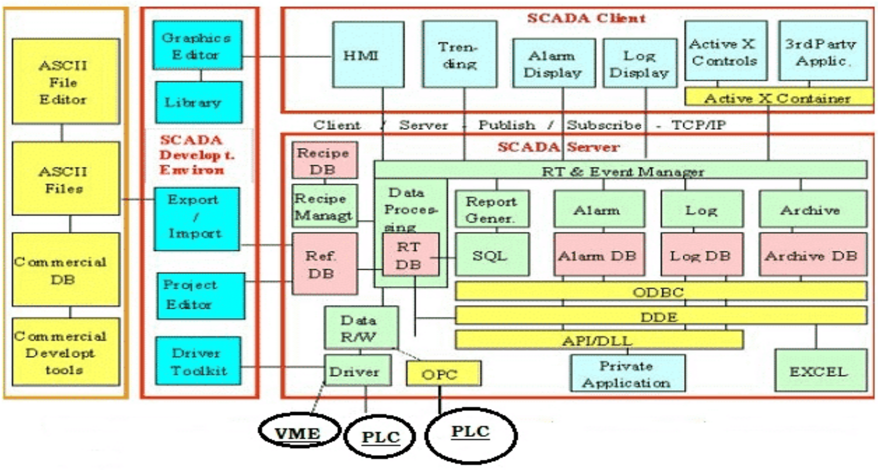


Figure III-3 Scada Software architecture

III.6 Scada protocols:

Protocols allow different functional units of Scada to communicate with each other [11]. The two widely used protocols for SCADA Applications are:

- HDLC (High Level Data Link Control).
- MODBUS.

III.6.1 ISO Model

The protocols are based on the ISO (International Standards Organization) standard seven-layer OSI (Open Systems Interconnection) model, the details of which are given below. The different layers are categorized based on the functions they perform.

The model makes it possible for communications to become independent of the devised system and shield the user from the need to understand the complexity of the network [11].

Table III-1 OSI Reference model layers

Layer name	Description
Application	This layer provides the network services to the user's application programs, even though actual application programs do not reside in this layer.
Presentation	The presentation layer primarily takes care of data representation, including encryption.
Session	The session layer provides the mechanism for opening, closing and managing a session between end-user application processes.
Transport	The Transport Layer manages the communications between the two end systems.
Network	The Network Layer is primarily responsible for the routing of messages.
Data link	The data link layer is responsible for assembling and sending a frame of data from one system to another.
Physical	The physical layer defines the electrical signals and mechanical connections at the physical level.

III.6.2 DNP3 Protocol

The DNP3 or Distributed Network Protocol is a set of communications protocols utilized in communication between functional units of Scada, DNP3 supports multiple-slave, peer-to-peer and multiple-master communications. It supports the operational modes of polled and quiescent operation. The latter is also referred to as reporting by exception.

This protocol is designed to avoid being distorted by legacy equipment, as well as EMI noise and low-grade transmission channels. This protocol shows an important reliable communication medium but it’s not secure from hackers and threats [11; 12].

Advantages of DNP3 protocol

- Open protocol.
- Optimized for SCADA communications.
- Provide interoperability between different vendor’s equipment.
- Supported by a substantial number of SCADA equipment manufacturers.
- Improved bandwidth efficiency which is accomplished through event-oriented data reporting.
- DNP3 has good ability to handle error detection.

III.6.3 IEC60870 Protocol

IEC 60870-5 is the collection of standards produced by the IEC (International Electrotechnical Commission). This standard can be used for interoperating various equipment from different suppliers through standardized protocols. It is widely used for controlling electric power transmission grids since provides tele-control and tele-protection of electric power systems through associated tele-communication [11; 12].

IEC standard 60870 has five parts, defining general information related to the standard, operating conditions, electrical interfaces, performance requirements and data transmission protocols. These parts are:

- IEC 60870-5-1: Transmission Frame Formats.
- IEC 60870-5-2: Data Link Transmission Services.
- IEC 60870-5-3; General Structure of Application Data.
- IEC 60870-5-4; Definition and Coding of Information Elements.
- IEC 60870-5-5; Basic Application Functions.

III.6.4 HDLC

HDLC (High Level Data Link Control) is a bit-oriented code transparent synchronous data link layer protocol developed by ISO. HDLC provides connection – oriented and connection – less services. Though HDLC can be used for point to point and multi-point connections, but is preferable to use one to one connections, known as asynchronous balanced mode (ABM). It forms the basis for all modern protocols [11; 12].

III.6.5 Modbus

MODBUS protocol is simple and robust which has become a widely used standard communication protocol for connecting industrial electronic devices. The protocol determines how each controller will know device address, recognize a message addressed to it determine the action to be taken and extract any information/data attached to it [11; 12].

The advantages of MODBUS protocol

- Industry centric.
- Open Source
- Easy to use and deploy
- Vendor independent

III.7 Open Platform Communications

III.7.1 Definition

The OPC (Open Platform Communications) is the standardized specification for industrial communication applications, based on Client/Server architecture, the clients send requests to the server and the server responds to the client requests. The client decides what data type should read from/write to the system and how frequently this can happen.

OPC has several protocols, each of which have their commands that only affect one protocol at the time, even if the OPC server supports different types of protocols. Some of these protocols are: DA (Data access) The most commonly used and oldest protocol, AE (Alarm & Events), HDA (Historical Data Access), XML DA (XML Data Access) and finally DX (Data eXchange). The following sections provide more details [13].

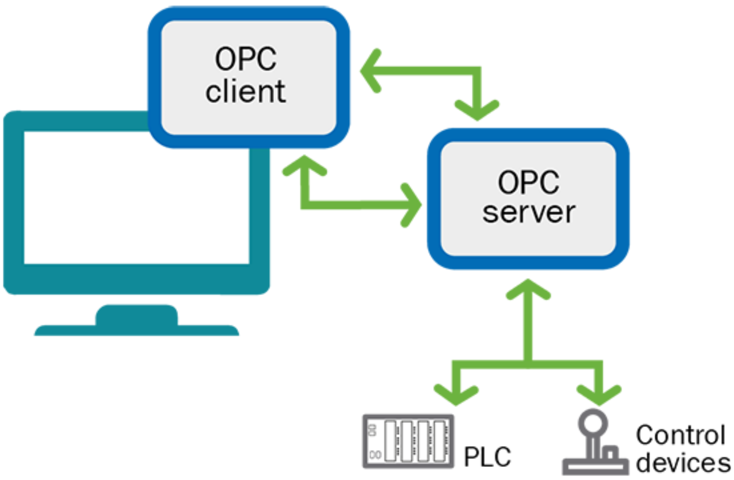


Figure III-4 OPC client server architecture

III.7.2 Data Access DA

The most basic protocol of the OPC stack is the Data Access protocol that defines how real-time data can be transferred between a data source such as PLCs, and a data sink like Human-Machine Interfaces (HMI), SCADA systems and also ERP/MES systems [13; 14].

There are three attributes associated with OPC DA data. These are:

- A value.
- The quality of the value gives a basic understanding if the data are valid or not.
- A timestamp. That gives the exact time when the value was read.

III.7.3 Alarms & Events AE

The second protocol to be added to the OPC stack was Alarms & Events, used to exchange process notifications and alarms, obtain a sequence of events, it is a subscription-based service where the clients gets all the events that comes in associated with a timestamp [13].

III.7.4 Historical Data Access HDA

The difference between DA, AE and HDA is that HDA contains historical data such as databases. Including raw, interpolated and aggregate data archived process data can be exchanged in a large amount. The protocol is not so widely used today and now the introduction of OPC UA makes it somewhat obsolete [13].

III.7.5 Unified Architecture

This protocol is an independent service-oriented architecture that integrates all the functionality of the individual OPC Classic specifications into one extensible framework. The other very important part of UA is the possibility to use structures or models. This means that the data tags or points can be grouped and be given context which make governance and maintenance much easier. Its characteristics are: [13]

- Focus on communicating with industrial equipment and systems for data collection and control
- Open - freely available and implementable under GPL 2.0 license.
- Cross-platform - not tied to one operating system or programming language.
- Service-oriented architecture (SOA).
- Inherent complexity.
- Offers security functionality for authentication, authorization, integrity and confidentiality.

- Integral information model, which is the foundation of the infrastructure necessary for information integration where vendors and organizations can model their complex data into an OPC UA namespace.

III.7.6 XML

This protocol is based on the OPC Data Access specifications and used to communicate data in XML facilitate the exchange of plant data across the Internet, via Web services according, which are available over the same TCP port as the built-in web server and upwards into the enterprise domain. It incorporates SOAP and Web services. The OPC server exposes simple data points and complex AST™ functions and. Because Web services are built for being routed across the Internet, the built-in OPC XML-DA server uses basic authentication for protection against unauthorized write access [13; 15].

III.7.7 OPC DX

OPC Data eXchange (OPC DX) designed to define how OPC servers exchange data with other OPC servers, and to address the needs of device-to-device or bus-to-bus communications without having to go up into the HMI or other higher layers. OPC DX does not specify a new method for the data transfers and relies on OPC Data Access (OPC DA) data transfer capabilities already in use, while a small number of vendors incorporated this specification in their products, there are no commercial implementations of this technology. The Characteristics of this protocol are: [16]

- OPC DX provides a standardized method for OPC Server to OPC Server data transfers.
- OPC Server vendors that implement OPC DX in their OPC Servers can in turn directly exchange data with other OPC Servers that implement OPC DX.
- OPC DX connections can be locally or remotely managed.

Chapter IV

Design and Simulation

IV.1 Introduction

The pumping station case study is part of the total water production system in the city of Oran. The SCADA system implemented within the technological building of SEOR allows the personnel to supervise and monitor the production system.

After defining the basic concepts and the fundamentals of the SCADA system in the previous chapters, we may now describe the functional analysis.

IV.2 Functional analysis

In order to design and build the SCADA system, a set of requirements are needed.

IV.2.1 Operator interface:

The operator interface includes:

- A graphical representation of the elements that constitute the pumping station such as: the pumps, the valves, the surge tanks, the pipes.
- Display of individual pump speed, the downstream and upstream pressures, instant and accumulated flow rate downstream of the station, number of running pumps and average running speed.
- Control elements such as trends, alarms view and acknowledgment.

IV.2.2 Data exchange:

Table IV-1 shows the data received:

Table IV-1 Received data

Name	Type
Instant flow rate	Real
accumulated flow rate	Integer
Downstream pressure	Real
Upstream pressure	Real
Pressure control valve position	Real
Deferential pressure	Real
By-pass valve state	Byte
Number of running pumps	Integer

Table IV-1 Received data (Continued)

Name	Type
Average frequency	Real
Total efficiency	Real
Energy cost	Real
Pump communication state [1]	Boolean
Pump state [1]	Byte
Pump speed [1]	Real
Hour meter [1]	Real
On duration [1]	Real
Off duration [1]	Real
Number of start-ups [1]	Integer
Pump bearing temperature 1 & 2 [1]	Real
Motor winding temperature 1 & 2 [1]	Real
Motor bearing temperature 1, 2 & 3 [1]	Real
Motor current [1]	Real
Individual Suction valve state [1]	Byte
Individual Discharge Valve state [1]	Byte
CR11 Valve state	Byte
Main suction valve	Byte
Main Discharge Valve	Byte
Local/Distance mode	Boolean
U/S WHP mode	Boolean
D/S WHP mode	Boolean
CR12 valves commands	Boolean

[1] For each motor-pump group

Table IV-2 shows the data sent:

Table IV-2 Transmitted data

Name	Type
Remote flow rate set point	Real
Mostaganem tank level	Real
Oran tank level	Real
CR12 valves limit switches (open & close)	Boolean
Pressure control valve position	Real

IV.2.3 Trends

Trends are essentially important for an industrial automation system. They are used to record real-time data from the field, retrieve historical data and present them in graphical ways allowing the operator to monitor the change in value over time. The following trends are requested:

- Instant flow rate.
- Downstream and Upstream pressures.
- Speed and current of each motor-pump group.
- Energy cost.

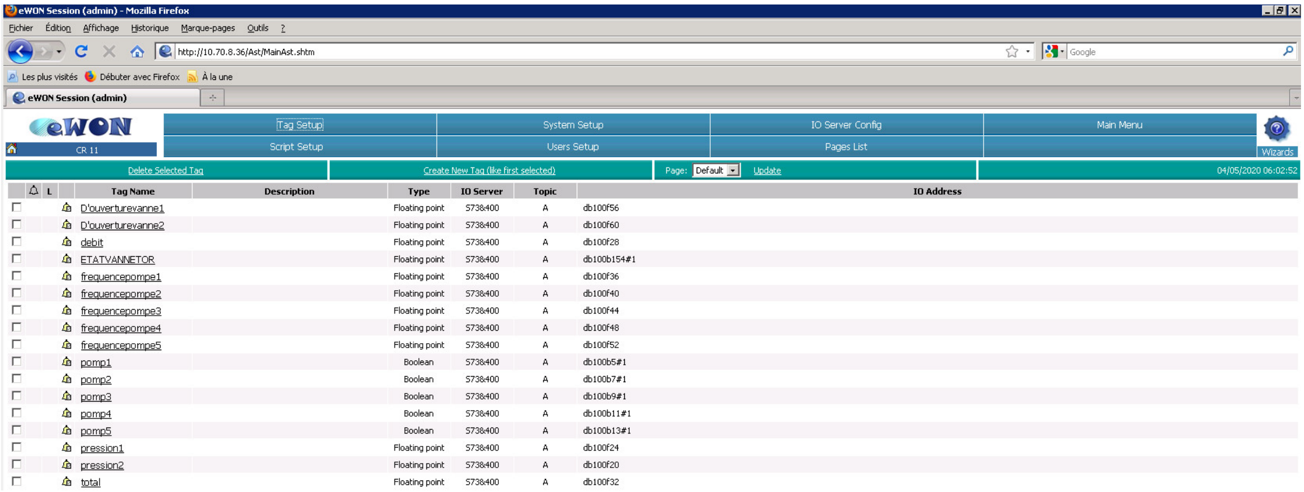
IV.2.4 Alarms

The control system generates several alarms that are used to notify the operator in case of any fault that may occur in the pumping station. These alarms are:

- Minimum suction pressure.
- Maximum and minimum discharge pressure.
- Faults in any motor-pump group.
- Fault in Upstream or downstream water hammer protections

IV.2.5 Communication medium

The eWON modem router is an industrial VPN router that can read data from various devices using built-in communication protocols. It also access of the data to other superior devices by Modbus or SNMP protocols, allowing machine builders and end users to monitor and collect important data from their PLC using VPN connection. It includes several features such as: data logging, alarming, built-in web interface, and emailing or texting capabilities. [2; 17]



Tag Name	Description	Type	IO Server	Topic	IO Address
D'ouverturevanne1		Floating point	S73&400	A	db100f56
D'ouverturevanne2		Floating point	S73&400	A	db100f60
debit		Floating point	S73&400	A	db100f28
ETATVANNETOR		Floating point	S73&400	A	db100b154#1
frequencepompe1		Floating point	S73&400	A	db100f36
frequencepompe2		Floating point	S73&400	A	db100f40
frequencepompe3		Floating point	S73&400	A	db100f44
frequencepompe4		Floating point	S73&400	A	db100f48
frequencepompe5		Floating point	S73&400	A	db100f52
pomp1		Boolean	S73&400	A	db100b5#1
pomp2		Boolean	S73&400	A	db100b7#1
pomp3		Boolean	S73&400	A	db100b9#1
pomp4		Boolean	S73&400	A	db100b11#1
pomp5		Boolean	S73&400	A	db100b13#1
pression1		Floating point	S73&400	A	db100f24
pression2		Floating point	S73&400	A	db100f20
total		Floating point	S73&400	A	db100f32

Figure IV-1 eWON tags

The data link is explained briefly in the following steps:

- The PLC is connected to eWON modem via ethernet.
- The modem is linked to talk2M cloud service.
- The programmer can connect to talk2M using the eCatcher software.
- The VPN tunnel is created establishing a connection between plc and remote access device.

For the data access, there is no additional configuration in the PLC itself, as it is all done in the modem web configurator.

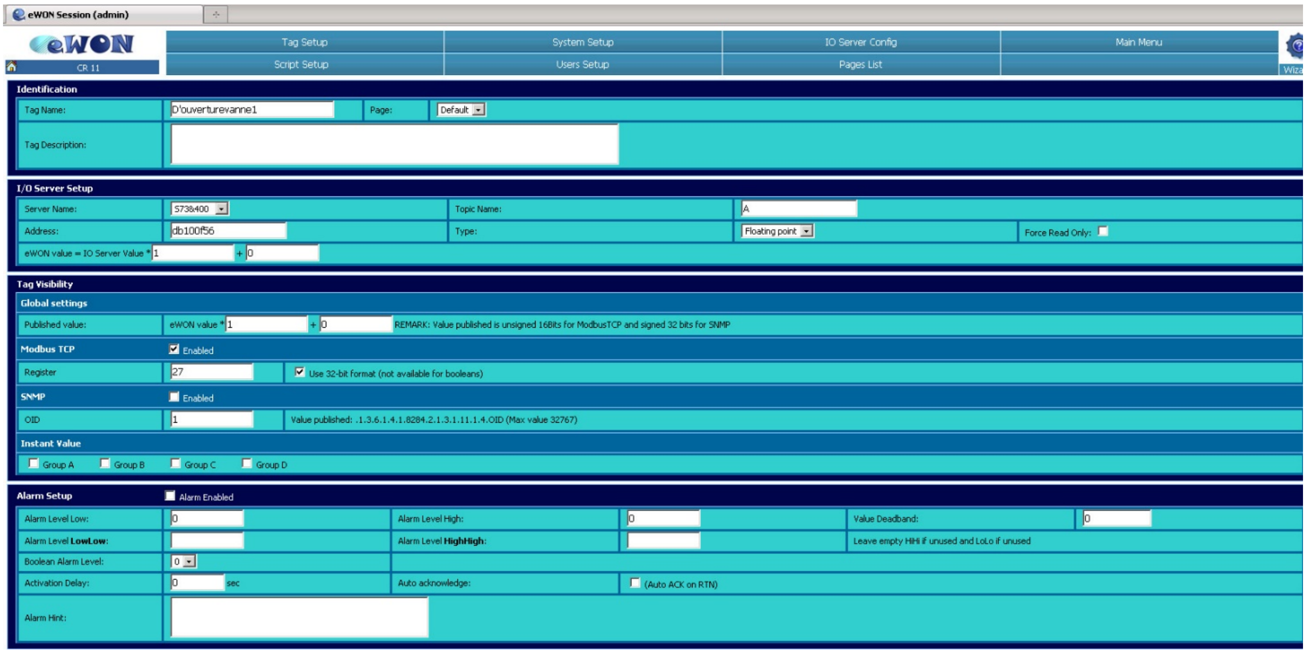


Figure IV-2 eWON tag configuration

IV.3 Configuration and Settings

In this part, details on the configuration of the project are described.

IV.3.1 Software components

Table IV-3 lists the software used in developing the Scada system and designing the user interface.

Table IV-3 Software component

Software	Version
STEP 7 Professional	V15.1
WinCC Professional	V15.1
Photoshop	CC2018

IV.3.2 Main screen

The main screen is presented in figure IV 3. It allows supervision and monitoring of the station.

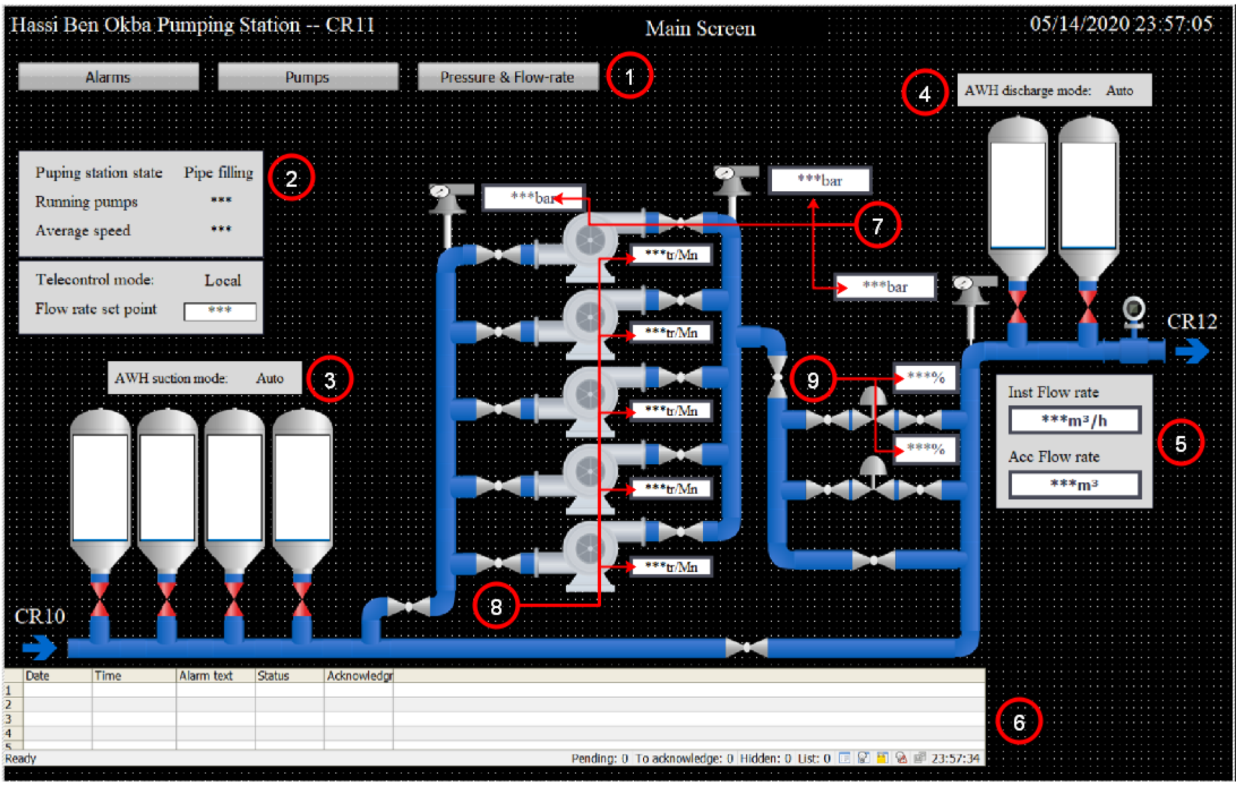


Figure IV-3 Main Screen details

Table IV-4 lists the nomenclature used in figure IV 3.

Table IV-4 Main screen nomenclature

Number	Description
1	Screen navigation
2	Pumping station details, including its state, number of running pumps and average sped, more over the telecontrol mode, in case of remote control the operator at the supervision station may set the flow rate according to the desired value.
3	Upstream water hammer protection details
4	Downstream water hammer protection details
5	Flow rate measurements, including instantons and accumulated flowrate
6	Active alarms
7	Display of upstream, main discharge and downstream pressures.
8	Running speed of each pump

IV.3.3 Alarms screen:

Figure IV-4 represents the alarm screen configuration.

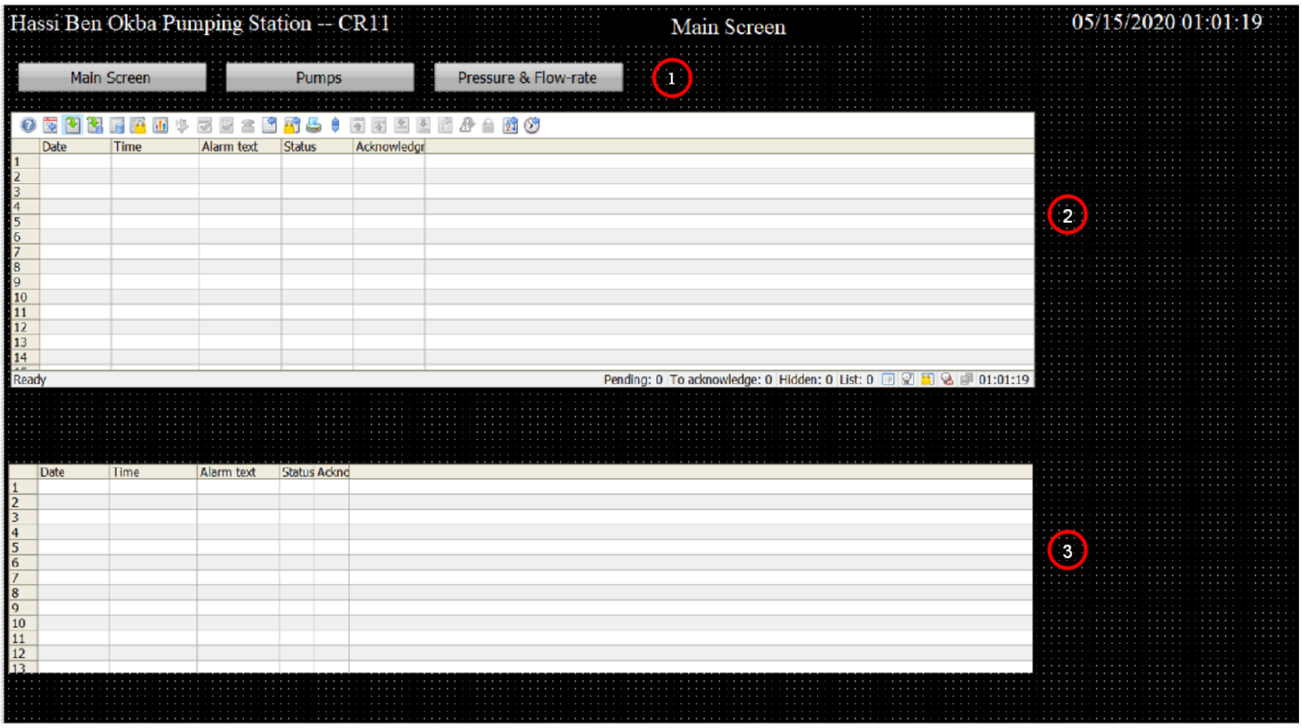


Figure IV-4 Alarm screen details

Table IV-5 lists the nomenclature used in in Figure IV 4

Table IV-5 Alarm screen nomenclature

Number	Description
1	Screen navigation
2	Active alarms
3	Alarm buffer

IV.3.4 Trends

Both of the Pressure & flow rate and pumps screens has the same structure as represented bellow:

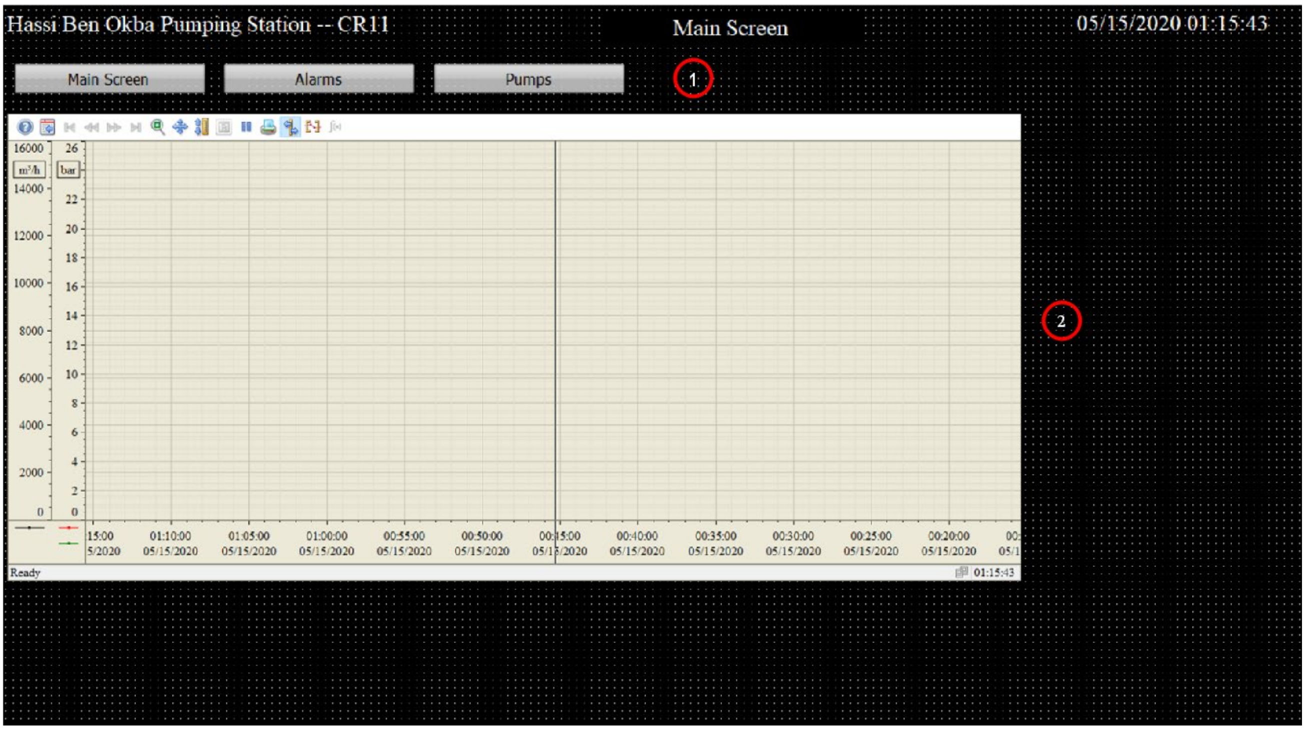


Figure IV-7 Trend screen details

Table IV-6 lists the nomenclature used in Figure IV 7.

Table IV-6 Trend screen nomenclature

Number	Description
1	Screen navigation
2	Trends

IV.3.5 Historical data

Historical data is used to collect, process and log process data. It is compiled, processed and saved in the log database in Runtime and can be output as a table or trend. The following logs are configured:

- Measurements: including flow rate and different pressure values.
- Details of each motor-pump group: current, speed, winding and bearing temperatures…

Tables IV-7, IV-8 and IV-9 represent the historical data configuration.

Table IV-7 Data logs

Name	Storage location
Msr	Database
Pump_1	Database
Pump_2	Database
Pump_3	Database
Pump_4	Database
Pump_5	Database

Table IV-8 Logging tags for Msr data log

Name	Process tag	Acquisition mode	Logging cycle	Logging cycle factor
Acum_FlowRate	GNRL_DATA_Accum_FR	Cyclic	1 s	1
D/S_Prs	GNRL_DATA_P_out	Cyclic	1 s	1
Inst_FlowRate	GNRL_DATA_FLOW_RATE	Cyclic	1 s	1
M_Dis_Prs	GNRL_DATA_P_Spr	Cyclic	1 s	1
M_Sxn_Prs	GNRL_DATA_P_Asp	Cyclic	1 s	1

Table IV-9 Logging tags for each pump data log

Name	Process tag	Acquisition mode	Logging cycle	Logging cycle factor
discharge_valve_state	Slaves_Data_pump_1.discharge_valve_state	On change	/	/
duration_motor_off	Slaves_Data_pump_1.duration_motor_off	Cyclic	1 s	1
duration_motor_on	Slaves_Data_pump_1.duration_motor_on	Cyclic	1 s	1
Hour_Meter	Slaves_Data_pump_1.Hour_Meter	Cyclic	1 s	1
motor_bearing_temp_1	Slaves_Data_pump_1.motor_bearing_temp_1	Cyclic	1 s	1
motor_bearing_temp_2	Slaves_Data_pump_1.motor_bearing_temp_2	Cyclic	1 s	1
motor_current	Slaves_Data_pump_1.motor_current	Cyclic	1 s	1
motor_winding_temp_1	Slaves_Data_pump_1.motor_winding_temp_1	On change	/	/
motor_winding_temp_2	Slaves_Data_pump_1.motor_winding_temp_2	Cyclic	1 s	1
motor_winding_temp_3	Slaves_Data_pump_1.motor_winding_temp_3	Cyclic	1 s	1
number_of_starts	Slaves_Data_pump_1.number_of_starts	On change	/	/
pump_bearing_temp_1	Slaves_Data_pump_1.pump_bearing_temp_1	Cyclic	1 s	1
pump_bearing_temp_2	Slaves_Data_pump_1.pump_bearing_temp_2	Cyclic	1 s	1
Pump_number	Slaves_Data_pump_1.Pump_number	On change	/	/

IV.3.6 Alarms:

Table IV-10 shows the alarms configuration:

Table IV-10 Alarms configuration

ID	Alarm text	Alarm class	Trigger tag	Trigger bit
1	Pumping Station General fault	Errors	GNRL_DATA_EMR_Stp	0
2	Upstream water hammer protection general fault	Errors	WHP_US_Data_EMR_STP	0
3	Downstream water hammer protection general fault	Errors	WHP_DS_Data_EMR_Stp	0
4	Fault, Minimum suction pressure limit reached	Errors	GNRL_DATA_NotifSC	25
5	Fault, Minimum discharge pressure limit reached	Errors	GNRL_DATA_NotifSC	26
6	Fault, Maximum discharge pressure limit reached	Errors	GNRL_DATA_NotifSC	27
7	Upstream water hammer protection in manual mode	Errors	WHP_US_Data_Mode	0
8	Downstream water hammer protection in manual mode	Errors	WHP_DS_Data_Mode	0
9	Pump 1 general fault	Errors	Slaves_Data_pump_1.Alarms	9
10	Pump 2 general fault	Errors	Slaves_Data_pump_2.Alarms	9
11	Pump 3 general fault	Errors	Slaves_Data_pump_3.Alarms	9
12	Pump 4 general fault	Errors	Slaves_Data_pump_4.Alarms	9
13	Pump 5 general fault	Errors	Slaves_Data_pump_5.Alarms	9

IV.3.7 Tags

Table IV-11 lists the configured tags

Table IV-11 Configured tags

Name	Data type	PLC tag
WHP_US_Data_EMR_STP	Bool	WHP_US_Data.EMR_STP
WHP_US_Data_Mode	Bool	WHP_US_Data.Mode
WHP_US_Data_Valve_State_1	Bool	WHP_US_Data.Valve_State_1
WHP_US_Data_Valve_State_2	Bool	WHP_US_Data.Valve_State_2
WHP_US_Data_Valve_State_3	Bool	WHP_US_Data.Valve_State_3
WHP_US_Data_Valve_State_4	Bool	WHP_US_Data.Valve_State_4
WHP_US_Data_Visual_Lvl	Real	WHP_US_Data.Visual_Lvl
WHP_DS_Data_EMR_Stp	Bool	WHP_DS_Data.EMR_Stp
WHP_DS_Data_Mode	Bool	WHP_DS_Data.Mode
WHP_DS_Data_Valve_State_1	Bool	WHP_DS_Data.Valve_State_1
WHP_DS_Data_Valve_State_2	Bool	WHP_DS_Data.Valve_State_2
WHP_DS_Data_Visual_Lvl	Real	WHP_DS_Data.Visual_Lvl
GNRL_DATA_Accum_FR	LInt	GNRL_DATA.Accum_FR
GNRL_DATA_EMR_Stp	Bool	GNRL_DATA.EMR_Stp
GNRL_DATA_FLOW_RATE	Real	GNRL_DATA.FLOW_RATE
GNRL_DATA_NotifSC	DWord	GNRL_DATA."Notif SC"
GNRL_DATA_P_Asp	Real	GNRL_DATA.P_Asp
GNRL_DATA_P_out	Real	GNRL_DATA.P_out
GNRL_DATA_P_Spr	Real	GNRL_DATA.P_Spr
GNRL_DATA_Pumping_station_state	Byte	GNRL_DATA.Pumping_station_state
GNRL_DATA_Remote_ctrl	Bool	GNRL_DATA.Remote_ctrl
GNRL_DATA_RP_Count	Int	GNRL_DATA.RP_Count
GNRL_DATA_SP_FR_Remote	Real	GNRL_DATA.SP_FR_Remote

Slaves_Data_pump_1	Pump	Slaves_Data.pump_1
Slaves_Data_pump_2	Pump	Slaves_Data.pump_2
Slaves_Data_pump_3	Pump	Slaves_Data.pump_3
Slaves_Data_pump_4	Pump	Slaves_Data.pump_4
Slaves_Data_pump_5	Pump	Slaves_Data.pump_5
Valves_State_CR11_State	Byte	Valves_State.CR11.State
Valves_State_MAV_State	Byte	Valves_State.MAV.State
Valves_State_MSV_State	Byte	Valves_State.MSV.State
Valves_State_PC_BPV_State	Byte	Valves_State.PC_BPV.State
Valves_State_PC_DSV1_State	Byte	Valves_State.PC_USV1.State
Valves_State_PC_DSV2_State	Byte	Valves_State.PC_DSV2.State
Valves_State_PC_PCV1_POS	Valve_PC	Valves_State.PC_PCV1
Valves_State_PC_PCV2_POS	Valve_PC	Valves_State.PC_PCV2
Valves_State_PC_USV1_State	Byte	Valves_State.PC_USV1.State
Valves_State_PC_USV2_State	Byte	Valves_State.PC_USV2.State
Sreen number	Int	Internal tag

IV.4 Simulation

IV.4.1 Simulation values

Table IV-12 list values used during the simulation.

Table IV-12 Simulation values

Pump 1	
State	Stopped
Suction valve	Opened
Discharge valve	Opened
Pump 2	
State	Running
Suction valve	Opened
Discharge valve	Opened
Speed	935 tr
Motor current	490 A
Pump 3	
State	Running
Suction valve	Opened
Discharge valve	Opened
Speed	935 tr
Motor current	486 A
Pump 4	
State	Fault
Suction valve	Closed
Discharge valve	Closed

Table IV-12 (Continued)

Pump 5	
State	Running
Suction valve	Opened
Discharge valve	Opened
Speed	935 tr
Motor current	488 A
Flow rate	
Instant	10,625 m^3/h
Accumulated	1,125,620 m^3
Pressure	
Main suction pressure	6.31 bar
Main discharge pressure	12.09 bar
Downstream pressure	11.97 bar
Valves	
Main suction	Opened
Main Discharge	Opened
Pressure control position 1 & 2	100
By-pass	Opened
CR11	Opened
WHP surge tanks valves	Opened

IV.4.2 Simulation results

Through the main screen, the operator can monitor the overall pumping station health, and interact when necessary. As shown in figure IV-9, the elements that constitute the station are well presented in a friendly user interface including the required information and functionalities.

The simulation scenario represents a normal operation condition, yet the pump number four is in fault state, an alarm is triggered which the operator has to acknowledge.

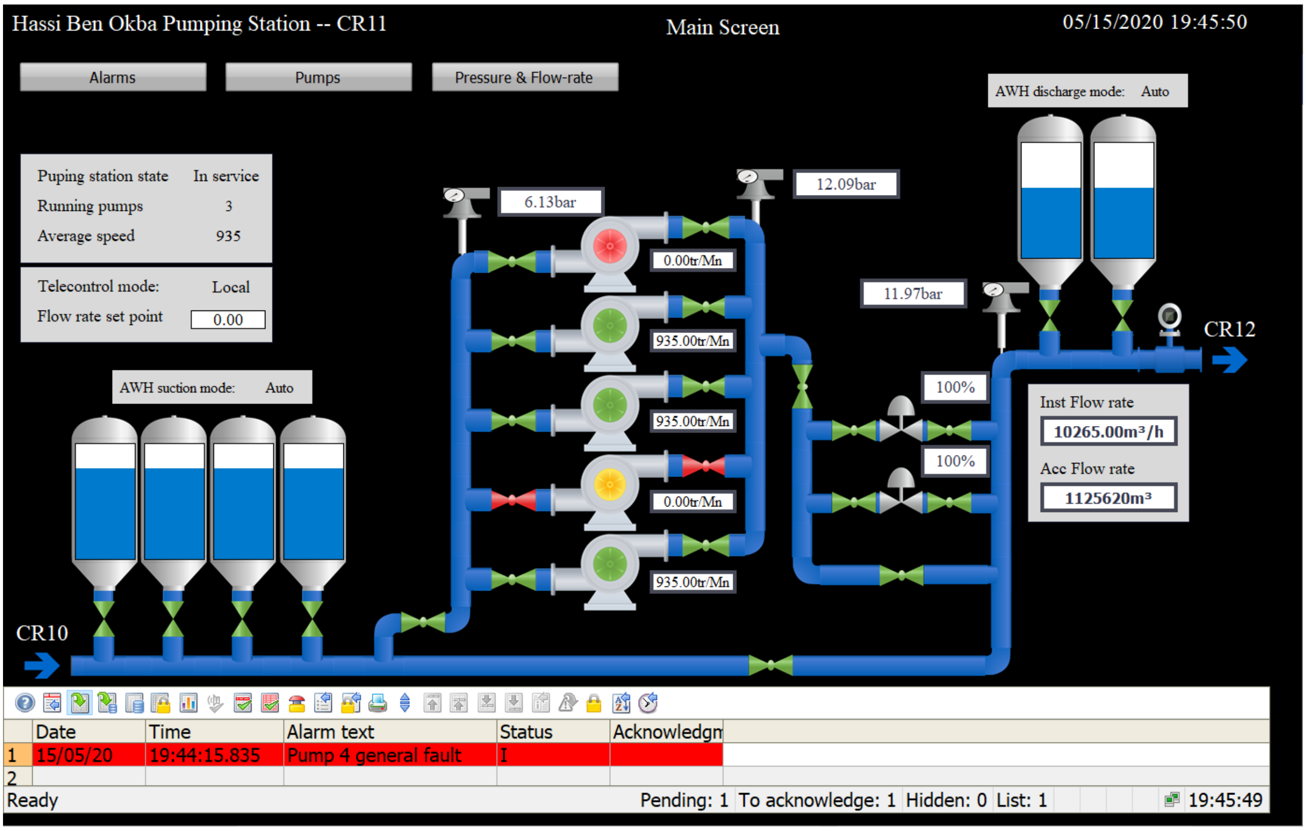


Figure IV-5 Main screen simulation results

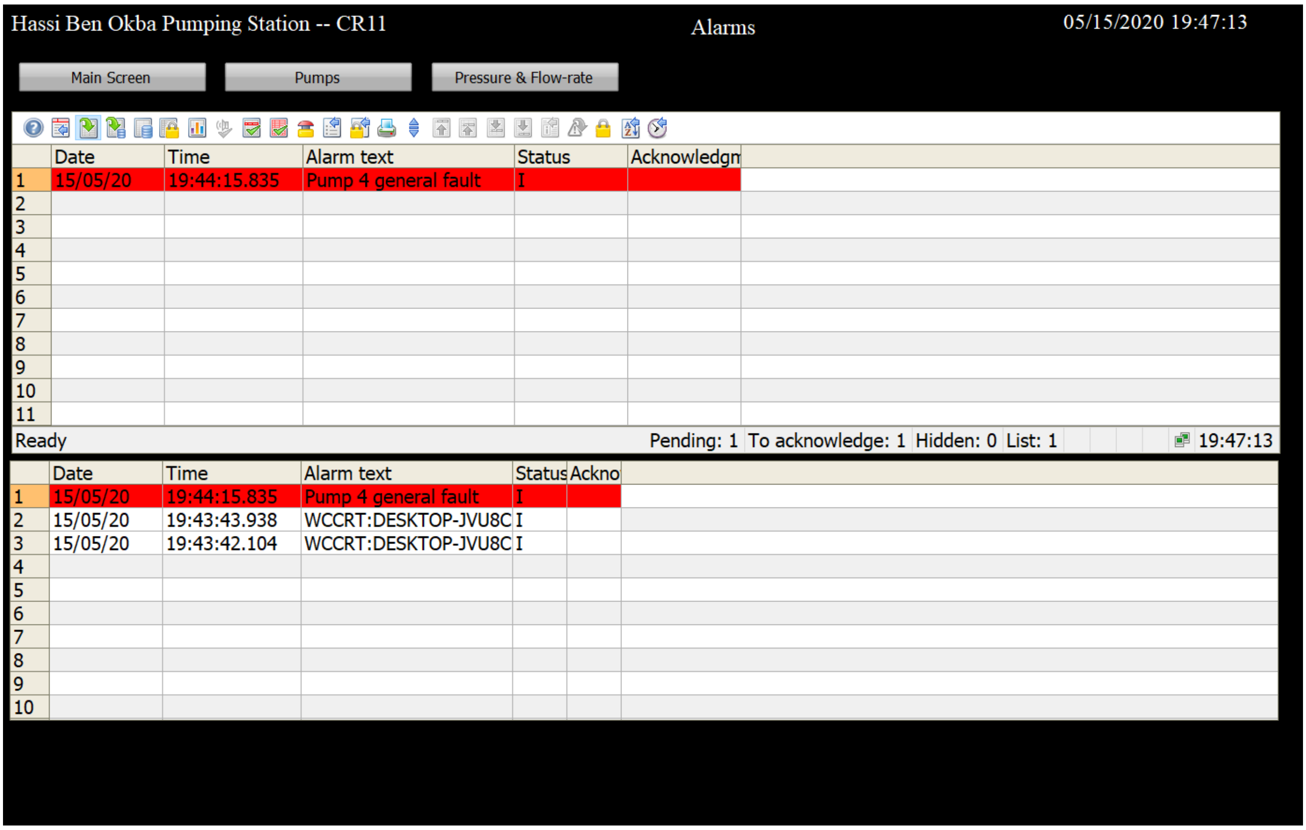


Figure IV-7 Alarm screen simulation results

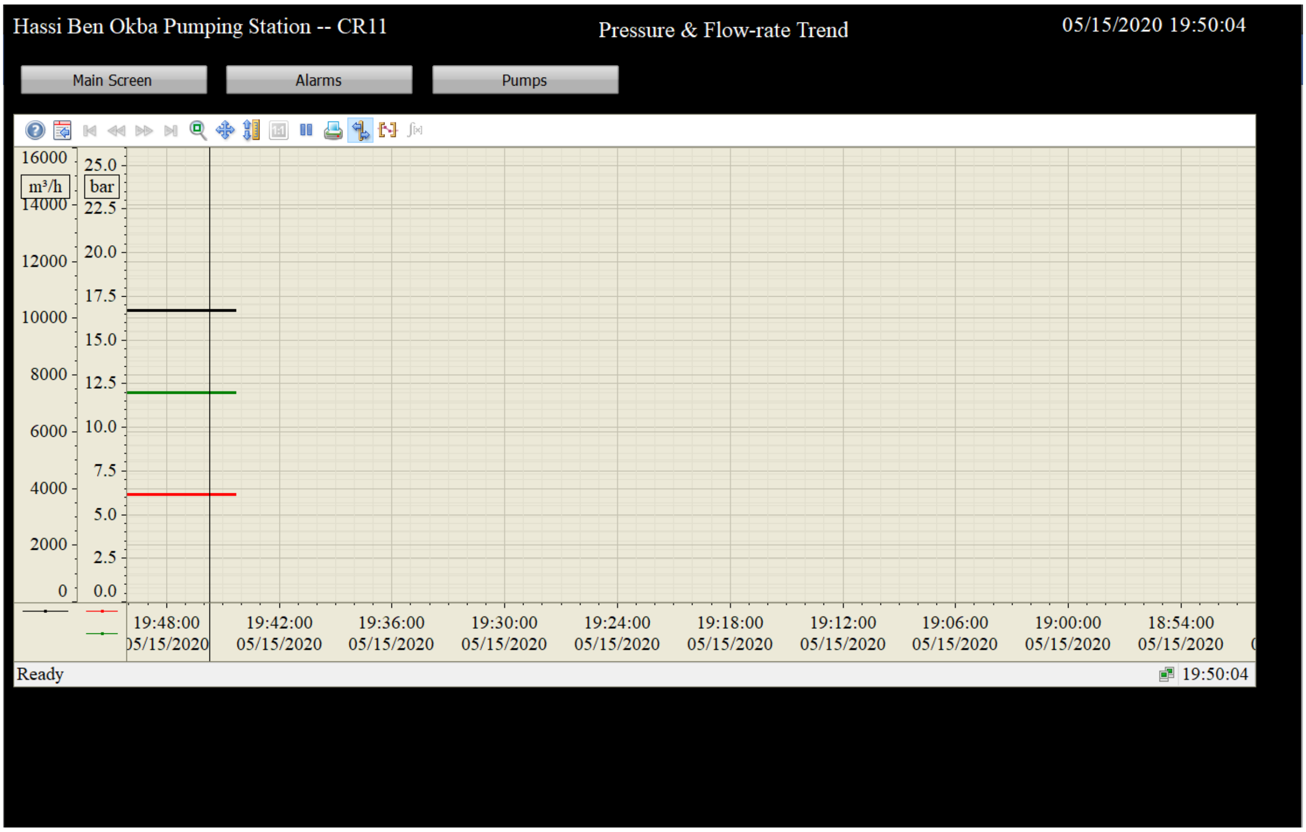


Figure IV-6 Trend screen simulation results

Chapter V

General Conclusion

Remote management is a discipline which mainly depends on automation, electronics, IT and telecommunications. It makes it possible to ensure the proper functioning of geographically distributed industrial installations by its security, its surveillance, remote control and command.

In water management systems, the requirements for a uniform operator control and monitoring concept are high in order to guarantee high operating conditions. Moreover, it is important for the maintenance of plants which can reduce time during failures, maintenance works, or a plant expansion.

The SCADA system implemented allows the operator not only to monitor the flow rate and pressure measurements, but also to have precise records of production states and cost that may be accessible from anywhere. The managers may access this data that can be studied, compared in more efficient, digital manner allowing them to have the most accurate knowledge from which to draw conclusions, and hopefully lead them to quicker results and faster action.

The work carried out in this thesis presents a SCADA system for the monitoring and control of Hassi Ben Okba pumping station used in the water distribution system of Oran city. It shows an increase in system efficiency and reduced communication cost.

The development and simulation software used is highly reliable and significantly reduces engineering time and effort.

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