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MODERNIZATION OF THE PROGRMMABLE LOGIC CONTROLLER OF A POLYMER MAKEUP UNIT

Bachelor’s thesis
Degree programme in automation engineering

2017

South-Eastern Finland
University of Applied Sciences

Author	Degree	Time
Sousa Kizua	Bachelor of Automation engineering	12 October 2017

Title	
Modernization of the Programmable logic controller of polymer makeup unit	44 pages 2 pages of appendices

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Abstract

An essential element in the dewatering process of wastewater sludge is the polymer dosage, the consistency of the preparation and dosing equipment. Cleaned wastewater is carried into the environment, for this reason all pollutants which wastewater contains must be removed in the treatment procedure. At the Mussalo wastewater plant, polymers are used in combination with sludge dewatering decanter for separating the water and, to improve the dry content of the sludge. The manufacturing equipment automatically makes the polymer preparation. The polymer used as well as the dosage are based on sludge pre-testing to ensure a sufficient drying result.

This study aimed to update, the programmable logic controller (PLC) of the polymer makeup unit, at Mussalo wastewater plant. The old programmable logic controller Siemens S5-100U will be replaced in the future with the new S7- 1200 logic controller, replacing should also be possible immediately if there are operational problems with the old logic controller, which is not any more technically supported by the manufacturer (Siemens Automation).

During the programming of the new controller, the simulator tested the functionality of the various circuits and devices, to ensure the reliability of the logic controller as well as the polymer preparation process. Since the treatment process of wastewater must not malfunction or stop due to the failure of the equipment or logic program, it was essential to test its functionality.

Keywords

PLC, polymer, wastewater, sludge

Tekijä	Tutkinto	Aika
Sousa Kizua	Insinööri AMK	12 syyskuu 2017

Opinnäytetyön nimi

Polymeerikoneen logiikan modernisointi

44 sivua
2 liitesivua

Toimeksiantaja

Kymen vesi Oy, Käyttöinsinööri Jukka Mäkitalo

Ohjaajat

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Tiivistelmä

Jäteveden lietteen vedenpoistoprosessissa tärkeänä osana on polymeeriannostelu ja etenkin luotettava annostelulaitteisto. Puhdistettu jätevesi johdetaan ympäristöön ja siitä syystä jäteveden käsittelyssä on poistettava kaikki jätevedessä olevat epäpuhtaudet. Mussalon jätevesilaitoksella polymeeriä käytetään lingon yhteydessä, erottamaan lietteessä oleva vesi ja parantamaan lietteen kuiva-ainepitoisuutta. Polymeerin valmistus tehdään automaattisesti valmistuslaitteistolla. Käytettävä polymeeri sekä annostus perustuvat lietteelle tehtyihin kokeisiin, joilla varmistetaan riittävä kuivatustulos.

Tässä työssä päivitettiin Mussalon jätevedenpuhdistamon polymeerin valmistuslaitteiston ohjelmoitava logiikka (PLC). Vanha logiikka Siemens S5-100U korvataan tulevaisuudessa uudella logiikalla S7- 1200. Korvaaminen pitää olla mahdollista välittömästi, mikäli tulee toiminnallisia ongelmia vanhan logiikan kanssa. Vanhaan järjestelmään ei saa laitevalmistajalta teknistä tukea (Siemens automation).

Uuden logiikan ohjelmoinnin yhteydessä testattiin eri piirien ja laitteiden toiminnallisuus simulaattorin avulla. Tällä tavoin saatiin varmistettua logiikan sekä valmistusprosessin toiminta. Prosessista johtuen oli tärkeää testata toiminnallisuus, koska jäteveden käsittelyssä ei saa tulla toimintahäiriöitä eikä alasajoja laitteiden tai ohjelmien toimintahäiriöiden takia.

Asiasanat

PLC, polymeeri, jätevesi, liete

CONTENTS

Appendix 1. Polymer and technical water control room process diagram

Appendix 2. Makeup unit technical measurement

ABBREVIATION LIST

CPU	Central Processing Unit
ANALOG	Signal corresponds directly to the value of the data to be transferred
DIGITAL	Binary, the only values used are 0 and 1
DB	Data Block
FBD	Function Bloc Diagram
FB	Function Block
FC	Function
HMI	Human Machine Interface
IEC	International Electronical Commission
I/O	Input /Output module
IP	Internet Protocol
LAN	Local Area Network
LD	Ladder Diagram
OB	Organization Block
PROFIBUS	Speed Optimized Fieldbus Protocol
PROFINET	Industry Ethernet Standard
RAM	Random Access Memory
ROM	Read Only Memory
SFC	Sequential Function Chart
ST	Structural Text
STEP 5	Siemens Programming Tool
STEP 7	Siemens Programming Tool
TIA Portal	Totally Integrated Automation

1 INTRODUCTION

The advance of the industry and the significant influence of the industrial processes in the global economy have driven high technology investments in the areas of control and automation. For the industry to grow, it is necessary to optimize it, and for this, there is a need to have a total control of the information about the process that occurs in the industrial plant. Many of this information is very accurate and complicated to access physically, which demands the application of exclusive technology.

The complexity and critical environment of the industrial process, has increased the dependency on automation technology for controlling, monitoring, safety, high productivity, efficiency, as well as quick decision making if any problem occurs. Automated process allows companies or individuals to take advantage of the technology to increase productivity across multiple processes environment. Companies must remain agile and responsive to the development of technology, and they also need to be accurate of changes introduced in automation technology.

2 MUSSALO WASTEWATER TREATMENT PLANT

Located near Mussalo port (Figure 1), the plant has a long history in wastewater treatment process. The facility and its capacity have been enlarged in last past years. The enlargement and renovation were completed in November 2009, and is now Finland's fourth-largest plant. Besides, an irrigation pipeline and some new pumping stations have been built across of its operating areas. The facility deals with wastewater from Kotka, Anjalankoski, Pyhtää, Miehikkälä, Virolavahti, and Hamina, covering about 99,000 inhabitants living in the area. The plant also handles wastewater from industries, hospitals, and some other labor facilities. As activated sludge plant, mechanical, chemical, and biological methods are used to clean impurities. The method of treating and cleaning wastewater is a measure aimed to deal with urban and industrial wastewater. Biological is the primary method used at Mussalo plant, which is based on nitrogen removal.

Figure 1 Mussalo wastewater plant

The facility operating range has more than 200 pumping stations. The water is pumped to the plant from three central pumping stations (Mussalo, Kotkansaari, and Hovinsaari). The amount of water treated varies according to the season of the year. During the dry period, the average flow rate is approximately 25,000 m^3/d and during spring up to 66,000 m^3/d.

The plant involves three treatment stages: the mechanical, the chemical, and the biological. The mechanical stage, consist in the separation of the roughest solids (screened waste and sand) from the wastewater by screening and pre-aeration. In the chemical phase, phosphorus which the wastewater contains is hastened by ferrous sulfate.

The plant is a characteristic activated sludge treatment facility, so the biological stage is aeration, where the dissolved organic materials are converted into biomass by using microbes. Excellent bubble aeration discs are placed in the bottom of the aeration tank, creating favorable conditions for the microbes to grow. The air is pumped into the aerators by four turbo compressors. The plant's purification capacity is approximately 98% biological oxygen portion and 96% for phosphorus. The plant eliminates more than 80% of nitrogen. Purified water, during the entire process is discharged to the sea by 750 meters long discharging pipe. The cleaning process also generates several products like sand, screened waste, grease, and sludge. The sludge is pumped from the aeration tank to the begin of the process, where it is mixed with the raw sludge on primary clarifier. From the first clarifier, mixed sludge is pumped into the thickener, where the excess water is removed by settling. After the thickener, the concentrated sludge has a solids content of 3 - 7 %. Focused sludge is pumped into the sludge dryer station, where a centrifugal force of the decanter centrifuge dries it. In the drying process, the polymer is fed to centrifuges to improve the drying performance.

About 15 000 tons are produced per year, and the dehydrated sludge is dropped into the silos from the centrifugal dryers, where it waits to be transported for further processing, which is made by the service agreement with Gasum Oy. The sludge cost to Kymen Vesi Oy, approximately € 820 000 annual. (Kymen Vesi Oy 2014.)

2.1 Wastewater treatment technologies

Several technologies are available for drinking water and wastewater treatment. The most used techniques to remove contaminants from wastewater are mechanical, chemical, and biological. Individual treatment procedures are combined into a variety of systems, classified as primary, secondary, and tertiary to reach the correct levels of contaminant removal.

More rigorous treatment of wastewater includes the discharge of specific pollutants as well as control of nutrients. Natural systems are used for the treatment of wastewater in land-based applications. Sludge resulting from wastewater treatment operations is treated by various methods to reduce its water and organic content, to make it suitable for final disposal and reuse. (Wastewater treatment technologies 2003, 5.)

Mechanical method, support the loading of sludge, separating the rust from the wastewater by sieving and settling. The mechanical process is applied predominantly in the pre-treatment phase of the wastewater purification, as is used to extract the most wastewater coated particles that would adversely affect the later stages of the process. Such particles include, for example, food sources, plastic, rubber, sand, and other heavy dirt. The mechanical method includes, for example, frost, separation of sand, and clarification basins. Processes based on purely in the mechanical cleaning are not available in Finland because they do not achieve the required cleaning results. (Laitinen et al. 2014, 42.)

An essential method for wastewater purification is also a chemical deposition, where the adverse soluble agent is added in the solid form by adding the chemical, and the result of this advanced agent is separated by settling.
The chemical method is practically the only phosphorus removal method in Finland because there are no biological purifiers that remove phosphorus. The chemical phosphorus removal does not exclude the biological phosphorus removal from the process entirely, besides the chemical precipitation, phosphorus is also organically bound to the sludge. The organic phosphorus removal can be made more efficiently, but the chemical addition is necessary to achieve the purification requirements. (Laitinen et al. 2014, 42.)
Illustration of Mussalo wastewater plant process stages in (Figure 2).

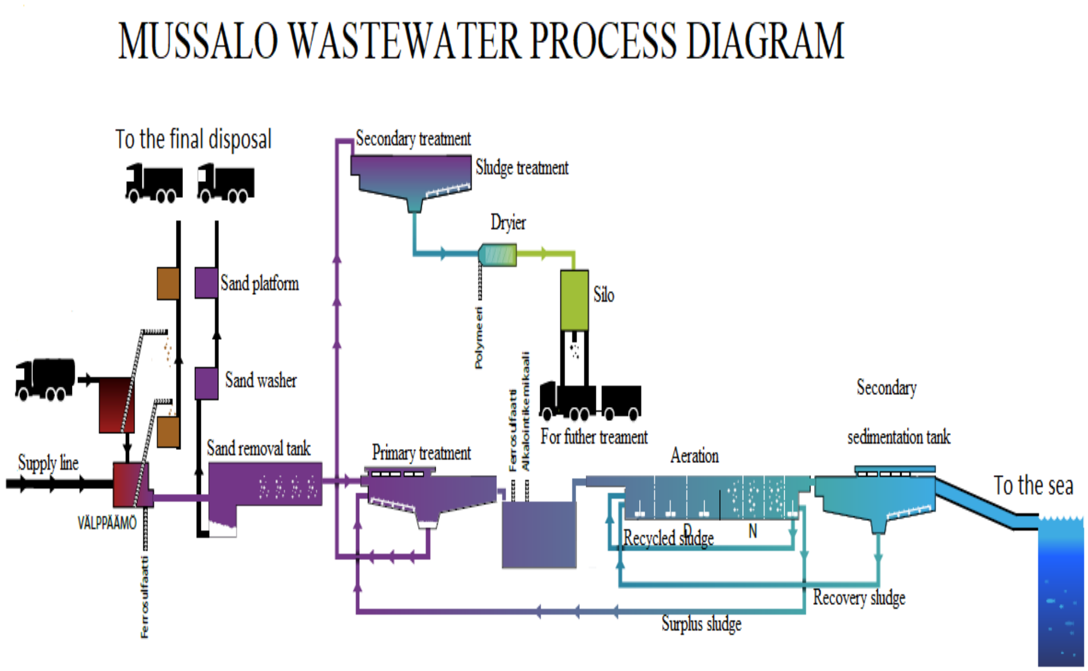

Figure 2 Wastewater process diagram (Kymen Vesi Oy)

Biological process reduces the amount of nutrient and organic substance contained in wastewater using microbial activity. In Finland, the nitrogen removal is based on natural microbial activity and phosphorus removal in the chemical precipitation, but the microbes can use and fix themselves to the phosphorus that is a lot in wastewater compared to their needs. It is possible to remove the phosphorus from the wastewater by biological method quite efficiently employing a different kind of arrangements, and, but the addition of chemical requires the introduction of today's rigorous licensing regulations. Because of the biological activity, even harmful substances are removed from the wastewater, improving the quality of the water. (Laitinen et al. 2014, 42.)

3 POLYMER

3.1 Polymer definition

The polymer is a chemical substance capable of agglomerating suspended particles present in the wastewater, transforming them into larger flakes and allowing their separation from the aqueous phase, either by decantation, flotation or by sludge dewatering. The products available on the market are mostly based on polyacrylamide and water soluble.

Specific polymers for use in the wastewater treatment are coagulants or flocculants. The flocculants are synthetic polymers, differing each other by chain size, shape, and load ionic. The coagulants promote the neutralization of the charges of the particles present in the wastewater to be treated and form the micro flakes, since the flocculants help the connection between them, generating flakes that will later be separated from the wastewater, either by sedimentation, flotation, or filtration.

The polymer solutions are prepared in concentrations between 0.05 and 0.5 %, depending on their application, which may still be requiring further dilution to increase the mixing efficiency between the polymer and the wastewater (kymen Vesi Oy 2008, 7). Polymers are presented in very different forms and concentrations. It is available also, in dry powder or in concentrated liquids. The purpose of wastewater treatment is to discharge back the utilized water into the environment as clean as possible. Besides the water purification, the other result of the wastewater treatment is the sludge. To reduce the moisture of the sludge, mechanical technique (dewatering) is used.

The use of chemical (polymer) to condition the sludge for dewatering is economical because increase the profits and a high flexibility is obtained. The chemical conditioning can reduce from 90 - 99 % incoming sludge moisture to 65 - 85 %, depending on the content of the substances to be treated (Kymen Vesi Oy 2008, 8). The chemical used include ferric chloride, lime, alum, and organic polymers.

3.2 Polymer makeup unit

The challenge in wastewater treatment is discovering the best way to subtract the solid particles and other materials found in the liquid stream. The most efficient method for eliminating undesirable impurities is using the polymers in a sludge producing process.

The polymers are used to coagulate suspended solids and produce large curds of solid materials (floc), which are more ease to remove from the wastewater treatment stream. Powder polymers require being moistened out with water which is commonly done via an automatic dry polymer makeup unit system. The solution needs to be combined in a mixing tank and consequently stored in the storage tank where subsequently is supplied to the wastewater treatment process.

A polymer makeup unit (Figure 3), is used to blend polymer electrolytes (powder or emulsion) with water so that they can be used effectively in a treatment process. The unit produce a controlled, automated, and consistent mix which increases the efficiency of the treatment system of the wastewater as well as removing the need for manual batch mixing (Polymer Makeup System 2017).

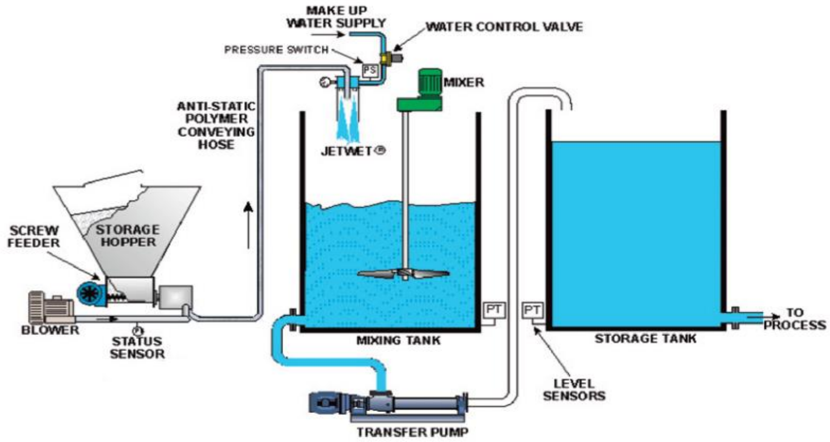

Figure 3 Polymer makeup unit system diagram (richardalanwater.co.uk)

A polymer makeup unit varies from the manufacturer to the manufacturer, but its composition and the working principles do not differ a lot from each other. The polymer makeup unit at Mussalo plant includes a mixing tank, a storage tank, a mixer, a storage hopper, a blower, the screw feeder (Figure 4), a disperser (JetWet), the water valves, a transfer pump as well as the sensors.

Figure 4 Mussalo wastewater plant equipment's

The most important part of the polymer makeup unit is the mixing tank, and the mixer, which is driven by a gear motor. The mixing tank also has a pressure sensor which will close the water valve in case of pressure disturbances in the water supply pipeline. The storage tank contains the feed pump and a bottom drain cover.

3.3 Polymer feed

The polymer powder is fed from the bag to the storage hopper. The screw feeder conveyor carries the powder to the pneumatic conveyor, which is blown by a separate blower with heated air, whereby the powder is mixed with air and is warmed up. At the top of the mixing tank, there is a disperser (Figure 5), which form the water shutter on the pathway of the powder. After passing through the water disperser, the warm moisture is sent to the mixing tank, where the smoothness of the polymer solution is improved.

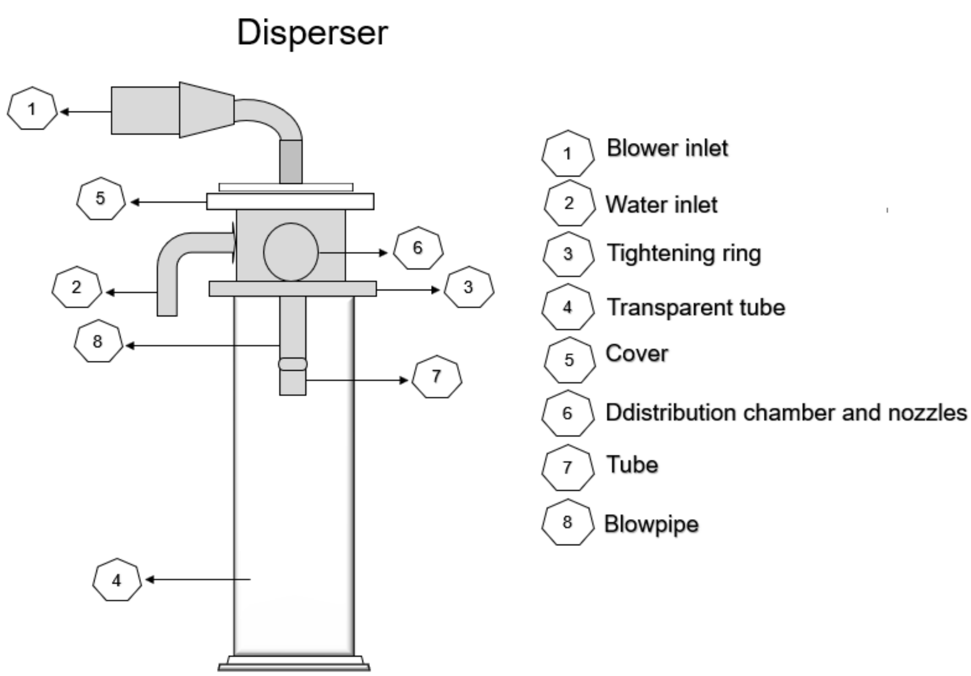

Figure 5 Disperser

The low-level switch in the mixing tank provides an impulse to the water valve, allowing the water to enter in the mixing tank. If the pressure is too low, the pressure switch breaks the water supply until the water pressure is sufficiently high. When the water level reaches the middle of the tank, the process level switch provides an impulse to the corresponding devices, then the feeding pipe begins providing the polymer to the disperser.

The polymer is fed into the disperser, where the water and the polymer are mixed. The pre-solution is set to the mixing tank. When the solution reaches the high-level in the mixing tank, the water valve closes.

The moisture is kept in the mixing tank (Figure 6) until the mixture is ready to be transferred to the storage tank. The transfer pump will receive the signal from the storage tank low-level switch to empty the mixing tank. When the complete polymer solution has been transferred to the storage tank, and the mixing tank surface reaches the low-level switch, the transfer pump closes. At the same time, a new production cycle will start. From the storage tank, the solution is pumped to the process.

Figure 6 Wastewater plant mixing tank

Because of the different molecular weights of the polymers, the evaluation test must be carried out before the startup and replacement of the polymer. The equipment’s must be connected to a voltage of 400/230 V, and the water pressure should be between 3.5 bar and 6 bars.

The water consumption should be at least 4.2 m^3/h and, the final concentration solution can be set to a maximum of 1.0%, but the recommended maximum concentration is 0.5% (Kymen Vesi Oy 2008, 9). From the start page of the Siemens control panel, the operator can select which mode to be used automatic or manual (AUTO/MAN). In the home settings section, modify the variables is possible, such as moisture concentration and the feeding time.

4 PLC HISTORY

Developed from the needs of the automotive industry with the aim of replacing the control panels with relays, the programmable logic controller (PLC) has become one of the most widely used automated systems.
In the 1960s, the Programmable Logic Controller was invented for the American automotive manufacturing industry used to replace re-wiring hard wired control panels with software program changes, when production modifications were required. Before the development of PLCs, thousands of relays, cam timers, drum sequencers and dedicated closed-loop controllers were used to manufacture the automobiles.

The need to update the manufacturing process by re-wiring the relays and other components was very time consuming and expensive. In 1968 GM Hydramatic requested a proposal for the replacement of the relay logic system. Bedford Associates won the contract and designed the first Programmable Logic Controller (PLC), the Modular Digital Controller (Modicon).

Richard Morley, one of the developers of the Modicon 084, is considered the father of the PLC. The Modicon 084 PLC was designed to be programmed in the Ladder logic which resembled the schematic diagrams of relay logic which it was replacing. This made the transition to Programmable Logic Controllers easier for engineers and technicians. The automotive industry is still one of the largest users of PLCs today. (History of the Programmable Logic Controller PLC 2016.)

4.1 PLC definition and design

A programmable logic controller (Figure 7) is a digital computer used for automation of electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or light fixture. PLCs are used in many industries and machines. The PLC is designed for multiple inputs and output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored in battery backed up or non-volatile memory. (Kumar 2014, 17.)

Figure 7 Siemens S7-1200 PLC

The basic components of a PLC (Figure 8) are:

- ✓ Central Processing Unit (CPU)
- ✓ Memory
- ✓ Power supply
- ✓ DI/ DO (Digital input modules and Digital output modules)
- ✓ AI/AO (Analog input and output)
- ✓ Communication buses

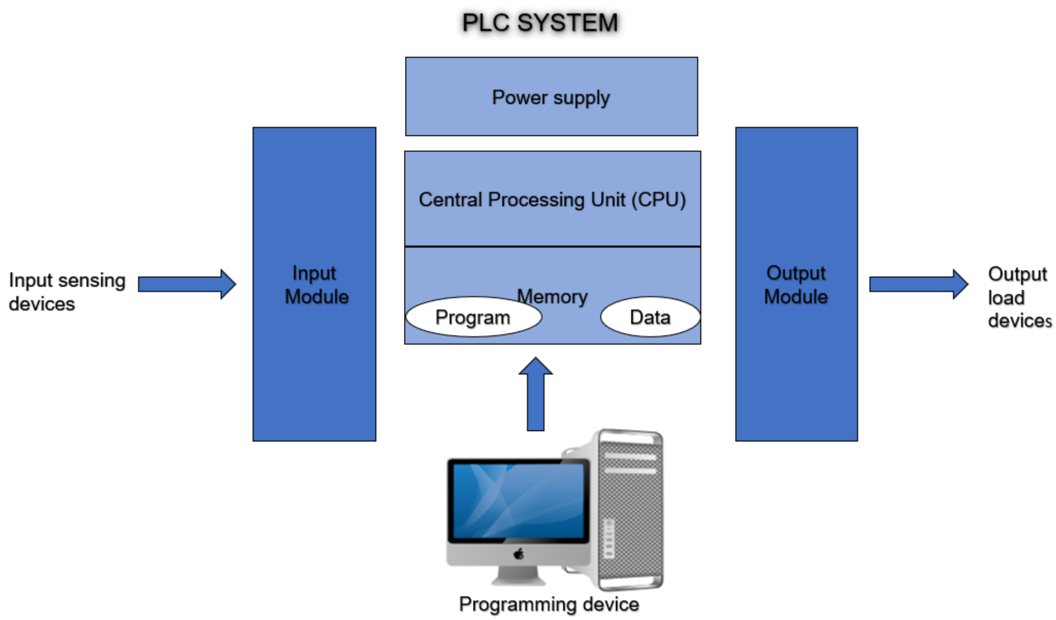

Figure 8 Programmable Logic Control system

Central Processing Unit

CPU includes the processor, microprocessor, microcontroller, memory system (EPROM and RAM) and auxiliary control circuits. The processor is responsible for commanding and managing system-wide activities. It has the following functions:

- Performs logical and arithmetic operations
- Communication with memory
- Scans and runs the user application
- Communication with the programming terminal
- Checks communication with external devices
- Checks system status and integrity

The microprocessor is the part responsible for logical and mathematical quickly operations, as such becomes the most complicated element of the PLC. The actions are executed sequentially, that is, in the same order that they were elaborated in the program. The microprocessor is then an essential part of the CPU (Central Processing Unit).

Memory

The memory system typically consists of EPROM and RAM memories. The program and data stored in the memory system are usually described using some concepts.

Power supply

The function of the power source is to supply the power required by the logic control unit and the I / O units. Additional, the power supply separates the logic from the network, by doing so called galvanic separation. Field devices are usually taken from a separate power supply. Power supply is available with 24 VDC or 230 VAC operating voltage

Input module

Input unit modules has four tasks: transmits on/off data from sensors to central processing unit, realizes galvanic isolation, solves sensor voltages on logic voltage and protects logic from interference.

Output module

The function of the output unit is to select information on the actuators, to implement the galvanic separation and to adjust the voltages for use by the logic and the actuators. Galvanic separation is most commonly performed on the output unit by the optocoupler or relay.

Analog input modules

The analog inputs measure the quantities in an analogue mode. To work with this type of input the controllers have analog to digital converters

Analog output modules

The analog output requires a digital to analog converter. The most common examples are: the proportional valve, drive DC motors, graphic displays.

4.2 PLC programming language

There are five standards languages used to program PLC: Ladder Diagram (LD), Function Block Diagram (FBD), Structured Text (ST), Instruction List (IL) and, Sequential Function Chart (SFC).

Ladder Diagram (LD)

Traditional ladder logic (figure 9) is graphical programming language. Initially programmed with simple contacts that simulated the opening and closing of relays, Ladder Logic programming has been expanded to include such functions as counters, timers, shift registers, and math operations. (What is a PLC 2017).

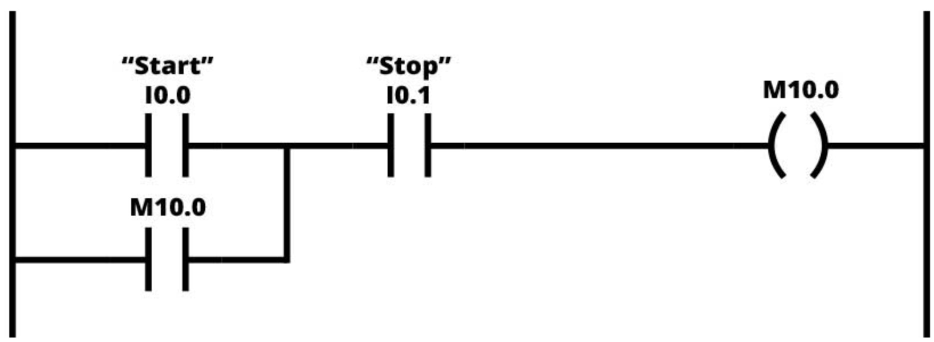

Figure 9 Ladder example (plcacademy.com)

Function Block Diagram (FBD)

This language consisting of a series of blocks that use combinatorial logic symbiology (AND, OR, XOR, etc.), usually used by those who have practice in digital and logical electronics, where the symbiology is the same. (Simatic S7 system manual 2015, 178.)

Structured Text (ST)

This programming mode uses its name to the indicated high-level structured text, that is, programming languages at the level of Pascal, C ++, Basic, among others. It is the most powerful type of language for PLC, and very complicated to understand and program. It requires some advanced programming knowledge.

Instruction List (IL)

This programming mode uses a sequence of low-level text-type instructions. It consists of a series of codes, that uses the processor instructions directly.

Sequential Function Chart (SFC)

This type of language is different from the previous ones, by the way, the functional diagrams are used, having until a rule only to describe these same rules the IEC 60848 Standard.

Based on sequencing the tasks to be performed by the PLC automatically, this is the instructions contained in the transitions are only fulfilled when the conditions inserted in the previous step are satisfied and creates a sequence of events that are executed step by step. It is written in the graphical language and uses alphanumeric commands. (Simatic S7 system manual 2012.)

5 WASTEWATER PLANT OLD PLC

The polymer makeup unit old Programmable Logic Control (PLC), has a (CPU) S5- 100U, serial number (6ES5-100 8MA02) with two digital inputs cards in a total of 16 addresses and two digital output cards in a total of 16 addresses.
S5- 100 is part of SIMATIC S5 variety of logic controllers. Composed by many functional modules, which can be used according to the duty to be performed.

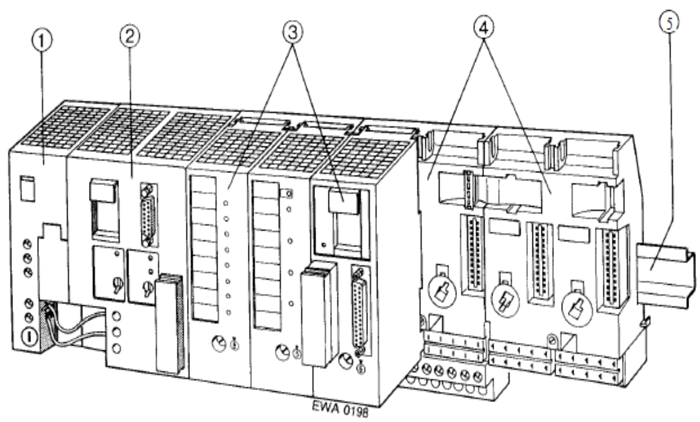

Figure 10 S5 PLC design (Siemens system manual 1992, 25)

1. Power supply
2. Central processing unit (CPU)
3. Input/output modules
4. Bus units with terminal blocks
5. Standard mounting rail

Digital input module

The digital input module converts external binary signal from an application process to the internal signal level required by programmable controller. The module is plugged into the system's bus unit establishing contact to the terminal block in which the input signal cables are connected. (Data Library 1994.)

Digital output module

The digital output module converts the signal level of the programmable controller into external binary signal ready for process application. The module is plugged into the system's bus unit establishing contact to the terminal block in which the input signal cables are connected. (Data Library 1994.)

5.1 S5 PLC programming language

The programming language that has been developed for the SIMATIC S5 family is called STEP 5. The basics language of STEP 5 are:

- Statement List (STL)
- Control System Flowchart (CSF)
- Ladder Diagram (LAD)
- GRAPH 5

Statement List (STL)

Represents the program as a sequence of operation mnemonics.

Control System Flowchart (CSF)

Represents logic operations with graphics symbols.

Ladder Diagram (LAD)

Graphically represents control functions with circuit diagram symbols.

GRAPH 5

Design for CPU 103 and higher describes the structure of sequence control systems. (Siemens system manual et al. 1992,121, 122).

Functional units

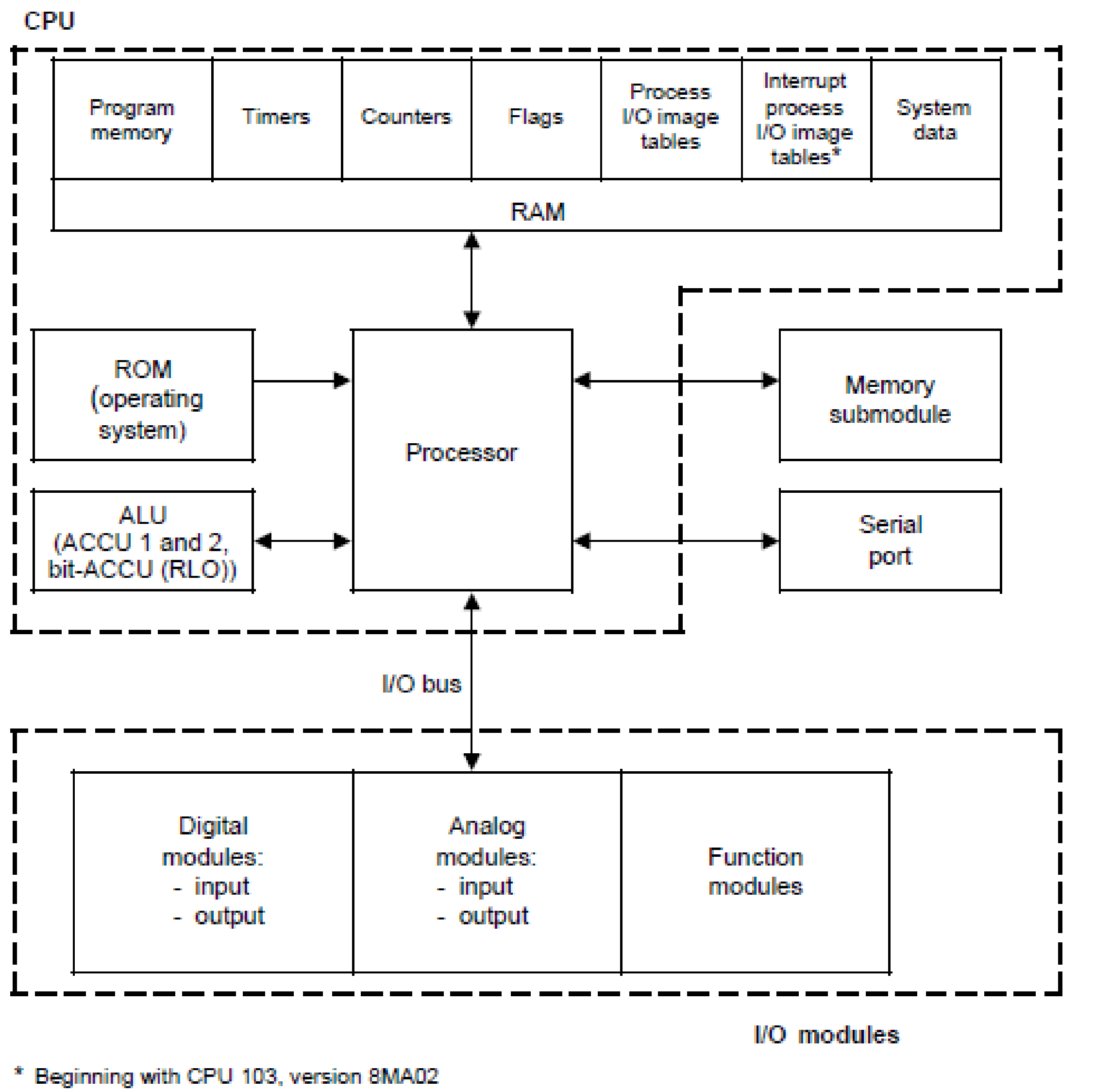

Figure 2-2. Functional Units of the S5-100U

Figure 11 (Siemens system manual 1992, 27)

6 SIMATIC S7-1200

The SIMATIC S7-1200 automation system is an integrated microcontroller system for small and medium power ranges.
In this model, there are several modules to apply in different tasks of automation. The S7 controller is composed of a power supply, a CPU, the input, and the output modules for the digital and the analog signals.

The functional and communication modules for the specific tasks, such as the stepper control, the data acquisition, and the I/O expansion, are also available. The programmable logic controller (PLC), monitors and controls an appliance or a process through the S7 software. In the S7 software, Input, and output (I/O) modules are queried through input addresses (% I) and output addresses (% Q).

The SIMATIC STEP 7 Basic system used throughout this work integrates both the controller and the HMI console since the TIA portal (Totally Integrated Automation) version V14, integrates WinCC and the Step 7 on a single platform. This capability means that this system has a great flexibility of intelligent solutions through scalable hardware and the possibility of the simplified creation of networks through coordinated communication. (The S7-1200 Basic Controller – All in one 2017.)

The SIMATIC S7-1200 series have four different PLC models: 1211C, 1212C, 1214C and 1215C. The CPU provides a PROFINET port for communication over a PROFINET network (Simatic S7 system manual 2015). The other additional modules available for communication are PROFIBUS, GPRS, RS485 or RS232 networks (Figure 12).

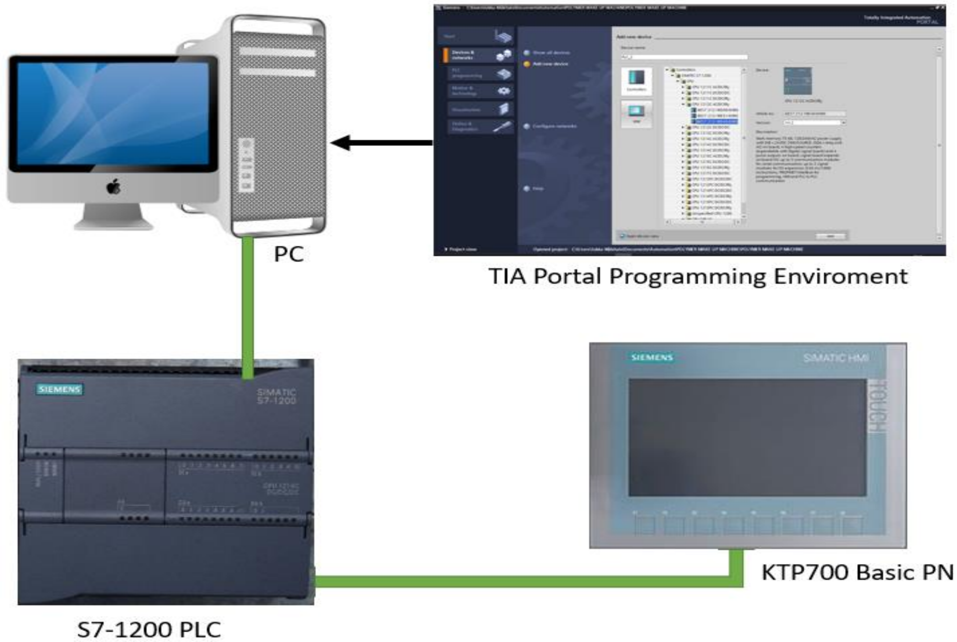

Figure 12 S7-1200 connection

6.1 S7-1200 programming language

Using the TIA Portal V14 version, several types of programming languages are available: Ladder Logic (LAD), Function Block Diagrams (FBD), Structured Control Language (SCL). (Simatic S7 system manual 2015.)

The existing code block, their organizational blocks (OB), which define the structure of the program has a predefined behavior. Typically containing the main program and are triggered by the specific events, so-called Function Blocks (FC). The Function Block (FC) does not have an instance associated with data blocks (DB). The call block passes parameters to the FC. The output FC block values must be written to a memory address.

Program size, data, and configuration are limited by available memory and functions (FB) containing the program code corresponding to specific tasks, and the parameter combination is a subroutine, so it is always called by other code blocks and data blocks (DB) that are used to store the data used by program blocks. Another fact of reference is the variables that will be defined in each block. The variables are subdivided into two groups:

The parameters that form the block interface for the call in the program.

- Input parameters are values read by the block (Inputs).
- Output parameters are values recorded by the block (Outputs).
- Transition parameters are values read by the block in the call and in which the recording is performed after processing.

Local data used to store intermediate states.

- Temporary local data, variables used for storing temporary states, and data during a cycle.
- Static local data, variables used to store static intermediate results in the instance data block. Static data is maintained until new recording, even for many cycles.

There are several types of organizational blocks. Among them, the startup block which allows the initiation of the main program whenever the PLC moves from Stop mode to run mode. The other one is the hardware interrupts block that interrupts the operation whenever triggered an event from the equipment when activated the PLC to the execution of any instruction.

The memory of the PLC is necessary for the use of the variables to be defined, and each variable has a single address. The address of each variable is identified using the I, Q, or M, corresponding respectively to the input, the output, and a bit memory. The data size is defined in byte, word, or doubleword. The use of tags is often used in program instructions; a tag is a variable used that can assume different values, which has the advantage of being able to change their address. (Figure 13) illustrates the category of function blocks used in the step7 (TIA Portal V14 version), programming environment.

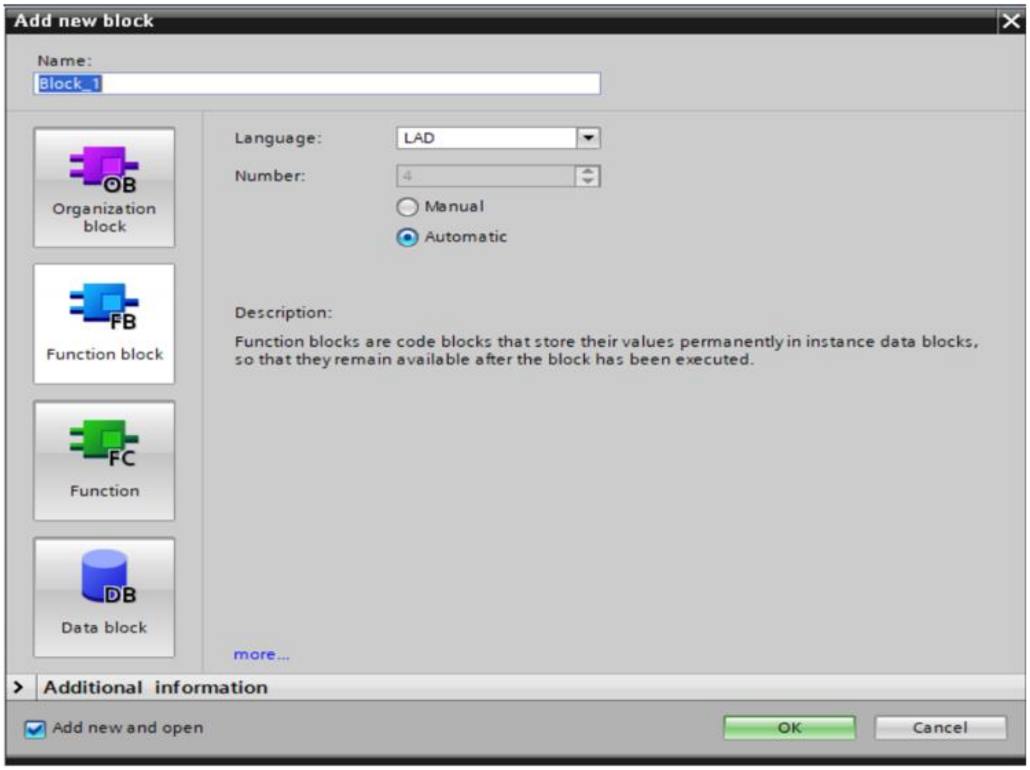

Figure 13 TIA portal V14 code blocks

6.2 S 7-1200 programming

Totally Integrated Automation Portal (TIA Portal) is the programming software used to configure the Siemens S7-1200 CPU.
The automation engineering, tasks can be simple or complex. Programming high performance algorithms often takes time, but repeating them, helps to be quick and easy in acquiring the ability to program.

TIA Portal software overview (Figure 14):

- Reuse of project components through libraries
- Diagnosis of the integrated system
- Trace functions
- Motion integration
- Proportional Integral Derivative (PID) controller
- Cross reference information throughout the project
- Complete simulation of controllers and HMI (Human-Machine Interface)

TIA Portal provides a user-friendly environment for developing all controller programming, configuring Human Machine Interface (HMI), visualization, and configuring network communication.

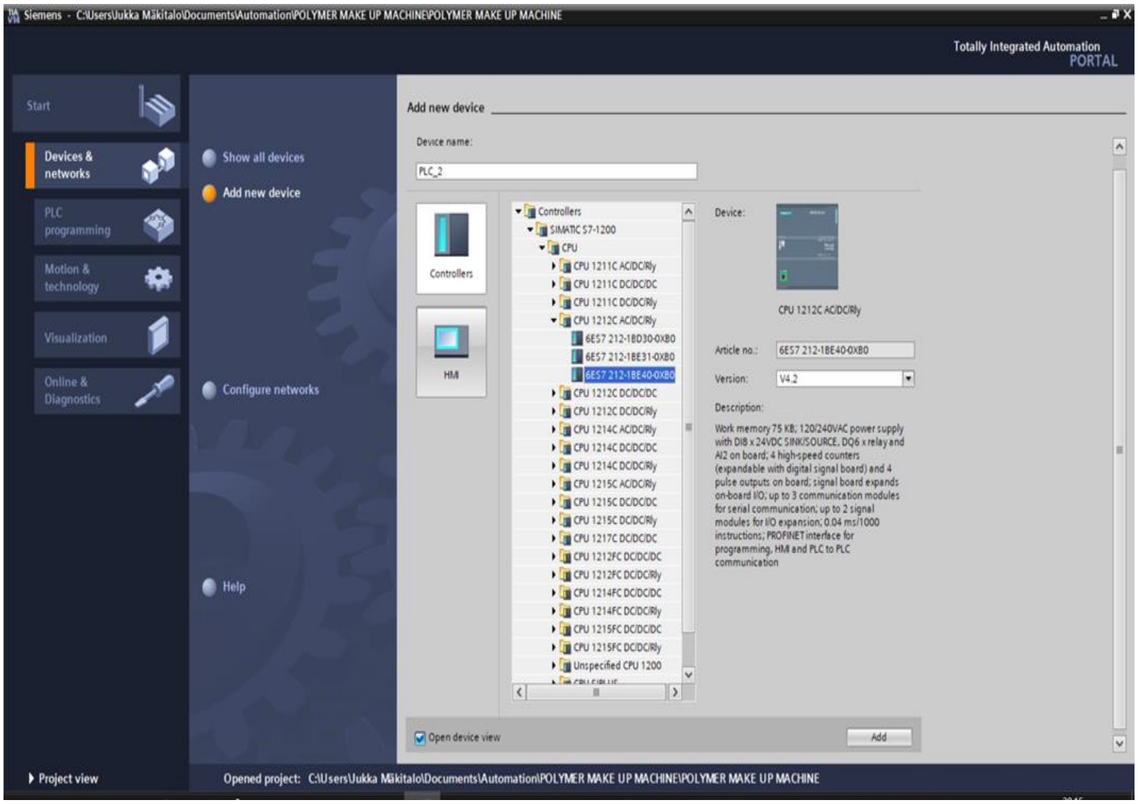

Figure 14 TIA portal overview

7 MODERNIZATION

The main reason for upgrading a PLC is obsolescence. Declining parts availability and lack of technical support will eventually cause a catastrophic unplanned downtime incident. This risk is minimized or eliminated by upgrading to a modern PLC platform.

Besides, older PLC systems may no longer have the capacity to handle changes in the operating environment. Their input/output and program capacity may be functioning at or close to the maximum possible. (Valmet 2010.)

Justifying the risk and expense of the control system upgrades is a challenge. Legacy systems operate in isolation and outdated equipment is costly to run. However, the threat of obsolescence may seem less daunting than upgrading. Today, smart manufacturing may cause to rethink that. To understand the risk of obsolescence, begin by conducting a lifecycle analysis of the equipment, spare parts, and software inventory. A thorough review of this information will help to prioritize the modernization needs and goals. (Modernization 2017.)

As described above, the oldness was the main reason for Kymen Vesi Oy to upgrade the logic controller of the wastewater plant. Two ways are available to modernize an S5-PLC (figure 15): migrate or a complete modernization. The term migration in automation environment means changing hardware and software by transferring data from the old controller to new one primarily via current technical infrastructure support.

Figure 15 Wastewater plant S5-100U old PLC

The industrial process diagram (figure 14) was the crucial tool for identifying the (I/O) input and output for the plant the control system. The feed pump is part of this diagram, but according to wastewater process control specifications, feeding belongs to other separated automation control system.

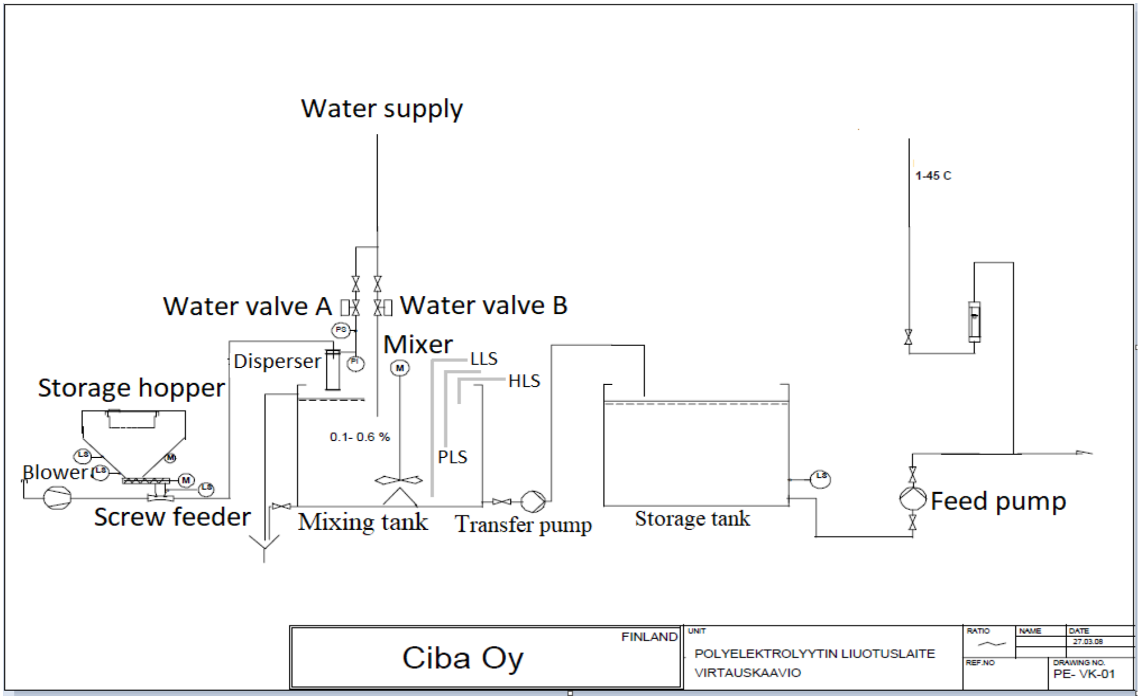

Figure 16 Wastewater PI diagram (kymen Vesi Oy)

7.1 Process description

When the mixer tank low-level switch is true, valve (A and B) are true.
When the mixer tank high-level switch is true water valve (A) is false.
When the process level switch is true

- Water valve (B) is false.
- Mixer (Motor) is true and the timer is (1500 seconds)
- Storage hopper vibrator (Motor) is true and the timer is (5 seconds true and 20 seconds false, elapsed time is (180 seconds).
- Screw feeder (Motor) is true and the timer is (299 seconds).
- Blower (Motor) is true and the timer is (350 seconds)

When storage tank level switch is true

- Transfer pump (Motor) is true
- Process level switch is false

When mixer tank low level switch is true

- Transfer pump (Motor) is false

Then the cycle is repeated.

System alarms

- Pressure switch alarm is true
- Alarm lamp is true
- All polymer unit system is false
- Alarm reset is true, alarms are false

Storage hopper alarms

High level switch alarm is true if the level of polymer is high

- Alarm lamp is true
- Alarm reset is true, alarms are false

Low-level alarm is true if the level of polymer is low

- Alarm lamp is true
- Vibrator motor is false
- Alarm reset is true, alarms are false

Screw feeder alarm

Level alarm sensor is true

- Alarm lamp is true
- Screw feeder motor is false
- Alarm reset is true, alarms are false

7.2 Hardware and software

The number and the nature of the devices the system will include is directly related to the number of I/O that will be required for the system. In this project, the PLC was chosen based on the amount of inputs and outputs required for the polymer makeup unit system and the module support of the signal type used by the devices installed. The hardware and the software used in project is described below.

- PLC S7-1200
- SIEMENS CPU 1212 C AC / DC / Rly controller (6ES7 212-1BE40-X0B0)
- I/O expansion card module (6ES7 223-1BH32-0XB0), DI 8X24VDC, DQ 8X24VDC

- HMI model KTP700 PN
- Ethernet hub
- Software (Simatic Step 7 V14 version Basics)

The choice was based on the number of devices to be controlled, the quantity of I/O inputs and outputs which the system requires, as well as a possible extension of the control process in the future.

7.3 Programming

Before programming, it is important to create a list which should include all the devices to be programmed. The polymer makeup unit have 16 digital input and 8 digital output modules. The (table 1) below illustrates the polymer makeup unit related physical digital I/O addresses.

Table 1 Program physical addresses

Abbreviation	Description	Input address
LLS	Mixing Tank Low Level Switch	I0.0
PLS	Mixing Tank Process Level Switch	I0.1
HLS	Mixing Tank High Level Switch	I0.2
LS	Storage Tank Level Switch	I0.3
LS	Storage Hopper Low Level Switch	I0.4
HS	Storage Hopper High Level Switch	I0.5
LS	Screw Feeder Level Switch	I0.6
PS	Pressure Switch	I0.7
AR	Alarm Reset	I8.0
AUTO 1	Automation 1 Mode	I8.1
AUTO 2	Automation 2 Mode	I8.2
MAN	Manual Mode	I8.3
ST MAN	Start Valve A/B Manual Mode	I8.4
ST MAN	Start Manual Mode (SC,BL,and VB)	I8.5
ST MAN	Start Mixer Manual Mode	I8.6
ST MAN	Start Trans Pump Manual Mode	I8.7
Abbreviation	**Description**	**Ouput address**
VA	Water Valve A	Q0.0
VB	Water Valve B	Q0.1
HV	Storange Hopper Vibrator (Motor)	Q0.2
SF	Screw Feeder (Motor)	Q0.3
BL	Blower (Motor)	Q0.4
M	Mixer (Motor)	Q0.5
TP	Transfer pump (Motor)	Q8.0
AL	Alarm lamp	Q8.1

In the Step 7 V14 version, creating a project begin by giving the name to the project and then the hardware configuration. The hardware configuration means adding to the PLC rack the corresponding CPU, the inputs, the outputs (I/O) cards as well as the power supply compatible with the PLC to be used. (Figure 18) demonstrate the PLC rack configuration of the polymer makeup unit upgrading project.

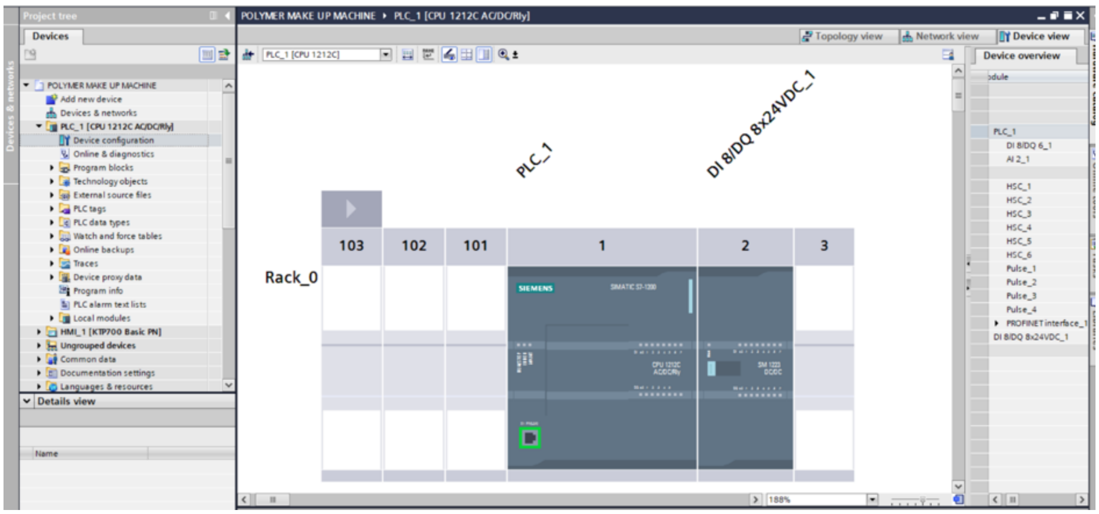

Figure 18 Device configuration in TIA portal V14 version

Once the project is created, and the configuration is done, the next step is to create the PLC tags table of the income inputs and the outputs were physical addresses and the data type are defined in the hardware with symbolic names used in the Simatic step 7 TIA portal (figure 19).

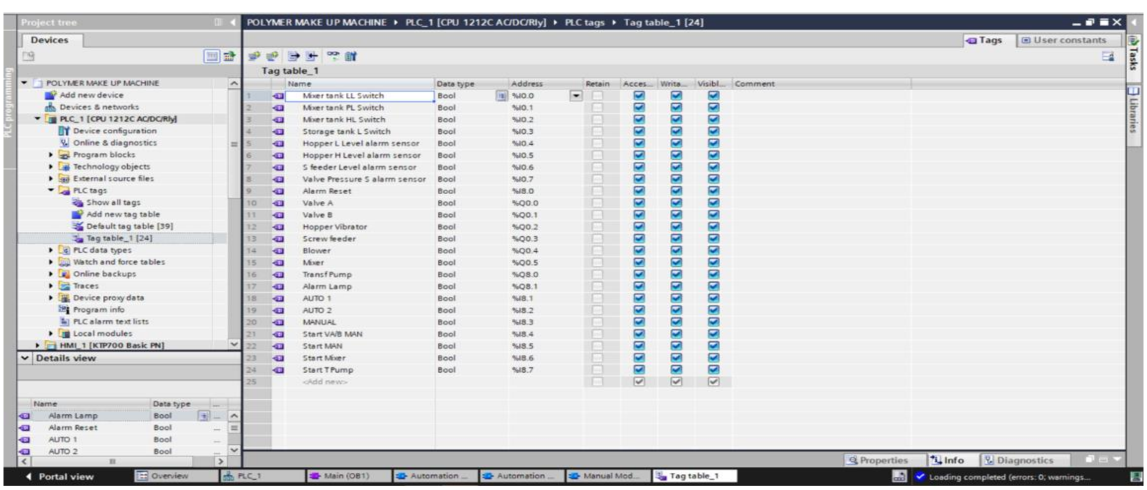

Figure 19 PLC program tags table

The polymer makeup unit programming project is based in existing control panel, which is divided as follows:

- Automation 1
- Automation 2
- Manual Mode
- Alarm Lamp
- Pause

The program was divided into two blocks, main organization block (Main OB1) and function block (FB).

Main OB1(Figure 20) included the Automation (1 and 2), as well as the Manual mode, which are the principal functions in control panel from the of polymer makeup unit. This block enables the operator to choose which programming mode could be run.

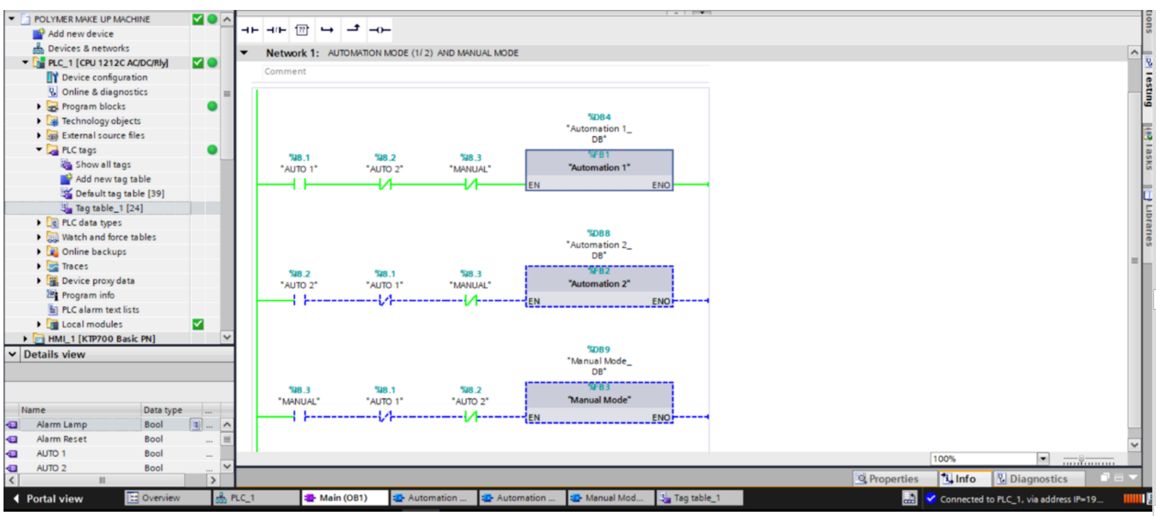

Figure 20 Program main organization block (OB1)

The FB block characterizes the physical devices programmed in different networks and divided into three distinct programs environment.

The function of (FB1/Automation 1) and (FB2/Automation 2) have the same operating principles, the difference between them is the mixing time. FB1 mixer operates with timer and the (FB2) without a timer, continues mixing until the storage tank level switch is activated, and consequently opening the transfer pump. When the water used to dissolve polymer is cold (1 - 20℃), (Automation 2) is the best operating option because the mixing time is undetermined. The polymer does not always dissolve when using cold water, see (Figure 21 and 22).

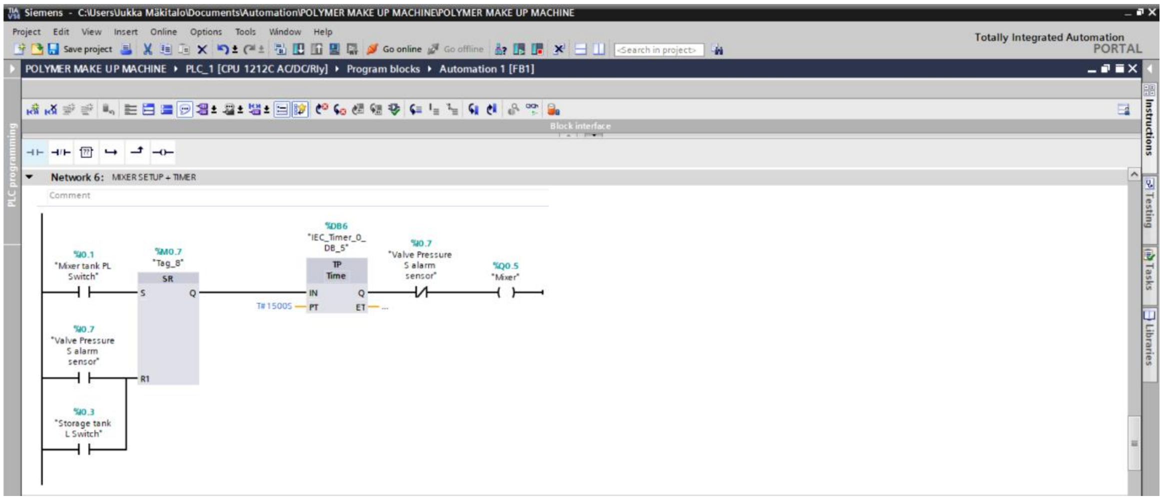

Figure 21 Mixer function block (FB1) network

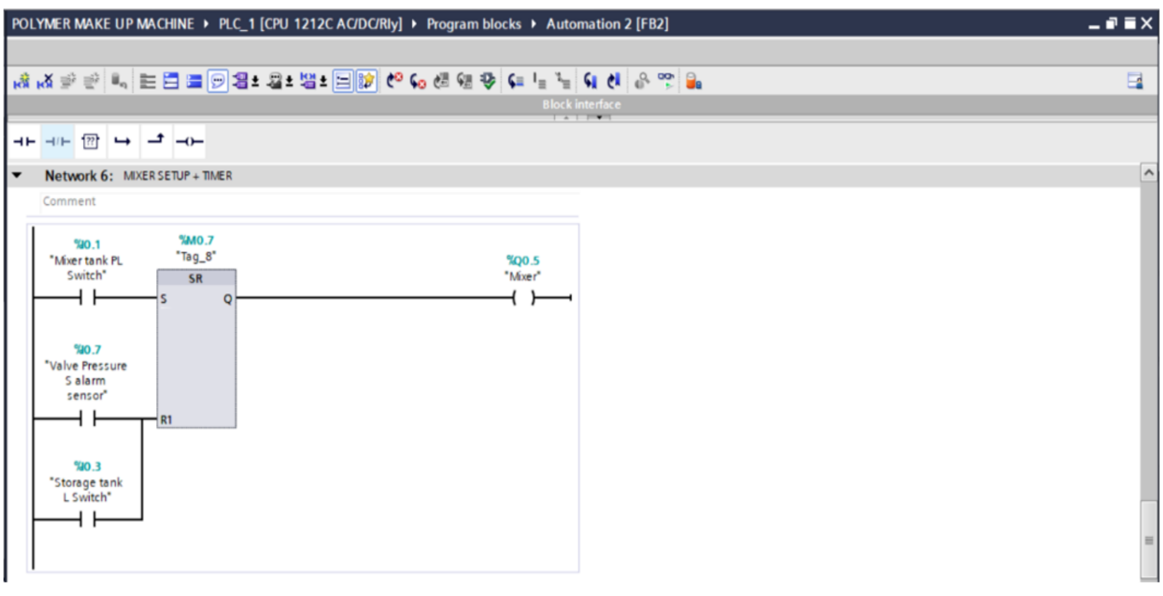

Figure 22 Mixer function block (FB2) network

The motors and valves can also be switched to the manual mode (FB3). This option is only available when the access control is turned to the manual position.

After the transfer pump ends the feeding, the screw feeder output must be measured at least before screwing.

It is recommended to use pause mode if the process must be suspended. The process will interrupt the automatic timing at any point, by turning the access control switch to the pause, so that while continuing automatic dissolution continues at the same location where the program ended.

7.3.1 HMI programing

After the HMI (Human Machine Interface) added to the PLC, a program utility is open to initiate a process of configuring the touchscreen interface. This function is called the HMI device wizard.
In the first screen of the configuration utility, the device PLC_1 must be selected through the browse button, so that, the connection link between HMI and PLC can be created. These devices are then ready to share variables each other. This procedure can be visualized in (figure 23).

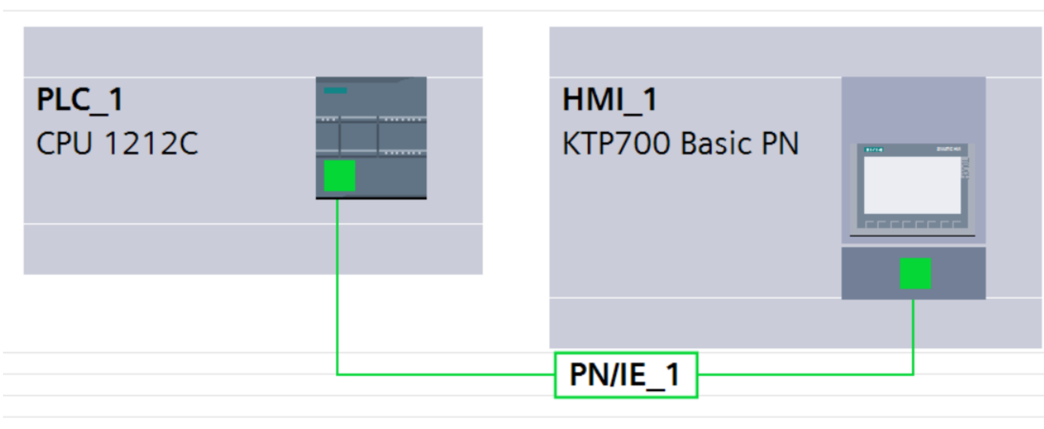

Figure 23 HMI interface configuration

The creation of tags in the HMI is nothing more than the conception of the variables that will be used in the screens of the HMI. These variables should be identical to the TAGs created in the controller. The way in which TAGs types which are associated with memory addresses are the same applied to the creation of TAGs in the controller. However, the association of the physical addresses to the TAGs should be done differently, since the HMI does not have input and output modules.

The TAGs created in the HMI are associated with the TAGs that correspond to the physical addresses of the PLC. This association has been done at the time of creation of the TAG in the HMI.

The KTP700 Basic PN panel (Figure 24 and 25) is more straightforward to program and is more illustrative compared to old one. The HMI panel arrangements are intended to be operated manually or automatically. The board has an 800-pixel horizontal image resolution, 480-pixel vertical image resolution, and 65 536-colors analog resistive technology display and contains eight free operating keys. The HMI panel has the Profinet connection to the bus, using the ethernet interface. The company will decide later, the possible enclosure of the Human Machine Interface (HMI) to the polymer makeup unit, as well as the mounting.

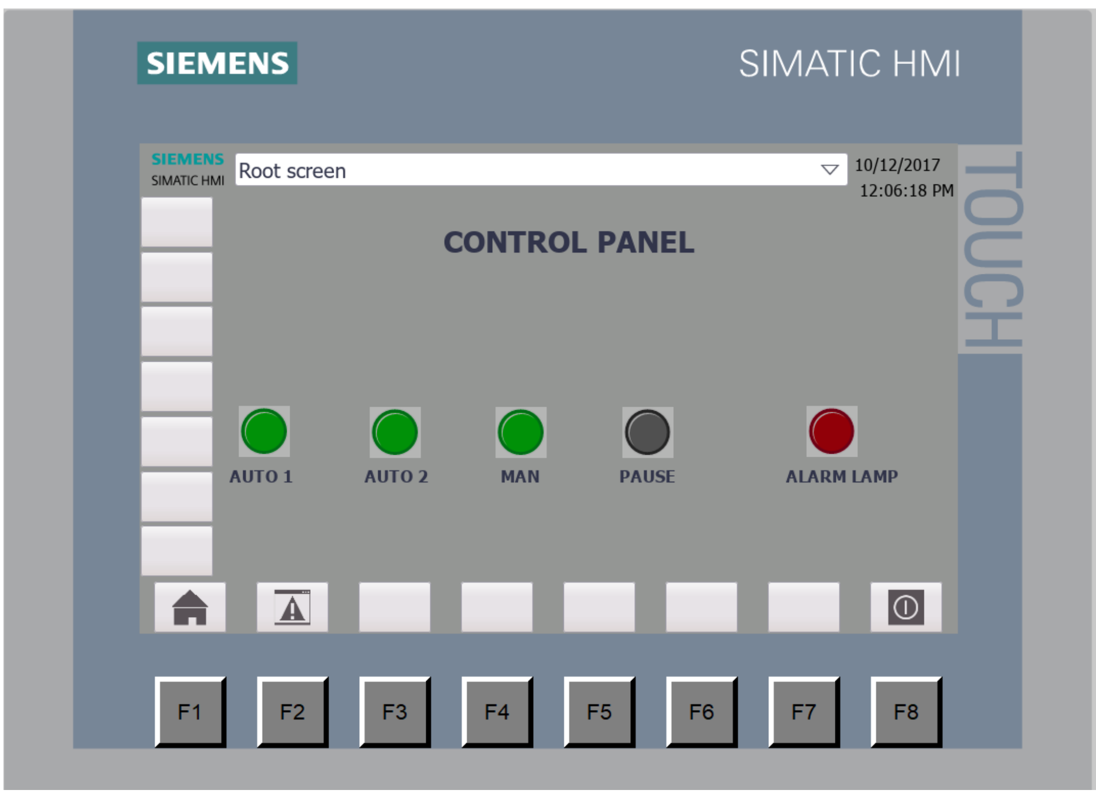

Figure 24 HMI control panel

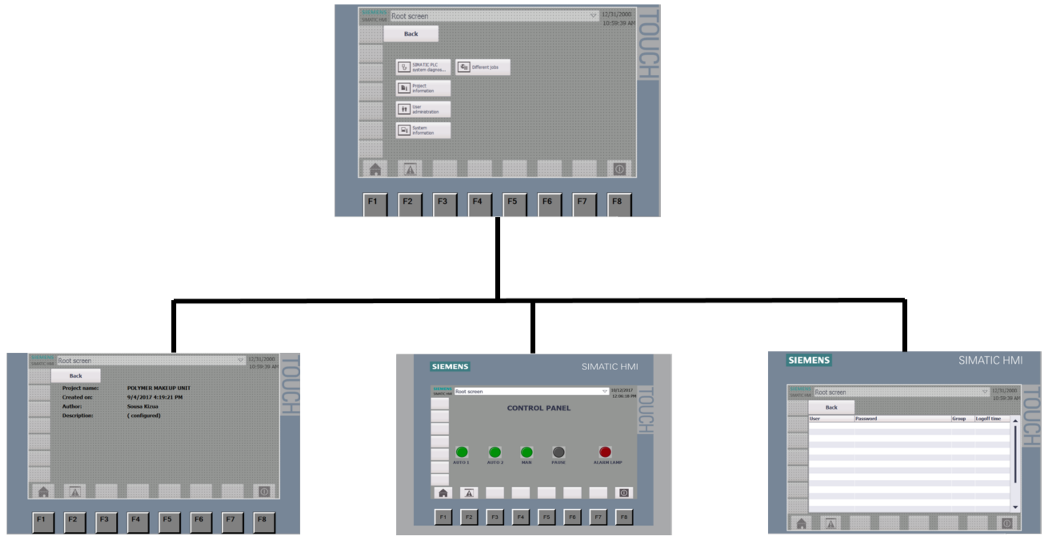

Figure 25 HMI structure

8 TESTING

First, the program test was carried out in the simulator which is part of TIA portal software. The simulation was only an indicator to verify the functionality of the program. At this stage, the information from the current input and output addresses were gathered, carefully simulated and scrutinized. However, simulation differs entirely with a physical test, in which the programmed devices are connected directly to the controller. It is important to mention, that program which functioned well on the simulator did not sometimes work in the same way as it should in practice. For this reason, a physical test was carried out, to guarantee, if the program was working as desired.

The program was subject to review, and some comment has been added to make the structure of the program more clear and understandable. At the same time, the errors found during the program improvement were subject to examination and subsequent correction, so that, the revised program could be tested again. The program has been tested several times and seemed to run all devices correctly as expected. Overall the functionality of the new controller and all devices tested with, worked as planned.

9 CONCLUSION

Modernization started as planned, the upgrading devices were identified as well as the old logic program. The information concerning the Siemens S5-100U logic was gathered via the Internet and some other sources. The data clarifications related to the selection of the new components of the logic controller to be installed were performed, specifically the Central Processing Unit (CPU), and the number of (I/O) input and output units, followed by selection of the suitable PLC for the upgrading process, and the selected device was S7-1200 series.

The initial idea of this study was to upload the software from S5-100U to S7-1200, which is possible with TIA portal programming software. Called (migrate), this function available in TIA portal programming environment, which allow the conversion of the Step 5 program into Step7. According to Siemens automation, is the best way to streamline an S5 PLC to S7 series. Seen has a straightforward procedure, migrate demands a set of conditions to be achieved. Unfortunately, the requirements for making it possible were not available at this study.

The company was not able to provide the Step 5 software which was used to program the old PLC, as well as the necessary technical support needed for a satisfactory investigation. It is important to mention here, that the vital tool obtained from the company in this study, was the industrial process diagram (PI diagram), which allowed the author of this study to understand the programmable devices in the polymer makeup unit. Owned by the chemical company Ciba Oy, the old control system of polymer makeup unit was rented to Kymen Vesi Oy at the beginning of its installation. In 2008 Ciba was sold to the German company BASF, and consequently Kymen Vesi bought the logic controller from BASF.

The goal of Kymen Vesi Oy was to renew the logic controller because it was an old model. Some technical information was available to facilitate the understanding of the system's functionality. The study was also done according to the investigation cared out in the field as well as the information gathered from the operating engineer and the process operators at the wastewater plant.

Possible installation time, wiring path and cable changes were not included in this study, because this study was intended to create a program in new hardware and software, ready to be used, in the case of probably failure of the old controller. Overall, the results of this study can be considered positive. Concrete results for both the company and the author were achieved. The bachelor's thesis was a great opportunity to the author learning ability in automation engineering and has also improved the knowledge of the Step7 programming in the TIA portal environment.

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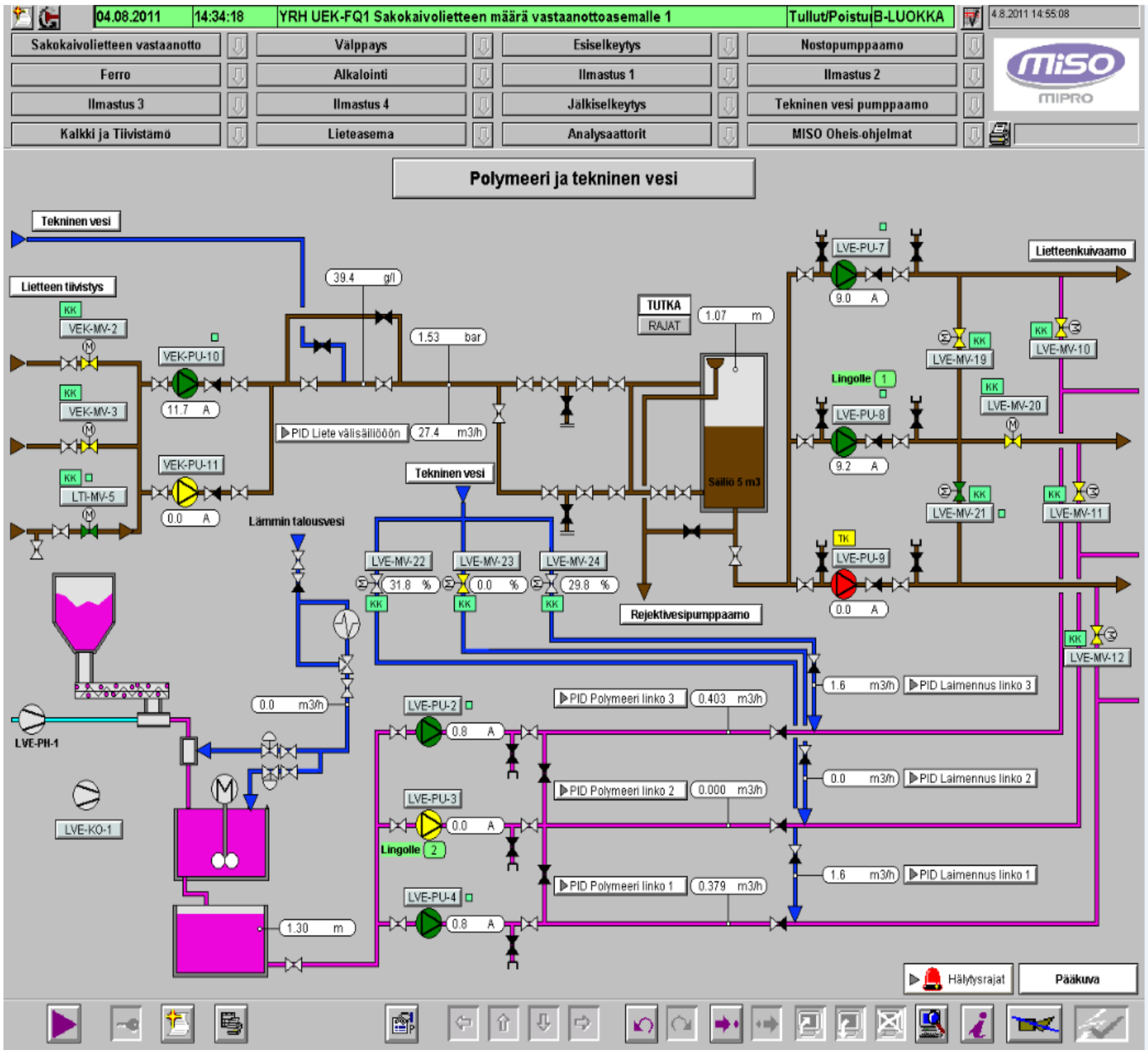
Appendix 1. Mussalo wastewater plant polymer and technical water process diagram.



Appendix 2. Polymer makeup unit technical measurement.