Design of a PID Controller Based on Programmable Logic Controller (PLC) and Human Machine Interface (HMI) for Water Level Control: A Case Study in Soufflet Malt Ethiopia Using Siemens Simatic WinCC

Biruk Seyoum Ayele

A Thesis Submitted to the Department of Electrical Power and Control Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Electrical Power and Control Engineering (Control Engineering)

Office of Graduate Studies

Adama Science and Technology University

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Declaration

I declare that this Master thesis entitled "Design of a PID Controller Based on Programmable Logic Controller (PLC) and Human Machine Interface (HMI) for Water Level Control: A Case Study in Soufflet Malt Ethiopia Using Siemens Simatic WinCC" is my own work and has not been submitted to any university for similar purpose. The references used in this proposal are duly recognized by proper citations.

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Recommendation

I, the advisor of this thesis, herby certify that I have read the revised version of the thesis entitled "Design of a PID Controller Based on Programmable Logic Controller (PLC) and Human Machine Interface (HMI) for Water Level Control: A Case Study in Soufflet Malt Ethiopia Using Siemens Simatic WinCC" prepared under my guidance by Biruk Seyoum Ayele submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Electrical Engineering.

Therefore, I recommend the submission of the revised version of the thesis to the department following the applicable procedures.

Prof. PhD Samsun MA	Samsun MA	12-07-2022
Major Advisor	Signature	Date

Approval Page

I, the advisor of this thesis, entitled "Design of a PID Controller Based on Programmable Logic Controller (PLC) and Human Machine Interface (HMI) for Water Level Control: A Case Study in Soufflet Malt Ethiopia Using Siemens Simatic WinCC" and developed by Biruk Seyoum Ayele, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Biruk Seyoum Ayele have read and evaluated the thesis entitled "Industrial Automation Using PLC and Developing Human Machine Interface using Siemens Simatic WinCC. (Using PID controller for Level control system)" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Electrical Engineering.

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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the office of postgraduate studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SDC).

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LIST OF ACRONYMS AND ABBREVIATION

AI	Analog input
AO	Analog output
CPU	Central Processing Unit
C/P	Current to Pressure
DC	Direct Current
DHP	Data Highway Plus
DO	Digital Output
FBD	Function Block Diagram
GM	General Motors
GPL	Graph Programming Language
GSM	Global System for Mobile Communication
HMI	Human Machine Interface
HVAC	Heating, Ventilation, and Air Conditioning
LAD	Ladder Diagram
LCV	Level control valve
LT	Level Transmitter
$\mathbf{M_P}$	Peak overshoot
PV	Process Variable
PID	Proportional Integral Derivative
PLC	Programmable Logic Controller
SCADA	Supervisory Control and Data Acquisition
SCL	Structured Control Language
SP	Serial Port
STL	Statement List
TCP/IP	Transmission Control Protocol / Internet Protocol
TIA	Totally Integrated Automation
$\mathbf{t_r}$	Rise time
$\mathbf{t_s}$	Settling time
VFD	Variable Frequency Drive

ABSTRACT

Water level control problem is a common process control problem in Soufflet Malt Ethiopia and most process control systems do not implement HMI based control system. This thesis focuses on the design and implementation of automatic water level control system based on a PLC, PID, and HMI. By using the existing PLC hardware, the water level control system is automated to minimize the need for human operators and the chance of human errors. This thesis has, three primary objectives: PLC and HMI system design, Auto-Tuning of PID controller and Simulation of the system using Factory I/O software. In PLC and HMI system design, hardware configuration of PLC, HMI configuration and visualization, Input and Output addressing, and the control algorithm is written. PID controller is configured and tuned using pre-defined auto tuning function of TIA portal. And finally, water level control system is simulated on Factory I/O software to check the functionality of the system. Automatic water level control system using PLC and HMI is designed to control the level of the tank and avoid wastage of water. The system automatically regulates the tank's water level based on the setpoint set on the HMI. And the system is visualized using a human machine interface (HMI). On the HMI level sensor feedback, pump animation, Fill and discharge valve opening percentage, alarms and trends are configured to have a better understanding of the process. Automating water level control system helps in reducing time consumption and human resource consumption, avoid water overflow, plant downtime because of low water level, increase production revenue by reducing downtimes caused by low water level or more safety and security for operators. It is noted from the simulation result that, the designed control system regulates the water level automatically without continuous human intervention as per the desired setpoint with minimum overshoot, faster settling time. In future by making some changes this project can be used in different industries related to fluids like petroleum industries or oil refineries for controlling the level of filling the tanks and avoid wastage. And with the latest PLC technologies and by maintaining secure connectivity and reliable data handling this system can be upgraded to cloud-based system for gaining remote connectivity to these on-site resources, accessing the data, and processing it.

Keywords: - *Siemens PLC, PID Controller, HMI, TIA portal, Factory I/O, Level sensor, Control valves.*

CHAPTER 1

INTRODUCTION

1.1 Background of the study

In recent years, an autonomous process control has arisen from the intuitive, particularly in industry. An efficient and effective solution is required to meet the rapidly expanding demand for industrial process control. The introduction of the first Programmable Logic Controller (PLC) in the 1960s ushered in technological changes in the industrial sector. As a result, designing a PLC-based level control system piques people's interest in learning about and comprehending PLC-based industrial control systems.

The automatic control refers to the representation of human control functions to technical electric equipment’s. The representation of human control functions to technical electric equipment is referred to as automatic control. The goal of automatic control is to apply mechanisms to the operation without requiring continuous human interaction. Automatic control is widely used in a variety of fields, including building climate control, traffic light control, process industries, and so on. With the rapid technological development in computer society, as well as the high labor cost and productivity requirement, automatic producing process control is becoming increasingly important in industry.

Certain variables are of Critical in most industrial processes, and they must be monitored and controlled to a desired value. In chemical process, for example, the temperature control is very important to maintain a steady output. The accuracy of the process control system is critical since it aids in increasing process productivity and preventing various irreversible concerns such as equipment damage, safety difficulties, and environmental issues. Process control systems are now widely employed in a variety of industries, including wastewater treatment, oil and gas purification, chemical manufacturing, pulp and paper manufacture, and food production.

PLCs were developed using computer technology, communication technology, and relay control technology, and they are now widely employed in industrial control sectors. In a PLC, programmable memory is used for internal storage procedures, and it can complete some functions such as logic, sequence control, timing, counting, and arithmetic operations. Digital or analog input/output can be used to operate various types of machinery or production processes. PLCs offer great anti-interference capabilities and reliability, and they can work in a variety of challenging operating environments. Liquid level control systems are essential in general industry, with liquid level control being widely utilized in water storage tanks, sewage treatment plants, power plants, pharmaceutical factories, and chemical plants, among other places. WinCC Advanced configuration software is a software platform solution for Supervisory Control and Data Acquisition (SCADA). WinCC can monitor the entire control process (Mahmood et al., 2018). PLC and configuration technology are widely employed in industrial control as a result.

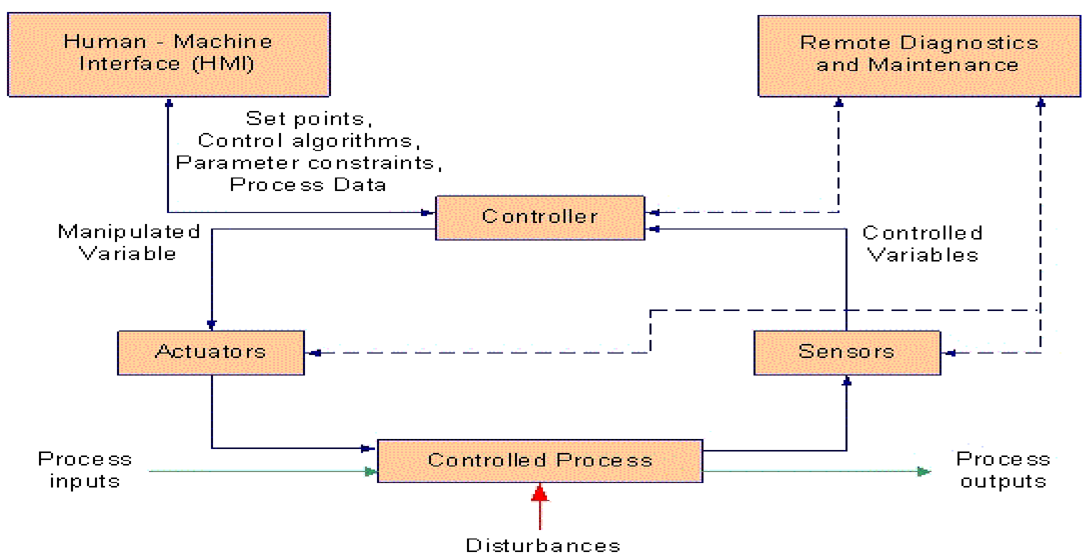


Figure 1.1. Overview of Industrial Control System

In a process control system, the controller is always important in transacting the system's operating conditions. Because of its advantages, such as fast reaction, quick and simple troubleshooting, low cost, and high reliability, the Programmable Logic Controller (PLC) is employed in most commercial implementations. As a result, in industry, a PLC-based process control system is commonly utilized.

1.2 Statement of the problem

Water is the main ingredient in malting process. Malting is a controlled germination. During the process enzymes will be produced and starch will become available. The grain will become soft and friable which is useful to be converted to flour by the brewer. From end to end the process last 8 days and is composed of 3 steps steeping, germination and drying. There are three main steps in malting process: -

1. Steeping: - In 4 vessels, 65 tons of cleaned barley will be soaked in each tank into the water for around 30h. The goal of this step is to initiate the germination of the grain, by increasing its moisture from 13% to 45%. During these 30h, there will be periods of immersion inside water and period of air ventilation after. This step consumes a lot of water
2. Germination: - After this 30hours of steeping, the 4 vessels will be unloaded, and the grain will be transported to the germination vessels thanks to conveyors and elevators and will stay in Germination Vessels for around 5 days for the germination step. After the malt will go from germination to the kiln with the conveyor. The goal of the germination step is the production inside the grain of the enzymes that will be essential for the beer production. In germination vessels, the atmosphere is monitored to bring the best conditions for germination of the barley
3. Kilning: -The purpose of the last step of malting will be to stop the germination process. To stop the germination process, the grain will be transferred to another vessel called "KILN" and will be dried in order to bring its moisture content below 4.5%. This step is called kilning.

Out of this three steps water is used in steeping and germination steps. And it is also used in

- Firefighting/hydrant system
- Cleaning of steeping vessels and Germination box
- Wastewater treatment plant and
- Domestic supply for sanitation and hygiene

Hence controlling the level of the water is very essential in the production process. Table below shows summary of water consumption per day.

Table 1.1. Water Consumption per day of Soufflet Malt Ethiopia

Date	Steeping (m^3)	Air Humidification (m^3)	Cleaning (m^3)	WWTP and Domestic supplies	Spraying (m^3)	Total (m^3)
02/08/21	2097	346	50	60	50	2683
16/08/21	1047	149	31	12	48	1210
23/08/21	1249	172	54	69	51	1830
30/08/21	998	209	53	81	50	1970
06/09/21	1246	200	59	77	49	2047
14/09/21	1482	297	146	69	53	4310
20/09/21	1062	226	62	131	48	1850
28/09/21	999	437	67	135	60	2350
11/10/21	1273	346	110	103	48	2190
19/10/21	787	232	37	67	50	1520
25/10/21	1052	316	144	133	48	2130
01/11/21	819	311	49	125	48	1680
20/12/21	992	192	32	33	54	1650
17/01/22	957	107	20	450	60	1590
23/01/22	980	224	120	300	48	1690
30/01/22	1094	356	210	340	54	2121
6/02/22	1907	198	78	250	48	2505
13/02/22	1087	389	184	105	48	1980
20/02/22	1390	367	146	130	62	2120
28/02/22	1567	372	246	330	48	2595

Note: Water consumption for firefighting system is not included b/c there is no way to measure water consumption of fire hydrant line

The current water level control system of Soufflet Malt Ethiopia is not state of the art control system, that the factory with huge water consumption needs. water is pumped by 37 KW motor from underground water reservoir. The operator manually starts the motor and manually checks level of the tank with a capacity of 1200 m^3 by climbing 5m high ladder. This can be done 3 to 4 times a day depending on the consumption of water. Which is tedious and risky job.

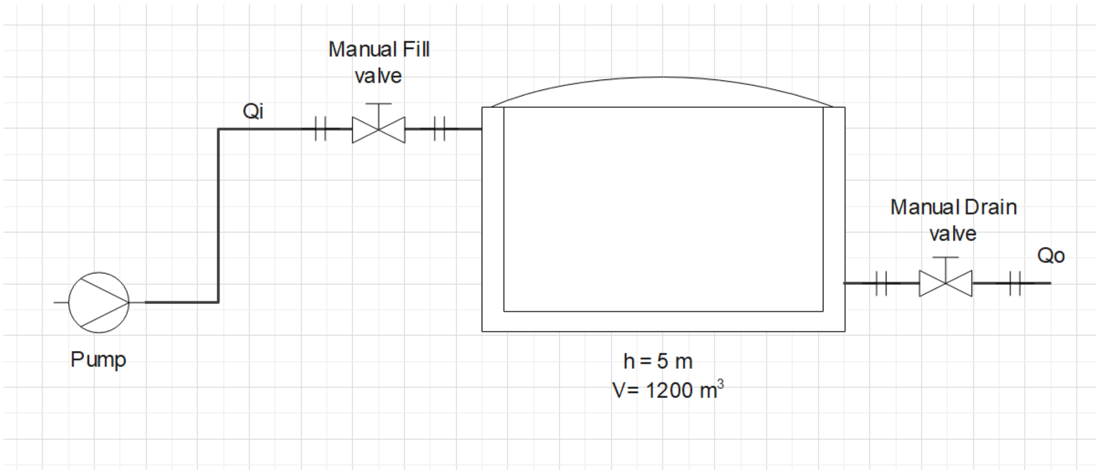


Figure.1.2. Existing Level Control System

1.3 Objective of the study

Existing water level control system of Soufflet Malt Ethiopia is manual control system and for a company in which water is the main resource for the production. And for a company which uses an average of more than 1800 m^3 of water per day needs automatic water level control system. This thesis focuses on automating water level control system with PLC and Human Machine Interface (HMI) for operators' visibility and maintenance simplicity. The only thing the operator will do is, set the required water level on the HMI and the system automatically control the level.

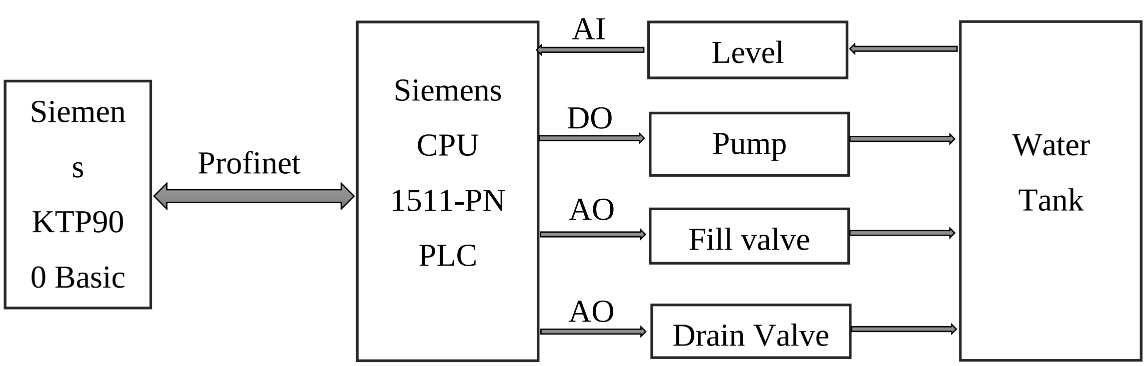


Figure 1.3. Composition of Designed Control System

Programming software, Design software and simulation software's are used for writing control algorithm, for designing mathematical model of the system and for simulation of the designed system respectively.

1.3.1 Specific Objective

The specific objectives of the thesis are: -

1. To develop mathematical model for the tank, level sensor and Actuator for selecting the appropriate type of sensors and actuators in relation to the process.
2. To design a Programmable Logic Controller (PLC) and PID based water level monitoring system.
3. To implement user friendly Human Machine Interface (HMI) visualization features on the water level monitoring system.

CHAPTER 2

LITERATURE REVIEW

In this thesis, few subject specific research articles, industrial engineering studies and research reports have been reviewed. Few company websites in addition to company manuals were also referred. The authors of the paper "Industrial Burner Automation Based on PLC, HMI, and SCADA" indicate that automation is based on PLC, HMI, and SCADA with remote monitoring and energy conservation. These researchers employed SCADA software for remote monitoring, a human machine interface (HMI) for burner control and monitoring, and a variable frequency drive (VFD) for motor speed control utilizing proportional integral derivative (PID) logic. The HMI display for monitoring the configuration screen, mode selection screen, VFD settings, and input-output status is explained by these authors. The data logging is done in CSV format (Pandey et al., 2015). Jayanthi et al. applied automation utilizing PLC, HMI, and SCADA in another study titled "process automation of demineralization plant using delta PLC, Wonderware in touch, and delta HMI." In their study of demineralization, the raw water obtained from underground, and lake is treated to meet standard as per usage and parameters monitored are PH and turbidity. Jayanthi et al. employed a project delta PLC that is interfaced with an HMI, and the HMI is further connected via Wi-Fi for remote monitoring and control, and SCADA is also interfaced with the PLC and PC in their investigation. This is used for improving the quality and quantity of dematerialized water (S, 2020). Control devices such as PLCs, PCs, and HMIs are used in industrial automation. While using these control devices, users can control the industrial processes and machine using less labor making it easy to operate. Control systems is most important part of Industrial automation. Automation is the control and monitoring of processes using cutting-edge technology such as ladder logic and controls, robots, and industrial software. Automation reduces the human work, save the money, and gain money (Nimawat & Shrivastava, 2016).The advantage of Industrial automation includes improvement in product quality, reduction in labor required, reduction in production cost, reduced routine manual tasks, improved safety, and assisted remove monitoring. Industry 4.0 means smart factory. In smart factory different types of digital devices are connected and then communicated with robots, raw material flow, machine tools, products and human. Industry 4.0 presents a change by digitalization as well automation of every company and manufacturing process. The manufacturer will communicate with the computers. According to Kagermann et.al. (2013), Industry 4.0 utilizes the power of communications technology and innovative inventions to boost the development of the manufacturing industry (Ing Tay et al., 2018).The advantages to Industry 4.0 include, improved productivity, improved efficiency, increased knowledge sharing & collaborative working, flexibility, increased profitability, reduces costs and a return on investment.

Automation of tank level using PLC establishment of HMI by SCADA. The system uses programmable logic controllers to enable simulation and component analysis for the creation of an automated level control system (PLC). Supervisory control and Data Acquisition (SCADA) were established, and HMI was created. In many tasks, the model effectively supervises the water level. The level data was sent to the PLC by three level sensors. The PLC uses this information to make the necessary decisions, which include turning ON and OFF the pump. PID Closed-Loop control analysis for automation with siemens PLC using Totally Integrated Automation (TIA) V13 by Yin Yin Soe and Pann Ei San (2019). Implementation of analog inputs to PLC and hardware configuration of S7-1200 CPU (Soe & San, 2019).

2.1 History of Programmable Logic Controller (PLC)

A PLC is a digital computer that is used to automate electromechanical processes. Unlike general-purpose computers, the PLC is built for multiple inputs and outputs, expanded temperature ranges, electrical noise immunity, and vibration and impact tolerance. Programs for controlling machine function are often stored in non-volatile or battery-backed memory.

PLCs were first used to replace relays in an industrial control system in the 1960s. A PLC was Abbreviated as PC during that time. The abbreviation has been changed to PLC to avoid the programmable logic controller being confused with a personal computer. General Motors (GM) creates the first PLC in the 1960s. Figure 2.1 below depicts the first generation of PLC. GM was inviting interested companies to create a gadget based on the GM's specifications. The goal for inventing PLC at the time was to find a way to regenerate complex relay control systems. The device must be easy to program, dependable, and inexpensive to maintain. The second PLC, the Model 084 PLC, is developed by Gould Modicon Company in 1968. The basic working principle of the first generation of PLCs is Boolean algebra, which asserts that one variable has only two states (on and off). Only the On /Off control is possible with the first PLC.

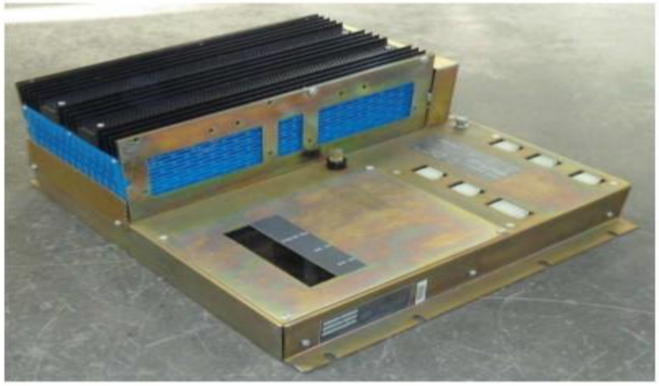


Figure 2.1. The First PLC of Allen Bradley.

Based on the first generation of PLC production, the second generation of PLC has more features and capabilities, which has boosted the use of PLC in industry. As a result, the PLC may be utilized to regulate a far more complex process. In addition, the PLC is becoming increasingly sophisticated, with features such as timer and counter functions, memory setting and resetting, and mathematical computation operations. All of these advancements can be attributed to advancements in microcontroller and software programming techniques. Nowadays, the PLC is made up of five basic blocks:

- Rack Assembly, this is where the input and output terminals, power supply, and CPU unit are mounted.
- Power Supply, which can provide direct current (DC) or alternating current (AC).
- Input/output Section, which are used for connecting external terminals for devices to the PLC.
- Central Processing Unit (CPU), controls all system activities and it is the brains of PLC.
- Programming Device is a device that is used to program the PLC.

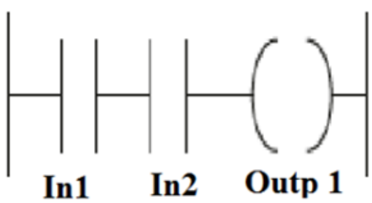
Another important property of a PLC is that it can directly deal with analog signals. This method simplifies the design of a process control system. Analog inputs and outputs, along with the basic digital inputs and outputs, were enlarged on a PLC at the end of the 1970s. The analog inputs and outputs in PLCs can be used to efficiently monitor and manage real-time data. As a result, a PLC-based control system can improve system response time and detect issues more quickly. Furthermore, the cost of installing a PLC is inexpensive, and the system is well-designed. Switches, lambs, pumps, valves, and other physical components can all be connected to the PLC's external terminal. Then, using PLC programming, all connected physical components may be controlled. In other words, program components are PLC programming representations of mechanical components, allowing one mechanical component to serve many control purposes. A system in industry can have thousands of switches or lamps, therefore lowering the amount of physical components can lower the system's total cost. In addition, each component has a service life. The components, on the other hand, can be represented by program components, giving a PLC-based control system a high level of reliability. Finally, the PLC has become widely employed in industry due to its ability to meet most of the needs of an industrial process control system.

2.2 PLC Programming Language

PLCs can be programmed in a variety of different languages and different PLCs from different manufacturers may implement slightly different variations of those languages. Not all PLCs support multiple languages, and the ones that do support more than one language do not necessarily allow for that language to be fully implemented. The general correlation between PLCs and language support comes down to cost – the more expensive a PLC is, the more likely it is to support more than one language type. Siemens PLCs, when programmed with TIA Portal, support multiple languages, even at the lower ranges.

The PLC accept many different programming languages, such as Ladder Diagram (LD), Graph Programming Language (GPL), Function Block Diagram (FBD), Structured control language (SCL), and Statement List (STL). These languages are supported by standard IEC 61131-3(*W. Bolton, Programmable Logic Controllers. Newnes, 2015. - Google Scholar*, n.d.). For programming particular specific editions of PLC, special software is used. Telepace Studio, for example, takes LD and FBD, while TIA Portal accepts all programming languages. The ladder diagram and the function block diagram are the two most common PLC programming approaches. The ladder diagram is in the shape of a ladder, with two vertical rails and a large number of rungs to program. Because the two vertical rails indicate the power supply, all components in a ladder diagram must be connected to both ladder rails. The current goes from the left to the right of the ladder. Figure 2.2. below shows an example of a ladder diagram. A ladder diagram is similar to a traditional electrical circuit diagram. In a ladder diagram, the symbols represent physical functions.

A Function Block Diagram, like the ladder diagram, is a graphical programming language. The blocks in the function block diagram, on the other hand, have no physical functions. A function block, on the other hand, explains the relationship or function between the inputs and outputs. A fundamental understanding of logic functions such as AND, OR, NAND, and NOR is required to design a function block diagram. The Figure 2.2 below shows the AND in both ladder diagram and Function block diagram. Because programming is largely concerned with implementing logic and switching operations, the term logic is employed. e.g., if A or B occurs switch on C, if A and B occurs switch on D. Input devices, e.g., sensors such as switches, and output devices in the system being controlled, e.g., motors, valves, etc., are connected to the PLC



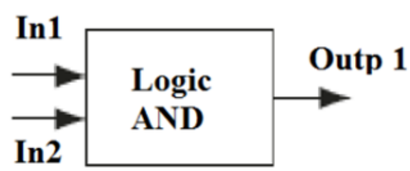


Figure 2.2. Examples of LAD And FBD

Structured control language (SCL) in Siemens is more commonly referred to as structured text. It is a textual language that is considered the most complex of the programming languages. SCL is one of the harder languages to learn due to it having a larger instruction set and syntaxes that need to be learned. SCL makes extensive use of instructions that are not available in other languages, such as IF and FOR. These additional instructions allow the language to perform repetitive or complex logic with much more ease than that of graphical languages(*PLC and HMI Development with Siemens TIA Portal: Develop PLC and HMI Programs Using Standard Methods and Structured Approaches with TIA Portal V17: Bee, Liam:* , 2022).

```
IF #Node_Index <> 0 THEN
    //Check if the mask for the alarm contains a 1, if so, process the alarm check
    "Global_Alarm_Manager"(Condition := #Temp_Diag_Data[#Master_Index].M1_LCE_Slave_A[#Node_Index] AND
                           #Alarm_Masking_Array[#Node_Index],
                           Index := ((#Master_Index + 225 + (#Master_Index * 64)) + #Node_Index) - (1 * #Master_Index),
                           Alarm_Data := "H1_Alarms".SYS,
                           AB_Data:= "H1_Alarms".AB,
                           ARM:= "H1_System".ARM,
                           Alarm_Active => #Alarm_Active,
                           Alarm_Status => #Alarm_Status);

END_IF;
```

Figure 2.3. Example of SCL

Statement list (STL) is another textual language that was very popular in the earlier Siemens days. STL is becoming less and less utilized in favor of SCL, but STL has some instructions that are not possible to use in SCL. STL, while text-based, is written differently to SCL and is not comparable to any other language set. It is a programming language that, unless you are very comfortable with it, will most likely require documentation to write.

Network 1: .....

Comment

```
//Amplify signal
        L       #Signal
        L       20                              20
        *I
        T       "Amplified_Signal"              %MW10

//Check Enable Signals And Enable Output Signal
        A       #Enable_1
        A(
        O       #Enable_2
        ON      #Enable_3
        )
        =       #Enable_Signal

```

Figure 2.4. Example Of STL

Similar to a sequential function chart, GRAPH is a graphical language that is best suited for managing sequences and parallel processes. GRAPH comes with additional features such as interlock monitoring for each step (the interlock must be healthy for the step to take place) and supervisions that fail a step and stop the sequence from continuing. TIA Portal does a good job at creating an environment that makes managing a sequence much easier, with all the relative building blocks in place already. GRAPH is not strictly a programming language in its own right. It relies upon ladder logic to set transitions, interlocks, and supervisions.

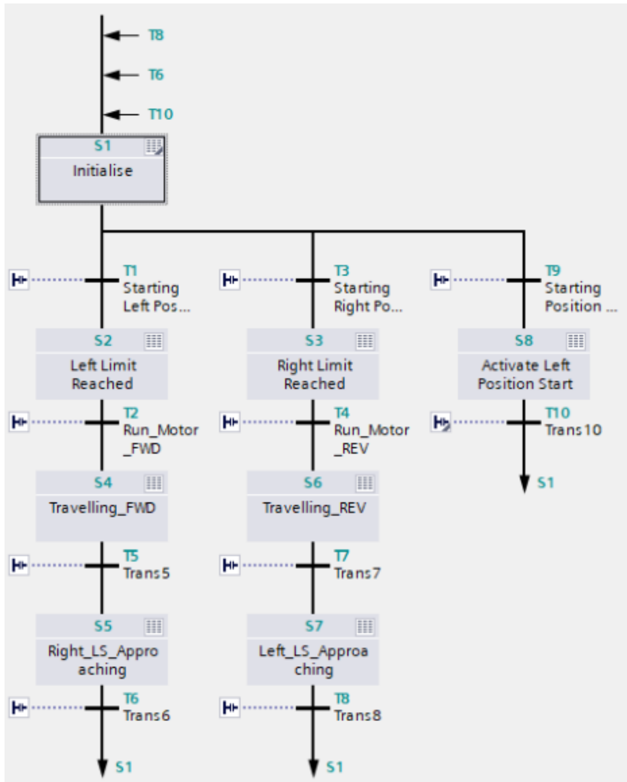


Figure 2.5. Example of GRAPH

2.3 PLC Applications

PLC control systems have been widely used in modern industry in a variety of applications, including water and wastewater treatment, sun-tracking, wind energy, photovoltaic applications, heating, ventilation, and air conditioning (HVAC) control, manufacturing, and so on. One common feature of these applications is that they can be modelled as process control problems. Pumps and valves in the water and wastewater treatment control system, for example, are controlled based on real-time data from the process. To be more specific, water level control problem is a typical process control problem. Therefore, in this section, some related literature is reviewed and discussed.

(Kondratenko et al., 2015) designed a PLC based system to control liquid level by using Radar sensor remotely. The liquid level, volume, temperature, and pressure are all measured and controlled remotely by this system. The Radar sensor, temperature sensors, discrete level sensors, and a programmable logic controller make up the system. PLC is programmed by the FBD programming language. The authors use an RS 485 bus with an ASCII-based protocol to send data between all the components. The authors state that communication protocol reduces or eliminates interference during the process of data transmission. To monitor the system, the authors also design a human machine interface (HMI). Finally, the experimental result corroborates the exactitude and reliability of their system.

(Panchal et al., 2015) carried a test on a PLC based single water tank control system using PID controller. In their system, an HMI which is programmed on NI-LabVIEW is connected to an Allen Bradley Micro830 PLC through the Modbus RTU communication protocol. According to Pooja et al., this system is designed for training purpose to have a complete understanding of PLC based process control system design. In their literature, some necessary modeling’s are introduced, such as the water tank modeling, transducer modeling, and the control valve modeling. Some parameters, such as the resistance of the control valve, and current to pressure (I/P) converter, are estimated depending on the experimental data by using the method of least squares. Furthermore, Pooja et al. applied PID algorithm into the PLC to achieve a better result. The PID parameters are calculated by using Ziegler Nicholas (Z-N) method. Finally, the authors conclude that the experimental result is matched with their prediction.

(Sreejeth et al., 2016) did a preliminary test on a liquid mixing and bottle filling system. This system is controlled by a PLC. In their literature, the system simulation based on MATLAB/Simulink and PLC ladder diagram programming are included. There are three subsystems in the ladder diagram for mixing, filling, and level monitoring respectively. Mini and Shilpa described that three water tanks, several level sensors and a DC motor consist of the system. They explain that two different kinds of liquid are stored in two tanks separately. Two pumps controlled by the PLC pump preset amount of the two types of liquid into an overhead tank for mixing. Then, the DC motor drives a conveyor belt carrying bottles for filling. To control the amount of filling, a control valve controlled by the same PLC is applied to the overhead tank. To avoid overflow of the mixed liquid stored in the overhead tank, three level sensors are used to monitor the liquid level. The sensors are used for tracking low, high and emergency level respectively. Furthermore, Mini and Shilpa used a PID controller as the algorithm of the system to achieve a better controlled result. As a result of using PLC combining with PID controller to control the system, Mini and Shilpa summarized that PLC based control system could reduce human intervention and operating cost. At the same time, it can increase producing efficiency and driving safety.

(Da’na et al., 2008) developed a networked platform which can be used for remote monitoring and controlling PLCs. The reason of that, Da’na et al. mentioned, is that the computing ability of PCs is increasing, and the available options of network protocols and standards are various. In their system, a Simatic S7 200/300 PLC is applied. The available communication methods of the PLC are LAN, WAN, or GSM. To achieve the final experimental goal, the key parts of their system are the Transmission Control Protocol / Internet Protocol (TCP/IP) setup and Global System for Mobile Communications (GSM).

In order to train engineering students on PID control processes (Engin et al., 2013)designed a level control system using PID control algorithm on a programmable logic controller. In their literature, a description of PID parameters tuning is introduced. Also, based on the PID parameters, a ladder diagram design of level control system is explained. The feedback sensor used in this system is a level transmitter. Finally, as the experimental result shown in their paper, the PLC based PID level control system is stable.

CHAPTER 3

METHOD AND EXPECTED HARDWARES

This study considered Siemens make modular type PLC, which is having on board display, 8 digital input module, 8 digital output module of 24 V and 1 analog input module having 4 channels with 4-20 mA and 1 analog output module having 4 channels. For programming of PLC TIA portal software is used as a programming platform to develop the logic, configuration and tuning of PID, testing and simulation. This thesis has considered Siemens HMI of 9 inches, touch screen having 1 internet port for interfacing with PLC. This is used for information exchange between the system and humans/operator. Simatic WinCC is used platform is used for development of the screen, reports, visualization, alarms, and data collection. All the basic parameters like Setpoint, Process variable, motor start and stop and PID parameters can be controlled and monitored on the HMI. The proposed system into divided into: - Design, Sensing, Decision making and Implementation using Factory I/O. SIEMENS S7- 1500 PLC controller, Siemens KTP900 Basic PN HMI and Factory I/O for simulation are used. level sensor, pump and pneumatic actuators are used to implement the system. The sensor detects the level of water. The reading of the sensor is used by the PLC to take the required decision and visualization of on the HMI has been implemented. The PLC takes the required action based on the control algorithm, which is written in Ladder diagram (LAD). Siemens TIA portal was used to implement the ladder logic.

The proposed system will continually control and monitor the tank's water level, ensuring that the needed level of water is maintained according to the Setpoint without the need for constant human interaction. The setpoint is set from the HMI and the process can be monitored on the HMI. Sustainability of available water resource in many reasons of the world is known to be dominant issue. Poor water allocation, inefficient consumption, and a lack of competent and integrated water management are all contributing to this problem. This system is suitable for industrial use. It can be used to avoid industrial accidents caused by overfilling of any open container, as well as to avoid overfilling of any closed container, resulting in an overpressure state. The PLC's enormous number of input and output ports will allow this single system to control a big number of tanks all by itself.

The system is operated by PLC so there is no need of human interference this could save the human resources and provides protections to individuals from danger of industrial accidents. The system is highly reliable, once programmed it does not need any inspections.

3.1 Materials

Both hardware and software components are required for the implementation of Development of PID Controller applying Programmable Logic Controller (PLC) and Human Machine Interface (HMI) for Water Level Control system.

3.1.1 System Software

System software's are used for implementation of automatic level control system and simulation of implemented system. Programming software's, Totally Integrated Automation portal (TIA) Version 15 and Siemens Simatic WinCC Advanced are used for hardware configuration, to write the control algorithm using ladder programming (LAD)language and to interface PLC and HMI and design and programming of HMI respectively.

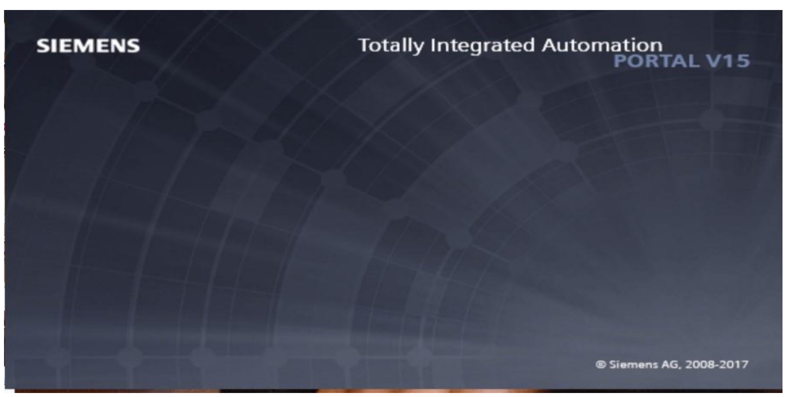


Figure 3.1. TIA Portal Programming Software

Wondershare design tool have also been used for the design of system Piping and Instrumentation Diagram (P&ID). Integrating level control valves (LCV), level transmitter (LT) and pump including the piping system. Factory I/O a 3D factory simulation software is used for the design, Virtual build, and simulation of the system.

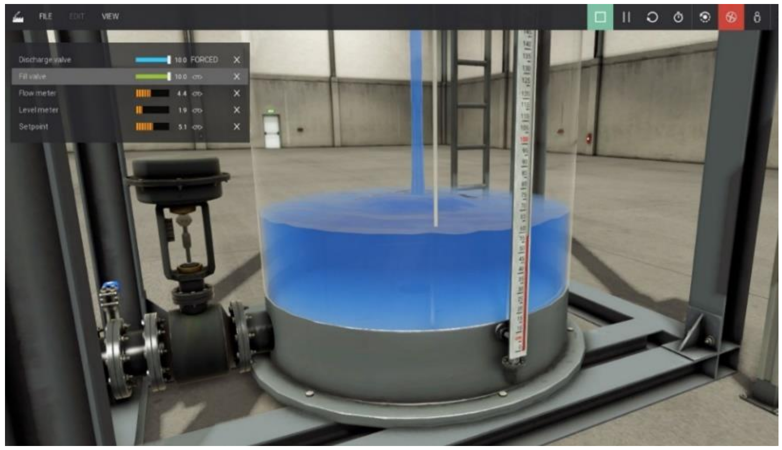


Figure 3.2. Factory I/O 3D Simulation Software

3.1.2 Expected Hardware’s

The required hardware’s are: -

1. PLC
2. HMI
3. Level control valves
4. Level transducer
5. Pump motor

3.1.2.1 Programming Logic Controller (PLC)

A programmable logic controller (PLC) is a special-purpose computing device used in industrial control systems and other systems that require high system reliability.

They were originally developed by the automation industry to replace hardwired relays, sequences, and timers used in the production process, but they have since grown in popularity and are now utilized in a variety of manufacturing processes, including robot-based lines. There is probably no factory in the world today that does not have a PLC-controlled machine or piece of equipment. The fundamental reason for their widespread adoption and use can be traced back to their robustness and ability to endure the rigorous handling/environment encountered on factory floors. They are also good examples of real-time operating systems since they have a high ability to produce outputs to specific inputs in a very short timeframe, which is important in industrial settings because a second delay might interrupt the entire operation.

PLCs are mostly employed in commercial and industrial settings. Industries rely on a diverse set of difficult-to-operate machinery. Motors, pneumatics, and hydraulic drive systems operate parts of every machine. Sensors are used to detect when machine parts are likely to move or malfunction, as well as external things that the machines process in order to make machine operations more efficient. PLCs are utilized to speed up the operations of these industrial machines. PLCs keep track of machine inputs, make decisions based on programming, and regulate outputs to automate machines and processes.

Input points or modules, output points or modules, and a CPU (central processing unit) make up a PLC. Inputs accept a wide range of analog and digital signals from various sensors/field devices and transform them to CPU-compatible logic signals. The CPU then makes the required decisions and executes control instructions in accordance with the memory's set program instructions. Output modules are responsible for translating CPU control instructions into analog or digital signals, which are then utilized to drive various actuators and field devices. Programming devices are used to input instructions that determine what PLCs do for specific inputs. Finally, an operator interface device facilitates the display of process information and input of new control parameters.

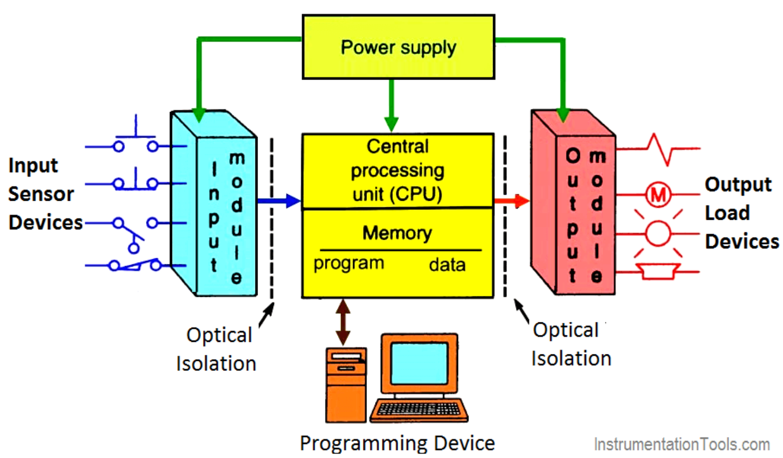


Figure 3.3. Programmable Logic Controller

PLCs are essentially made up of a processor module, the power supply, and the I/O modules. The central processing unit (CPU) and memory make up the processor module. In addition to a microprocessor, the CPU has at least one programming interface (USB, Ethernet, or RS232) and is connected to communication networks. The power supply is usually a separate module, and the I/O modules are separate from the processor. Discrete (ON/OFF), Analog (continuous variable), and special modules like motion control or high-speed counters are examples of I/O modules. The I/O modules are connected to the field devices.

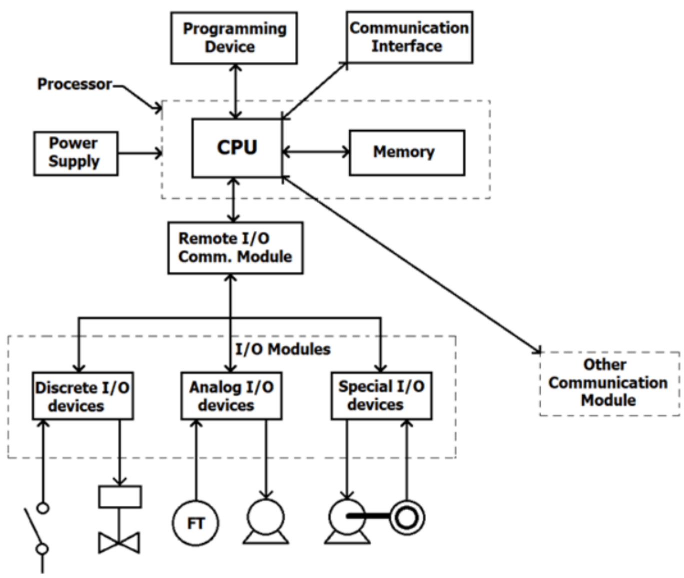


Figure 3.4. PLC Architecture

PLCs are classified as compact or modular depending on the number of I/O modules. The number of inputs and outputs in a Compact PLC is fixed. Because the manufacturer determines I/O capability, not the user. The number of inputs and outputs in a Modular PLC is not fixed. The user can add inputs and outputs to the modular PLC systems.

PLCs are designed to work with industrial-grade sensors, actuators, and communication modules; therefore, they have current and voltage ratings that are often incompatible with microcontrollers without the use of additional hardware. Ethernet and numerous versions of the RS- serial series, such as RS-232 and RS-485, are commonly used by PLCs for communication. With the rise of the industrial internet of things, the number of connected PLC equipment capable of exchanging data across wireless communication interfaces is increasing.

Modern PLCs are typically programmed using application software written in one of the Programming languages and running on a PC linked to the PLC by one of the following interfaces: USB, Ethernet, RS232, RS-485, or RS-422.

Because PLCs employ a separate controller, they can only handle one program at a time. A scan is a single cycle through the program, similar to how a microcontroller cycle through a loop. The START UP function is the first thing a CPU does when it switches from Stop to Run mode. This routine does the following: -

1. The input area of the process image (I memory) is cleared.
2. The outputs are initialized with the last value.
3. Any interrupt events are queued for processing during RUN mode.

After starting up, the CPU will run the startup OB (OB100), as indicated in Figure 3.5 below. OB 100 will be executed once before OB 1 begins, so it's a good location to configure control bits, reset old alarms, and so on before letting the program begin.

The application accesses a memory space in the CPU's system memory and distributes I/O rather than scanning the signal status on the input signal modules. The process image is the name for this memory area. The system reads the status of the physical inputs and transfers it to the process image before running the main program. The CPU is now ready to execute the main program (ladder logic), which is run through the main OB (OB 1). Functions (FC) and function blocks (FB), system memory (through memory flags), timers, and counters are all called in the main OB. If any of the FCs or FBs are not being called in the main OB it will not be executed as the scan cycle focuses just on the main OB. After the primary OB is completed, the scan cycle will copy the updated output status to the process image (output image) in order to prepare for the next phase. After the user program is executed with all blocks that are called in it, the cycle ends with writing the process image memory (output image) to the output physical modules. If an interrupt occurs during the scan cycle, the CPU will instruct the operating system to call the appropriate OB interrupt (OB 121, OB 80, OB86, etc.) as indicated in Figure 3.5 below. After all these stages are completed, the operating system prepares the CPU to repeat all of these procedures at a speed of up to 10:15 milliseconds each scan cycle. The scan cycle is depicted in Figure 3.5

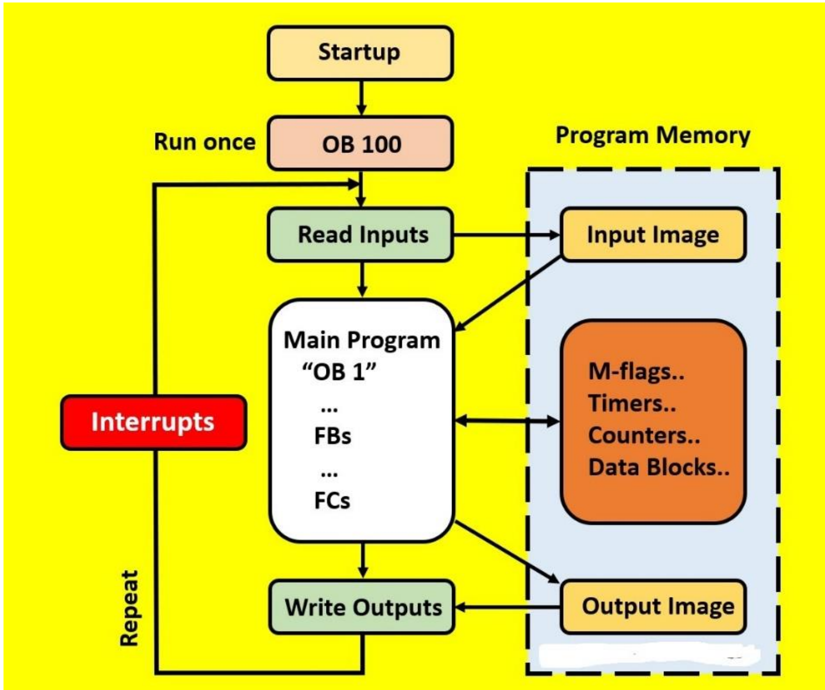


Figure 3.5. PLC Scan Cycle

PLCs are the primary control elements used in industrial control systems. They're used to control industrial machinery, conveyors, robots, and other production-line equipment. They're also employed in SCADA systems and systems that require a high level of reliability and the ability to tolerate harsh environments. They're used in a variety of industries, including:

a. Continuous bottle filling system
b. Malting factory
c. Batch mixing
d. Sugar Factory
e. Traffic light control and so on

3.1.2.2 Human Machine Interface (HMI)

A Human Machine Interface (HMI) is a device for providing the means of controlling, monitoring, managing and visualizing device processes. The operator can manage the machinery using either external buttons or the touch screen, with controls and readouts graphically presented on the screen (Normanyo et al., 2014). HMI can also be defined as the interaction between a PLC system and an operator. The interaction is presented by a screen with dynamic icons, figures, and text. An operator can monitor the production and control it to a certain level by the help of an HMI panel or PC. As technology systems grow more complex, issues of end-product equipment safety, ease of operation and reducing the risk of human error are becoming extremely important. Designers today know that the operational performance, efficiency, and safety of a wide range of systems are closely related to the interaction between humans and machines in other words the HMI. HMI components such as switch controls, actuators, and indicators, as well as their selection and smooth integration, are important to the success of equipment designed for human operation (Normanyo et al., 2014). The purpose of human-machine interaction at the user interface is efficient machine operation and control, as well as input from the machine to assist the operator in making operational decisions. The user interface includes hardware and software components. User interfaces are available for a variety of systems and provide a form of input that allows users to control the system as well as output that allows the system to show the effects of the users' manipulation. Poor design of HMI however can lead to bad temper and even to negative health effects such as frustration caused by depression. High quality graphics for realistic representations of machinery and processes, alarms, trends, simulation, messaging, equipment animation based on operator standards, hardware cost reduction, and communication such as Serial Port (SP), Data Highway Plus (DHP), ethernet, and Dynamic Data Exchange are the most important features of having HMI (DDE) (Nachreiner et al., 2006).

3.1.2.3 Level Control Valve (LCV)

Two pneumatically actuated with I/P positioner control valves have been selected to control the level of the tank. One is for fill control and the other is for drain control. Opening and Closing percentage of both valve is controlled by PID controller.

A valve positioner is a device that adjusts the air load pressure driving a control valve's actuator until the stem of the valve is balanced with the output signal from a process variable instrument controller. For linear sliding stem control valves, positioners are often installed on the side-yoke or tope casing of the pneumatic actuator, and at or near the end of the shaft for rotational control valves. The valve positioner is mechanically attached to the valve stem or valve shaft in the basic design so that their position may be compared to the position indicated by the controller. This mechanical feedback linkage functions in such a way that the process controller instructs the positioner to change position; the feedback linkage then reports back to the positioner, confirming that the valve stem has changed position and providing a sense of the magnitude of the change in position (*Basics of Control Valve Positioners ~ Learning Instrumentation And Control Engineering*, n.d.).

Reason for the use of valve positioner are:

a. Increase control system resolution i.e., fine control
b. Minimize valve stem packing friction effects and the resulting hysteresis
c. Increased speed of response to a change in process; allows faster loading and venting
d. Allow distances b/n controller and control valve
e. Allow wide range of flow variation. i.e., operates at less than 10% travel under normal condition
f. Allow increased usage of 4-20mA/0-10 Vdc electronic signal
g. Permits use of piston actuators with high instrument air supply pressures.
h. Negate flow induced reactions to higher pressure drops. i.e., compensate for internal force imbalances.

Figure 3.6. I/P Positioner Pneumatic Control Valve

3.1.2.4 Level Transducer

LMP307 type submersible Level Transmitter has been selected for the study. The LMP 307 submersible level transmitter is a versatile sensor that can be used to monitor the level of fresh water or other moderately corrosive liquids. It can be used to determine the level of water in reservoirs, lakes, open flow channels, and weirs, as well as the level of groundwater in boreholes. Despite its 27mm diameter, the LMP307 submersible level transmitter can measure rather low water levels. This is accomplished by combining an extremely sensitive tiny silicon diaphragm with a very thin silicone oil-filled isolation membrane (*LMP307 Submersible Level Transmitter*, n.d.).

This is a Submersible level transmitter with a 4-20mA current loop or a 0-10V voltage output, as well as optional Atmospheres Explosible (ATEX) approval for inherently safe use in hazardous environments in ranges from 1mH2O to 250mH2O. The LMP307 can be supplied with a drinking water certificate and is safe for use on potable water with no leaching.

3.1.2.5 Pump

Induction motor driven water pump is used to feed borehole water into the tank. Name plate data of the motor

Pump Model = FM6W-370TMH

P= 37 KW

V= 380-400 VAC

RPM= 2860

Q= 60 m^3/h

3.2 Method

Control system of liquid level is shown in Figure 3.7 below with SIEMENS S7- 1500 PLC is selected as controller. The LMP307 submersible level transmitter measures the tank's real-time level, and the sensor serves as feedback for the PID compact in the PLC. The PID reads the measured process value and compares it with the required setpoint which is set via HMI. from the resulting control deviation, the controller calculates an output value to adjust the setpoint deviation or the disturbance variable if necessary. The Analog input module (AI) of the PLC turns the analog signal from the level sensors into a digital signal. The digital signal is then processed using the control algorithm, resulting in a digital output/control signal. The Analog output (AO) module then converts the Digital output (DO) signal to an analog signal.

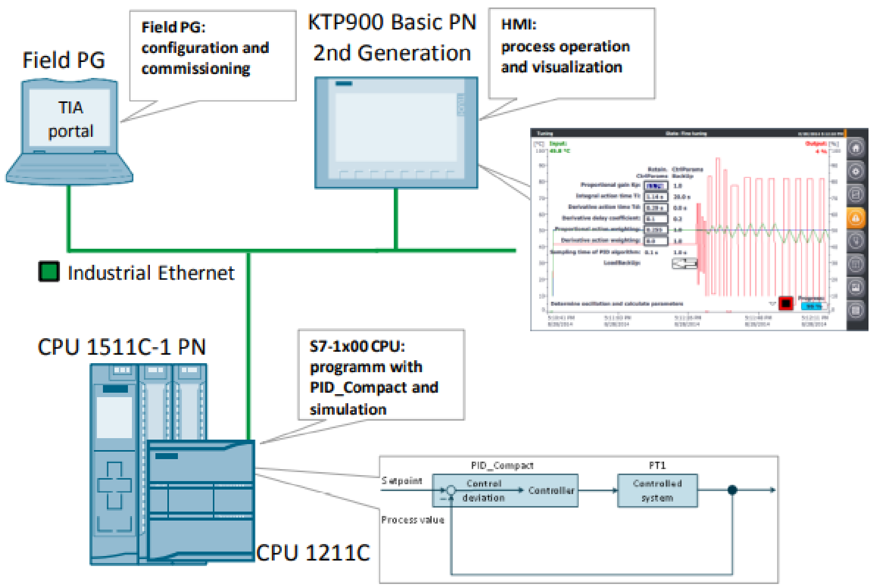


Figure 3.7. Control System Design Concept

3.2.1 System Mathematical Modelling

The concept of Mathematical modelling is widely used to describe dynamic system behavior. The developed system is a single tank level control system with level control valves and level transducer and is represented in Fig block diagram. Mathematical model has been developed for each component in the system. i.e.

1. Water tank
2. Level transducer
3. Level control valve

The designed control system is shown in Figure 3.8 below

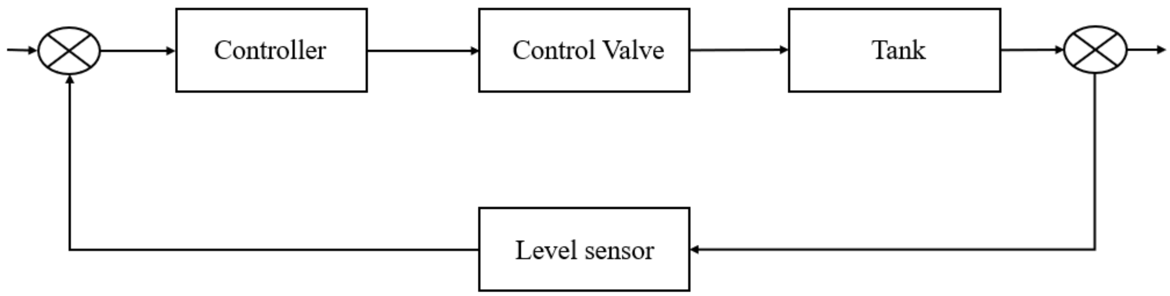


Figure 3.8. Systems General Block Diagram

3.2.1.1 Tank Mathematical Model

The model developed is based on mass-balance principle.

$$Input = Accumilation + Output \tag{3.1}$$

$$Where, Accumilation{=}height$$

Process is defined as the change in the level of liquid in the tank. The input parameter is the flow into the tank i.e., qi (t) (m^3/s). The output parameter is the height of liquid in the tank.

$$Rate\ of\ change\ of\ volume\ of\ liquid = inflow - Outflow \tag{3.2}$$

So, if the qi was equal to the qo, then there would be no change in volume of the liquid in the tank and is obtained by: -

$$\frac{dy}{dt} = qi(t) - qo(t) \tag{3.3}$$

The tank in study a concrete type of tank with dimensions of $l \times w \times h = 21.5 \times 12 \times 4.95$ and volume of 1277.1 m^3. It is the main water reservoir of the factory. Water is pumped into the tank using induction motor from bore hole with. Below is name plate data of the motor.

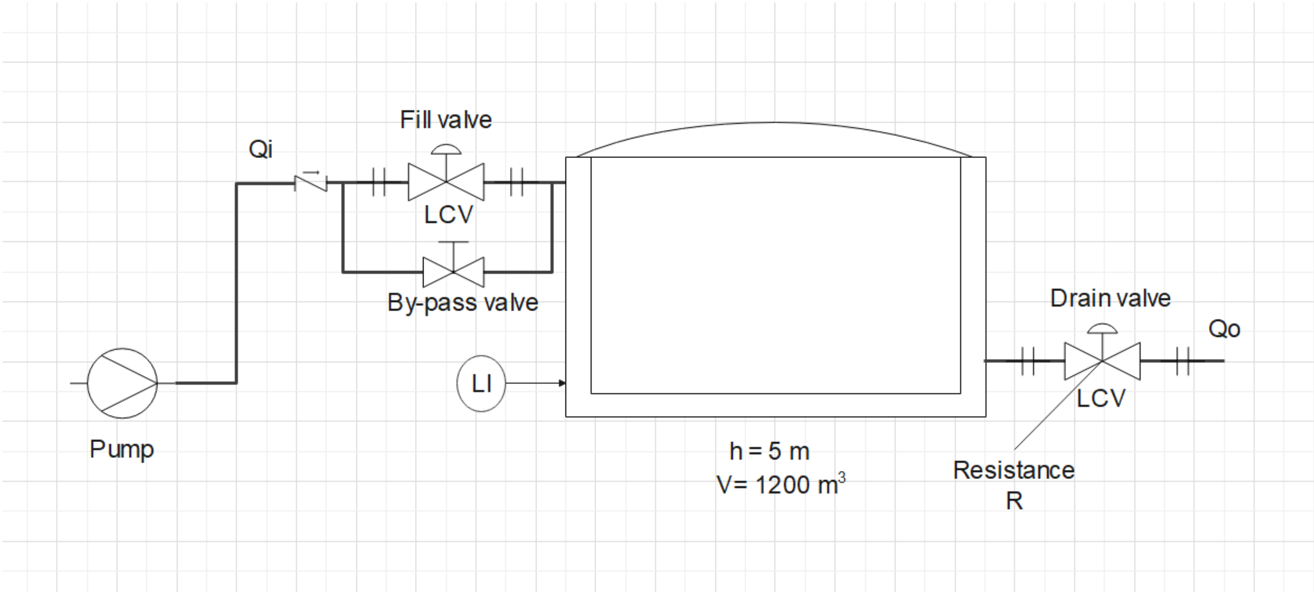


Figure 3.9. Designed System P&ID

Using mass-balance principle mathematical model of the tank is developed. i.e., using eqn. (3.1)

$Input = Accumilation + Output$, when re-arranged gives eqn. (3.2)

$The\ rate\ of\ change\ of\ volume\ of\ liquid = inflow - Outflow$

$$\rho qi(t) - \rho qo(t) = \frac{d}{dt}(\rho Ah) \tag{3.4}$$

Where $\rho\ is\ specific\ gravity$

h is height of the tank and

A is Area of the tank

$$qi(t) - qo(t) = \frac{d}{dt}(Ah) \tag{3.5}$$

Where $qo = \frac{h}{R}$ (3.6)

Putting eqn. (3.6) into eqn. (3.5)

$$qi - \frac{h}{R} = A\frac{dh}{dt} \tag{3.7}$$

At steady state

$$qs - \frac{hs}{R} = 0 \tag{3.8}$$

Subtracting eqn. (3.8) from eqn. (3.7)

$$q - qs = \frac{1}{R}(h - hs) + A\frac{d(h - hs)}{dt} \qquad (3.9)$$

Where, $Q = q - qs$ and

$$H = h - hs$$

Substituting the above into eqn. (3.9) gives,

$$Q(S) = \frac{1}{R}H(S) + AsH(S) \qquad (3.10)$$

Therefore, Tank is represented by below mathematical model.

$$\frac{H(S)}{Q(S)} = \frac{K}{\tau S + 1} \; where\; \tau = AR \; and \; K = R \qquad (3.11)$$

3.2.1.2 Level Transducer Mathematical Model

The transmitter directly measures the pressure exerted on it and converts it into 0-10 VDC electrical signal. It indirectly measures level of the tank. i.e., the more pressure exerted on the sensor the higher is the level of the tank and vice versa.

The pressure p(t) is dependent on the height of liquid h(t), above the transducer i.e., above the reference level of tank. As the level sensor is placed at the base of the tank, output of the electrical transducer is in Voltage V, hm (t), which represents the measurement of liquid head or height.

$$P = \rho g h = 1000\frac{kg}{m^3} \times 9.81\frac{m}{s^2} \times h$$

$$G1 = \frac{P(t)}{h(t)} = 0.0981\frac{bar}{m} \qquad (3.12)$$

For G2, the maximum input pressure to be exerted on the sensor when the tank is full and that is when the level is at its maximum i.e., h=5m

$$P = \rho g h = 1000\frac{kg}{m3} \times 9.81\frac{m}{s^2} \times 5m = 78480\,Pa = 0.785\,bar$$

Therefore, the level transmitter has an input range of 0 to 0.785 bar and converts this pressure signal into 0 to 10 VDC.

3.2.1.3 Level Control Valve Mathematical Model

A pneumatic signal (typically 3-15 pisg) is delivered to pneumatic positioners. The positioner converts this to a needed valve position and provides the required air pressure to the valve actuator to move the valve to the correct position. The Actuator takes control signal which is in mA and converts it into pressure signal, which in turn produces a valve position. Supply pressure is 3 bar which is supplied by air compressor and regulated by air filter regulator. this supply pressure is varied according to input parameter (4-20 mA).

Current to pressure (I/P) Characterization. I/P Characterization is shown in table below.

Table 3.1. I/P Characterization table

Input and Output	**Range**
Input (mA)	4-20 mA
Output (bar)	0-3 bar

Therefore, $G3 = \frac{3}{20-4} = \frac{3}{16} = 0.1875\ bar/mA$

Stem position is in linear relationship with input pressure at valve diaphragm. Stem position=15mm, Cv=0.12, and Travel=15mm are given in the control valve datasheet.

Therefore, $G4 = {x(t)}/{P(t)} = \frac{15mm}{3\ bar} = 5\ mm/bar$

Final block diagram of the system is shown in the Figure 3.10 below

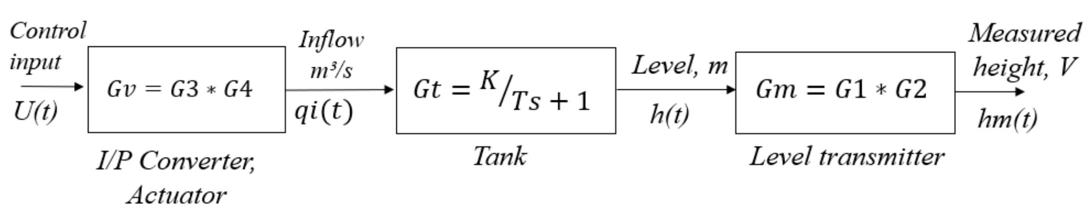


Figure 3.10. System Block Diagram

3.2.2 Interfacing components with PLC and HMI

To control the system, level transmitter and I/P converter must be interfaced with PLC and HMI. The PLC can read the level input given in terms of current by the level transmitter. Based on the control strategy, it can decide the current output given to I/P converter. The desired height of the tank is set on the HMI and interface b/n HMI and PLC is established using Profinet communication system. HMI is used to set the control input and to have visual representation of the whole system, to make maintenance and troubleshooting easy. on the HMI visualization of the system, alarms and trends has been designed to have a full picture of the system during operation.

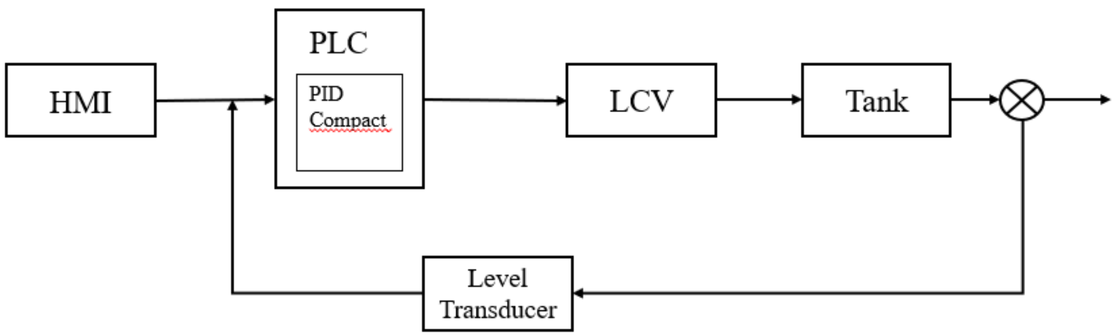


Figure 3.11. System Interface with PLC And HMI

3.2.3 Flow Chart of system design

Sequential operation of the designed system is shown in simplified flow chart below.

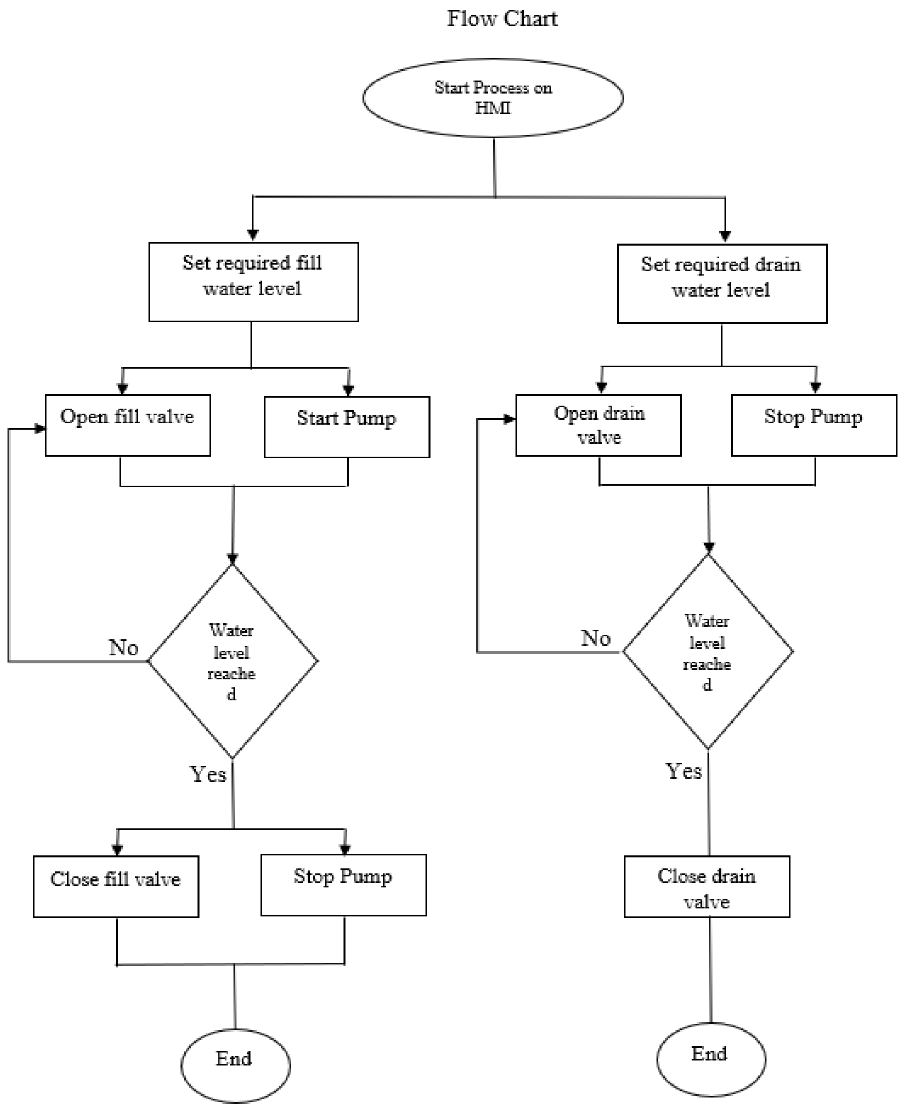


Figure 3.12. Simplified Flow Chart Presentation of Operation Sequence

3.2.4 PLC Programing

Programming and configuration of PLC is done by using siemens TIA portal version 15 software. Totally Integrated Automation (TIA) Portal is an all-in-one engineering platform that allows users to effectively commission, program, and diagnose Siemen's automation hardware and software, all within a single software interface that allows for integrated system diagnostics, communication, and other features. New hardware and updated programming functions are added to the large range of products and options offered by TIA Portal as new versions are launched. With TIA portal it is possible to configure and program S7-300/400/1200 and 1500 Simatic Controllers, whereas STEP 7 (earlier version programming software) is only applicable to S7-300/400 Simatic controller.

TIA Portal combines drive, PLC, and HMI configuration, programming, and troubleshooting into a single software package. HMI tags can be symbolic and linked to PLC tags directly. The HMI tag will continue to work even if the PLC tag is renamed. The PLC will continue to function even if the HMI tag is renamed.

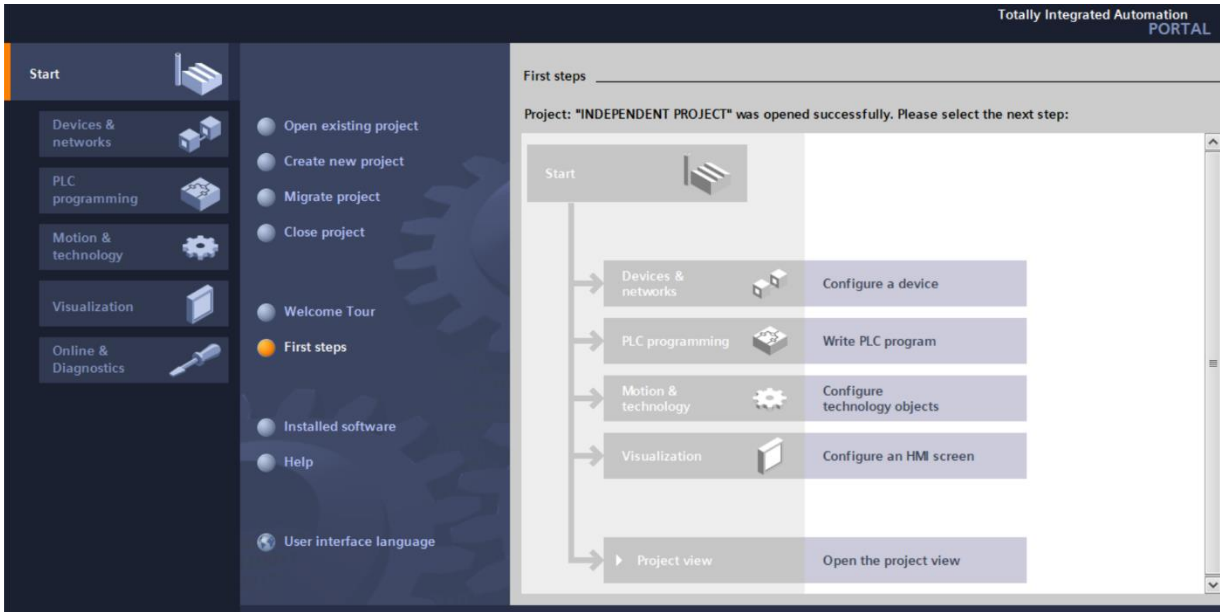


Figure 3.13. TIA Portal Version 15

Many programming languages are supported by the PLC, including Ladder Diagram (LD), Sequential Function Charts (SFC), Function Block Diagram (FBD), Structure Text (ST), and

Instruction List (IL). The IEC 61131-3 standard supports these languages. The ladder diagram and the function block diagram are the two most common PLC programming approaches.

The ladder diagram (LAD) programming language and TIA portal software were utilized in this thesis. The ladder diagram is shaped like a ladder with two vertical rails and numerous rungs to program. Because the two vertical rails indicate the power supply, all components in a ladder diagram must be linked to both ladder rails. The current goes from the left to the right of the ladder figure.

Defining the required Inputs and Outputs is the first step in developing a control algorithm. There are two different sorts of inputs and outputs. PLC and HMI inputs, as well as PLC and HMI outputs.

Table 3.2. Input and Output devices assignment.

Inputs		**Outputs**	
PLC	**HMI**	**PLC**	**HMI**
Level sensor	Set point (SP)	Fill valve	Process Variable (PV)
		Discharge valve	Fill valve position
		Pump start	Discharge valve position
		Pump stop	Trend
			Alarm

After each input and outputs have been defined, the next step is assigning them to respective modules in PLC with specific address. This is called PLC hardware configuration. In the hardware configuration analog input (AI), Analog output modules (AO) and Digital output (DQ) modules are configured. Analog input module takes the signal from the level sensor and the Analog output module (AO) produce output signal for controlling of the control valves. Digital output (DQ) is used to start and stop feeder pump depending on the level of the tank.

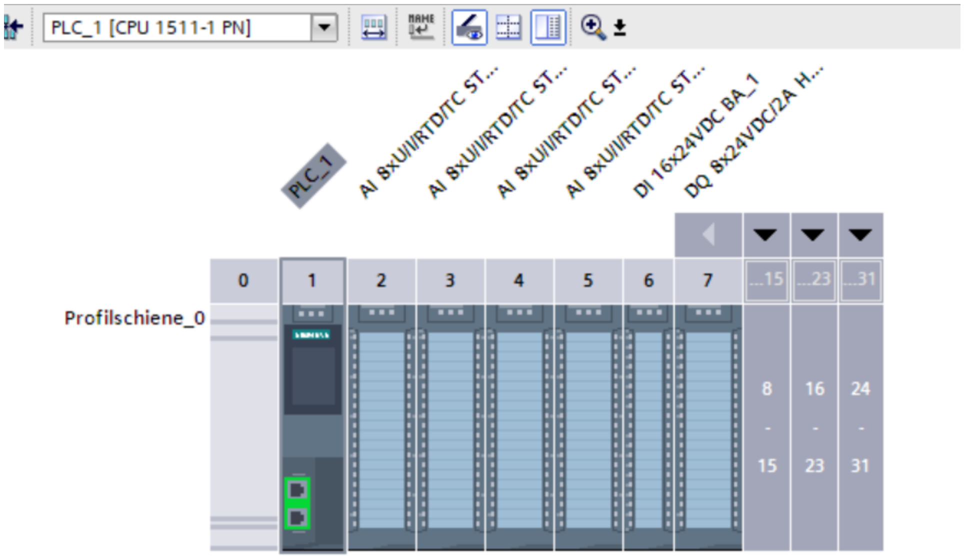
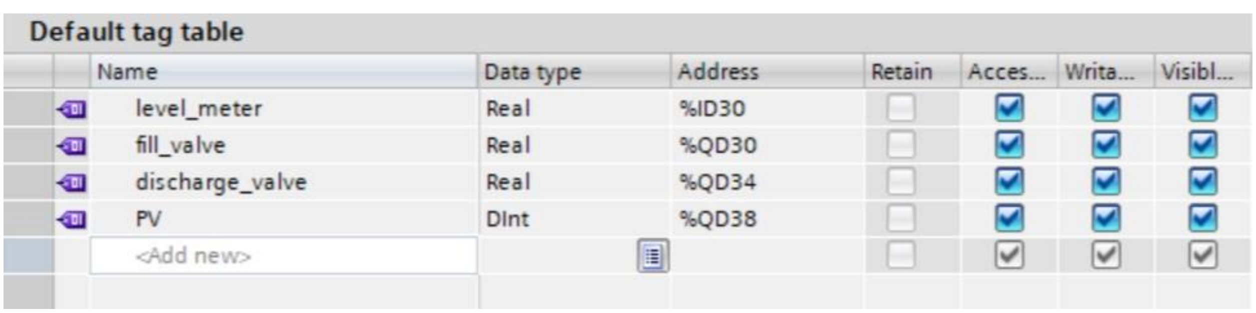


Figure 3.14. Hardware Configuration

Data types and Address of each input and output module has also been configured. There are different data types used in PLC during PLC programming. And they are

a. Bit
b. Byte
c. Integer
d. Double Integer
e. Real and
f. String

Real and bit data types are used for Analog and Digital signals in PLC respectively.


Default tag table

Name	Data type	Address	Retain	Acces...	Writa...	Visibl...
level_meter	Real	%ID30	☐	☑	☑	☑
fill_valve	Real	%QD30	☐	☑	☑	☑
discharge_valve	Real	%QD34	☐	☑	☑	☑
PV	DInt	%QD38	☐	☑	☑	☑
<Add new>			☐	☑	☑	☑

Figure 3.15. Input And Output Devices Addressing

The program has been written using Function blocks (FB). Three Function blocks has been created

- Tank Control Function Block
- HMI Control FB and
- PLC and Factory I/O FB

Function blocks are code blocks that store their values permanently in instance data blocks, so that they remain available after the block has been executed.

The program's first network uses NORMX and SCALEX instructions to scale the setpoint. Scaling is the process of receiving a signal from a sensor, such as a process variable, voltage, or current output, and applying computations to deliver it to the operator in the control room in a more meaningful format in terms of engineering units, such as PSI, °F, or percent RH. The NORMX block gets the setpoint from the HMI and converts it to 0 to 1 range and saves it to memory double word (MD100), then the SCALEX block converts this value to a range of 0 to 500 which is the actual height of the tank.

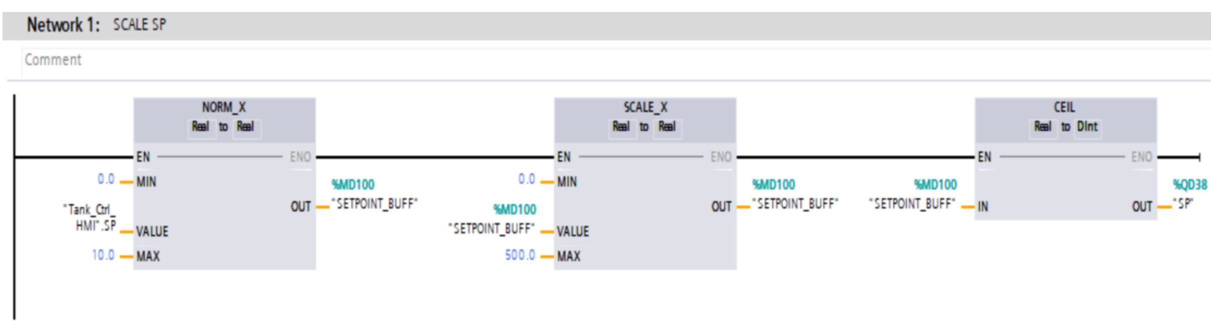


Figure 3.16. Setpoint Scaling

Network 2 of the program is scaling the level meter (ID30) reading of 0 to10v from AI module to 0 to 300 which is the actual height of the tank.

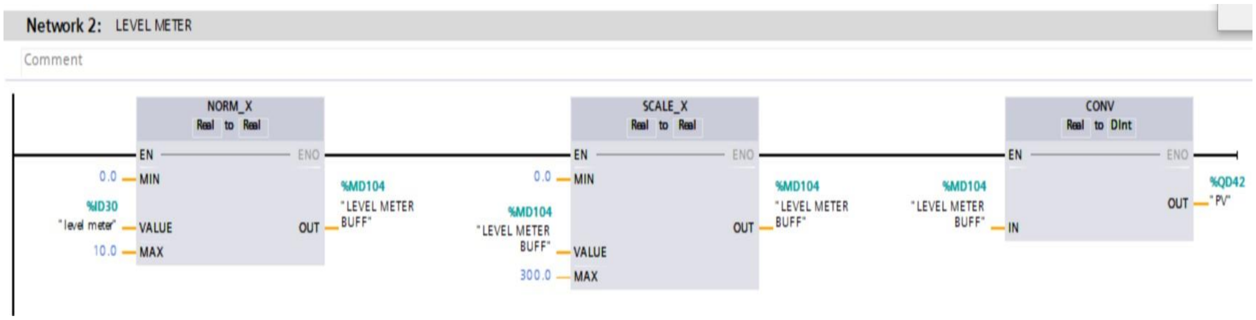


Figure 3.17. Level Sensor Feedback Scaling

The water level is controlled with Siemens's built in PID control instructions. As both Fill and drain valves are controlled with an analog control signal the PID-Compact instruction is used. The next step is creating a cyclic interrupt block for the PID compact for fill valve. This PID controller controls the fill valve through output address of MW116 with the setpoint and the input to the block is set from HMI. A "Cyclic interrupt" OB allows to start programs at periodic intervals, independently of cyclic program execution. The intervals can be defined in this dialog or in the properties of the OB. This block is executed every 10sec and has its own data block (DB1) which can store its data.

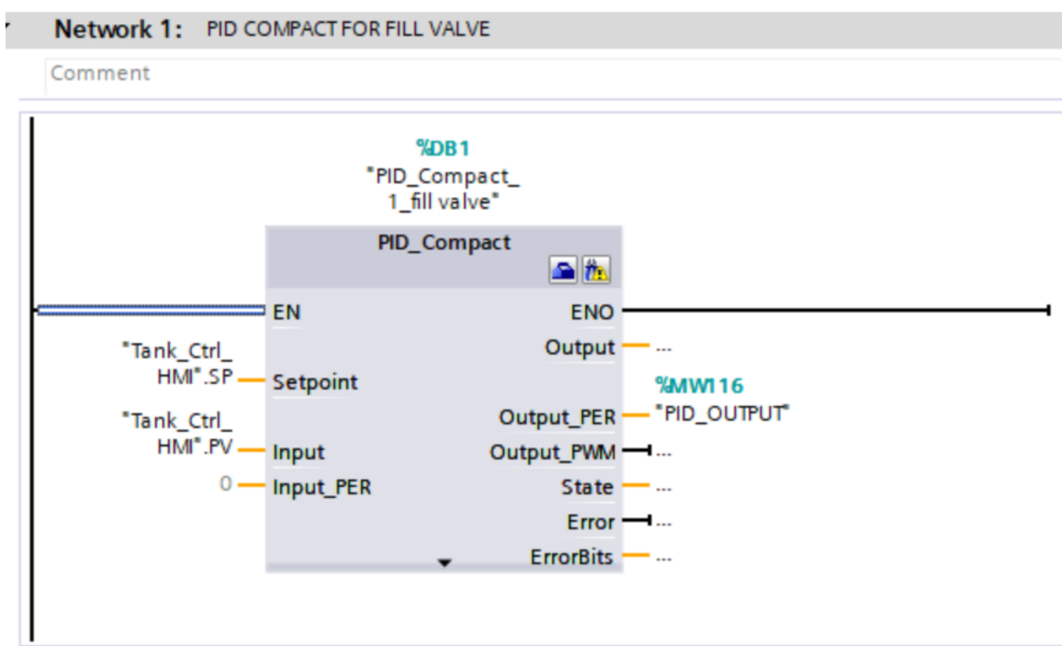


Figure 3.18. Fill Valve Controller PID

The next step is scaling the PID_OUTPUT from 0 to 27648 to 0 to 10 V control signal to control the fill valve. NORMX and SCALEX blocks are used to scale the values. The output of the SCALEX block is given an address of output word 30 (QD30) which is on AO module for fill valve.

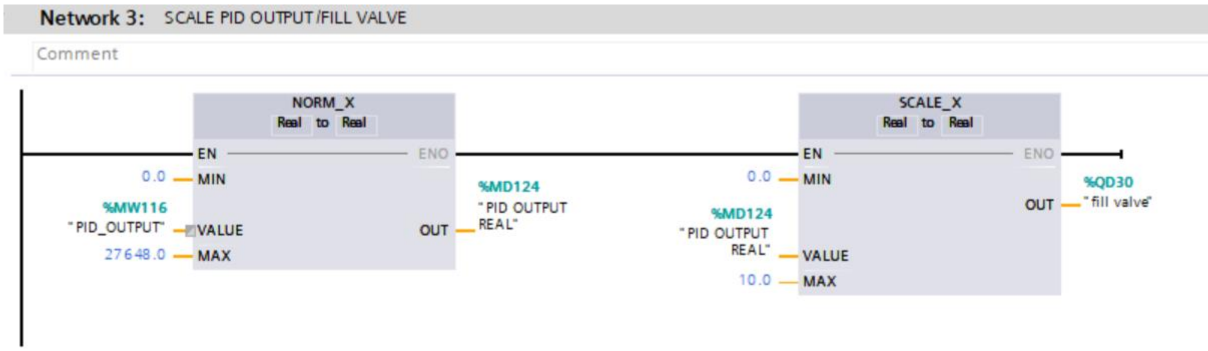


Figure 3.19. Scaled PID Output

Another PID compact controller is also used for the discharge valve, which controls the level of the water through discharge valve when the actual water level is greater than the desired water level. It uses the same setpoint and input as the PID for fill valve. Here the only difference is the control logic is inverted.

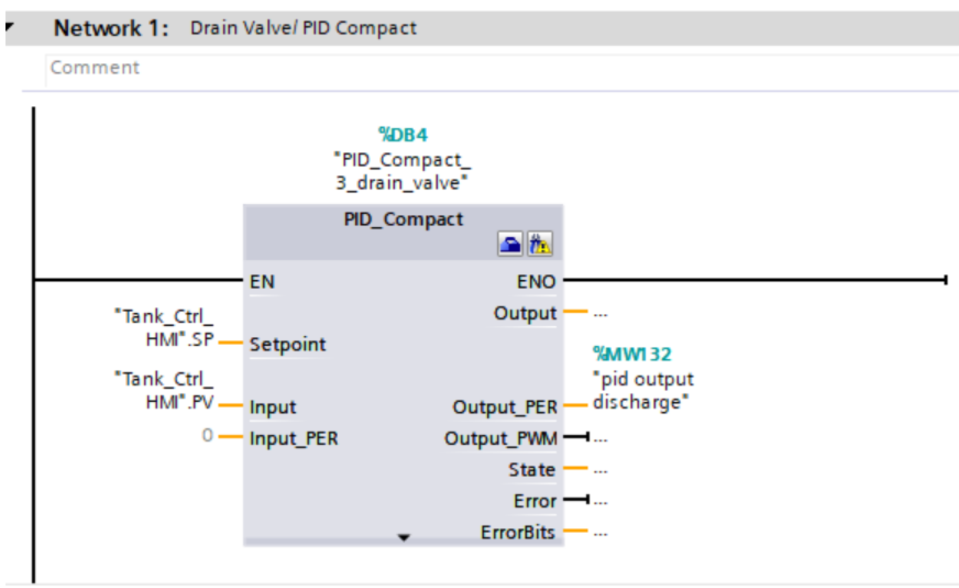


Figure 3.20. Discharge Valve Controller PID

The output of PID compact discharge valve which is stored in memory word address of MW132 has to scaled using NORMX and SCALEX blocks to control the discharge valve with a control signal of 0 to 10V DC with an address of Analog output of QD34.

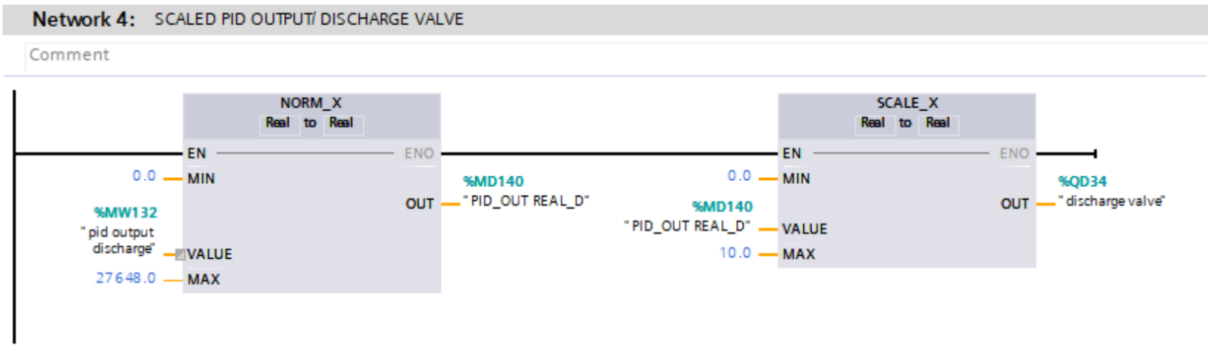


Figure 3.21. Scaled PID Output

The pump start condition is dependent upon Fill and discharge valve position. If the fill valve is closed, the pump will not start to avoid overpressure on the pipe and overload on the motor.

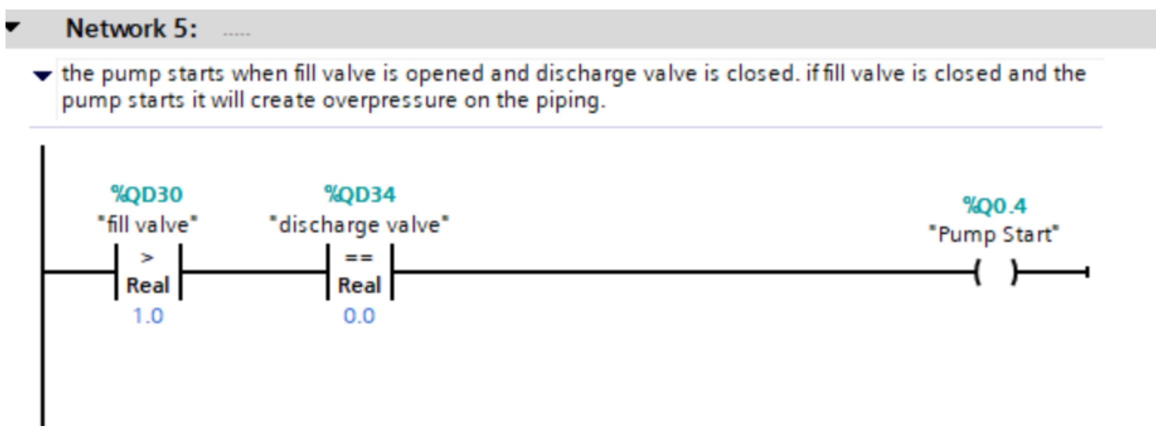


Figure 3.22. Pump Start condition program

3.2.5 PID Compact Configuration and Tuning.

Proportional-Integral-Derivate controllers are used to control process values. They calculate an output value from the error between the current setpoint for the process value and the current measurement of the process value. The control value is a sum of three different terms, the proportional term P, the integral term I and the derivative term D. Controllers can also consists of different combinations of the three terms, for example P, PI or PD. In this case only the used terms are summed to produce the output value. The output value is used to control actuators such as pumps or valves to control process values.

The proportional term P, also called gain, multiplies the error with a set constant, producing a proportional output value relative to the current error value. Its purpose is to remove the error between the setpoint and process value. If the controller consists only of the P term, it may leave a permanent constant error. The integral term I, is proportional to the magnitude and duration of the error. It is used to remove the permanent error remaining after the proportional term. The derivate term D is the derivate of the error value and its purpose is to speed up the controller's reaction to the error value.Controllers are also used in a wide variety of applications in automation technology, for instance level control. For the SIMATIC S7-1200/S7-1500, the technology object "PID-Compact" is provided for proportional actuators.

The output value of the PID controller consists of three components:

- P component
  The P component of the output value is proportional to the control deviation.
- I component
  The I component of the output value is the integral component. This increases if there is a control deviation.
- D component
  The D component is the differential component and increases as the rate of change of the control deviation increases.

A mathematical description of the PID controller is shown in the following equation.

$$u(t) = K_P \left[e(t) + \frac{1}{T_I} \int_0^t e(\tau)\, d\tau + T_D \frac{de(t)}{dt} \right] \tag{3.13}$$

Where u(t) is control signal and e(t) is the error signal. The reference value is the Setpoint (SP). The difference between the Process Variable (PV) and the Setpoint (SP) is called error signal e(t)

$$e(t) = PV - SP \tag{3.14}$$

K_P, K_I and K_D are the proportional gain, the integral gain and the derivative gain respectively. By tuning the PID, these values are calculated automatically.

Laplace transform of PID controller equation (3.13) above gives: -

$$G_{PID} = \frac{U(s)}{E(s)} = K_P\left(1 + \frac{1}{T_I s} + T_D s\right) \tag{3.15}$$

Where $U(s)$ is the control signal, $E(s)$ is error signal, s is the variable of Laplace transfer function,K_P is proportional gain, T_I and T_D are the integral and derivative time constants respectively.

The PID control signal is the sum of three terms

$$U(s) = K_P E(s) + K_I \frac{1}{s} E(s) + K_D s E(s) = U_P(s) + U_I(s) + U_D(s) \tag{3.16}$$

$$\text{Where } K_I = {K_P}/{T_I} \ and\ K_D = K_P T_D \tag{3.17}$$

The “PID-Compact” technology object has the “tuning” commissioning functionality with which the P, I and D parameters can be calculated automatically depending on the controlled system. However, it is also possible to control parameters manually. The automatic tuning is divided into tuning types:

1. Pre-tuning: - Pre-tuning performs a jump change in the output value of the controller and calculates PID parameters from the maximum slope and dead time of the controlled system
2. Fine Tuning: - Fine tuning usually produces better PID parameters than pre-tuning, while fine tuning is being processed a constant oscillation of the process value is generated and the PID parameters are calculated from the amplitude and frequency of the generated oscillation

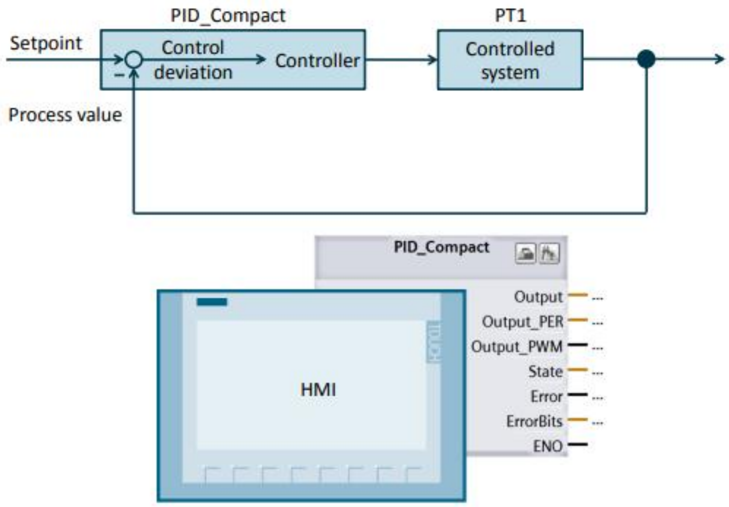


Figure 3.23. PID Compact Controller Overview

The configuration of the technology object "PID-Compact" determines the functionality of the compact controller. In configuration setting, controller type, Input and output parameters process value limits, process value scaling and PID parameters are configured. Controller type is configured as length for both fill and drain valves since the aim is to control water level. The only difference is in drain valve the logic is inverted so that it can act opposite to fill valve. See Figure 3.23 below for controller type configuration.

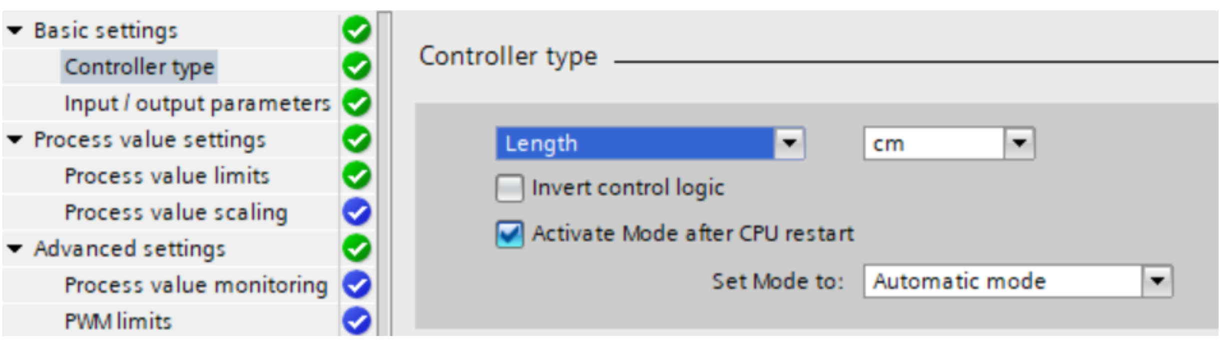


Figure 3.24. Controller Type Configuration

Process value setting is configured depending on the actual process value. i.e., on the actual height of the tank and that is between 0 and 5 meter of tank height. See Figure 3.25 below for process value configuration.

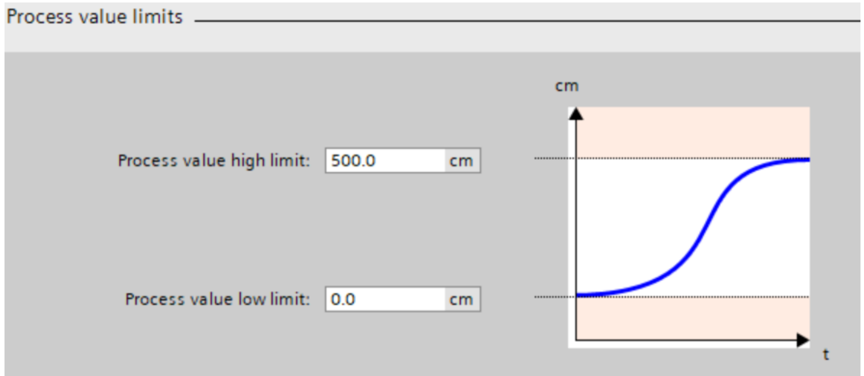


Figure 3.25. Process Value Limit Configuration

PID parameters are also configured. There are two ways for PID parameter configuration. Manual and automatic type of configuration. Manual type of configuration is done manually (try and error) setting the parameters. But in this thesis, it is done by using pre -defined function of automatically tuning the PID online during operation and saving the parameters.

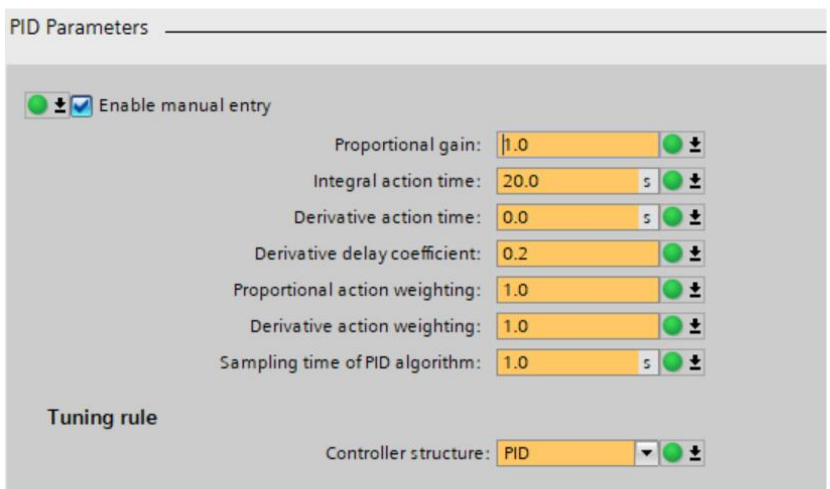


Figure 3.26. PID Parameters Configuration

Self-tuning or Auto-tuning refers to such procedures continuously executed while the controller is online regulating the process. "Autotuning" refers to operations that are run on demand when the controller is turned off. The input (control effort) and output (process variable) of a process are measured by an autotuning proportional-integral-derivative (PID) controller, which then updates its own tuning parameters to meet the operator's closed-loop performance specifications. By continually varying the input parameter to the PID the controller is tuned automatically. Ones the tuning is done, the parameters are uploaded and saved. See Figure 3.25 above for loaded parameters. See Figure 3.27 below autotuning procedure performed in this thesis.

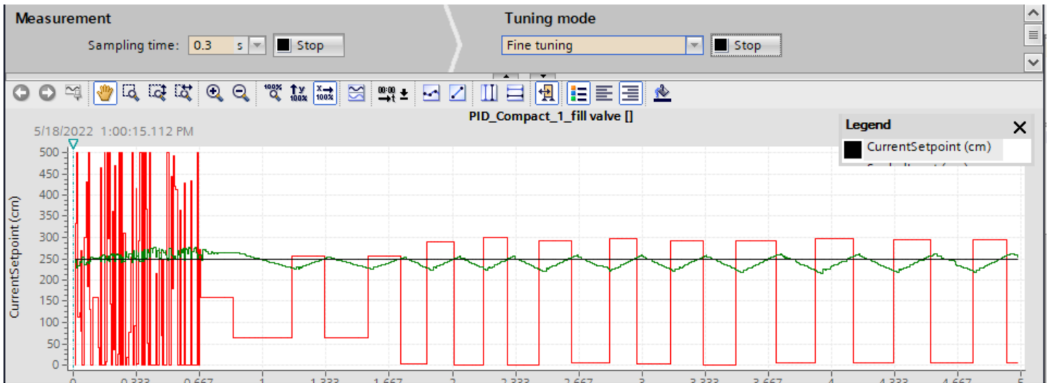


Figure 3.27. Auto-Tuning of PID Controller

The generated control output signal is calculated from equation (3.16) above and from Tuned PID parameters of Figure 3.26.

$$U(s) = K_P E(s) + K_I \frac{1}{s} E(s) + K_D s E(s) = E(s) + \frac{1}{20s} E(s) \qquad (3.18)$$

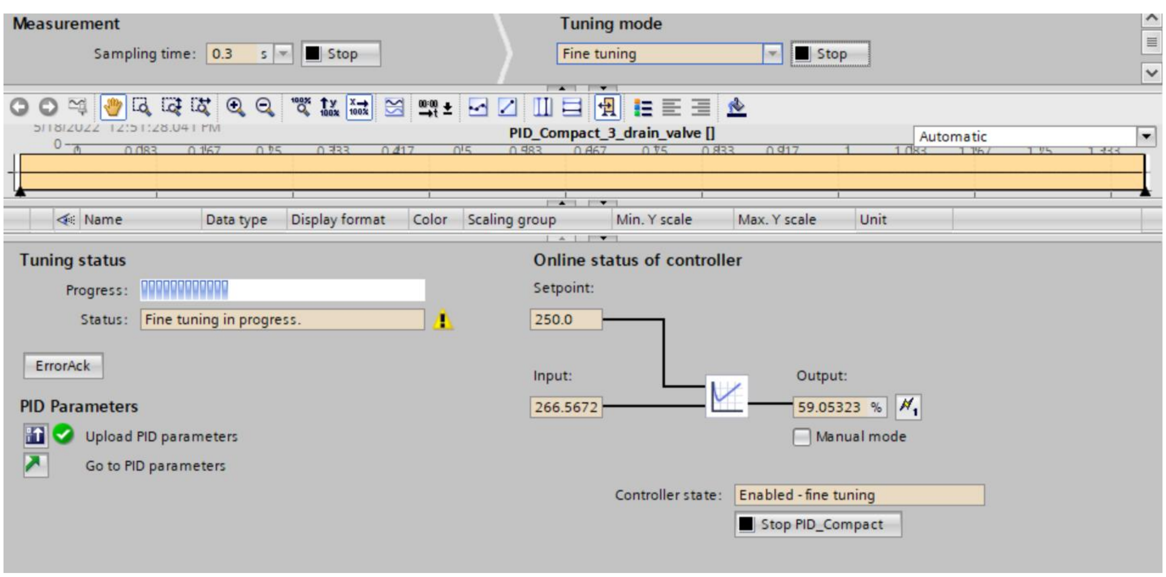


Figure 3.28. Fine Tuning Process

3.2.6 HMI Configuration and Programming

HMIs are important to the overall feel of a project as they are the mechanism by which people interact with the project. For Human Machine Interface configuration, WinCC Advanced software which is one of TIA portals packages has been used. HMI configuration software is a technology that bridges the gap between humans and technology by providing an interface that allows the two identities to communicate. Human Machine Interface (HMI) configuration software is an innovation to bridge the gap between the internal process or machine status and what machine operator sees or experiences.

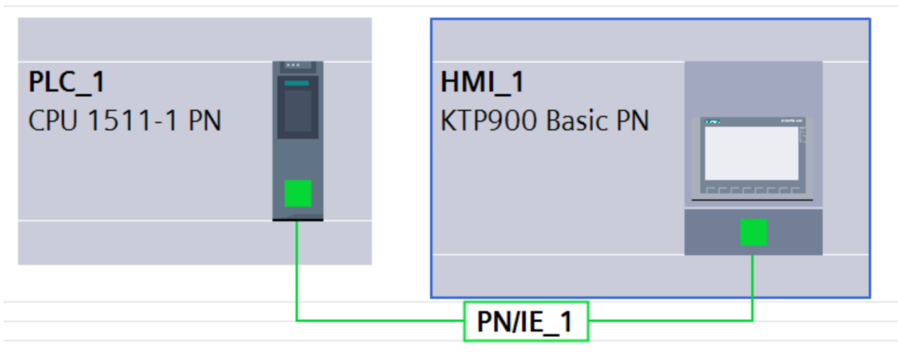


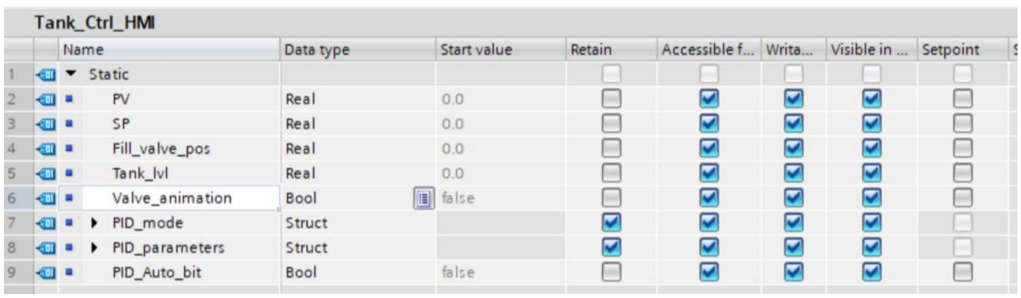
Figure 3.29. PLC And HMI Interface

It is an analytical software that displays the programs of associated controls and aids in the efficient management of the system. Software modules can be added or removed depending on the functions of linked devices, and they can also be customized for a variety of appliances. This ensures operational transparency and brings the device's exact throughput forward. HMI not only empowers automation but also helps the operator make informed decisions by granting supervisory control such as SCADA systems. In the HMI the following process control parameters:-

- Alarms
- Trends
- Animations
- Set points (SP)
- Process variables (PV) has been configured.

KTP900 Basic PN with 9 inch screen an already existing HMI in the plant for the control of step process has been used.

Data block has been created which is used by HMI. HMI access the address of each input and output from data block. Data blocks interface with the PLC so that data can be written and read between the HMI and PLC. The interface connection profiles, where Internet Protocol (IP) addresses, and other protocols are defined to allow the HMI to connect to other equipment like PLC.



Tank_Ctrl_HMI

	Name	Data type	Start value	Retain	Accessible f...	Writa...	Visible in ...	Setpoint
1	▼ Static			☐	☐	☐	☐	☐
2	PV	Real	0.0	☐	☑	☑	☑	☐
3	SP	Real	0.0	☐	☑	☑	☑	☐
4	Fill_valve_pos	Real	0.0	☐	☑	☑	☑	☐
5	Tank_lvl	Real	0.0	☐	☑	☑	☑	☐
6	Valve_animation	Bool	false	☐	☑	☑	☑	☐
7	▸ PID_mode	Struct		☑	☑	☑	☑	
8	▸ PID_parameters	Struct		☑	☑	☑	☑	
9	PID_Auto_bit	Bool	false	☐	☑	☑	☑	☐

Figure 3.30. HMI Data Block

Different steps have been taken for configuration of HMI and are discussed briefly below

Step 1. A project tree has been created by selecting the appropriate HMI type from hardware configuration. KTP900 Basic PN type HMI screen has been selected from hardware configuration.

Step 2. In the project tree window of HMI_1[KTP900 Basic PN] under screen subfolder new screen has been added with a name of PID WATER LEVEL CONTROL.

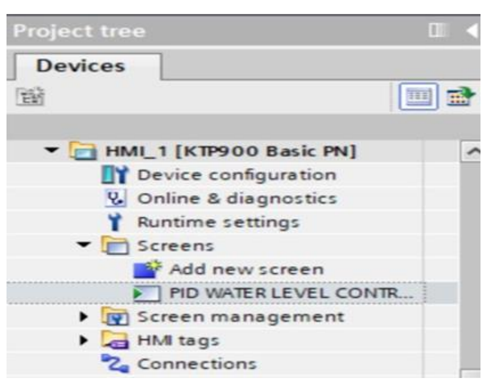


Figure 3.31. Creating Project Tree and Adding HMI Screen

Step 3. Screen layout has been configured. i.e. Configuration of background colour, date and time and Logo (Soufflet Malt Ethiopia Logo).

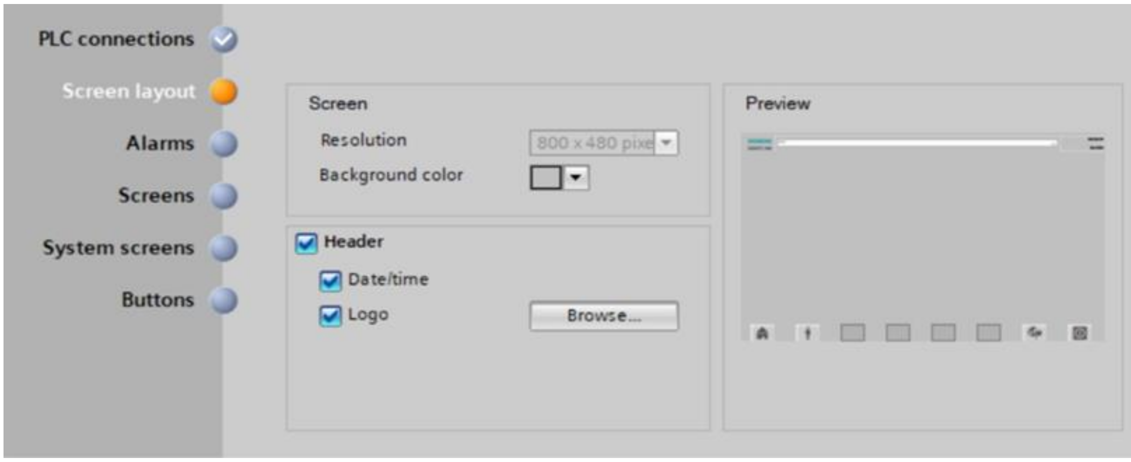


Figure 3.32. Screen Layout Setting

Step 4. The screen has been set as screen 1, because main screen has been set as step process control screen. A screen is a visualization object; it is the area that contains objects that will be presented to the end user on a physical HMI device. An HMI can consist of many different screens that hold objects. These screens collectively form different areas of a project and require navigation methods to switch between screens. At least one screen must be created for an HMI to compile correctly. The start screen (the screen the HMI will display on startup) is denoted by a small green arrow in the Project tree pane shown in the Figure 3.30 above.

Figure 3.33. Root Screen

After root screen has been set, blank screen has been generated in which the virtual build of the whole system is designed and configured. This is where visual elements are built so that the HMI can display them to the end user.

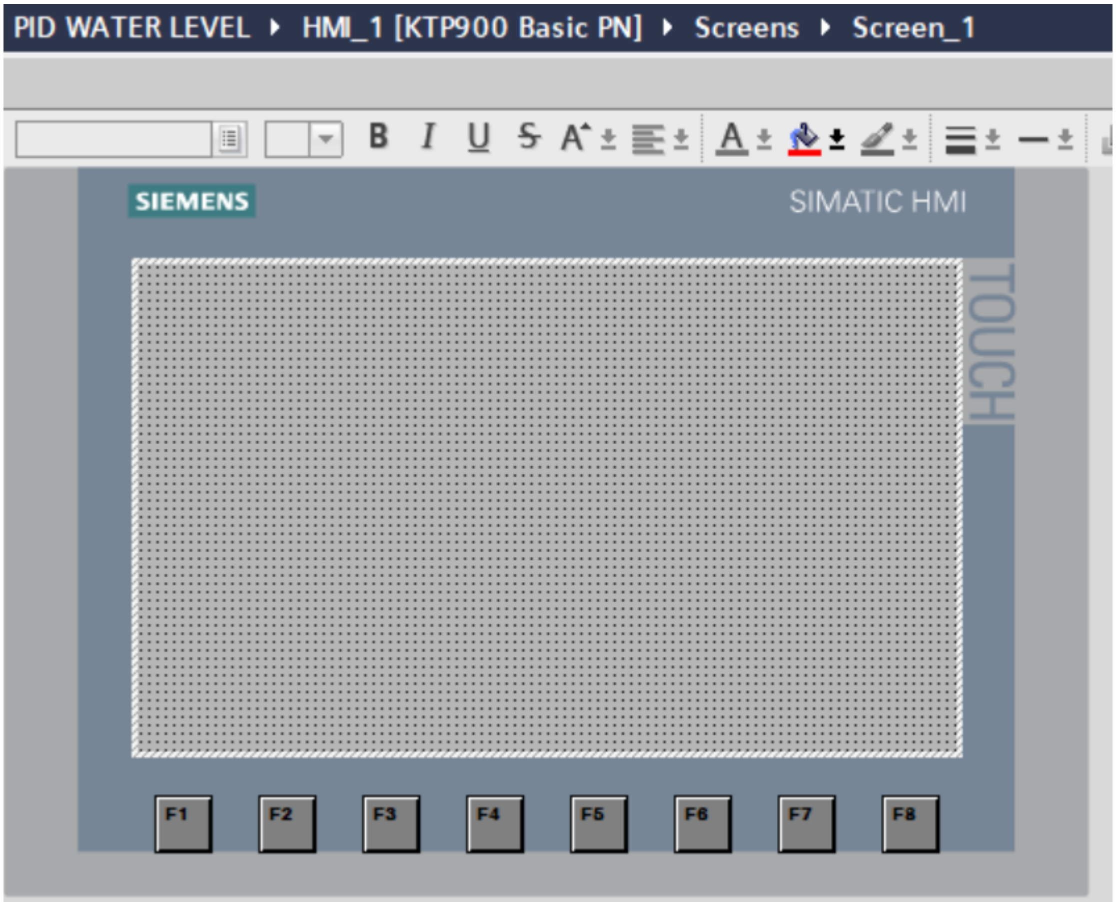


Figure 3.34. Working Screen

Step 5. In this step components and equipements which are needed to build the control system are configured from toolbox. Toolbox contains all the necessary objects required to build a visual interface for the screen selected. Toolbox objects are split into different categories, ranging from basic objects to smart elements and controls, and Siemens-supplied graphics and widgets. The control system is composed of tank, pipings, valves, pumps, I/O fields level bar and texts has been designed, built and Configured from WinCC graphic folder. TIA Portal comes equipped with two types of special objects: Elements and Controls. Both types of objects have a range of pre-built properties and events that relate to their designated purpose. Both

Elements and Controls can be found in the Toolbox window to the right in TIA Portal when a screen is open, as illustrated in the following screenshot:

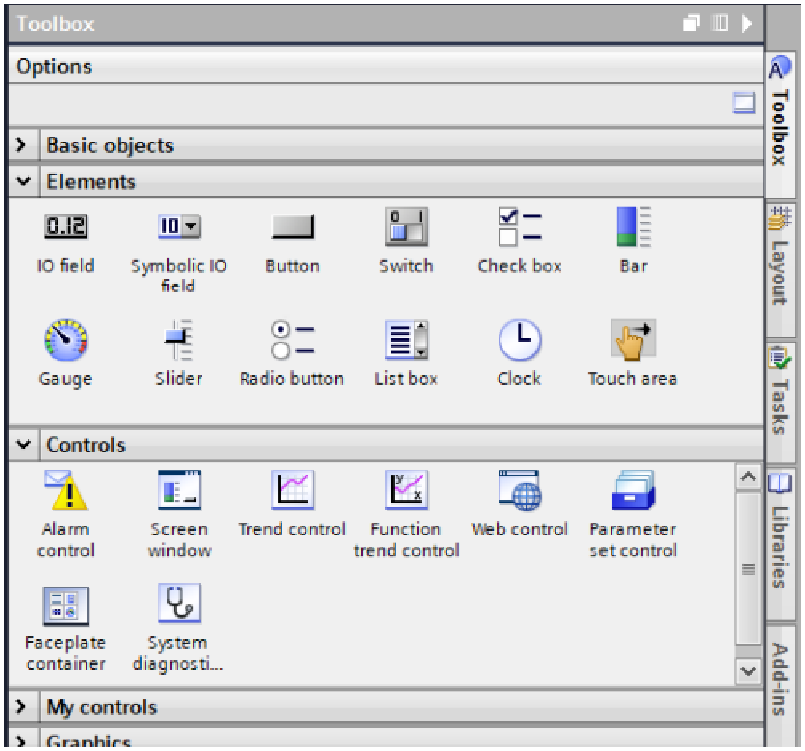


Figure 3.35. Elements And Controls in Toolbox

These objects have more specific roles than Basic objects. Elements are typically objects that a user may interact with, such as a button or slider. Controls are objects that allow a TIA Portal's Unified environment to make use of a particular function, such as displaying a faceplate or managing alarms.

Elements are essentially ready-made faceplates that programmers can drop into a project to enable quick visualization of data. Elements are highly configurable, allowing easy configuration and dynamization of options and signals. Building these controls from scratch can be done; however, these types of controls and indicators are well known in HMI development, and it makes sense to use a highly configurable object instead of starting from scratch.

Controls are more involved than Elements, from a configuration point of view. Controls are objects that directly interact with the background systems in the TIA Portal and Unified environment, allowing access to data stored in alarm databases and tag logging.

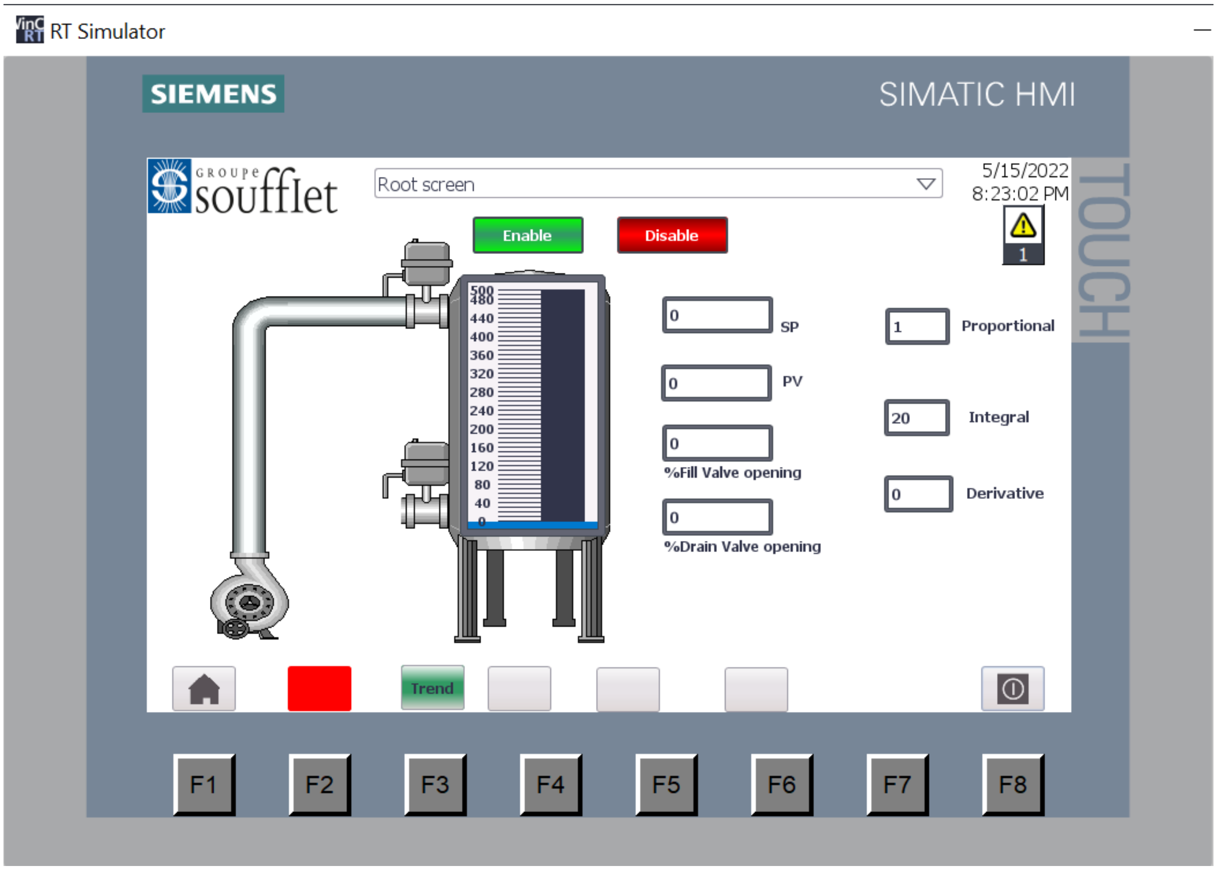


Figure 3.36. Design of Configured Control System on HMI

The system is designed to control the level of water in the tank according to the required set point (SP), which can be set on SP input field. SP input field has been configured as input mode, Decimal display format and three digit input field. See Figure 3.36 below.

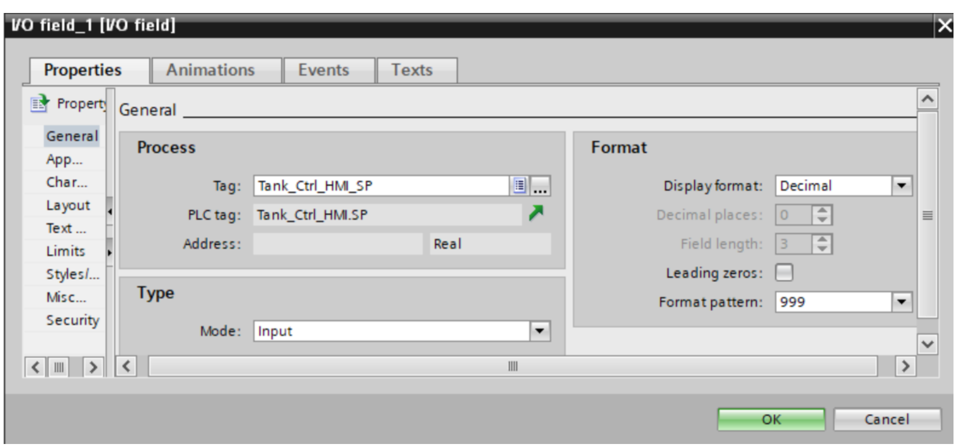


Figure 3.37. Setpoint Configuration

The actual level water in the tank has been configured as Process variable (PV). It shows actual level of the water by getting feedback signal from level sensor. PV is configured as output mode, decimal display format and three digit output field as shown on Figure 3.37 below.

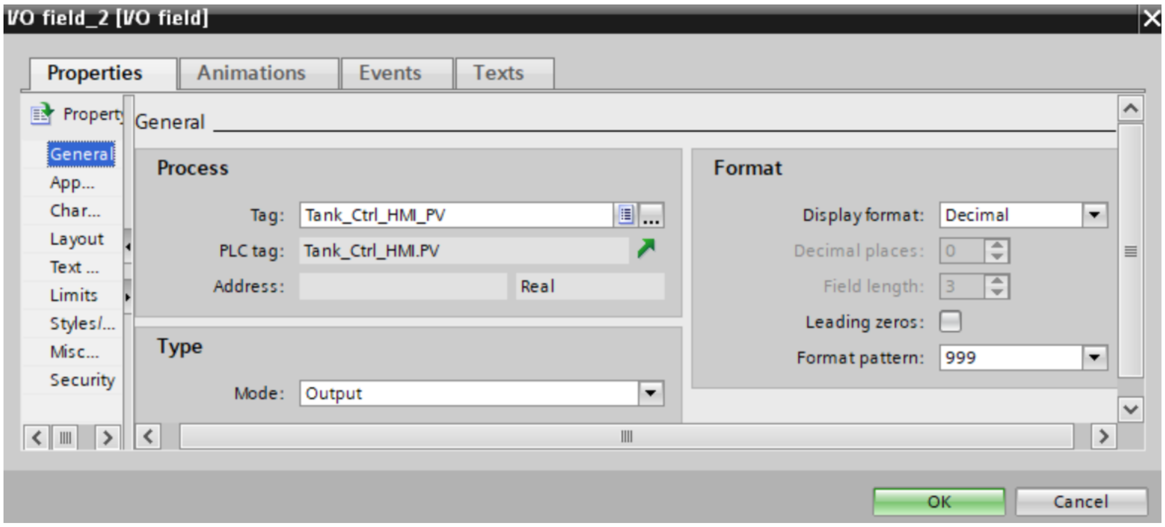


Figure 3.38. Process Variable Configuration

% Fill valve opening and % Drain valve opening also configured as output mode, decimal display format and three digit output field. The only difference is the tag number which is assigned to each output fields.

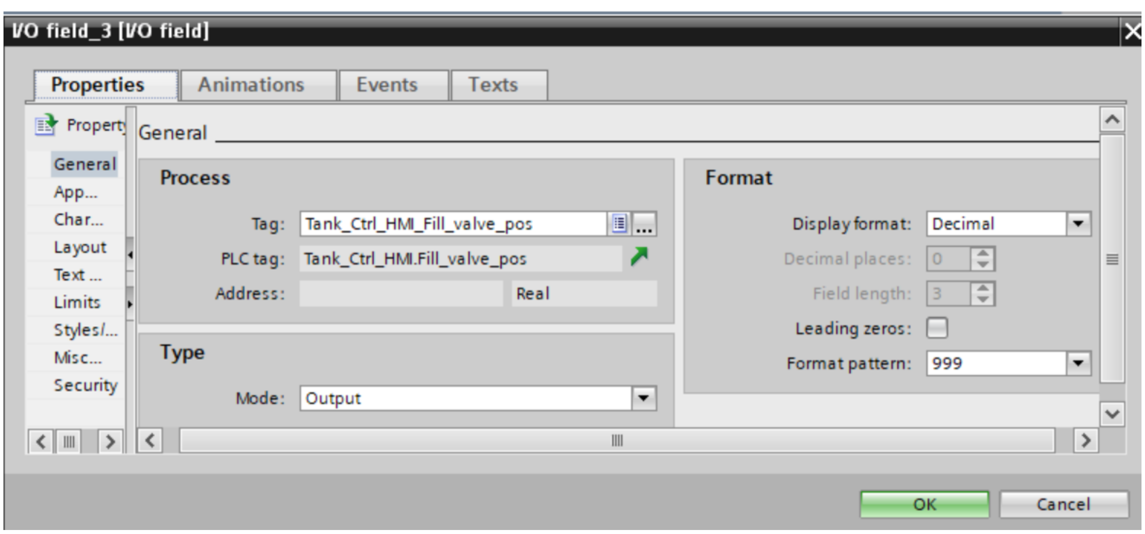


Figure 3.39. Fill and Discharge Valve Opening Configuration

Analog level signal display bar has been configured to show actual water level with the scale from 0 to 500 cm which corresponds to the actual height of the tank.

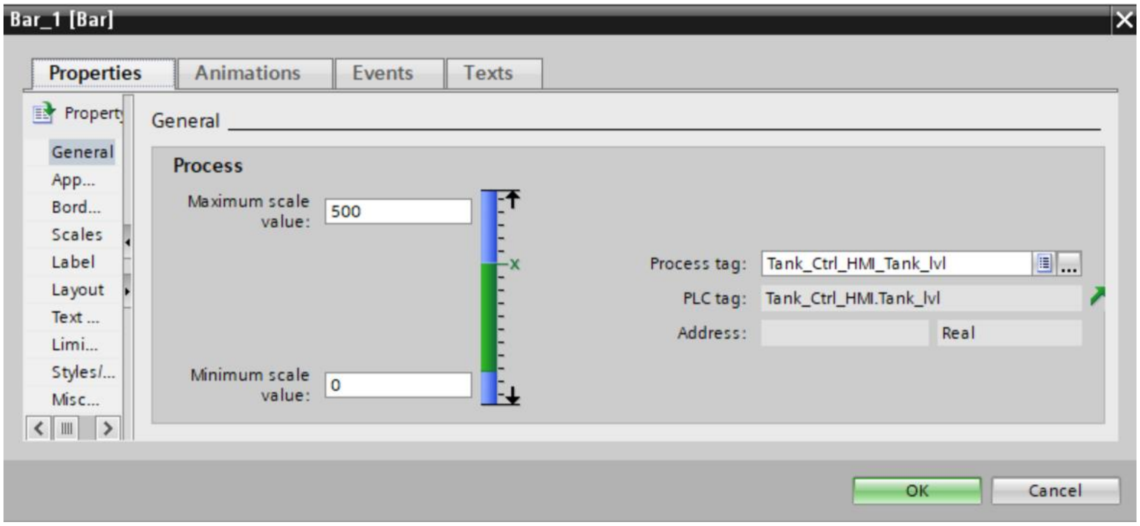
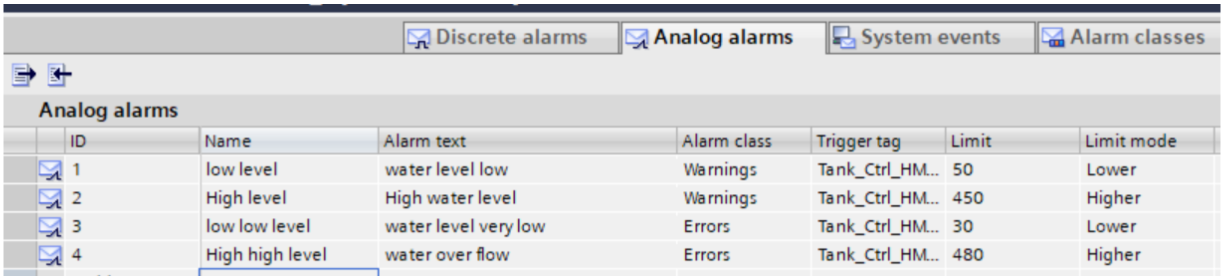


Figure 3.40. Water Level Bar Configuration

Fill level valve, Drain level valve and pump graphics has also been configured. It is configured in a such a way that when fill valve is opened, animation have been added to show opening of the valve and same is true for drain valve. When the pump is active, animation has also been configured, showing that the pump is running.

Alarm

One of the main reasons for an HMI to be included in a project is so that alarms can be relayed to an operator or end user. Analog type of Alarm has been developed and Classified as warnings and Errors. If water level is below 30cm, water level very low error alarm is generated and if water level is below 50cm, water level low warning alarm is generated. And If water level is above 450cm, high water level warning alarm is genearted and if water level is above 480cm, water overflow error alarm is generated to avoid water overflow and inform the operator. Alarm configuration is shown in screen shot below.



	ID	Name	Alarm text	Alarm class	Trigger tag	Limit	Limit mode
	1	low level	water level low	Warnings	Tank_Ctrl_HM...	50	Lower
	2	High level	High water level	Warnings	Tank_Ctrl_HM...	450	Higher
	3	low low level	water level very low	Errors	Tank_Ctrl_HM...	30	Lower
	4	High high level	water over flow	Errors	Tank_Ctrl_HM...	480	Higher

Figure 3.41. Analog Alarm Configuration

<u>Trends</u>

Trends have been programmed to show the comparision between setpoint and actual water level for analysis of PID controller including table summary. Trend wimdow is shown in the screen shot below.

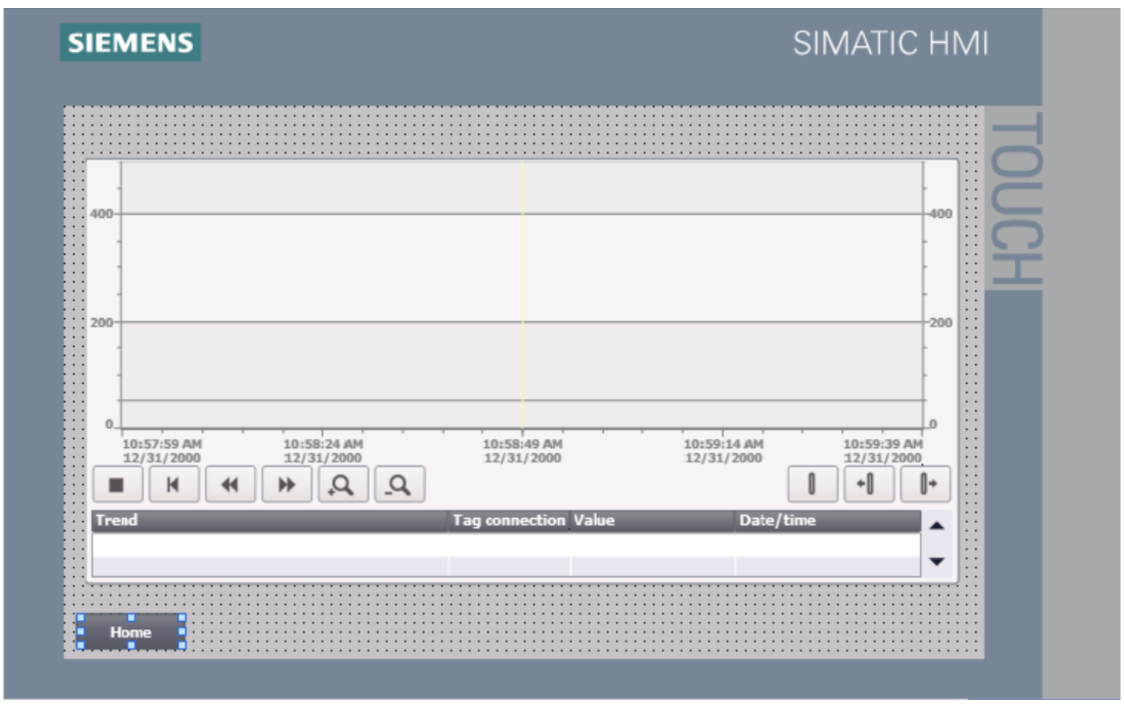


Figure 3.42. Process Trend Configuration

After Human Machine Interface (HMI) has been designed and configured, HMI control algorithim has been developed.

3.2.7 Programming of HMI control algorithm

Function block for the Human Machine Interface (HMI) has been set as HMI control. under the HMI function 6 networks have been used and each network with different functions.

Network 1: The process variable (PV) which is the actual water level from the level sensor reading is displayed on the HMI in the range of 0 to 500cm, which the actual height of the tank. MOVE instruction has been used to move MD104 value to the tank control data block.

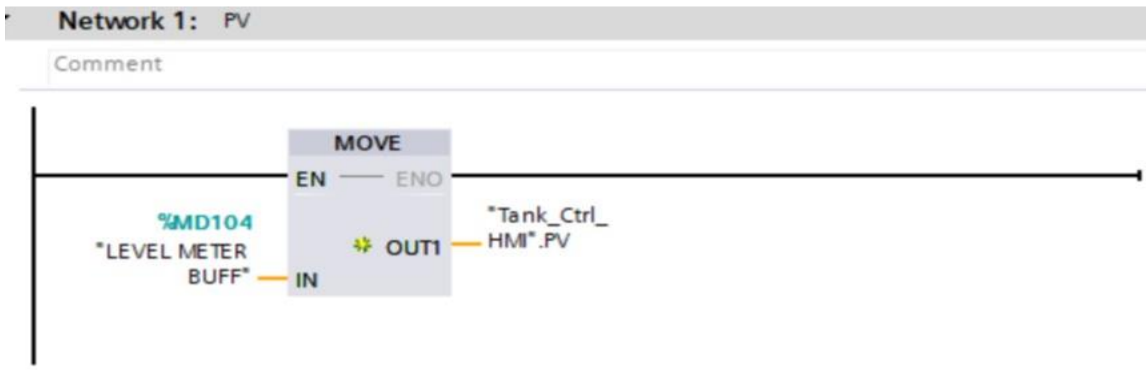


Figure 3.43. PV Display Program

Network 2: Is used to display percentage of fill valve position on the HMI.in this network mathematical operation instruction MUL and DIV have been used to express valve position in percentage (%) from 0 to 100 %.

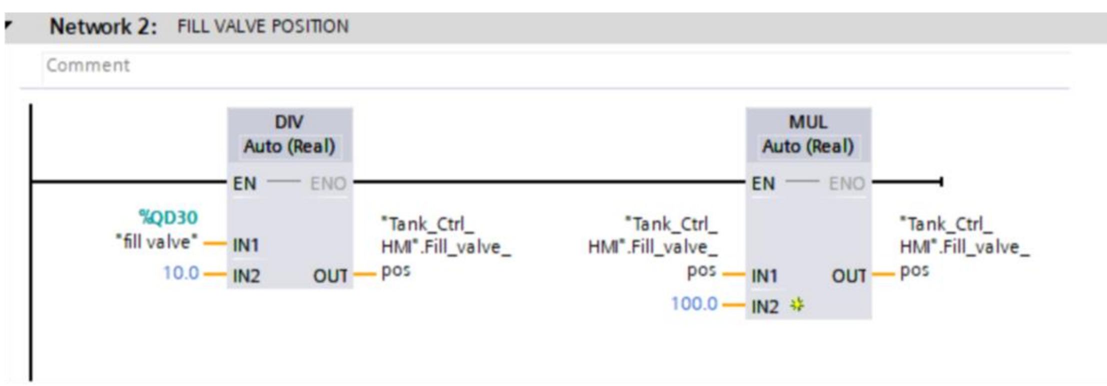


Figure 3.44. Fill Valve Position Display Program

Network 3: Is used to display percentage of fill valve position on the HMI.in this network mathematical operation instruction MUL and DIV have been used to express valve position in percentage (%) from 0 to 100 %.

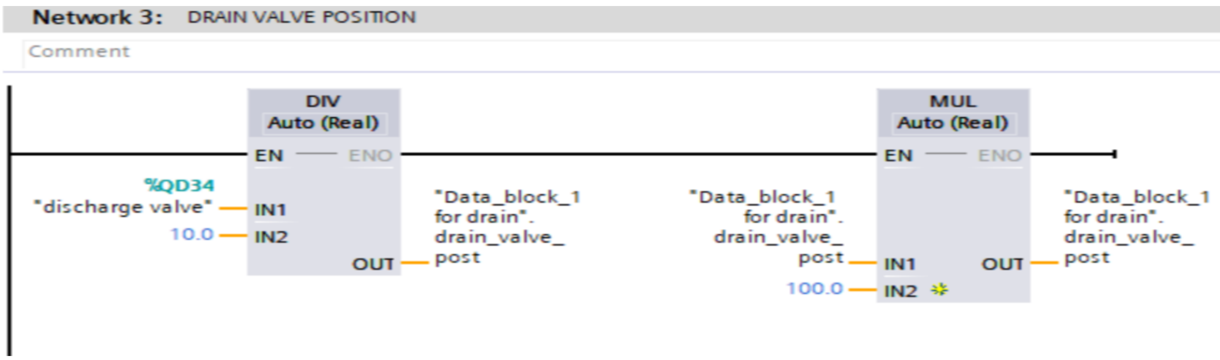


Figure 3.45. Discharge Valve Position Display Program

Network 4: Is used to display the level of the tank using the bar on the tank. the range of the bar has been configured from 0 to 500cm, which is the actual height of the tank.

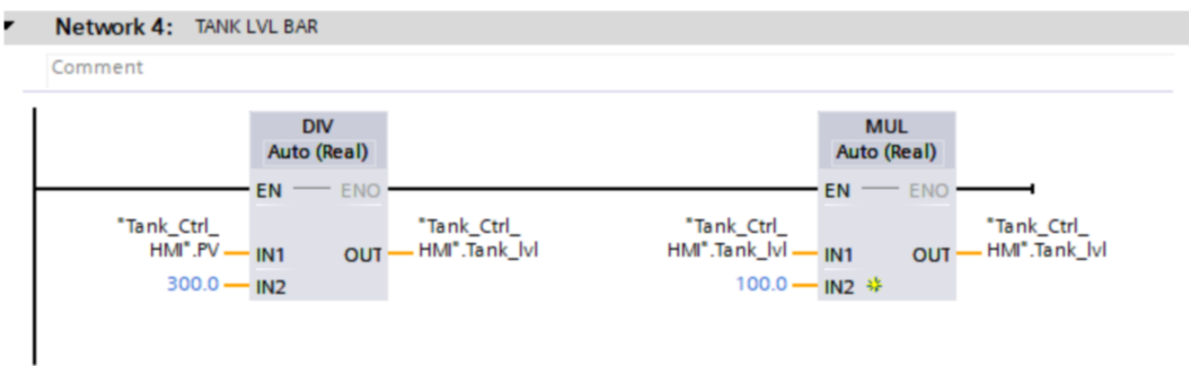


Figure 3.46. Water Level Display Program

Network 5: Is used to animate the fill valve. Clock memory is used to have the valve blinking ON and OFF with a clock frequency of 0.5 Hz. when the fill valve is open i.e., the valve position is greater than 0, animation is visualized on the HMI.

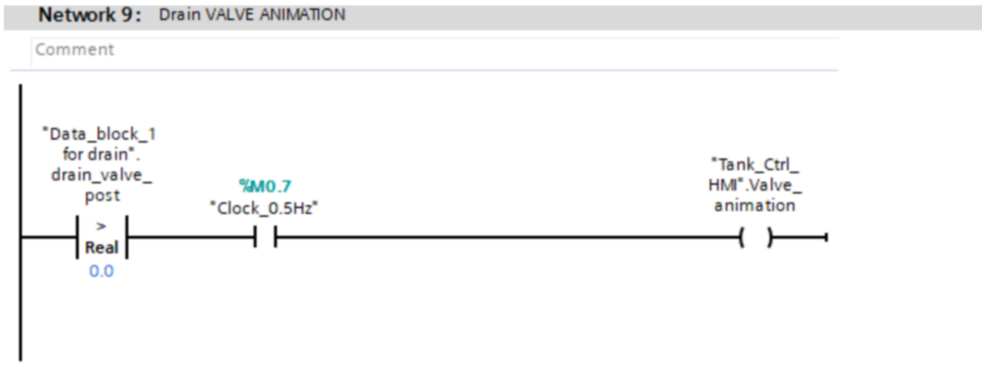


Figure 3.47. Fill Valve Animation

Network 6: Is used to animate the discharge valve. Clock memory is used to have the valve blinking ON and OFF with a clock frequency of 0.625Hz. clock frequency 0.625Hz is used to differentiate it from fill valves clock frequency. when the fill valve is open i.e., the valve position is greater than 0 then the animation will be visualized on the HMI.

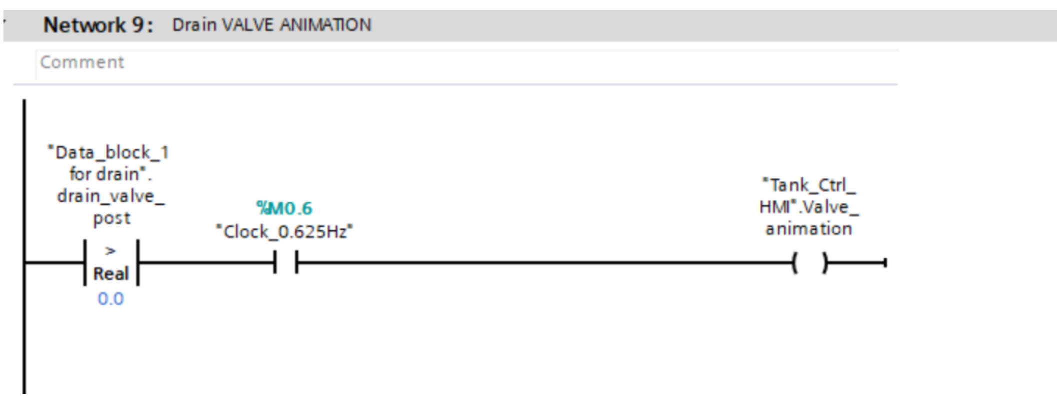


Figure 3.48. Discharge Valve Animation

Network 7: Is used to animate pump motor. When the pump is active/running, it changes color from silver to green.

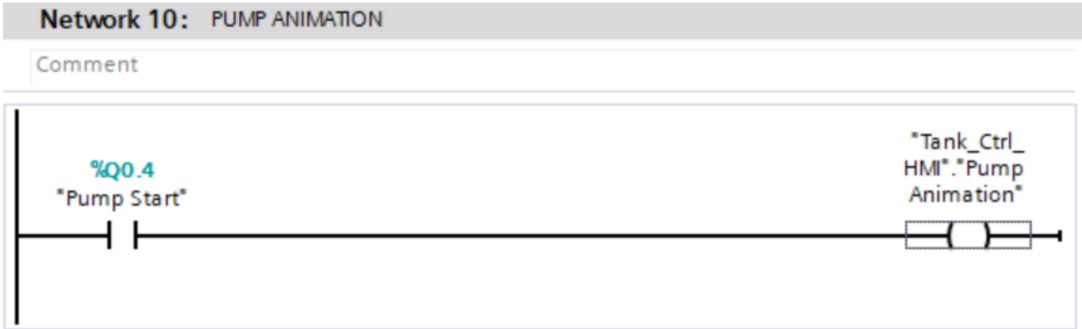


Figure 3.49. Pump Animation

The control algorithm has been compiled with no error and loaded into the PLC.

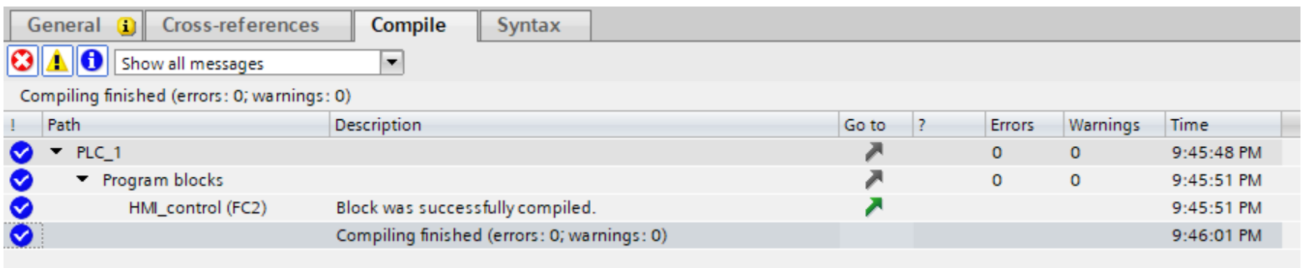


Figure 3.50. Compiled Program Block

CHAPTER 4

RESULT AND DISCUSSION

Factory I/O simulation software has been used to emulate the study. By using Factory I/O the Virtual build of water tank level control system has been designed and simulated to check the functionality of the system. All the required hardware components are also included. i.e. level sensor, fill and drain valves. For simulation of the study communication between TIA portal V15 using PLC Sim V15, and Factory I/O has been established.

Figure 4.1. Virtual Build of Water Level Control System on Factory I/O

4.1 Simulation of PLC and HMI programs

Simulating a program before installing it in a machine is one technique to uncover difficulties in industrial automation. PLCs may be simulated with Siemens TIA Portal's built-in simulation program PLCSIM, and HMIs can be simulated with WinCC Runtime Advanced. Simulation is used to test the response between the HMI program and the PLC program. The Siemens PLC simulator software, PLCSIM is used for the simulation. The simulation process is as follows

- Launch PLCSIM and TIA portal. To lunch PLCSIM in TIA portal select the PLC and simply start simulation button on tool bar.

Figure 4.2. PLC Simulator

- Select the appropriate controller type (S7-1500/S7-1200/ET200SP) to load the PLC program.
- With the S7- 1500 CPU selected and Power on simulator and go back to TIA portal.
- Click Blocks in the left pane to select all the programmed blocks in the right pane. Finally, click on the download device icon on the menu bar to download the program to the PLC. Then check before loading and error window if any pops up. With no error click on the load button.

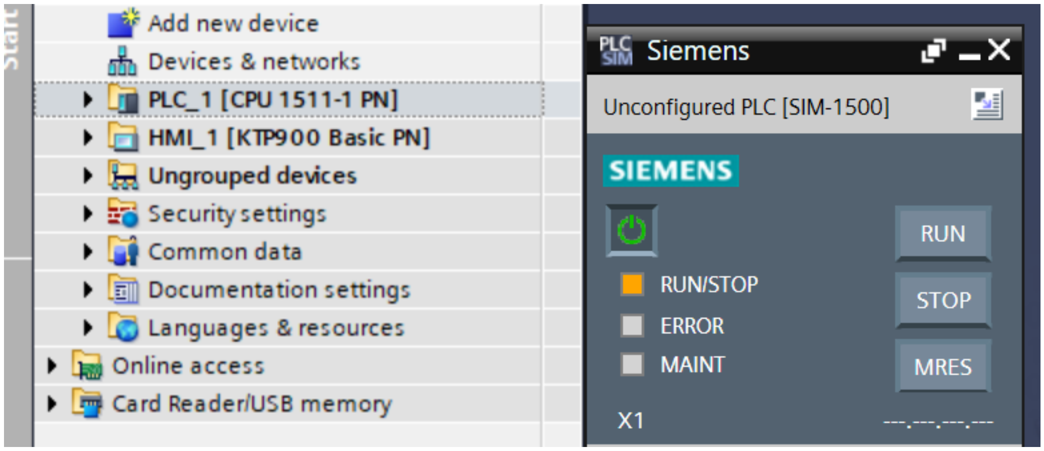


Figure 4.3. Program Loaded to PLC

Check before loading window pops up and click on load to finally load the program on PLC and click finish icon.

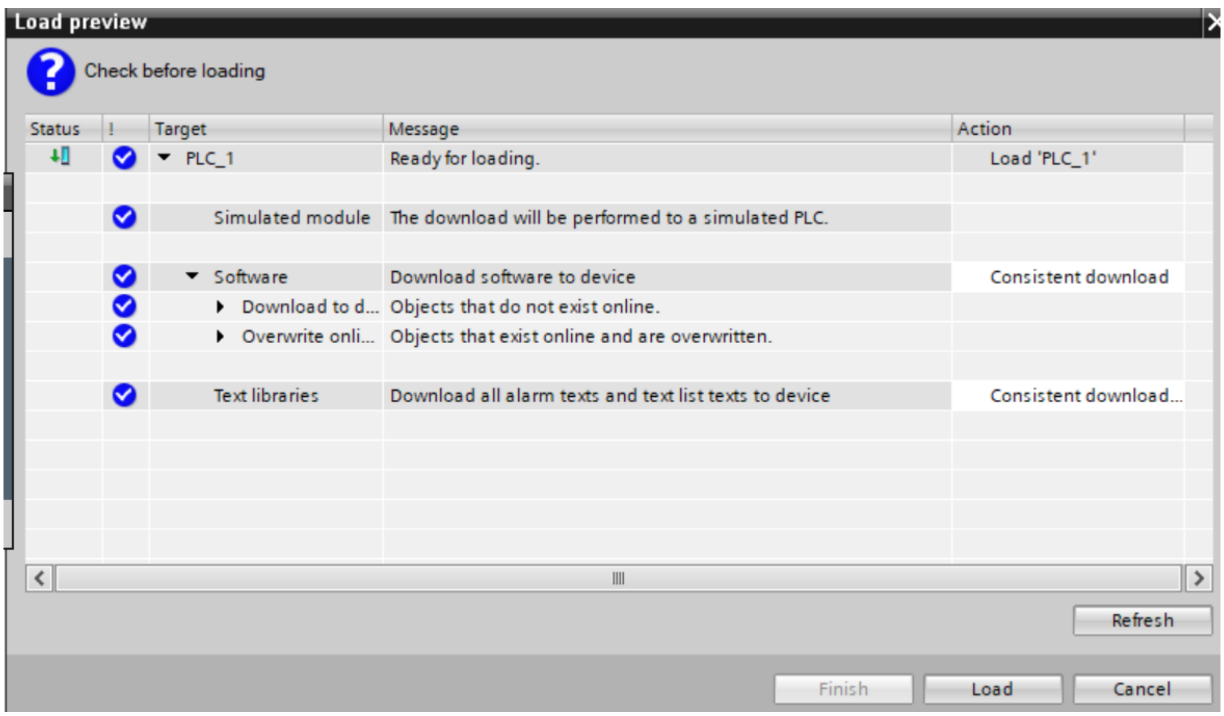


Figure 4.4. PLC Program Load Preview Window for Checking Errors

- Switch the PLCSIM CPU into run mode by checking the run option on the PLCSIM and set the PLC program into online mode.

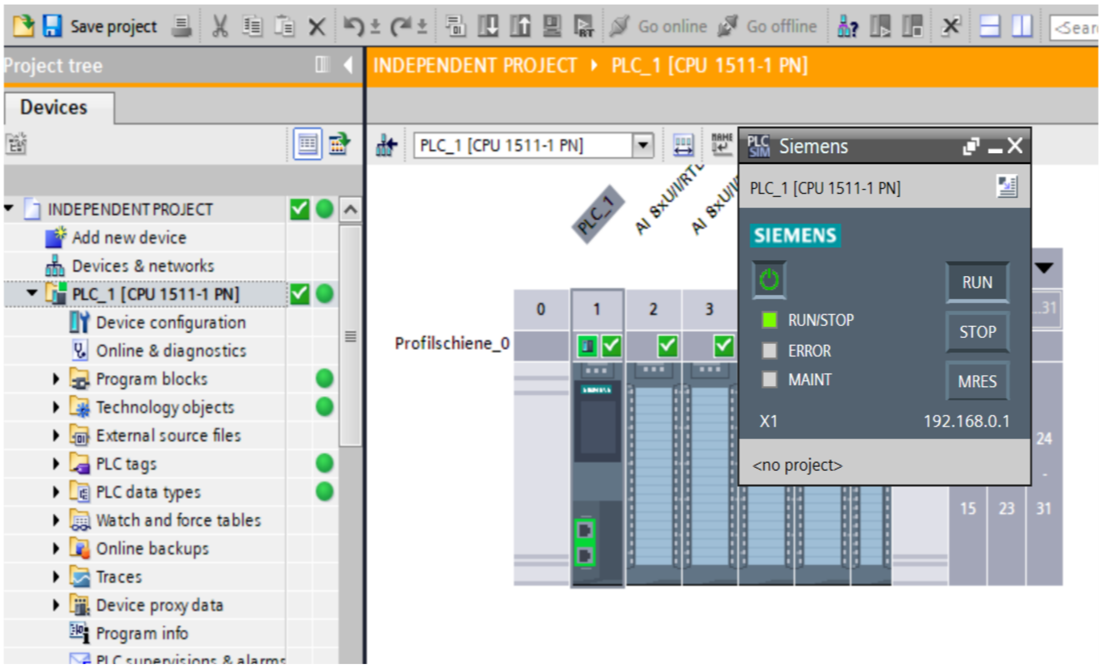


Figure 4.5. CPU in Run and Online Mode

For the next testing process of switching the HMI program also into runtime or simulation mode is achieved by selecting HMI_1[KTP900 Basic PN] on the right pane of TIA portal and click on start simulation icon on the menu bar. The runtime or simulation icon shown in Fig. 40 above; The step 7 launches the HMI program in RT Simulator.

4.2 Connecting TIA Portal with Factory I/O

For simulating the study on Factory I/O, Communication between TIA portal and Factory I/O has been established through a code which is written in SCL programming language (Appendix A). To have the communication between the software's control algorithm has been simulated and it is error free. And has been loaded to the controller 1511-1 PN CPU.

Now the CPU is in the RUN and online mode and TIA portal is ready for communication with the Factory I/O software.to achieve the communication in the driver section of the factory I/O the appropriate type of controller has been selected. i.e., siemens step7- PLCSIM.

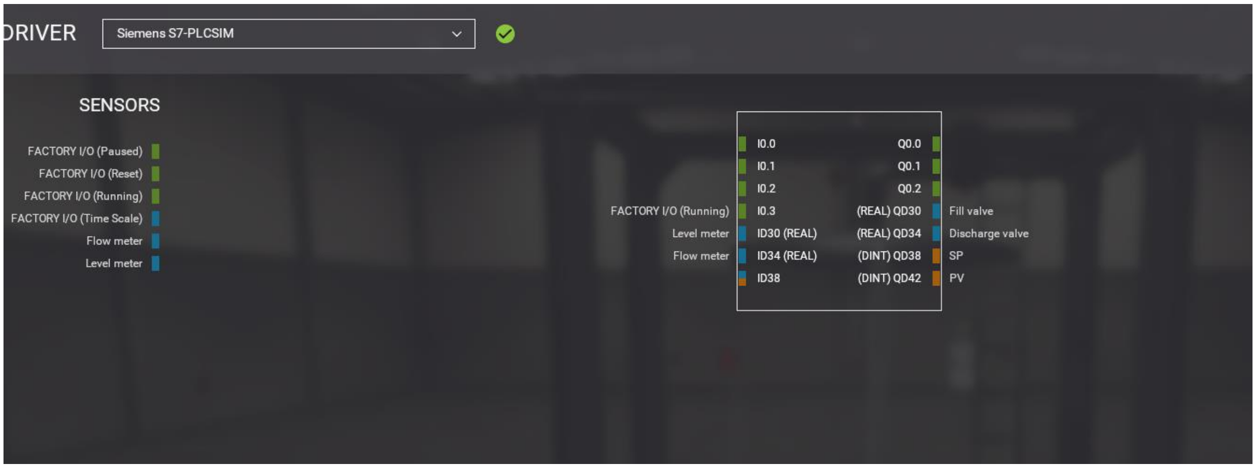


Figure 4.6. Communication Between TIA and Factory I/O

4.3 Simulation Results

Testing the functionality of the automated water level control system using PID, PLC and HMI are designed in such a way that in runtime when operating from the HMI, the operator sets the required water level from HMI and the required water level is achieved by opening and closing of fill and drain valves. The opening percentage for both valves is shown on the HMI as well as fill and drain valves animation whenever the valves are opened to inform the operator. Actual water level is also shown and status of the pump on HMI through animation. Alarms will be generated if the water level is below 50 cm and overflow alarm if the water level is above 480 cm. Comparison between set point and actual water level is also configured through trends and table format.

The functionality of the system is tested by taking different set points and comparing the difference between the actual and required water level, using generated trends. Alarms has also been tested by setting the required water levels which generates low level and overflow alarms.

Different set points (SP) are taken to test the functionality of the system by comparing the difference between the actual and the required water level. Setpoints taken to the functionality of the system are 0,45, 90,150, 290, 370, 450 and 490. The first and the last SPs are to test the generated alarms.

Set point set to 0 cm, both fill and drain valve closed (0 % opening) and low water level alarm activated in red on HMI. Level sensor, fill valve opening and drain valve feedback signals also shown in Fig below

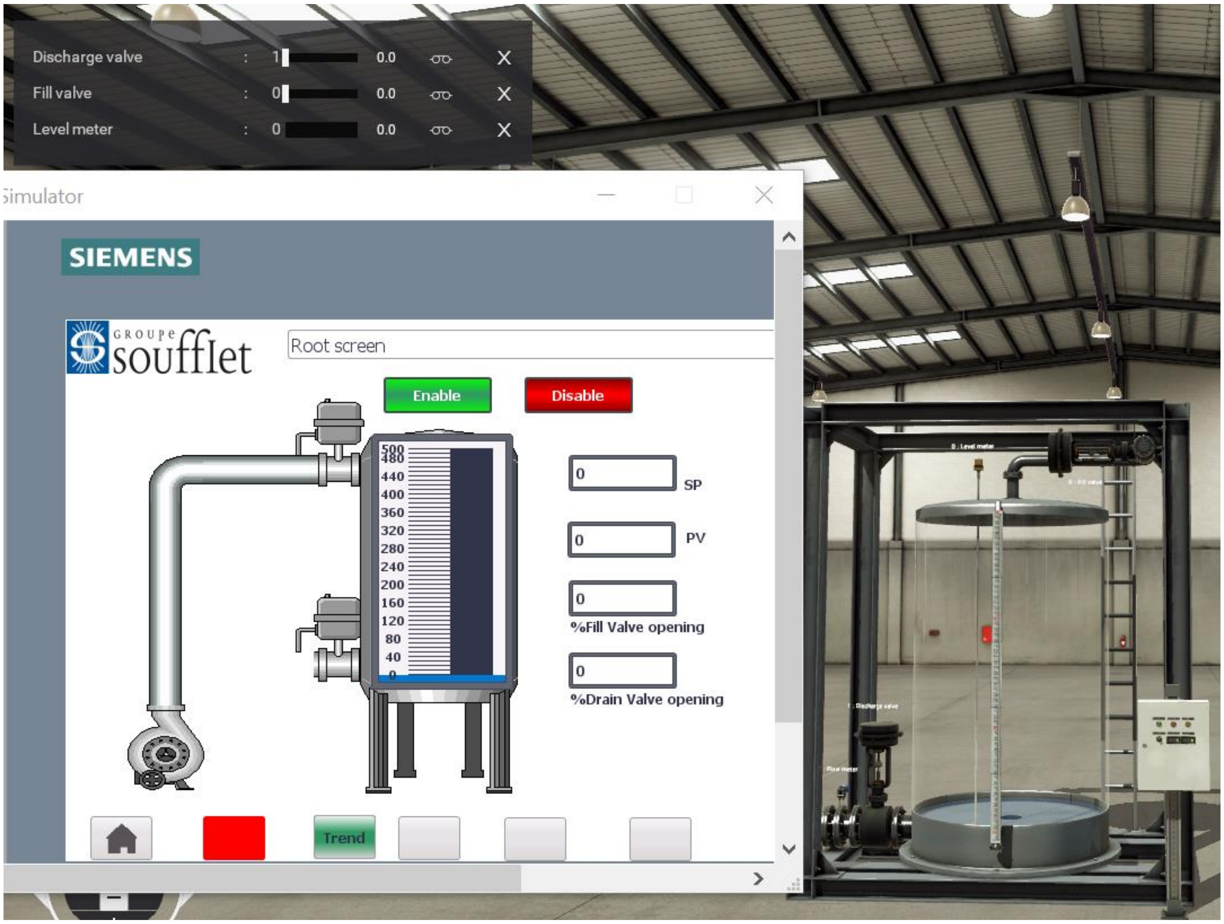


Figure 4.7. Result of Setpoint Set at 0

Set point (SP) set to 45 and actual water level is also reached 45 shown on HMI. Comparison and analysis using trends and low water level alarm is generated on HMI. Level sensor, fill valve opening and drain valve feedback signals is shown in Figure 4.8 below.

Figure 4.8. Result of Setpoint Set at 45

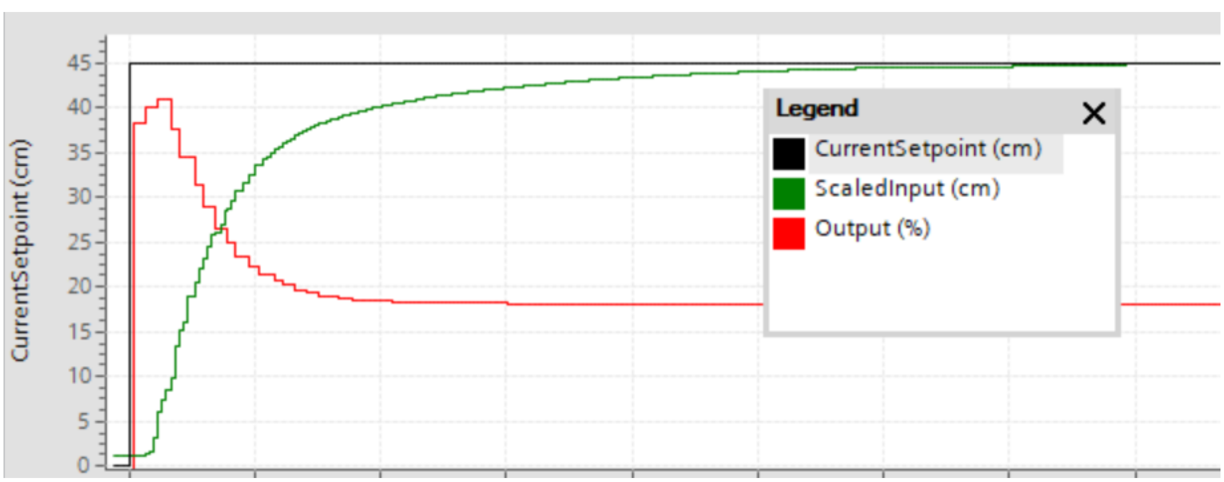


Figure 4.9. Trend Result of ST Set to 45

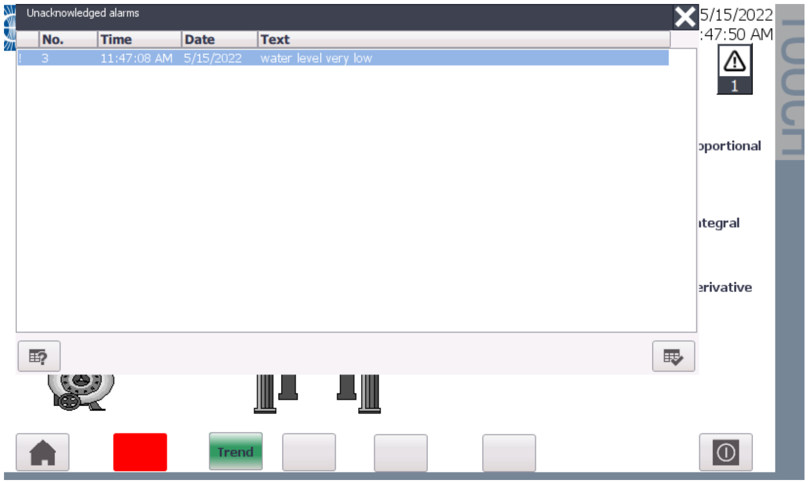


Figure 4.10. Low Water Level Alarm

Set point (SP) set to 90 and actual water level is also reached 90 shown on HMI. Comparison and analysis using trends shown on HMI. Level sensor, fill valve opening and drain valve feedback signals is shown in Figure 4.11 below

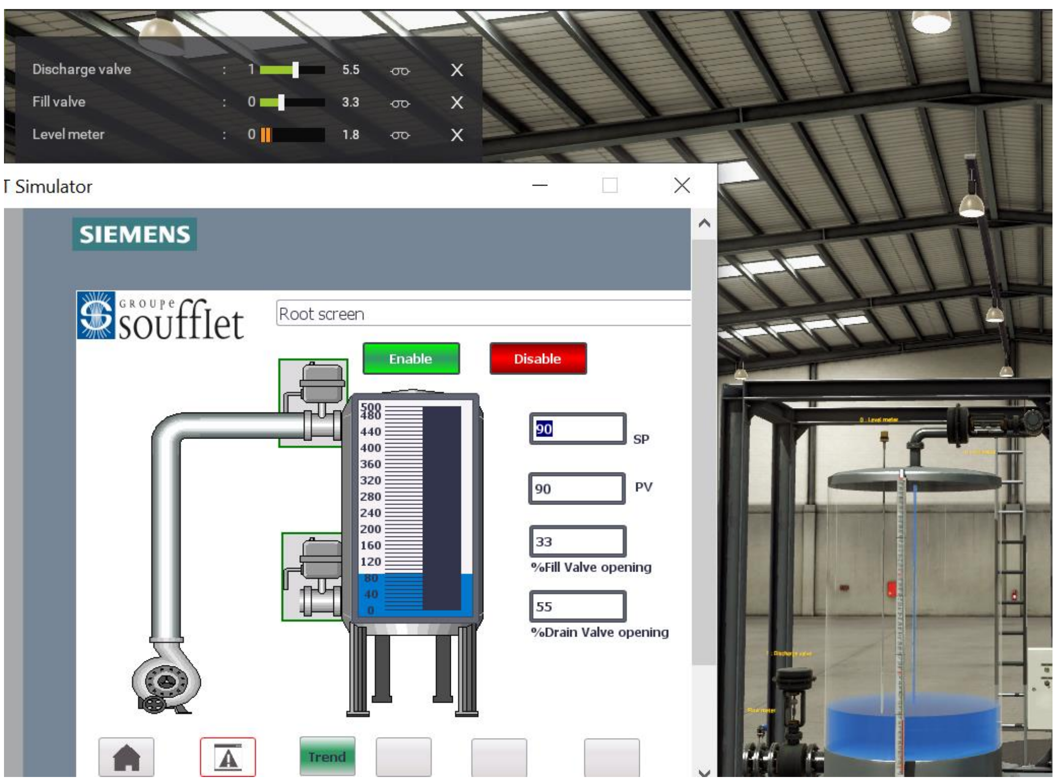


Figure 4.11. Result of SP Set to 90

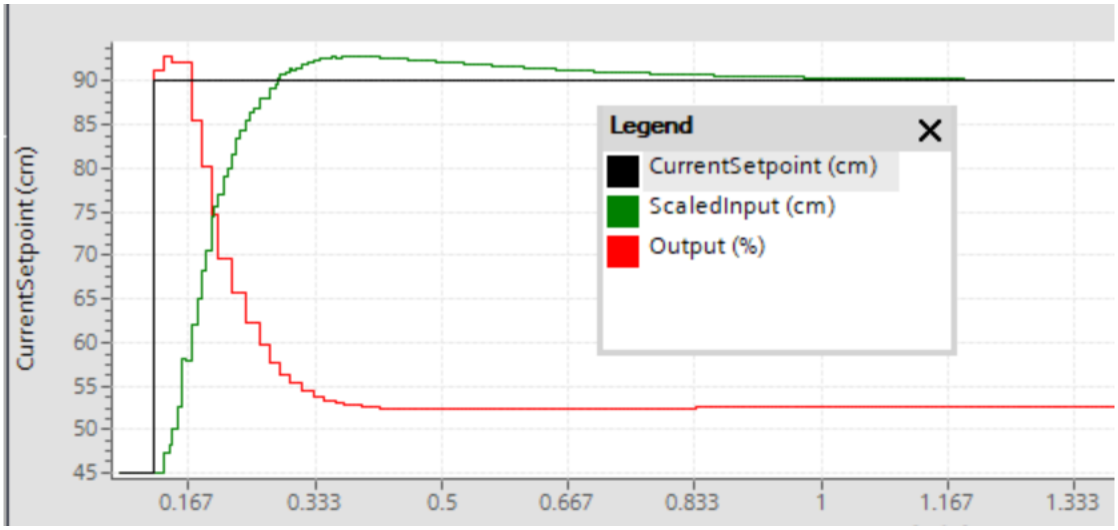


Figure 4.12. Trend Result of SP Set to 90

Set point (SP) set to 150 and actual water level is also reached 150 shown on HMI. Comparison and analysis using trends shown on HMI. Level sensor, fill valve opening and drain valve feedback signals is shown in Figure 4.13 below

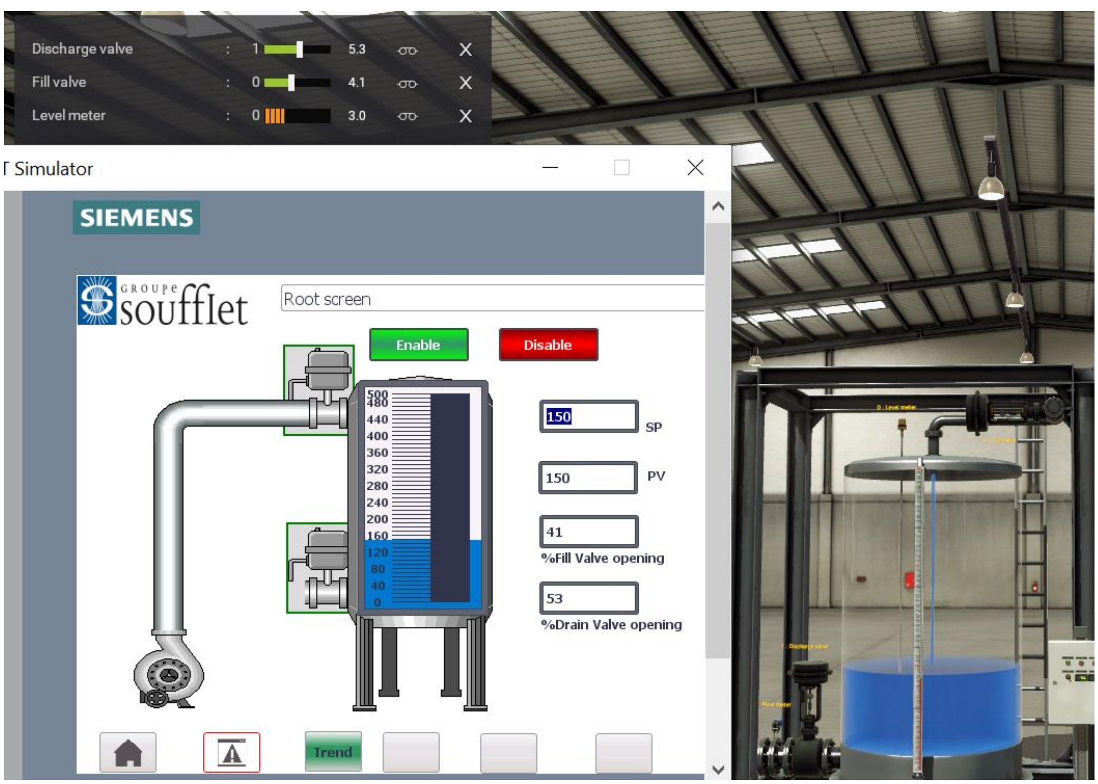


Figure 4.13. Result of SP Set to 150

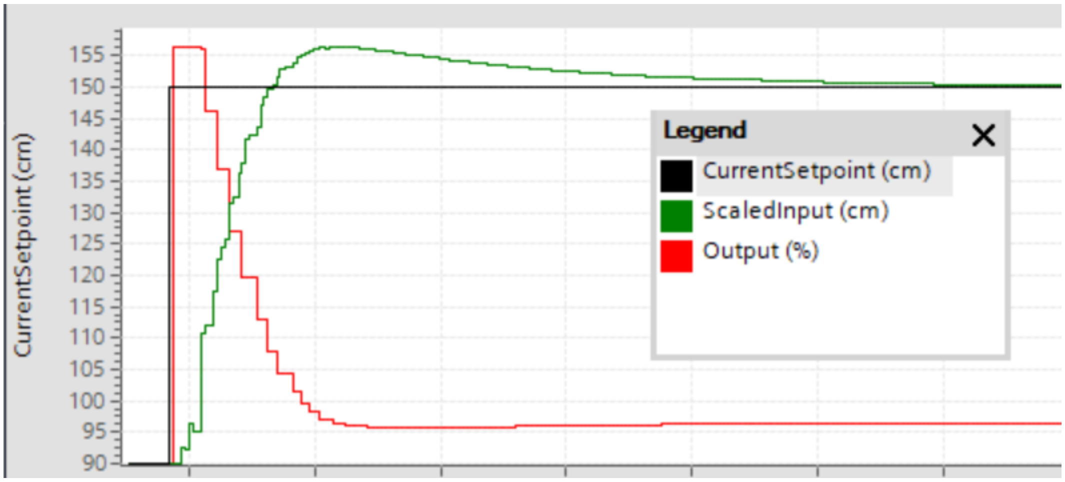


Figure 4.14. Trend Result SP Set to 150

Set point (SP) set to 290 and actual water level is also reached 290 shown on HMI. Comparison and analysis using trends shown on HMI. Level sensor, fill valve opening and drain valve feedback signals is shown in Figure 4.15 below.

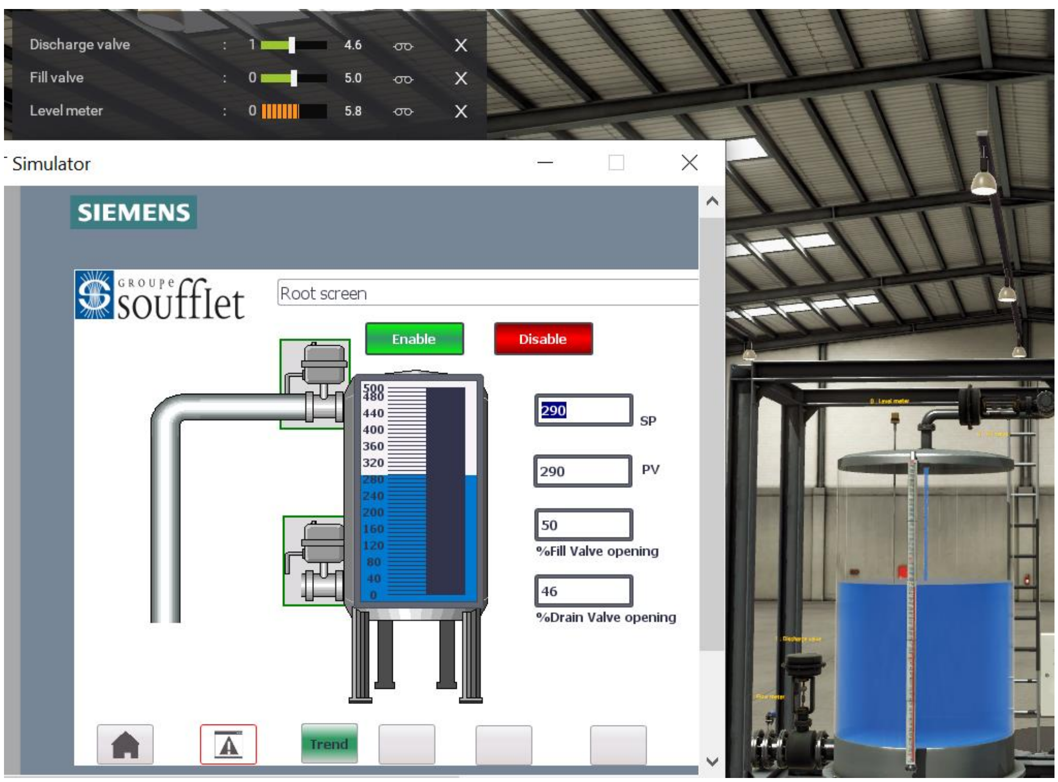


Figure 4.15. Result of SP Set to 290

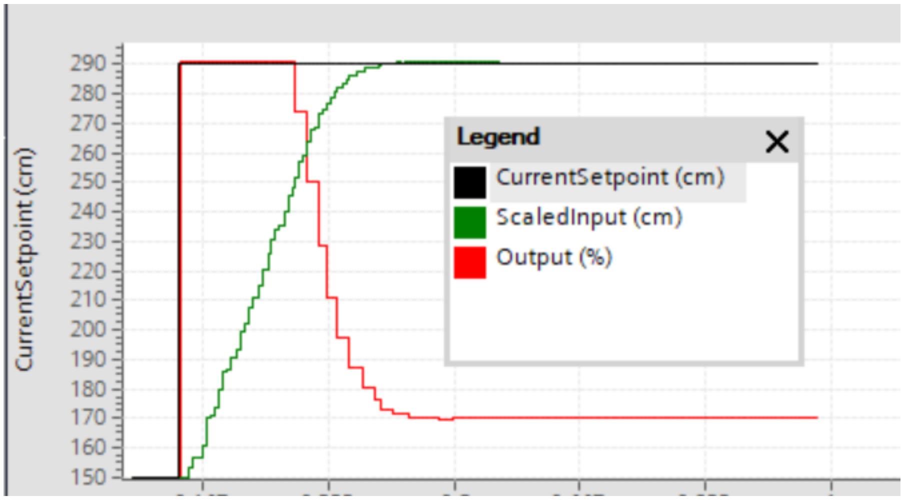


Figure 4.16. Trend Result SP Set to 290

Set point (SP) set to 370 and actual water level is also reached 370 shown on HMI. Comparison and analysis using trends shown on HMI. Level sensor, fill valve opening and drain valve feedback signals is shown in Figure 4.17 below.

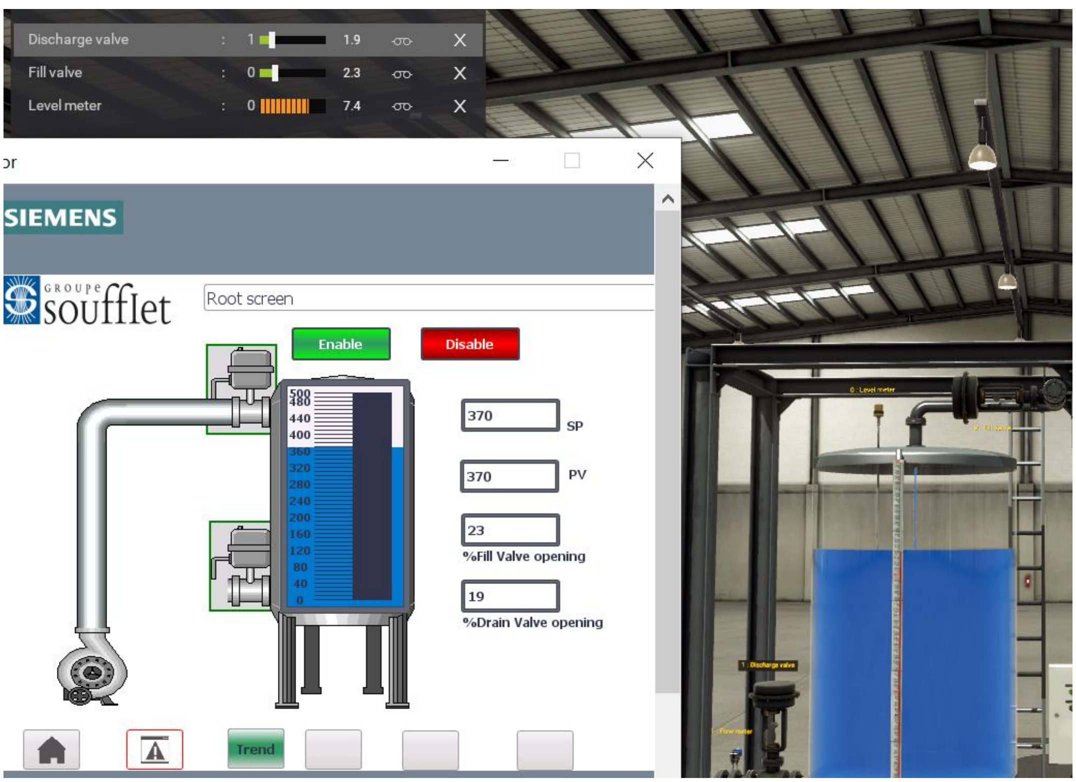


Figure 4.17. Result Of SP Set to 370

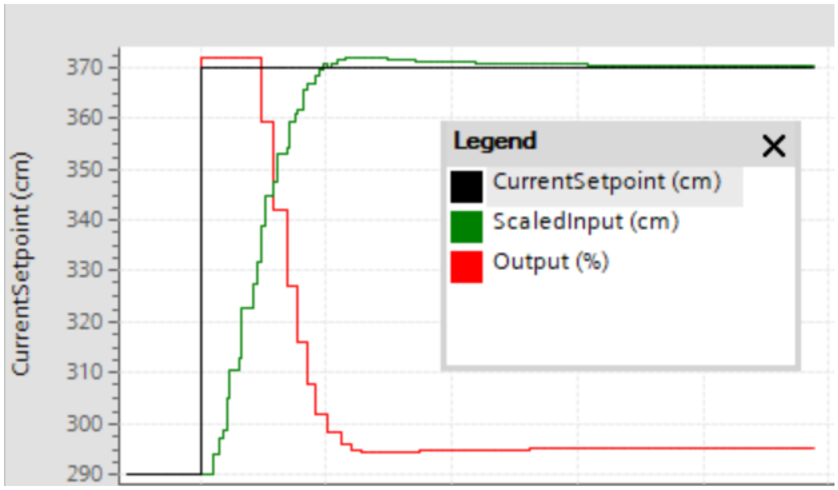


Figure 4.18. Trend Result of SP Set to 370

Set point (SP) set to 450 and actual water level is also reached 450 shown on HMI. Comparison and analysis using trends shown on HMI. Level sensor, fill valve opening and drain valve feedback signals is shown in Figure 4.19 below.

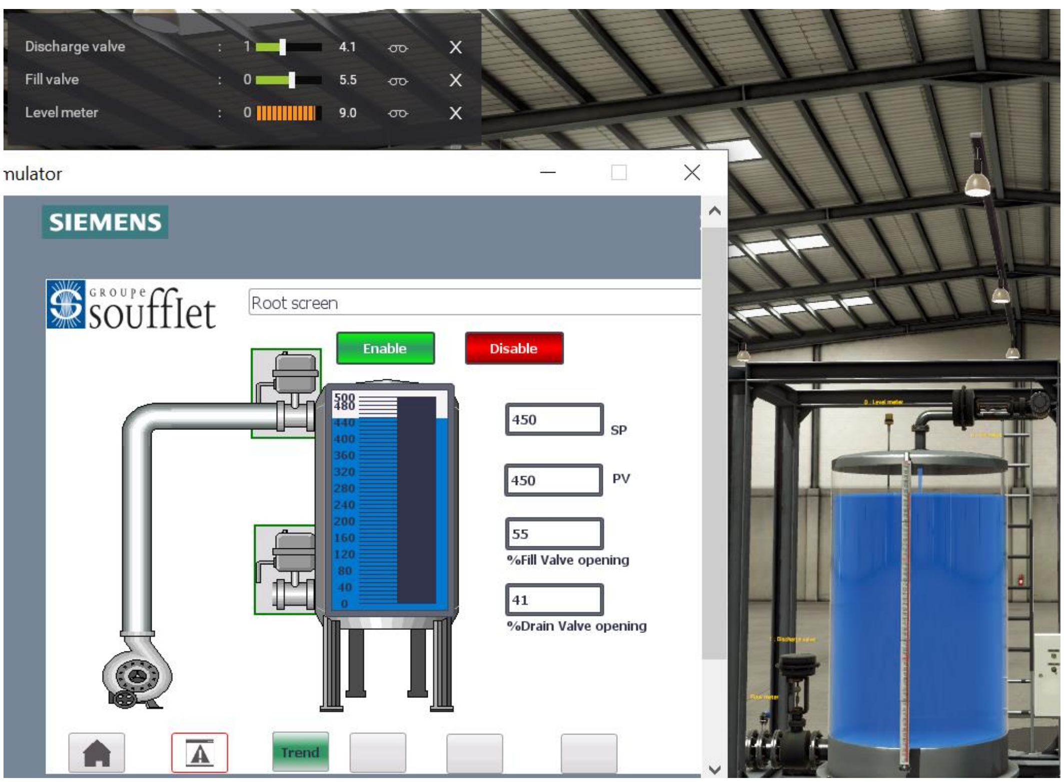


Figure 4.19. Result of SP Set to 450

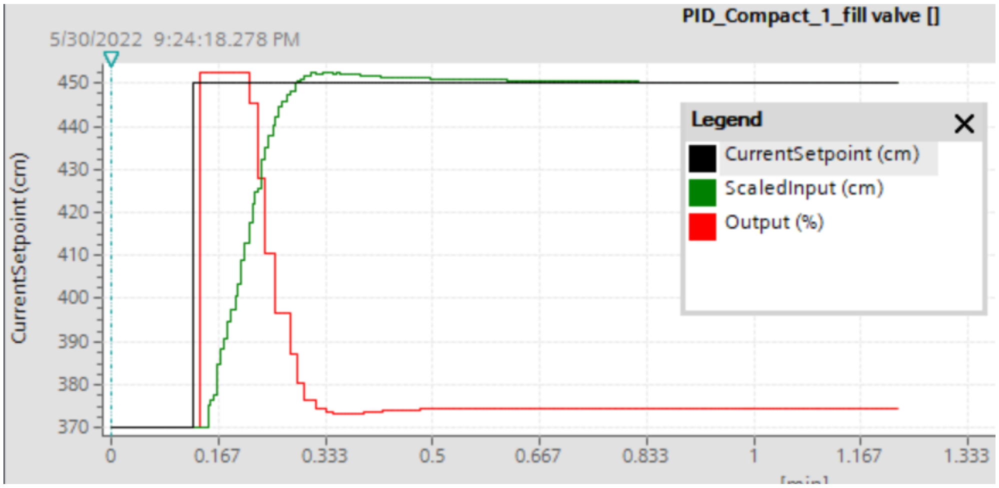


Figure 4.20. Trend Result SP Set to 450

Set point (SP) set to 490 and actual water level is also reached 490 shown on HMI. Comparison and analysis using trends and overflow water alarm is shown on HMI. Level sensor, fill valve opening and drain valve feedback signals is shown in Figure 4.21below.

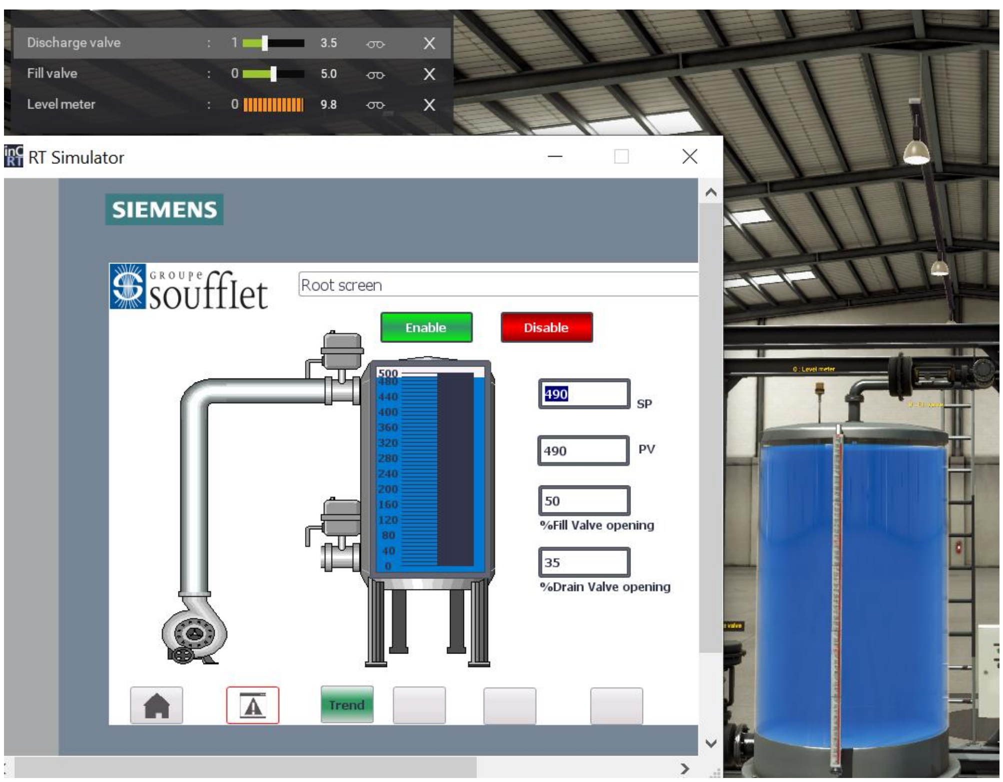


Figure 4.21. Result of SP Set to 490

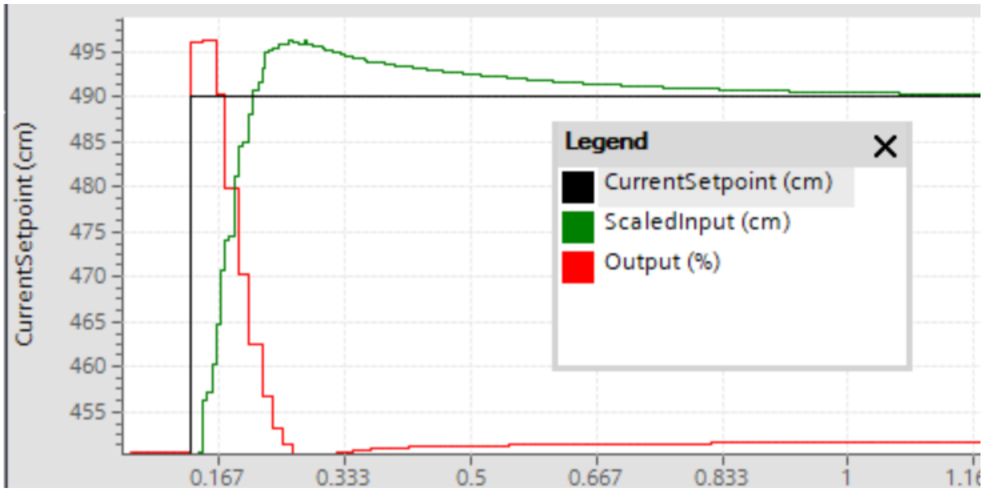


Figure 4.22. Trend Result SP Set to 490

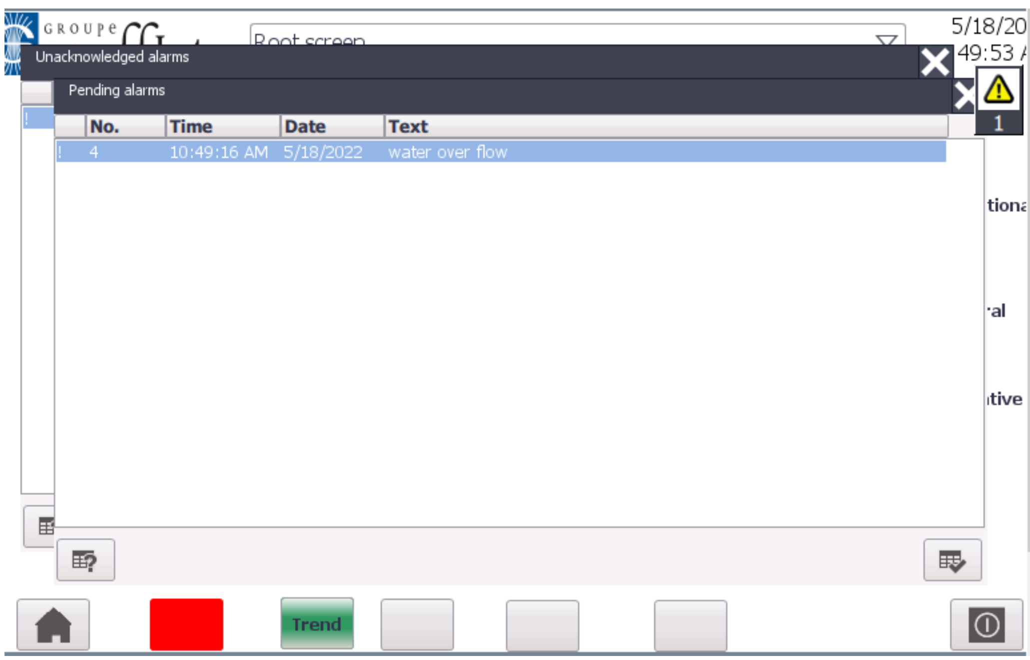


Figure 4.23. Water Overflow Alarm

Table 4.1. SP, PV, % Valve opening and Closing and Level sensor summarization

No	SP (cm)	PV (cm)	Fill Valve opening (%)	Drain valve Opening (%)	Level sensor feedback (v)	Alarms
1	0	0	0	0	0	Low water level
2	45	44.9	23	53	0.9	
3	90	90.3	33	53	1.8	
4	150	150.62	41	53	3	
5	290	290.098	50	46	5.8	
6	370	370.71	23	17	7.4	
7	450	450.06	55	41	9	
8	490	490.68	50	35	9.8	Overflow

Comparison between Setpoint (SP) and process variable (PV) is done and the result shows that PID compact controls the water level as per the set point. Linear relationship b/n setpoint and process variable. Figure 4.24 below for the comparison between SP and PV.

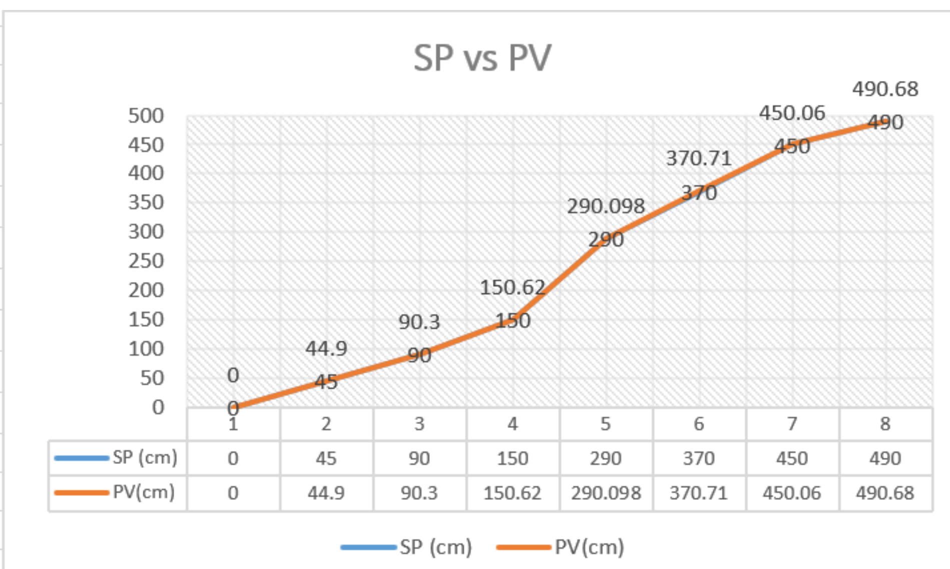


Figure 4.24. Setpoint and Process Variable Comparison

Comparison between Actual water level (process variable) and level sensor feedback is shown in Figure 4.25 below.

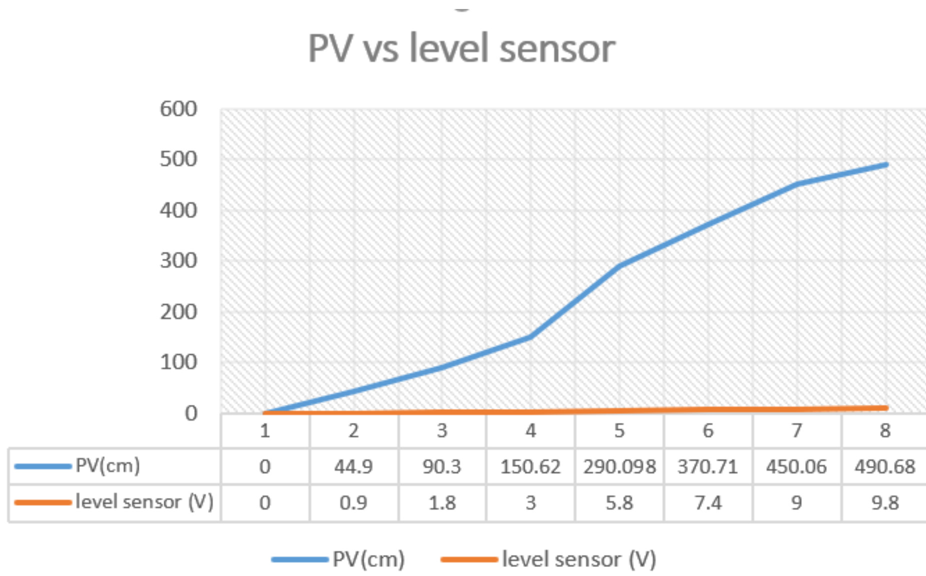


Figure 4.25. Process Variable and Level Sensor Comparison

Table 4.2 below shows Peak overshoot (M_P), Rise time (t_r) and Settling time (t_s) in comparison with different setpoints.

Table 4.2. Peak overshoot, Rise time and Settling time

Setpoint (SP)	**Peakovershoot (M_P)**	**Rise time (t_r) in (sec)**	**Settling time (t_s) in (sec)**
45	0	71.64	71.64
90	3	7.6	51
150	5	7.8	66.24
290	0	16.2	25.8
370	2	9.35	30.6
450	3	9.84	28.98
490	6	5.22	52.2

4.4 Discussion of simulation result

Correct tag development for the screen elements to match the real-time status of the industrial plant resulted in successful programming of the proposed HMI. The tagging mechanism enabled and ensured reliable communication between the HMI and the PLC. As the desired water level is increased the Fill valve opening also increased depending on the difference between desired value and actual valve. As the water level increase so does level sensors feedback signal which is in volt. Low water level alarm is generated when the water level is below 50 and water overflow alarm is generated when the water level is above 480.

As shown in the Table 4.2 above, higher Overshoot occurred at 150 and 490 setpoints. And higher rise time (t_r) is recorded during process start up. With a low overshoot, the rise time is longer, and the settling time is shorter. Overall, the target output was reached through automatic tuning.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this thesis, data is analyzed based on diverse industrial components like PLC, HMI, and Factory I/O. During analysis, software's like TIA portal for logic development, Simatic WinCC Advanced for HMI design and visualization are used.

The thesis dealt in detail with PLCs and HMI. PLCs and HMI make available advantages like flexibility, easy implementation of changes, correcting errors, low cost, visual observation, easy programming method, reliability, maintainability, documentation, reporting and data logging.

During analysis, all the operations are controlled from the HMI. The process parameter controlled was water level using sensors and actuators like level sensor, fill valve, discharge valve and pump through PLCs analogue input and output system and Digital output systems. start /stop operation is done from the HMI through PLC and Process parameters like water level, Percentage of fill and drain valve openings, alarms and trends are monitored on the HMI. Simulation of the program using "Simatic PLCSIM" was conducted to check the functionality of the PLC program created. Simulation results with Factory I/O validated the correctness and applicability of the designed system and the generated HMI program. The designed HMI is commensurate with:

- A real-time view of the industrial plant.
- reduction in the troubleshooting time for faults
- And safety of operating personnel.

From the simulation result it is observed that the automation can make the engineering more efficient, less time consuming, flexible, more useful, and interactive from the operation point of view. Also, automation makes system more accurate and can act more safety and protective to the personnel, equipment, machinery, and processes. Therefore, it is concluded that automatic water level control system can be implemented in Soufflet Malt Ethiopia if the required hardware's are made available.

Last but not least, Manufacturing industries can easily adapt to the implementation of PLC and HMI as part of their industrial automation systems to make process automation and visualization of the plant easier, locate faults rapidly and to help replace humans in tasks done in dangerous environments.

5.2 Recommendations

The water level control system based on PLC, PID, and HMI is utilized in this thesis to keep the water level at a desired level. The simulation findings reveal that the PLC helps to a precise and consistent performance. But due to financial limitations and equipment limitations this thesis focused only on design and simulation. Hardware implementation of the system is not considered.

Production and manufacturing will no longer be the only fields where automation will be used. For example, many automation projects will be implemented in the so-called smart environment. Future automation projects in transportation, buildings, and health care will be closer to people's daily life. Many non-traditional fields will benefit from automation. These advancements will have a significant impact on people's lives through increasing convenience. Automation technologies will be a crucial component in the future, creation and operation of intelligent and automated societies. The productivity of smart applications in a smart environment can benefit from this autonomic network paradigm. This effort will also make it easier to examine novel automation tactics, such as cloud-based automation systems that use PLCs and HMIs to improve automation security management.

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APPENDIXS

Appendix A1: Factory I/O and TIA portal Communication.

Communication between TIA portal and Factory I/O is established by using Structured Control Language (SCL) Code below.

```
#Value:=PEEK(area := 16#82,
    dbNumber := 0,
    byteOffset := 511);
#Value := #Value + 1;


POKE(area := 16#82,
    dbNumber := 0,
    byteOffset := 511,
    value := #Value);


POKE(area := 16#82,
    dbNumber := 0,
    byteOffset := 1016,
    value := #Value_01_DW);
POKE(area := 16#82,
    dbNumber := 0,
    byteOffset := 1020,
    value := #Value_02_DW);
```

```
FOR #ForCounter := 0 TO 63 DO
    #Value:=PEEK(area := 16#1,
         dbNumber := 0,
         byteOffset := #ForCounter);
    POKE(area := 16#81,
         dbNumber := 0,
         byteOffset := #ForCounter,
         value := #Value);
END_FOR;
#Value := PEEK(area := 16#1,
               dbNumber := 0,
               byteOffset := 512);
POKE(area := 16#82,
     dbNumber := 0,
     byteOffset := 512,
     value := #Value);
```

Appendix A2: LMP307 submersible Level Transmitter data sheet

IMPRESS
SENSORS & SYSTEMS

BELL
Flow Systems

LMP 307

Stainless Steel Probe

Stainless Steel Sensor

accuracy according to IEC 60770:
standard: 0.35 % FSO
option: 0.25 % / 0.1 % FSO

Nominal pressure

from 0 ... 1 mH_2O up to 0 ... 250 mH_2O

Output signals

2-wire: 4 ... 20 mA
3-wire: 0 ... 20 mA / 0 ... 10 V
others on request

Special characteristics

- diameter 27 mm
- small thermal effect
- excellent accuracy
- excellent long term stability

Optional versions

- IS-protection zone 0
- SIL 2 (Safety Integrity Level)
- cable protection via corrugated pipe
- different kinds of cables
- different kinds of seal materials

The stainless steel probe LMP 307 is designed for continuous level measurement in water and clean or waste fluids.

Basic element is a high quality stainless steel sensor with high requirements for exact measurement with excellent long term stability.

Preferred areas of use are

Water / filtrated sewage
drinking water system
ground water level measurement
rain spillway basin
pump and booster stations
level measurement in container
water treatment plants
water recycling

Fuel / Oil
fuel storage
tank farm

Input pressure range														
Nominal pressure gauge	[bar]	0.1	0.16	0.25	0.4	0.6	1	1.6	2.5	4	6	10	16	25

Level [mH_2O]	1	1.6	2.5	4	6	10	16	25	40	60	100	160	250
Overpressure [bar]	0.5	1	1	2	5	5	10	10	20	40	40	80	80
Burst pressure ≥ [bar]	1.5	1.5	1.5	3	7.5	7.5	15	15	25	50	50	120	120

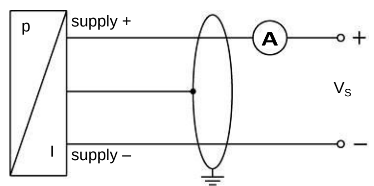
Output signal / Supply		
Standard	2-wire: 4 ... 20 mA / V_S = 8 ... 32 V_{DC}	
Option Ex-protection	2-wire: 4 ... 20 mA / V_S = 10 ... 28 V_{DC}	
Options 3-wire	3-wire: 0 ... 20 mA / V_S = 14 ... 30 V_{DC} 0 ... 10 V / V_S = 14 ... 30 V_{DC}	
Performance		
Accuracy	standard: nominal pressure < 0.4 bar: ≤ ± 0.5 % FSO nominal pressure ≥ 0.4 bar: ≤ ± 0.35 % FSO option 1: nominal pressure ≥ 0.4 bar: ≤ ± 0.25 % FSO option 2: for all nominal pressures: ≤ ± 0.1 % FSO	
Permissible load	current 2-wire: R_{max} = [(V_S – V_S min) / 0.02 A] Ω current 3-wire: R_{max} = 500 Ω voltage 3-wire: R_{min} = 10 kΩ	
Influence effects	supply: 0.05 % FSO / 10 V load: 0.05 % FSO / kΩ	
Long term stability	≤ ± 0.1 % FSO / year at reference conditions	
Response time	2-wire: ≤ 10 msec; 3-wire: ≤ 3 msec	
[1] *accuracy according to IEC 60770 – limit point adjustment (non-linearity, hysteresis, repeatability)*		
Thermal effects (Offset and Span)		
Nominal pressure P_N [bar]	< 0.40	≥ 0.40
Tolerance band [% FSO]	≤ ± 1	≤ ± 0.75
in compensated range [°C]	0 ... 70	
Permissible temperatures		
Permissible temperatures	medium: -10 ... 70 °C storage: -25 ... 70 °C	
Electrical protection [2]		
Short-circuit protection	permanent	
Reverse polarity protection	no damage, but also no function	
Electromagnetic compatibility	emission and immunity according to EN 61326	
[2] *additional external overvoltage protection unit in terminal box KL 1 or KL 2 with atmospheric pressure reference available on request*		
Electrical connection		
Cable with sheath material [3]	PVC (-5 … 70 °C) grey PUR (-10 … 70 °C) black FEP (-10 … 70 °C) black	
[3] *cable with integrated air tube for atmospheric pressure reference*		
Materials (media wetted)		
Housing	stainless steel 1.4404 (316L)	
Seals	FKM others on request	
Diaphragm	stainless steel 1.4435 (316L)	
Protection cap	POM	
Explosion protection (only for 4 ... 20 mA / 2-wire)		
Approvals DX19-LMP 307	**IBExU 10 ATEX 1068 X / IECEx IBE 12.0027X** zone 0: II 1G Ex ia IIC T4 Ga zone 20: II 1D Ex ia IIIC T 85°C Da	

Safety technical maximum values	U_i = 28 V, I_i = 93 mA, P_i = 660 mW, C_i ≈ 0 nF, L_i ≈ 0 µH, the supply connections have an inner capacity of max. 27 nF to the housing
Ambient temperature range	in zone 0: -20 ... 60 °C with p_{atm} 0.8 bar up to 1.1 bar in zone 1 or higher: -20 ... 70 °C
Connecting cables (by factory)	cable capacitance: signal line/shield also signal line/signal line: 160 pF/m cable inductance: signal line/shield also signal line/signal line: 1µH/m
Miscellaneous	
Option SIL[4] 2 application	according to IEC 61508 / IEC 61511
Current consumption	signal output current: max. 25 mA / signal output voltage: max. 7 mA
Weight	approx. 200 g (without cable)
Ingress protection	IP 68
CE-conformity	EMC Directive: 2004/108/EC
ATEX Directive	94/4/EG

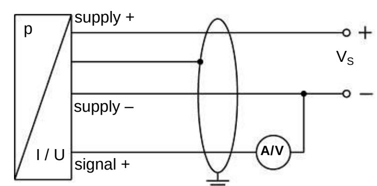
[4] not in combination with the accuracy 0.1%, only for 4...20mA / 2-wire

Wiring diagrams

2-wire-system (current)

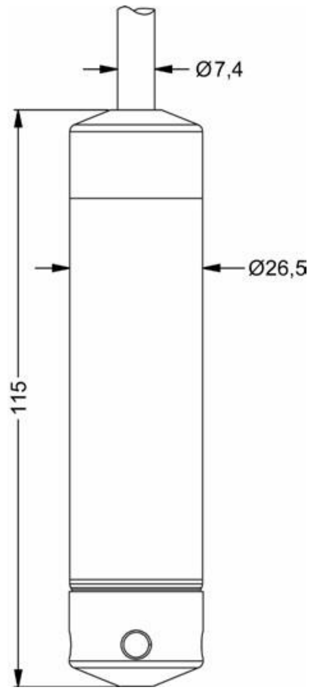


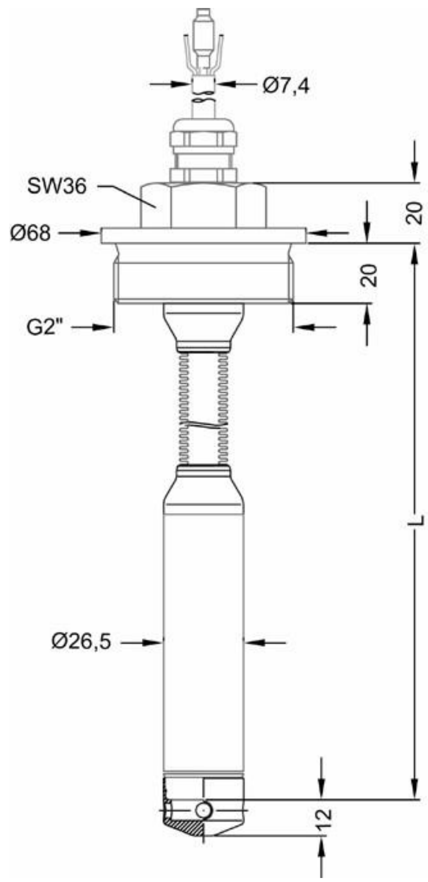
3-wire-system (current / voltage)



Pin configuration	
Electrical connection	cable colours (DIN 47100)
Supply + Supply – Signal + (only 3-wire)	wh (white) bn (brown) gn (green)
Shield	ye/gn (yellow / green)
Dimensions (in mm)	

standard **option**





cable protection
with corrugated pipe

⇨ Total length of devices with accuracy 0.1 % FSO IEC 60770 increases by 35 mm!