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Water treatment plant automation using PLC and SCADA

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Finally, to our parents, sisters, and brothers

many thanks.

Abstract

This is an overview of the project description and the importance of water treatment plants in public life. The water treatment plant has many stages, for example Preliminary treatment, Primary treatment, and Secondary treatment. Our project deals with secondary treatment, especially the Filtration process, and deals with the design and Lab implementation of Hardware in the Loop (HIL) for filter control in water treatment plants as software and hardware.

Water treatment is a group of operations that occur on raw water that is taken from many sources, for example, rainwater, underground water, river water, and seawater, and this water is not usable for human use due to contamination and pollution, so it is treated in chemical and mechanical ways until it becomes available for use in drinking and agriculture. In industry, some companies need to make a water treatment plant to save water by treating the water resulting from its manufacture and reuse. Some industries need salt-free water, so they are building their treatment plant so that you can get these types of water in the generation of electrical power, some power 9 stations need salt-free water to cool machines and electrical devices, so you need to create their treatment plants. After reviewing these reasons, treating water has an importance for us.

Content

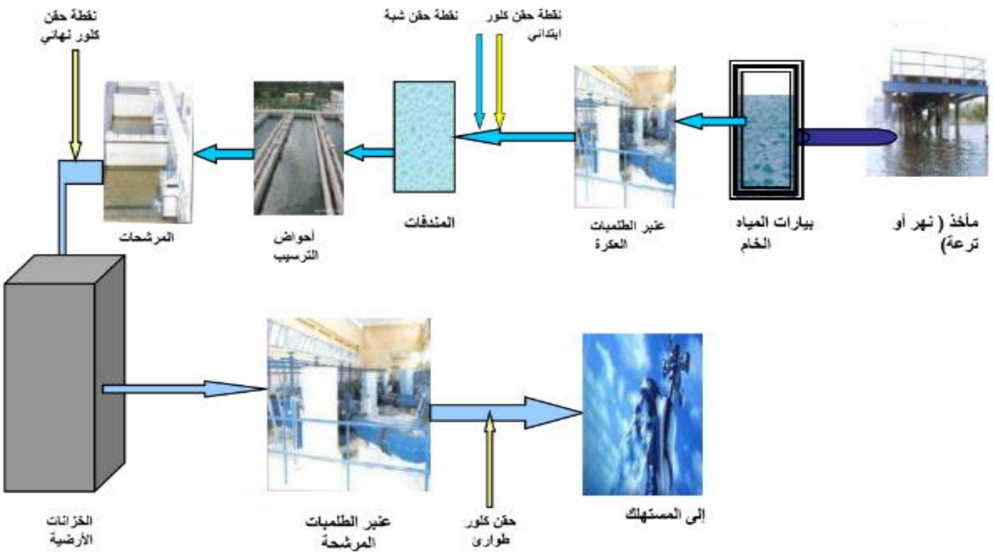
Chapter 1 Introduction

1.1 Drinking water plant components

1.1.1 Overview

The drinking water plant generally consists of:

- The basic facilities include:
  1. Inlet facilities (mechanical screening)
  2. Inlet pipe (which is the part that connects the inlet facilities and the raw water tank)
  3. A raw water tank
  4. Pump ward
  5. Clarifiers (Coagulation – Flocculation – Sedimentation)
  6. Filters
  7. Underground tanks
- Facilities and auxiliary wards, including:
  1. Chlorine injection and storage ward
  2. Injection and storage of alum
  3. Sediment cesspools and sediment removal system



1.2 Inlet

1.2.1 Definition

What is meant by it is to create an opening for water on the canal or the river in which the raw water is located. The inlet must be equipped with barriers of wire and wood, to prevent the entry of floating materials, carcasses of dead animals, weeds, and plankton that may cause blockages and problems in the pipelines for withdrawing turbidity pumps, and the operating workers must consider the periodic cleaning and maintenance of these networks and barriers to prevent clogging.

1.2.2 Types of inlets

- Shore inlet
- The pipe inlet
- The deep inlet
- Temporary inlet
- Tower inlet

1.2.3 The pipe inlet

This type of inlet is usually used in large rivers. It consists of one or more pipes extending into the water source a sufficient distance away from the shore to avoid possible pollution, provided that this extension does not impede navigation and that the pipe is carried inside the water source on a bridge and provided with the necessary valves to control the flow of water.

However, in all cases, the following conditions must be observed in all types of intakes:

1. That its capacity is sufficient to supply the city with the necessary water for a long future period.
2. The location of the intake shall be above the stream relative to the city or any source of pollution. The location of the intake shall be protected from any direct pollution.
3. Reviewing the water levels in the stream over several years and making sure they are appropriate. And review the maximum

change between the highest and lowest level, to consider the type of pumps in design (horizontal or vertical).

4. Straightening the watercourse at the proposed intake site to avoid problems of sedimentation and erosion that arise from the presence of curves in the stream.
5. The location of the inlet should be far from the city, a distance that allows the city to be supplied in the future.
6. Provide the inlet with a network of iron bars that are easily accessible for cleaning, to prevent floating substances from entering the inlet pipe.

1.3 Mechanical screens

The purpose of the screenings is mainly to seize large objects such as twigs, plants, fish, and other floating objects that can block, damage, or disable the station equipment. There are types of them that may also be used to seize plankton and small organisms. Screening is the first step in purification and must be done at the point of turbid (raw) water withdrawal.

1.3.1 Types of screens

- Bar screens
- Mesh screens
- Micro strainers

1.3.2 Bar screens:

It is made of welded steel bars spaced between each other with different sizes as follows:

- Screens with small eyes: (3 - 15 mm)
- Screens with medium eyes: (15-25 mm)
- Large eye Screens: (155 - 55 mm)

The most used screens with medium or large eyes

It is installed in the path of the water entering the water outlet at an angle of inclination of 65-85 degrees horizontally to facilitate the cleaning process and to prevent clogging. It is cleaned either manually or automatically for large stations.

1.4 Inlet pipe:

It is the connecting pipe from the outlet building on the water source to the low-pressure pump well. It may be small to become a pipe of flexible cast iron or steel, and it may be large to become a tunnel of reinforced concrete. However, it must be designed with a sufficient capacity to supply the city with water for a long time in the future, and its cross-sectional area should be designed so that water flows through it at a sufficient speed to prevent sedimentation of suspended materials at the bottom of the pipe.

Bearing in mind that the speed should not exceed the limit that causes corrosion in what is created.

Pipes are inclined, albeit small, in the direction of water flow for the same purpose and to prevent air from accumulating in the aspirate is between 40-100 cm/sec. Concrete pipes are the most widely used pipes for inlet pipes.

1.4.1 Raw water tanks:

It is a room/rooms made of concrete in which the lines for the withdrawal of turbid pumps are placed, and there are locking valves on it at the entrance, and in some cases, there are valves or gates to connect or separate these wells.

1.4.2 Preparing raw water pumps

Turbidity pumps must be prepared before the operation, and the pump cannot be operated unless the water level in the pipe is adjusted ventilation of the pump intake chamber (pump casing)

Pumps room

Green pumps for raw water & Blue pumps for filtered water

1.5 Water disinfection process:

It is the most important step in water treatment, as it gives it the characteristic of viability and secures it against infectious diseases transmitted by the method of diseases-borne water. Water is treated in several ways, including Chemical treatment: It depends on the use of chemicals for disinfection and sterilization, including chlorine, carbon dioxide, potassium permanganate, ozone, lime, bromine, and iodine.

1.5.1 Conditions to be met in disinfectant materials:

1. It should kill germs and not affect human health
2. It should be cheap, available locally, or easy to import throughout the year
3. Its use is easy and safe
4. Easy to store and handle safely

1.5.2 Chlorine industry:

Chlorine is prepared in the industry by electrolysis of a sodium chloride solution (table salt), and the gas collects at the positive electrode and is withdrawn, where it is liquefied and kept in large tanks until it is filled in cylinders used in water plants or textile factories

1.5.3 Chlorine is used in drinking water plants for:

1. Disinfection: killing harmful and disease-causing bacteria
2. Eliminate taste and odor problems
3. Oxidation: the oxidation of several chemical impurities present in water, such as iron, manganese, ammonia, and hydrogen sulfide.

1.5.4 Addition of chlorine:

Chlorine is added to water in one of two ways:

1. Add chlorine in high doses and then remove excess chlorine
2. Adding chlorine after determining the percentage by careful laboratory experiments

1.5.5 Factors affecting the disinfection process (chlorine effectiveness):

1. Chlorine dose
2. Duration of interaction between chlorine and water (contact period)
3. Temperature
4. The degree of hydrogen ion
5. Water turbidity and impurities percentage
6. Alkalinity and acidity of water
7. The presence of nitrogenous compounds in the water
8. The presence of iron and manganese compounds
9. The type and number of bacteria to be eliminated.

1.5.6 Places of adding chlorine in purification plants:

1.5.6.1 Prechorination:

That is, injecting chlorine before the purification stages (before rapid mixing), with the aim of:

1. Reducing the number of bacteria and disinfecting the filter sand
2. High efficiency in removing color from water as well as removing taste and odor
3. Reducing the growth of microorganisms inside the filters

1.5.6.2 Addition of final chlorine

It takes place after the filtration process at the entrance to the ground reservoir, and the chlorine is more effective on bacteria because the water is free of any turbidity or impurities.

1.5.6.3 Emergency stage

Here chlorine is added to eliminate harmful bacteria and disease-causing factors in specific doses at different stages of the purification process so that it does not cause any harm to human or animal health and without causing a change in the taste, color, and smell of the water.

1.6 Coagulation & Flocculation tanks

Flash Mixing: It is mixing the flocculant materials with raw water to create a uniform distribution of the flocculent material (alum) through the water, and this process takes place within seconds.

1.6.1 The Flocculation processes

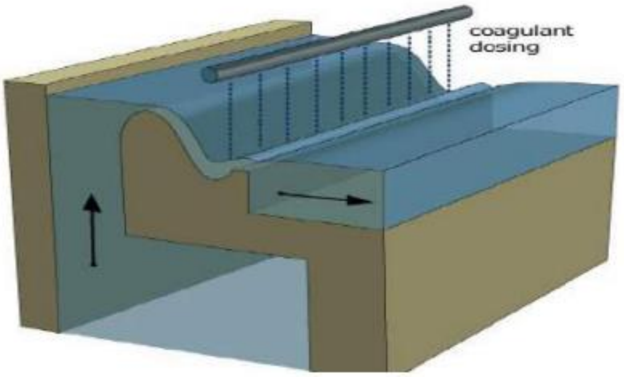
- It is intended to carry out the appropriate mixing with a sufficient period and the appropriate speed for mixing, using mechanical mixing using mixers or hydraulic mixing by the passage of water through concrete barriers whose dimensions are calculated, and the period of passage is also calculated, taking into account the variable mixing speed during the passage and in general This mixing process usually takes place after adding doses of chemicals (alum - chlorine), whose quantities were determined by the station’s laboratory. This process produces what is known as flocculation (FLOCS), it is the main mechanism of the sedimentation process.

- It is a slow mixing of alum that collects small granules to form larger granules that can be sedimented (time ranges from 15-25 minutes).
- The purpose of the flash mixing and flocculation process is to remove impurities, especially those that are not subject to natural sedimentation, and to remove turbidity from the water.

1.6.2 The coagulation mechanism:

The flocculation process and its quality depend on the basic coagulation operations, which are:

a. Flash mixing: This process depends on the location of the alum injection point, and whether the injection takes place in an open stream.

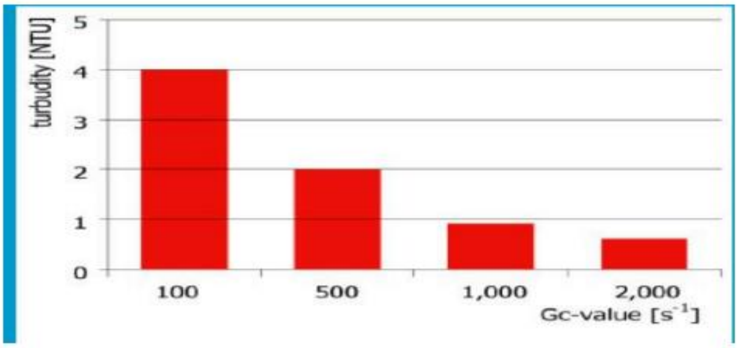


b. Or it is done in a closed pipe

In both cases, appropriate calculations must be made for the required injection capacity to achieve the best flocculation

It is noted that the calculated value is directly affected by several factors, the most important of which is the rapid mixing time, as well as the mixing height value.

Which ultimately represents the ability of flocculation and directly affects the value of the external turbidity



1.7 Flocculation mechanics:

The best shape of the flocs can be identified through the slow mixing process, which is represented by the Jar test which must be It is done periodically at the station

1.7.1 Factors affecting the process of coagulation and flocculation.

1. pH concentration (for alum from 5.5-5.7 and for ferrous sulfate greater than 5.8)
2. Water alkalinity: the sedimentation process takes place faster with higher alkalinity (the alum interacts with the alkalinity part (calcium bicarbonate). In the absence of alkalinity, lime or caustic soda is added.
3. Mixing conditions (speed and homogeneity)
4. Turbidity percentage of raw water (higher is better in certain proportions)
5. Dripping dose (JAR TEST)
6. The design and shape of the flash mixer basin and flocculation basin
   - The size of the flocculant is directly proportional to the dose of alum added within certain limits, and therefore it is necessary to determine the dose of alum that achieves the formation of flocculants in the size of a pinhead.

1.8 Sedimentation basins

The sedimentation process is known in the stages of treatment and purification of drinking water as the main procedure for the sedimentation of materials and plankton from the water and the preparation of water to enter the next stage, which is the filtration process and depends on the removal of heavy materials and mud by up to 80%

In sedimentation basins, generally, the higher the efficiency of the sedimentation process, the better the performance of the filters, and thus an increase in station efficiency.

Sedimentation basins: It is a circular or rectangular basin in which the largest number of plankton is disposed of at the bottom of the sedimentation basin, which is then removed in various ways, either through slurry spaces, hand traps, or any other methods.

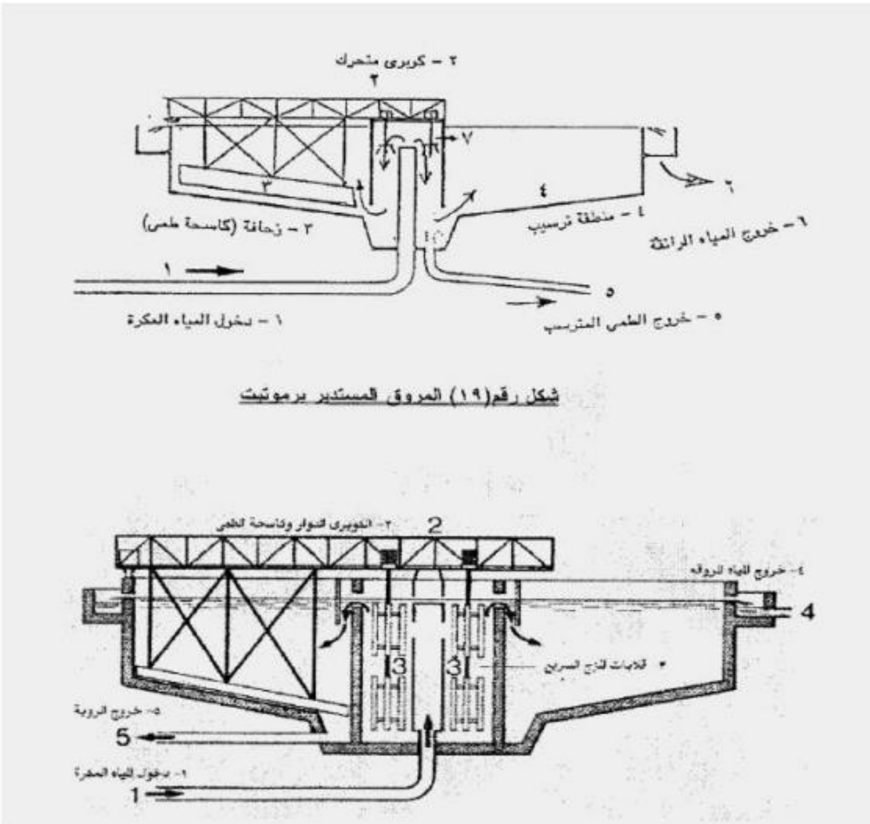
In general, the type of station is usually known as the type of sedimentation basin, meaning that the purification type of the station, for example, is named after (Vertical sedimentation - horizontal sedimentation – pulsator).

1.8.1 The types of sedimentation basins that are popular and used in Egypt

1. Normal rectangular clarifier
2. Round clarifier (this is what is used in our project)
3. vertical sedimentation
4. pulsating clarifier

1.8.2 Round sedimentation clarifier:

Many designs fall under this type, and in general, the sedimentation process depends on diagonal sedimentation.



1.8.3 Factors affecting the sedimentation process.

1. Particle size

2. The shape of the granules
3. The density of the granules
4. Water temperature
5. The electric charge of particles
6. The speed of water flow in the basin (not more than 35 cm/min)
7. Time Detention (3-4 hours) = basin size/rate of disposal
8. The ratio between the length and width of the sedimentation basin in rectangular ponds reduces the chance of dead zones forming when the basin width is increased.

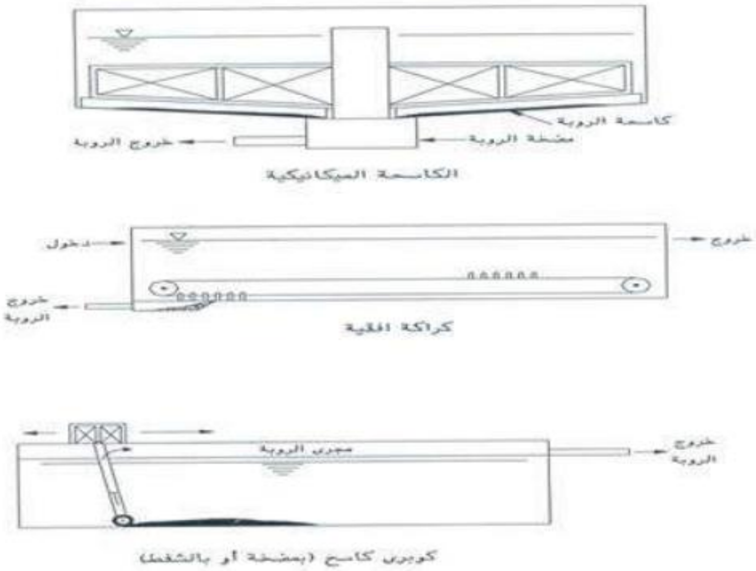
1.8.4 Removal and drainage of sludge from sedimentation basins

The sludge consists of remnants of the slurry material (alum) with solid sediment, and the sludge occupies 15-3% of the basin space, and in sedimentation basins with horizontal flow, 55% of the flocs are deposited in the first third of the basin length, and this is considered in the design of the slurry extraction system from basins.

1.8.5 Reasons for the drainage of sludge:

1. Preventing interference with the circulating water and re-turbidity
2. Preventing the multiplication of bacteria that cause an unacceptable taste and odor
3. Avoid occupying a large area of the basin and reduce the length of stay (reducing the size of the basin).

1.8.6 Sludge drainage system:



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أنواع الأنظمة الميكانيكية المستخدمة في إستخراج الروبة

1.8.7 Steps to remove the sludge from the bottom of the clarifier

1. The sweeper is operated periodically according to the size of the sludge and the samples taken by the laboratory. In some stations, there are other manual systems for removing sludge.
2. Open the sludge stopcocks.
3. Upon completion of the scavenging process, close the sludge removal valves.

1.8.8 Preservation of the sludge layer

The rate of occurrence of the sludge removal process, either by drainage method or by removing it by scavenging, depends on the quantity and nature of the sludge, based on experience. Additional sludge removal operations can be carried out by control panels in the sludge removal process.

When clarifiers are in service, the upper surface of the slurry should be between 1m and 5.1m below the surface of the water. If the flocculant level is allowed to rise too high, the slurry may move to the filters.

1.9 Filters

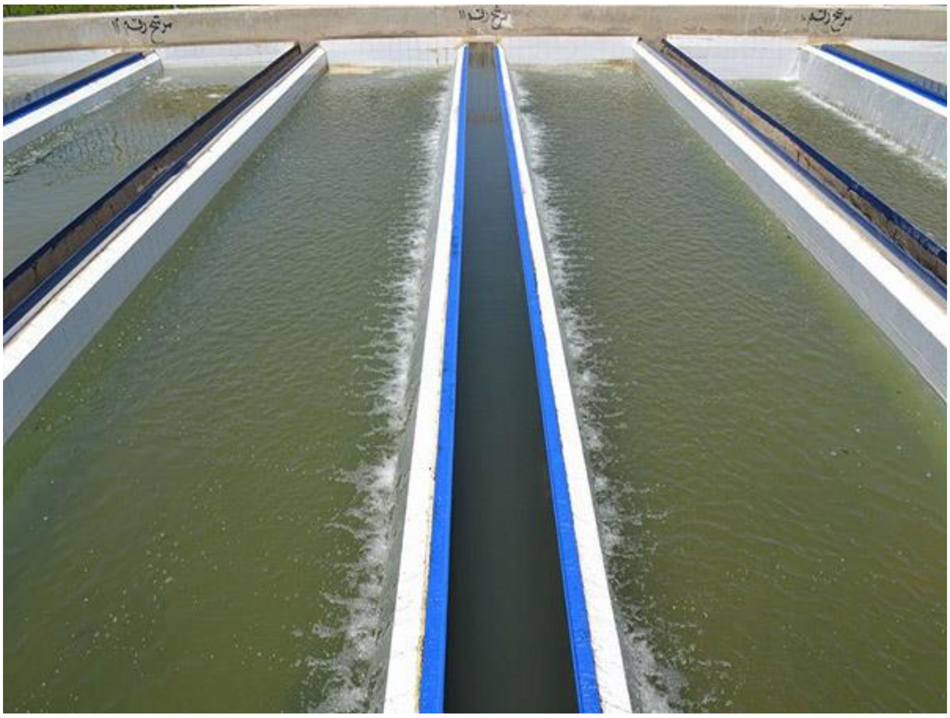
The water filtration process is defined as the procedure that takes place to completely rid the water of plankton, bacteria, and algae.

The water is completely potable and subject to standard specifications. Filters are divided into two types

1. Pressure filters (closed)
2. Open filters

Normally, the filter is designed to contain the following valves for normal operation and washing modes

1. The circulating water inlet valve
2. Filtered water outlet valve
3. Washing water inlet stopcock
4. Washing air intake valve
5. Valve (gate) for the exit of wastewater or filter washing



1.9.1 The washing process:

It is carried out for the filter periodically according to the rise in the level or the expiry of the operational hours prescribed for the filter, which are determined by the experience process or when the quality of the water leaving the filter changes for the worse.

The washing process is usually carried out using air initially at low pressures in the range of 5 to 1 bar, to separate sediment, and plankton from the filter layer, then the air is washed with water for another period of period the sediment, then the air is stopped and the water continues. In the work until the filter layer is completely cleaned and we get the lowest pressure loss of the filter.

There are usually two or three pumps for washing and 2 or 3 air blowers, and one unit is in service and the rest is in reserve.

The design of the washing pumps and blowers takes into account the height of the filter layer above the level of the units and the thickness of the filter layer.

And its specific weight, as well as the surface area of the filter

The washing process cannot be carried out if the alarm goes off with a low level in the reserve wash water tank or an alarm with a high level in the wastewater collection tank, and it is also assumed that there is something that prevents washing more than one filter at one time

1.10 General

As previously mentioned, shutting down the intake or filter pumps will stop the station from working. Therefore, upon start-up, all units of the station phases must be restarted

1.11 Sludge

Here the sludge, suspended materials, and sediments are collected and then finally go to the drain.

1.11.1 The purpose of the presence of ground tanks in the station

1. Provide an amount of water for washing the filters
2. Meets the need to bridge the difference between the maximum daily intake and the design behavior
3. Provide a period of contact for chlorine with water (at least 35 minutes).
4. Facing the increase in consumption during peak and emergency periods (from 4-15 hours of daily production
5. Providing water to deal with faults at the station.
6. Provide an amount of water to meet the fire requirements
7. Reducing the overall costs of the purification process, as without it the process capacity must be able to meet the maximum required discharge (usually up to 5.2 times the average discharge).

1.11.2 Treated water tank

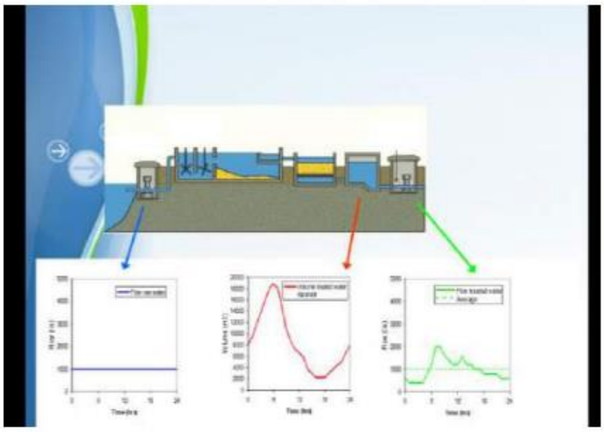
Mostly, the underground reservoir is divided into two halves (or more), each of which is isolated by the entrance valve, and the water is filtered using the drain valve through the drainage well into the drain pump well, and the water is pumped to the drain using the submersible pump for drainage

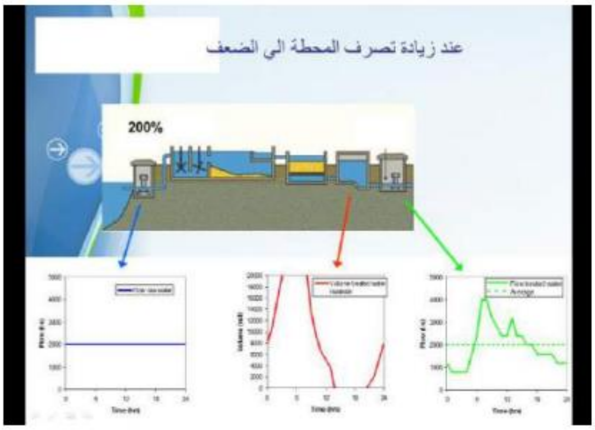
Each of the two halves of the tank contains a dry tempering chamber which can be emptied as follows:

1. Close the inlet valve
2. Open the softening chamber vacuum cock

- The wastewater is taken from the two halves of the tank through two valves to the sewage pump septic tank and the sewage pump septic tank (treatment water pumps building)

The following figures show a comparison between the use of the ground tanks in the case of operating the station correctly at its designed disposal and the operation of the station at poor disposal.





1.11.3 Treated water Pumps:

After the filter stage, the treated water is transferred from the storage tank to the people by blue pumps.

Where Emergency chlorine is injected to eliminate harmful bacteria and disease-causing factors in specific doses

Chapter 2 Programmable Logic Controllers

2.1 Introduction to control systems

Did you ask yourself before "How could life be without PLCs?" Today we are going to go through the Classic Control Basics. First, we need to learn some basics that would make us more familiar with the whole Automation field.

2.2 Modern Automation Vs. Classic Control

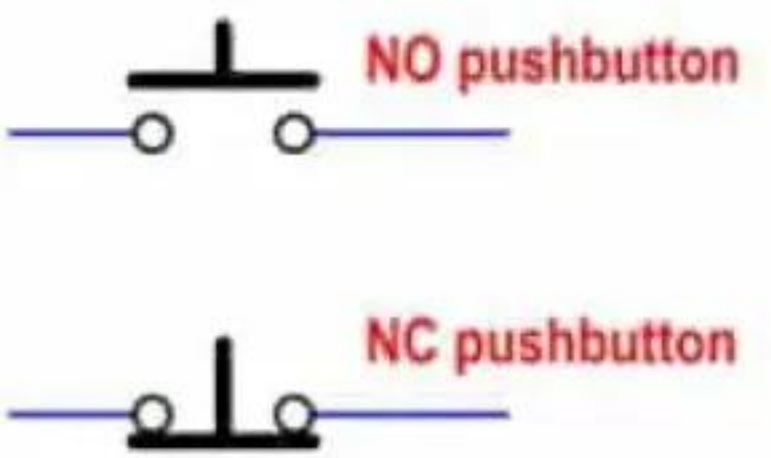
Let us begin by Introducing the word "Automation". This word refers to eliminating human power and increasing the production rate with the best quality at the industrial processes.
That is the concept of Automating. Automation is "How to operate the process Automatically without the intersection of human factors".
You may have a 30% Automated system or 70% or maybe a Fully Automated system. All these depend on your needs and your design.

- Simply the Modern control (PLCs, Micro-controller-based devices) is a compact form of the classic control. The concept is the same, but the point is the volume of your panel. As PLCs and controllers have a compact form that contains a huge number of (relays, timers, counters, and special function blocks). This feature helps a lot to minimize the volume of the control panel. Unlike the classic control components, it must have some space to build your control room.
- The PLCs also provide a great advantage over the classic control circuits. This is because ease of programming and the ease of rewiring and designing control signals. On the other hand, classic circuits use many wires which makes troubleshooting and the redesign of your circuits completely difficult.
- However, the PLCs can solve many problems with the control circuits. However, we still need to use the classic circuits as it is the basis of everything in the Automation world.

2.3 Basic Components of Classic Control

Here we are going to discuss briefly the hardware elements that are used in the classic circuits.

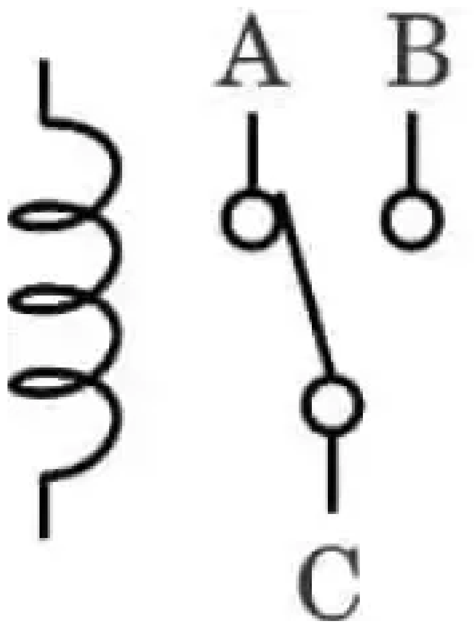
2.3.1 Push Buttons NO\NC



- NO (normally open) push button is the contact that delivers zero logic and when we press it turns to true logic.
- NC (normally close) push button is the contact that delivers true logic and when we press it turns to zero logic.

2.3.2 Relay

This device consists of a coil and NO/NC contacts. When we energize the coil, the flapping contact moves. The flap movement causes relay contacts to change from NO to NC and Vice versa.



Its contacts have a limited-rated operation current that should not be exceeded.

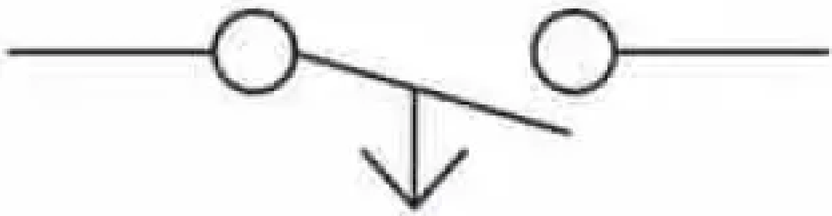
It is considered the most important component of the classic control circuits. It allows the separation between two voltage-level signals. We can control the coil with a 24V DC signal and connect its contacts to a 220V AC signal.

2.3.3 Contactor

Contactors are a specialized form of a relay. Both relay and contactor work on the same working principle. The main difference between them is that the contractor is capable of switching higher power loads. The higher power loads are motors, lighting, and electric heaters.

2.3.4 Timer

There are many types of timers. The functioning of the timer depends on the same idea of the coil and flapping contact.



We will focus on the main types such as:

- ON Delay Timer turns on a circuit after a predetermined time has elapsed. You have to set the time and trigger the coil of the timer, and the relay starts counting time. Once the set time is over, at that moment supply (or input) goes forward to the circuit or the next stage.
- OFF Delay Timer turns off the input (or supply) after a predetermined time delay has elapsed. You cut off the supply or give a trigger to this relay when the relay starts counting time. Once the set time is over, input or supply to the relay is cut off from its output side (the next stage).

Finally, you have to be sure that “You cannot be the best Automation Engineer without a deep understanding of the Classic control basics”

2.4 The History of PLCs:

The first PLC was introduced in the late 1960s. A programmable logic controller is an industrial computer. It is designed to help in the control of manufacturing processes.

The automobile sector was the first industry to deploy PLCs into its operations. They aimed to replace the hardwired relays and timers with programmable and flexible controllers.

Since then, PLCs have been broadly adopted as the standard automation control system in discrete manufacturing industries.

2.4.1 The inception of PLC Programming

The first PLC began being developed in 1968. General Motors designed a specification for a "Standard Machine Controller" and distributed it to vendors for a quote. Some of the major elements of the specification included:

- Should use solid-state components which should be modular and expandable
- Should contain 16 units that can be expanded to 256
- Should have 16 outputs that can be expanded to 128
- Should offer easy programming and reprogramming
- Should not lose stored programs during power outages, therefore, have at least 1k of memory that can be expanded to 4k

Richard E. Morley, who worked for Bedford Associates, designed a device known as the Modular Digital Controller.

This device met all the requirements the Standard Machine Controller was asking for. When the Modular Controller was tested in General Motors, it showed a 60 percent reduction in downtime

2.4.2 Modicon PLC

Following this success, Bedford Associates changed its name to Modicon PLC. They began producing the Modicon 084, the first PLC.
What differentiated Modicon 084 from other products in the market was its programming technique. The others were utilizing ‘Boolean Statements’ to manipulate their equipment.
Boolean algebra was by the Irish Mathematician George Boole and presented in The Mathematical Analysis of Logic (1847). Boolean mathematics is the math of ones and zeros, True and False. At its core, it consists of three expressions, AND, OR, and NOT. All computers use this type of logic.
Despite the simplicity of Boolean Logic and The Genius of George Boole, Boolean Statement programs were okay for computer scientists. However, plant engineers found them difficult to work with, as compared to relay logic.
The engineers were used to relay control systems that employed ladder diagrams. This is because whenever relay circuits are drawn between a hot and neutral common, they resemble the rungs of a ladder.
Morley’s genius idea was to incorporate ‘ladder logic’ into his system. Ladder Logic is essentially a graphic representation of Boolean Logic. This was the game changer. The engineers would find it easier to understand and use than Boolean Logic.

Example of how Boolean can be expressed as Ladder Logic.

2.4.3 Process Description

A heating oven with two bays can heat one ingot in each back. When the heater is on it provides enough heat for two ingots. But, if only one ingot is present the oven may become too hot, so a fan is used to cool the oven when it passes a set temperature.

2.4.4 Control Description

If the temperature is too high AND there is an ingot in only one bay, turn the fan on.

Define Inputs and Outputs

B1 = Bay 1 ingot present

B2 = Bay 2 ingot present

F = Fan

T = Temperature sensor

By the time the 70s were coming to a close, Allen-Bradley and other competitors had developed systems that rivaled Modicon. Innovation started becoming key to capturing market share.

PLCs were becoming faster and more powerful. There was also the rapid evolution of programming and documentation tools.

The initial PLCs did not have a platform for program documentation. Thus, a program had to be hand-written or drawn on a drafting board before it was entered later.

This is the period that saw the development of the Data Highway by Allen-Bradley and Modbus by Modicon. These innovations allowed PLCs to exchange information with each other.

There was also the development of programming terminals. These allowed programmers to remotely enter logic programs. The final program could then be recorded on cassette tape and then downloaded to a PLC.

They could also generate printouts. This eliminated the need for hand drawings that consumed a lot of time.

2.4.5 The 1980s

The ‘80s saw the introduction of the first personal computers in offices. While you can’t compare their speed to today’s computers, they were still a lot faster than drawing on drafting boards.

Nearly every designer had replaced their drafting board with a desktop computer by the time the 1980s were coming to a close. The adoption of personal computers was not relegated just to the design arena, but also to the shop floor.

The PCs began being used to interface with PLCs directly. Coupled with software improvements, this made monitoring machine motions a lot easier.

By this period, the PLC program was widely recognized as the most useful diagnostic tool. It allowed for effective troubleshooting; thus, many considered it to be the window to machines.

Nonetheless, machine diagnostics were still in their primitive stages.

2.4.6 More powerful programming languages evolve

As PLCs evolved, other programming languages were developed. These include flow charts, structured text, and instruction lists. Nonetheless, ladder logic remains popular due to its graphical and intuitive design.

2.4.7 The Late 70s

Development of the IEC 61131-3
One of the most significant milestones in PLC history was the introduction of the International Electrotechnical Commission (IEC) 61131-3 specification in 1982.
It was the standard by which PLC software being developed was to be held against. It became published in 1993 as IEC 1131 International Standard for Programmable Controllers.
The introduction of the IEC 61131-3 was necessary as it brought consistency to all the software products on the market. This allows engineers and technicians to easily understand logic and program flow from any PLC software.

2.4.8 The 1990s

As the ‘90s rolled in, end users began making special requests. They wanted their new machinery to come with industrial terminals that had PLC monitoring software.
Plant managers wanted their technicians to do actual troubleshooting. As such, the PLC programs at that time were simple in design.
In an attempt to save time, plant managers wanted to have machines that could tell them what was amiss. Instead of spending hours troubleshooting.
This is what led to the development of the programmable human-machine interface (HMI).

2.4.9 Programmable Human Machine Interface

The prototype HMIs were modest pushbutton replacers. However, they were thought to be uneconomical for applications that had less than 20 pushbuttons.
Nonetheless, their popularity started growing as manufacturers began finding more uses for them.
Machine monitoring information was becoming more and more vital.
This included information such as machine problems, time in auto, manual interventions, production counts, and more. All that was being monitored and displayed in HMI screens then later sent to the factory’s central computers.
As the 1990s drew to an end, the logic controlling functions were just a slight part of what a PLC program could do. This is because HMIs had so much data that technicians hardly looked at program logic.
The end of the ‘90s saw the introduction of a new generation of PLCs.
These new devices are what eventually brought internet connectivity to the factory floor.
Megabytes became the new standard for measuring processor memory.
There was also the introduction of User-defined data types. These allowed for the manipulation and sharing of machine data in many ways.

2.4.10 PLCs Today

Since the beginning, there has always been a need to reduce the size of automation systems to make support and maintenance simpler. This is why we are witnessing the following trends in PLC technology:

2.4.10.1 Better, Smaller, and Faster

Circuit boards, processors, and other electronic components are rapidly shrinking. These improvements are influencing how PLCs are being designed.

However, some things are affecting the acceptance of these changes. These include the need for ruggedness, reliability, and stability.

Thus, the most prevalent enhancement in the PLC industry is speed. This is enabled by faster processors. They improve cycle time, have new communication features, and enhanced memory capacity.

As the market continues to make demands, a lot of functions and features traditionally allocated to high-end PLCs are making their way to lower-end products.

You can, therefore, expect to see smaller PLCs spotting features associated with top-tier machines. This allows for a smaller and more compact solution that today’s users desire.

2.4.10.2 Memory Size

Today’s PLCs are also taking advantage of the dramatically declining sizes and costs of solid-state memory.
This is allowing for enhanced local data storage. This enables PLCs to be used in a lot of applications that traditionally required expensive data acquisition systems.
This feature also allows for additional utilities. This includes the ability to store information on board, thus expediting troubleshooting.

2.4.10.3 Memory Devices

Another technology that is making its way to the industrial controls market is portable memory devices. These devices are highly beneficial to the PLC user.
They provide you with massive amounts of extra storage in small packages. For example, a microSD card can add up to 32 GB of extra memory to the PLC.

2.4.11 The Merging of PLCs and PACs

Programmable automation controllers (PACs) are hardened modular industrial controllers. They often utilize a PC-based processor. This allows them to have more flexibility and depth in programming.

For a long time, suppliers in the industrial controls industry have been citing the differences between PACs and PLCs.

However, as PLC technology evolves, automation engineers cease to care about their differences. Instead, they will start focusing on the performance and available features. This will allow them to define their systems better.

PACs and PLCs will continue merging as they evolve. As that happens, there are bound to be opportunities in the market for both high and low-end processors.

As hardware technology continues to evolve, advanced features will start being incorporated into low-tier processors as well.

As a result, manufacturers of higher-end devices will be forced to include even more options and features in their products.

2.4.12 Advanced Features

As processors become faster and memories became even larger. It allowed a floodgate of advanced features into the market. This included vision system integration, motion control, as well as synchronized support for multiple communication protocols. All that while maintaining the simplistic nature that makes the PLC ideal to most consumers.

In the period that PLC and PAC have been going head-to-head, we have witnessed a more rapid development of both products.

PACs are allowing their consumers to test the limits of what is regarded as traditional industrial automation. This is forcing PAC manufacturers to develop products that can meet those demands.

Thus, product designers are having to come up with innovative designs. These sustain the available components and build them into rugged systems. This allows them to withstand the harsh industrial environment.

2.4.13 Ladder Logic Is Here to Stay

As mentioned earlier, about half a century ago, the ladder diagram replaced hardwired relay logic. While ladder logic made things simpler for engineers and technicians, it has some drawbacks. Most notably, it is not efficient in data handling and process control.

This saw the development of other industrial controller programming languages by the IEC 6113. The standard covers the following:

- Ladder Logic
- Structured Text
- Function Block
- Instruction List
- Sequential Function Charts

For instance, sequential flow charts are better for process control. Structured text is good for data manipulation.
Other languages have their strong points as well. Nonetheless, the ladder diagram has stayed on course through various advancements. It remains the most desired language in PLC programming languages.
Connected Factory
The most impactful change expected in the future of PLCs is their integration with Enterprise Resource Planning. As well as synchronizing with other high-level computing systems to the factory premises.
In the past, extracting data and feeding it upstream to those systems was a major integration task. However, future technologies are expected to have features, functions, and hooks that allow for simplified integration.

2.5 The difference between the classic control and the PLC

2.5.1 What is a PLC?

The Programmable Logic Controller (PLC) is an industrial computer control system that constantly monitors the state of input devices and makes decisions
based on software intended to control the state of output devices.
Almost any production line, machine function, or process can be greatly improved by using this type of control system. However, the biggest benefit of
using a PLC is the ability to change and repeat a process or process while collecting and transmitting vital information.
Another advantage of the PLC system is that it is modular. This means that you can mix and match types of input and output devices to best suit your application.

2.5.2 Why PLC after classic control?

We use PLC after classic control for a lot of reasons some of these because Classic Control is:

- More Complicated
- Longer time for maintenance
- Time-consuming troubleshooting
- Occupies larger area in switchboards
- Requires more wiring

and in large projects requirements, plc has:

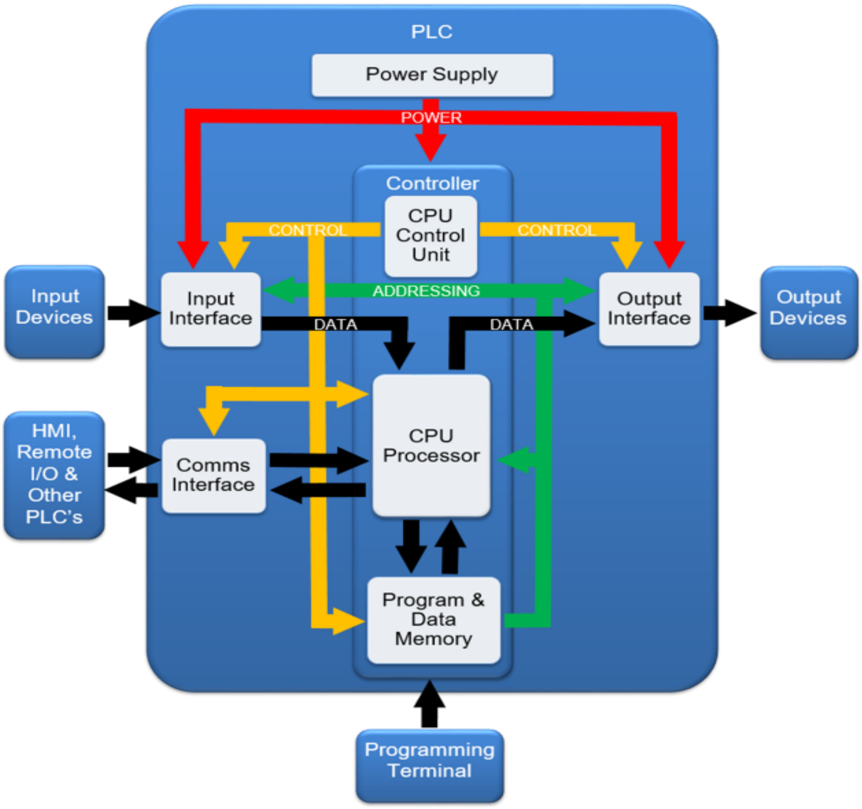
- More inputs and outputs points
- Complex programming instructions
- communication with other equipment
- Deal with analog signals
- Deal with a large number of counters, times, and auxiliary points (Markers)

2.5.3 What Is PLC Architecture?

The term PLC architecture refers to the design specification of the various PLC hardware and software components and how they interact with one another to form the overall PLC system. The architecture of a PLC is based on the same principles that are used in standard computer architecture. However, PLC architecture does differ because the design is based on providing high reliability, immunity to harsh industrial environments, ease of maintenance, and access to large amounts of peripheral inputs and outputs.

2.5.4 The Basics of How PLC Architecture Works

The heart of the PLC system is the CPU (Central Processing Unit). It is made up of a control unit and a processor. The CPU control unit manages the interaction between the various PLC hardware components while the CPU processor handles all the number crunching and program (eg ladder logic) execution.
The block diagram below explains the basic architecture of a PLC



- Data flow is from the input devices, through the CPU processor and then to the output devices. The CPU processor also exchanges data with the program and data memory. Once all the data is gathered the program (eg ladder logic) is processed cyclically. The resulting data flows to the output interface for conditioning and execution of the output devices.
- The CPU also controls and exchanges data with the communication interface and devices.
- An addressing system is used for data organization that is shared between the various hardware components.
- A programming terminal is used to formulate the PLC program (eg ladder logic), load the program into the controller and monitor/control the PLC and its program.
- The power supply is responsible for supplying and managing the power requirements of the various PLC hardware components.

2.6 Types of PLC Architecture

The 3 distinct types of PLC architecture available for use in industrial automation are known as fixed, modular, and distributed. The terminology surrounding PLC types can vary between PLC manufacturers, especially when talking about fixed

PLCs. There is also a crossover between PLC types with some fixed type PLCs having modular type features and some modular type PLCs having distributed type features.

When considering PLC architecture types, we can generally say that fixed PLCs are used for smaller-sized, less complex applications. Modular PLCs are generally used for medium-sized, more complex applications. Whereas distributed PLCs are used for large-sized, extensive applications spread across multiple locations.

2.6.1 PLC Types Comparison Table

PLC TYPES	FIXED PLC 	MODULAR PLC 	DISTRIBUTED PLC 
CPU Performance	Low	Medium to High	High
Program & Data Memory Size	Small	Medium to Large	Large
Power Supply	Embedded	Module	Module
Input Interface	Embedded	Modules	Modules

Output Interface	Embedded	Modules	Modules
Communication Interface	Embedded	Modules	Modules
Mounting System	Single Unit	Rack, Backplane, Rail, or Chassis.	Rack, Backplane, Rail, or Chassis.
Physical Size	Small	Medium to Large	Medium to Large
Flexibility	No	Yes	Yes
Customizable	No	Yes	Yes
Applications	Basic applications with a small number of inputs and outputs.	Medium to high-end applications with a large number of inputs and outputs.	High-end applications and plant-wide control with a very large number of inputs and outputs.
Cost	Low	Medium	High

2.7 What are the advantages and disadvantages of PLC?

2.7.1 Advantages of PLC

1. **Reliability** – PLCs are designed to be reliable and durable, and can operate for long periods without requiring maintenance. This makes them ideal for use in industrial and manufacturing settings, where continuous operation is important.
2. **Versatility** – PLCs can be programmed to control a wide range of processes and equipment. This makes them suitable for use in a variety of industries, including manufacturing, transportation, and energy production.
3. **Ease of use** – PLCs are easy to use and can be programmed using simple programming languages. This makes them accessible to users with a range of technical backgrounds and skill levels.
4. **Cost-effectiveness** – PLCs are generally more cost-effective than other types of control systems, especially over the long term. They can be used to automate processes and reduce the need for manual labor, which can lead to cost savings.

5. **Safety** – PLCs can be programmed to ensure the safety of equipment and personnel. For example, they can be programmed to shut down equipment in the event of an emergency or malfunction, which can help to prevent accidents.

Thus, we have learned that PLC is more beneficial in automation.
Let’s move to another side of it.

2.7.2 Disadvantages of PLC

1. **Initial cost** – PLCs can be expensive to purchase and install, especially for larger or more complex systems. This can be a barrier for some companies, especially those with limited budgets.
2. **Programming skills** – PLCs require programming skills to be used effectively. This can be a disadvantage for companies that do not have staff with the necessary programming skills, as they may need to hire additional staff or contract out the programming work.
3. **Limited flexibility** – PLCs are designed to control specific processes and equipment. While they can be programmed to perform a wide range of tasks, they may not be as flexible as other types of control systems.
4. **Complexity** – PLCs can be complex systems, especially for larger or more sophisticated applications. This can make them difficult to understand and operate for users who are not familiar with them.
5. **Maintenance** – PLCs require regular maintenance to ensure they are operating properly. This can be time-consuming and costly and may require specialized skills and knowledge.

These are only a few disadvantages as compared to the advantages.

2.8 The manufacturers of PLC:

There are several manufacturers of PLCs, including:

2.8.1 Siemens

Siemens is one of the largest PLC manufacturers in the world, offering a range of products for various industries, including manufacturing, energy, and transportation. Siemens PLCs are known for their high reliability, flexibility, and scalability, and they come with a wide range of features and options for programming, communication, and diagnostics. Siemens also offers a variety of software tools for programming and configuring their PLCs, including the popular TIA Portal software.

2.8.2 Rockwell Automation

Rockwell Automation is a leading PLC manufacturer under the Allen-Bradley brand. Their PLCs are used in a wide range of industries, including automotive, food and beverage, and pharmaceuticals. Allen-Bradley PLCs are known for their durability, flexibility, and ease of use, and they come with a variety of features and options for programming, communication, and diagnostics. Rockwell Automation also offers a range of software tools for programming and configuring their PLCs, including the popular Studio 5000 software.

2.8.3 Mitsubishi Electric

Mitsubishi Electric is a Japanese-based company that offers a range of PLCs for various applications, including manufacturing, transportation, and building automation. Their PLCs are known for their high reliability, performance, and ease of use, and they come with a variety of features and options for programming, communication, and diagnostics. Mitsubishi Electric also offers a range of software tools for programming and configuring their PLCs, including the popular GX Works software.

2.8.4 Schneider Electric

Schneider Electric is a French-based company that offers a range of PLCs under the Modicon brand, as well as other automation products for various industries, including oil and gas, food and beverage, and transportation. Modicon PLCs are known for their high reliability, scalability, and ease of use, and they come with a variety of features and options for programming, communication, and diagnostics. Schneider Electric also offers a range of software tools for programming and configuring their PLCs, including the popular Unity Pro software.

2.8.5 ABB

ABB is a Swiss-based company that offers a range of PLCs and other automation products for industrial and manufacturing applications, including robotics, motors, and drives. ABB PLCs is known for their high performance, reliability, and flexibility, and they come with a variety of features and options for programming, communication, and diagnostics. ABB also offers a range of software tools for programming and configuring their PLCs, including the popular Automation Builder software.

2.8.6 Omron

Omron is a Japanese-based company that offers a range of PLCs and other automation products for various industries, including automotive, food and beverage, and pharmaceuticals. Omron PLCs are known for their high performance, reliability, and flexibility, and they come with a variety of features and options for programming, communication, and diagnostics. Omron also offers a range of software tools for programming and configuring their PLCs, including the popular CX-Programmer software.

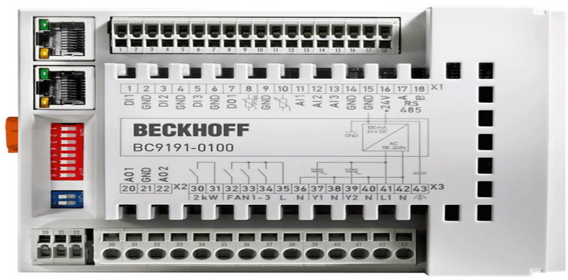
2.8.7 B&R Automation

B&R Automation is an Austrian-based company that offers a range of PLCs and other automation products for various industries, including packaging, printing, and food and beverage. B&R PLCs are known for their high performance, reliability, and flexibility, and they come with a variety of features and options for programming, communication, and diagnostics. B&R also offers a range of software tools for programming and configuring their PLCs, including the popular Automation Studio software.

2.8.8 Delta Electronics

Delta Electronics is a Taiwanese-based company that offers PLCs and other automation products for a variety of applications, including building automation and energy management. Delta PLCs are known for their high reliability, scalability, and ease of use, and they come with a variety of features and options for programming, communication, and diagnostics. Delta also offers a range of software tools for programming and configuring their PLCs, including the popular WPLSoft software.

2.8.9 Beckhoff Automation



Beckhoff Automation is a German-based company that offers a range of PLCs under the TwinCAT brand, as well as other automation products for various industries, including aerospace and defense. TwinCAT PLCs are known for their high performance, scalability, and flexibility, and they come with a variety of features and options for programming, communication, and diagnostics. Beckhoff also offers a range of software tools for programming and configuring their PLCs, including the popular TwinCAT software.

2.8.10 Phoenix Contact

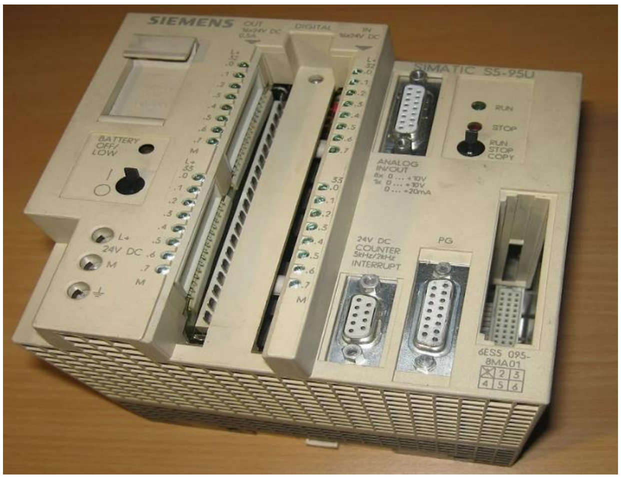
Phoenix Contact is a German-based company that offers a range of PLCs under the PLCnext Technology brand, as well as other automation products for various industries, including transportation and infrastructure. PLCnext Technology PLCs are known for their high flexibility, openness, and scalability, and they come with a variety of features and options for programming, communication, and diagnostics.

Phoenix Contact also offers a range of software tools for programming and configuring their PLCs, including the popular PLC next Engineer software. The Top PLC Manufacturers are Siemens, Allen Bradley, ABB, Omron, Delta, Schneider Electric, and Mitsubishi.

2.9 Siemens PLC

In this first of an upcoming series, we investigate Siemens as a major PLC manufacturer, learning about the hardware, software, and key applications of each product lineup.
Siemens AG is the largest energy and industrial manufacturing company in Europe, and with more than 170 years of history, it is also an innovator in many fields. An essential part of its vast portfolio of products within its Industry division consists of programmable logic controllers (PLCs). Siemens' line of PLCs is named SIMATIC.

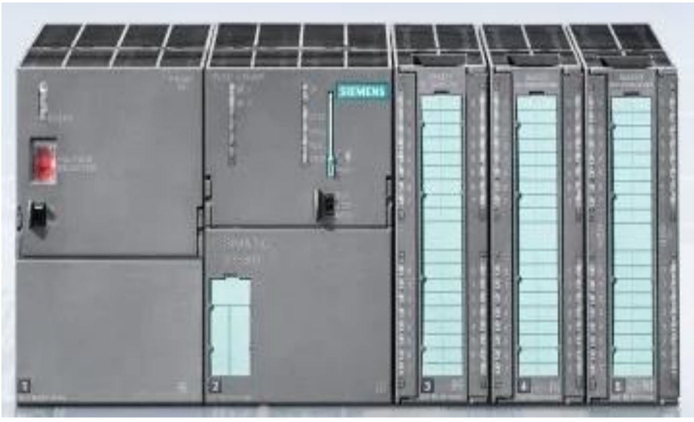
2.9.1 SIMATIC History



The SIMATIC line was first released in 1958, and there have been four major generations of it since. The SIMATIC G launched in 1959, revolutionizing the world of relay controls with compact and energy-efficient transistors. Although not a significant generation change, the SIMATIC N provided faster and more reliable devices thanks to the introduction of silicon as a conductive material.
Then, in 1973, the company launched the SIMATIC S3 line, which introduced microprocessors and integrated circuits. For the first time, PLCs could be programmed via software, owing to the advances in computer science. The SIMATIC S5 line was introduced only six years later, in 1979. S5 PLCs were programmed using STEP 5, one of the first advanced computer-based PLC programming tools. It first ran on the CP/M and MS-DOS operative systems and was later available on Windows. The S5 PLCs allowed the control of complex processes because of this flexible programmability.
1994 was another groundbreaking year with the arrival of the SIMATIC S7. Along with S7, Siemens released the first version of Profibus and introduced the

concept of industrial networking to the world of PLCs. There were originally three main product classes in the S7 line: the S7-200, S7-300, and S7-400 PLCs. Out of the three models, the S7-300 became the most popular due to having the broadest range of CPU sizes and being well-suited for nearly all applications. Another significant milestone was the Totally Integrated Automation (TIA) concept launch in 1996. With it, Siemens began to design solutions to automate the entire production chain. This eventually led to the release of the TIA Portal platform. Two more S7 product classes were released several years later, the S7-1200 (2009) and the S7-1500 (2012) PLCs. Both increasingly pushed the boundaries of performance while at the same time being more cost-effective solutions.
With a basic understanding of Siemens PLC's history, let’s review the three leading SIMATIC PLCs present in the market today: the S7-300, S7-1200, and S7-1500.

2.9.2 S7-300 PLC



The S7-300 PLC became the most popular among the first S7 product classes released, and its success helped establish Siemens as a leader in the automation industry. The S7-300 is a mid-range controller with a serial bus connector suited for extensive and complex process control tasks.
Compared with the S7-400, the S7-300 CPU is less powerful and supports less memory and less I/O. However, the S7-300 also has a smaller footprint and is more cost-efficient. The S7-300 provided a better balance of processing power and cost leading it to have higher popularity in the market.
Siemens offers 22 different versions of the S7-300 CPU, which fall into four main categories: standard, compact, failsafe, and technology. The standard CPUs are designed for small to medium plants with different requirements in terms of scope and networking needs. The compact CPUs technically cover the same range as the standard CPUs, but they are better suited for environments where saving space is crucial. The failsafe CPUs integrate safety-rated controls into the system in one single device. Finally, the technology CPUs are specially

equipped for advanced motion control. Siemens programmers may recognize the use of this terminology with ‘technology blocks’, commonly used for motion control in the TIA platform.
The S7-300 PLC has been on the market for nearly three decades, and Siemens has officially announced the start of the product phaseout. The S7-300 will be “definitively available” until 2023 and will be available as “spare parts” until 2033 according to the product phase-out notification. In the meantime, the industry is migrating the existing installed base to the more modern S7-1200 and S7-1500 PLCs.

2.9.3 S7-1200 PLC

When the S7-1200 was released, the intention was to solve several technical challenges presented with the S7-300, primarily being smaller with embedded IO, yet still having modular expandability. However, it is not considered the official successor of the S7-300, that task is left up to the S7-1500. In that sense, the S7-1200 is a sort of transitional model. It can do most of the functions of the S7-1500, and the software can be easily migrated from one model to the other. What sets it apart from the S7-1500 is its compact size, but it generally contains less I/O and has less memory and processing power.
The compact size of the S7-1200 with embedded IO leads it to be an excellent choice for on-machine control panels. Many applications, especially new installations, turn to this system or rely instead on distributed IO blocks controlled by a central S7-1500.

2.9.4 S7-1500 PLC

The S7-1500 line offers all of the flexibility and scalability advantages of the S7-300, but it is designed with the future of control automation technologies in mind. Therefore, many case study applications for this line revolve around Industry 4.0 and data analytics. There are three main S7-1500 PLC categories:

standard, compact, and failsafe. The application range for each one is similar to that of the S7-300.

Processing power, performance, and code length are all significantly improved with the S7-1500. In addition, Profinet is the standard protocol used with the S7-1500 controllers, and they are designed for extensive network scalability. This processor would be commonly used alongside both local IO modules as well as distributed IO including the ET 200 series.

As technology advances, more projects are turning to the cloud to handle complex data manipulation and trends. The S7-1500 is designed just for these use cases, with protocols and networking capabilities for edge and cloud computing.

Until recently, the S7-1500 would still be compared against the S7-300 to choose the best solution for a new automation project. However, with the announcement of the S7-300's obsolescence, the S7-1500 has become the official solution. Now, many companies are planning to migrate to it.

2.10 What are the applications of an industrial PLC?

An industrial PLC can be used in many different applications such as process control functions, manufacturing production, mobile automation, monitoring machine tools, steel industry, robotic automation systems, glass industries, food processing systems, paper industry, and more!

2.10.1 Manufacturing production

The Internet of Things (IoT), intelligent automation, advanced robots, and other Smart Factory projects have made the production process much more efficient. PLCs continue to serve an important role in manufacturing, acting as a central processor for all real-time decisions, despite fast technological developments. PLC gives reliable data, such as sensor performance and other information, which can be combined with cloud computing to create a more holistic picture, or “big data.” Plant managers and others can use analysis tools to better leverage resources, batch scheduling of jobs, logistics, supplier timing, and other essential operations to develop more efficient manufacturing processes.

2.10.2 Automobile automation

They use PLC in Automobile automation processes to standardize the production process and increase their ROI (Return on Investment)

2.10.3 Monitoring machine tool

A PLC serves as a machine tool to monitor inputs and outputs to make decisions based on the program stored in the PLC’s memory. The use of PLCs helps to reduce human decision-making efforts to gain higher efficiency.

2.10.4 Steel industry

Every operation, such as managing temperature and pressure in boilers, raising electrodes, feeding oxygen lance for steel, controlling cooling bed, and so on, has relied heavily on PLC.

2.10.5 Robotic automation system

Robots are designed with powerful PLC software embedded into the robot controller. This program allows a small group of robots to operate independently from a centralized PLC, which has implications for the industry. This equates to significant cost reductions for smaller businesses that would otherwise have to spend in a standard PLC integration.

2.10.6 Glass industry

PLCs are used to control the material ratio and process flat glasses. The advanced technology of the PLC has allowed them to be in high demand in the field.

2.10.7 Food processing system

A PLC is the food processing system that serves for contaminant levels in the water, and flow rates in major parts of the water treatment plant, and alternatively, valves that control in-process water flow can be controlled remotely.

2.10.8 Paper industry

The function of a PLC in the paper industry is to automate processes at high speed to ensure efficiency.

A PLC controls and supervises the creation of book pages or newspapers.

2.10.9 Conclusion

Siemens is a leader in many areas of digital technology, both hardware and software.

Chapter 3 SCADA System Fundamentals

3.1 Introduction

Just as different countries have their languages so do different technologies. The first step to understanding a new technology is learning the unique language of that technology. This course is intended to provide you with an understanding of the terms and equipment associated with Supervisory Control and Data Acquisition (SCADA) systems.

SCADA systems at their fundamental level are Industrial Control Systems. They are computer-based control systems that monitor and control industrial processes that exist in the physical world. SCADA systems can be found in manufacturing facilities, oil production and processing, pharmaceuticals, energy, water treatment, distribution, and the list goes on. They are the best control method for processes that have large amounts of data that need gathering and analyzing, are spread over large distances, or require critical control in fast-paced processes.

3.2 A Brief History of the SCADA System

Modern SCADA systems can span across large geographical locations and provide operators with a complete overview of their processes, as well as remote control of equipment, advanced alarming, and powerful data processing capabilities. However, when SCADA was first conceptualized in the late 1950s, many of these functions were not possible or were very limited. Looking back at the brief history of SCADA systems, it took multiple generations of development before we achieved the level of connectivity and functionality that today’s systems provide.

3.2.1 Monolithic Systems: First Generation

The first SCADA concepts were based on mainframe systems, which had little to no networking capabilities. Because of their limited networking capabilities, the first generation of SCADA systems were unable to interconnect with each other making them standalone systems.

Despite their lack of interconnectivity, the first generation of SCADA systems could still create a wide area network (WAN). However, at the time, the only function of these wide area networks was to connect to different remote terminal units (RTU) to communicate data back and forth from the master computer. To communicate with the RTUs, the first generation of SCADA systems only used proprietary protocols developed by RTU vendors that were only compatible with master computers from the same vendor. Additionally, these protocols only provided the ability to scan, control, and exchange data between the master computer and the RTUs sensors and inputs in the field.

These first SCADA systems quickly became in high demand from manufacturers across industries. However, as SCADA became more widely adopted, manufacturers began to pressure the RTU vendors to improve the system's communication protocols. This push for improvements led to the first evolution of SCADA and ushered in the second generation of systems.

3.2.2 Distributed SCADA: Second Generation

With manufacturers pushing for improvements, the second generation of SCADA arrived, bringing system miniaturization and local area network (LAN) technology. Termed distributed SCADA, the improved systems were now able to communicate with each other allowing for multiple stations that could exchange data in real time. The systems also became smaller in size and were less expensive than the first generation of SCADA.

The second generation of SCADA also brought the first instances of common system components, which included communication processors, human-machine interfaces (HMI), RTUs, and databases. While Distributed SCADA systems were smaller, less expensive, and more connected, the second generation was still limited to only being compatible with hardware, software, and peripheral devices provided by the vendor.

3.2.3 Networked SCADA: Third Generation

The third and current generation of SCADA was brought on by advances in industrial automation, and the vendor's willingness to understand and adapt to the needs of the market.

Now dubbed networked SCADA, the third generation finally breaks away from relying on the vendor's proprietary components and introduces an open system architecture. This open architecture allows for the use of open communication protocols and standards, which enables SCADA functionality to be distributed in WANs versus only being able to use closed LANs. Additionally, an open architecture also allowed for the use of third-party peripherals, which unlocked even greater functionality over the previous generation of SCADA systems. With the ability to use WANs for more than just connecting to different RTUs to exchange data, the third generation of SCADA introduced WAN protocols, such as Internet Protocol (IP). This was a groundbreaking development, as it enabled all components of a SCADA system to communicate with each other through an ethernet connection.

3.3 SCADA SYSTEM SIGNALS

The very basic components of a SCADA system are these signals:

- DI – Discrete Input
- DO – Discrete Output

Discrete signals (also called Digital signals) provide an ON or OFF input to a SCADA system. This is the same binary signal format used in computer processors.

The next basic types of signals are:

- AI – Analog Input
- AO – Analog Output

Analog signals are continuous. A change in signal value reflects a change in the parameters being monitored. Examples of analog signals are temperature and pressure.

The signals generated by the instruments being monitored by a SCADA system are voltage or current based. Analog signals can be formatted as 4-20 mA, 0-20 mA, 1-5VDC, 0-5VDC, -10VDC to 10VDC.

Values (whether discrete or analog), when used in a SCADA system, they need to be seen by Operators to be of any use.

3.4 WHAT ARE THE FUNCTIONS OF SCADA?

The SCADA system of software and hardware enables:

- automated control and management of industrial processes & machines in real time from a remote location
- data collection and analyses
- event and alarm notifications
- report generation
- historical data logging, archiving, and retrieval

3.4.1 SCADA SYSTEM DATA GATHERING

The Operator’s access to a SCADA system is by:

- OIT – Operator Interface Terminal
- HMI – Human Machine Interface

OITs provide a local interface, typically in a remote location or into an isolated system like skid-mounted equipment. Screens to display information have a simple layout since displays are not large; anywhere from 4 inches to 14 inches.

HMI software is used at the Central Control location. Software is installed on computers with faster processors and larger monitors so the screens display more information. They also make use of animation to emphasize critical data or focus operator attention on important areas of a process or annunciate an alarm.

The workhorse of the SCADA system that effectively grabs data from instruments converts the information to a format a computer program can understand, and handles high-speed communication is the:

- PLC – Programmable Logic Controller

The Programmable Logic Controller (PLC) was invented in 1968 to support the automobile industry by Bedford Associates' engineer Dick Morley. The first PLC was called a **MO**dular **DI**gital **CON**troller, aka MODICON.

Over time variations of the PLC have developed. The two primary ones are:

- RTU – Remote Telemetry Unit
- PAC - Programmable Automation Controller

The Remote Telemetry Unit (RTU) was developed to gather data and then transmit that data to a remotely located processor. An RTU has the communication capabilities of a PC and the IO capability of a PLC, as well as being industrial-hardened. However, it does not control processes using an internal program. It functions as a Data logger that can transmit data at a certain time to Central or when polled. A hybrid version of the RTU contains a PLC that does control local processes and performs the communication functions of an RTU.

A PAC is the next generation of a PLC. It has the same form and function as a PLC, but its processor is more related to a computer in its speed and computing methods. Its greatest advantage is the communication function which allows it to work more effectively with modern communication networks that are Ethernet-based.

3.5 SCADA SYSTEM TYPES

Data gathering and system control at the highest level are broken into two basic systems:

- SCADA – Supervisory Control and Data Acquisition
- DCS – Distributed Control System

The definition of SCADA is a Monitoring and/or Control System that utilizes a central computer for storing information and onsite/remote hardware to monitor facilities and processes. Control may be automatic or manual and may occur at the remote units or the central computer.

The definition of DCS is a Monitoring and/or Control System that utilizes a central computer for storing information and onsite/remote hardware to monitor facilities and processes. Control may be automatic or manual and may occur at the remote units or the central computer.

While a SCADA system and a DCS system are essentially the same at all levels, there is a very basic difference. A SCADA system is event-driven and operator concentric. It is data gathering orientated. Data is stored in a database and control is usually remotely originated. Whereas, a DCS is process state driven. It is directly connected with field devices and control is done locally and automatically. The operator is just informed of what has happened.

A SCADA master station generally considers changes of state (both status points and analog changes leading to alarms) as the main criteria driving the data gathering and presentation system. Any undetected changes in the state simply cannot be missed. A change of state will cause the system to generate all alarms, events, database updates, and any special processing required relating to that. Event lists and alarm lists are of major importance to the operator, sometimes more so than data screens. S is for Supervisory - an Operator takes action.

Conversely, DCS systems are process control systems that are state-based and consider the process variable's present and past states to be the main criteria driving the DCS. PLC protocols are generally register scanning-based, with no specific change of state processing provided. Should a point toggle between scans, it will not be seen by the DCS. If any change of states is critical (as some would be for a DCS used for SCADA applications), a point must be latched on until it is confirmed it has been scanned, which can be difficult and non-deterministic. DCS software tasks are generally run sequentially, rather than event-driven. If a process starts to move from a set parameter, the DCS responds to maintain that parameter value. Notifying the Operator is a secondary consideration. Events and alarm lists are secondary in importance to the process displays, and filtering may not be as complex and flexible. On the upside, the generation and display of data, especially analog trends and standard process blocks, is far more user-friendly and easier for both operators and engineers.

3.5.1 Proprietary SCADA System:

- All or most components are manufactured by one supplier.
- Installation and service from the same single source
- Lack of compatibility with other products

- Uses proprietary communications and programming.

3.5.2 Alarm Management

3.5.2.1 Introduction

Maintaining a safe and stable plant is the objective of everyone involved in the manufacturing process. As Peter Drucker once said, "A well-managed plant is silent and boring," but it takes a lot of work and effort to ensure this is the case.

Alarm management in the plant is not just another project that gets executed, but it is a philosophy, a way of life just like safety. We won't ever enter the process area without wearing PPE, so why work in an environment where there is no strategy for alarm handling? The alarm management system is one of the most important aspects of the plant and, like everything else, it must be maintained to meet the ever-changing needs of the plant.

In the early days of control systems, before the Distributed Control System (DCS) became commonplace, the configuration of alarms used to be done through mechanical means with annunciators, light boxes, etc. Now with the advent of the DCS, the cost of making extra alarms available has significantly reduced as it can be mostly done by software. However, the operator still becomes overwhelmed with unnecessary alarms if the control system design is not approached correctly. To fully understand the purpose of the alarm management system, we must look at the basic meaning of what an alarm is. Anything that requires an operator to take action to maintain the safety and integrity of the process.

An alarm is designed to prevent or mitigate process upsets and disturbances

Most alarm problems exist because the above criteria are not met. Understanding this definition is key to implementing a successful alarm management system. Alarm rationalization is a process of optimizing the alarm system for safe operation by reducing the number of alarms, reviewing their priority, and validating their alarm limits. By undertaking such steps, we help reduce the workload of the operators and promote a safer working environment within the plant, and when a plant upset does occur, more visibility is available on the alarms that matter.

As highlighted previously, alarm management is not just a project that has a start and end date; it's a continuous cycle. Once the alarm system has been reviewed and improvements have been identified, we must check that controls are in place to ensure the alarm system remains functional. The key is to ensure that the system is continuously monitored, and any changes are fully documented. Any initiatives regarding alarm management must have management support available, otherwise, little improvement will be made in reducing the alarm counts and improving overall safety and improvement in the process.

3.6 Seven Key Steps for Alarm Management

There are seven key steps for alarm management. Rationalization is one of those critical steps.

3.6.1 Alarm Philosophy Creation

The alarm philosophy document is critical and, without it, there can be no way to implement a successful alarm management system. This document forms the basis of the overall design guidelines and will record all the expected KPIs that will be used to measure the success of the alarm management system. The alarm philosophy should also cover the design of the interface to the operator so the graphics are clear and upsets are easy to spot etc.

3.6.2 Alarm Performance Benchmarking

To measure the success of any alarm management system, we must know how big the alarm problem that is currently being experienced. How many alarms are being generated per day, how many alarms does the operator handle on an hourly basis, and what are the deficiencies we currently have in the control system? These are all valid questions and benchmarking is the starting point. Perhaps even performing a HAZOP-like study at this stage would be advantageous.

3.6.3 Bad Actors Resolution

Most alarms in the control system come from relatively few sources, and checking these and fixing them will make a big difference to the overall alarm count. Reviewing the Top-10 list helps to keep it under control. Yokogawa's Exaquantum/ARA software can provide this list daily by email or, by using Yokogawa's Exaplog alarm/event analysis tool, we can manually extract the bad actors.

3.6.4 Documentation/Rationalization

The most important step of the alarm rationalization process is to ensure that each change is documented and the alarm changes comply with the alarm philosophy. Alarms can be eliminated by re-engineering the DCS or adopting suppression techniques.

3.6.5 Audit/Enforcement

Once the rationalization is done, the hard work is not over! Without proper change management controls in place, the alarm system will slip back into its old ways. Consider adopting a Management of Change (MOC) approach to the alarm system to ensure all changes are tacked. Exaquantum/AMD can also help by identifying changes to the alarm settings and, if required, the optimal settings can be enforced automatically.

3.6.6 Real Time Alarm Management

For day-to-day operations, we should adopt alarm management techniques that will support rather than hinder the operator by providing Alarm Shelving, state-based alarming, or other alarm suppression technologies.

3.6.7 Control & Maintain Performance

Continued compliance with the alarm philosophy is crucial by continuously monitoring the alarm KPIs and making any required changes through a MOC type procedure. Nominate an "alarm champion" that will oversee and manage day-to-day issues. Remember that alarm management is not a one-step process.

3.7 SCADA SYSTEM COMPONENTS

These are the four basic parts of a SCADA system.

- Field Instruments
- PLC/Remote Terminal Unit
- Communications Link – open standard (like MODBUS) and proprietary
- Central Computer Station including HMI Software – Proprietary for specific RTUs or open including interfacing many products

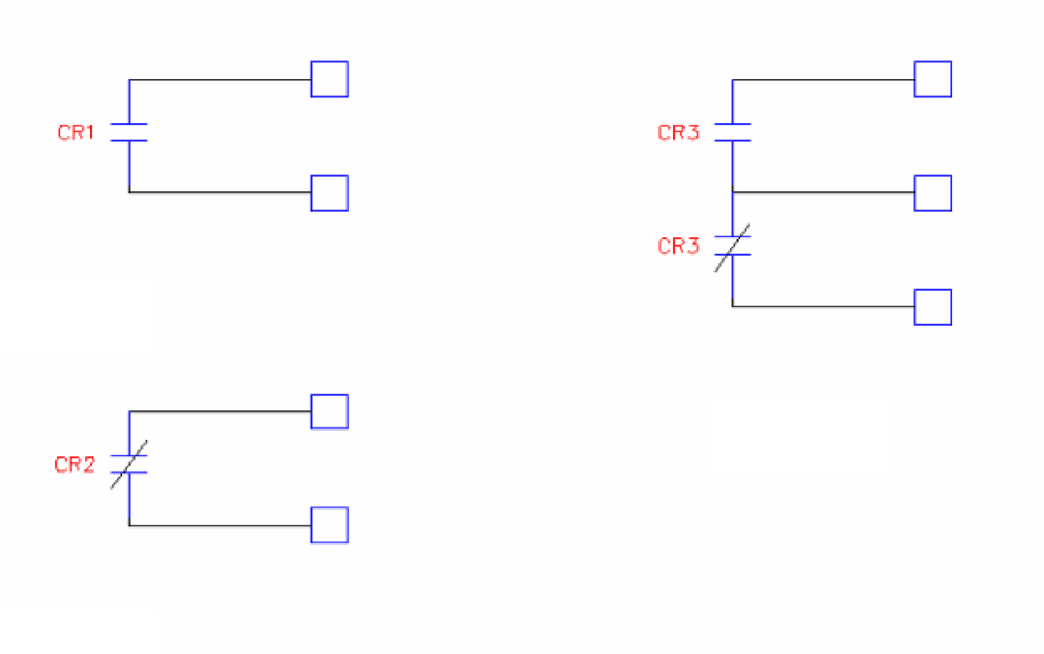
We are going to look at each of these parts and identify the basic components for each:

3.7.1 FIELD INSTRUMENTS

Discrete signals are generated by:

Limit switches	
Pushbuttons	
Float switches	
Flow switches	
Relay contacts	
Selector switches	

Discrete signals have three basic configurations that are used:



Form A - Normally Open

Form B - Normally Closed

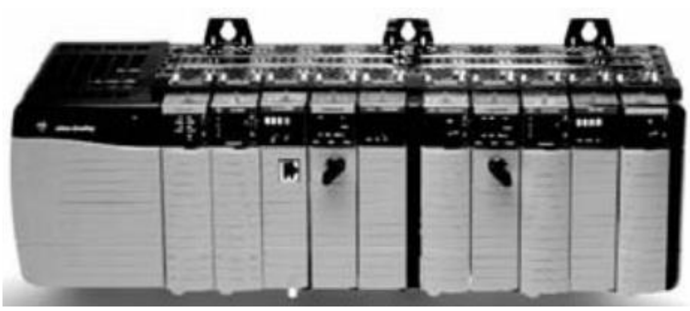
Form C - Normally Open-Normally Closed combined

3.7.2 PLC/RTU

PLCs come in a wide variety of sizes and shapes. They are used for controlling nuclear power plants controlling a sump pump in a parking garage.

High-end PLCs can handle multiple racks of IO modules, and various communication modules, and may be installed in a redundant configuration so the loss of a power supply or processor will not stop control of a facility.

The latest step in the evolution of PLCs is the Programmable Automation Controller (PAC).



A PAC has a computer processor, so it works better with Ethernet networks (routers/switches) which are becoming prevalent in SCADA systems. Programming can also be done in more mainstream programs (C++, etc)
Smaller PLCs are configured for just a few points. Sometimes they may only have discrete signals and function as intelligent relays. They are not typically expandable to add more IO points.
Programming is usually simple.

Sometimes the programming can even be done with the keys on the front of the PLC.
Relay Ladder Logic was the first programming language for PLCs. It mimicked the wiring diagrams electricians were used to seeing in control panels in software. Electricians were the first PLC programmers.
As hardware and software changed, the companies making the products started diverging. It became apparent that standards had to be developed so the software and hardware could work together. There also started to be programmers who were familiar with multiple high-level programming languages and never saw the inside of a control panel. In Europe, IEC developed standard 61131 which specified five styles of programming to be used in PLCs:

- Relay Ladder Logic
- Function Block Diagram
- Structure Text
- Instruction List
- Sequential Function Chart

3.7.3 Communication

Radios are the most common communication method in large SCADA systems. Licensed radios were originally used. Then in 1987, the FCC marked a radio frequency band segment for Industrial Scientific Medical (ISM) use. This was an unlicensed segment that was opened for use and did not require a license. The ISM is in the low 900MHz range.

The ISM band is limited to a maximum of 1 Watt transmitting power. This was the method selected to reduce interference by limiting the range of transmissions. Licensed radios are still used in SCADA systems for operators who have a long distance that needs to be covered between sites.

Characteristics of the most frequently used frequencies are:

1) Licensed VHF – 132-174 MHz, 400MHz

• Up to 5 Watts of Power
• Very Good Signal Transmission

2) Licensed UHF – 380-512 MHz

• Good Signal Transmission

3) Unlicensed Spread Spectrum – 900 Mhz

• 1 Watt max. Power
• Line-of-Sight, weather dependent
• Ethernet protocol versions are available in all frequencies.

A recent trend in SCADA systems has been the incorporation of video cameras and still cameras to provide Operators with real-time images of what is happening at remote sites. The need for increased security was the driving force behind this trend.

3.8 Central Computers

One of the first steps in designing a SCADA system is to determine which Communication Protocol will be used. The most common protocols used are:

- MODBUS RTU or MODBUS ASCII (the original protocol used)
- DEVICENET
- CONTROLNET
- Profibus
- Foundation Fieldbus
- DH+, DF1
- DNP3
- Ethernet (MODBUS TCP, ETHERNET IP)

Protocols are the languages that the equipment uses to communicate. Just as people speak English, French, German, etc., so have different protocols been developed by different manufacturers. These different protocols are intended to maximize the hardware benefits of their equipment. Some of these protocols are open for anyone to use and some are proprietary.

The second step is determining the hardware:

- Computer Hardware Inc. UPS – Off-the-shelf
- Central RTU – Sometimes for polling
- Communication Interface – Radio/Antenna, Telephone Modem, DSL Modem
- HMI – Human Machine Interface
- Common HMI – Intellution, Wonderware, Citec, Trihedral Engineering VT-Scada
- Internet Based – Mission
- Web-based - Inductive Automation

At the high-level end of a SCADA system, you see the equipment and software that the Operators use to interface with the system. At this level communication is the key process. There is the hardware and software to interface with all the field components.

Also, there is hardware and software to interface with the operators. This side of the process is very graphic-oriented.

- SCADA Fundamentals
- Alarm Annunciation
- Remote Control
- Trending – Real-Time/Historical
- Data Logging / History
- Alarming
- Reporting
- Security
- High-Level Optimization Strategies
- Auto-Dialer / Pager
- Remote Monitoring

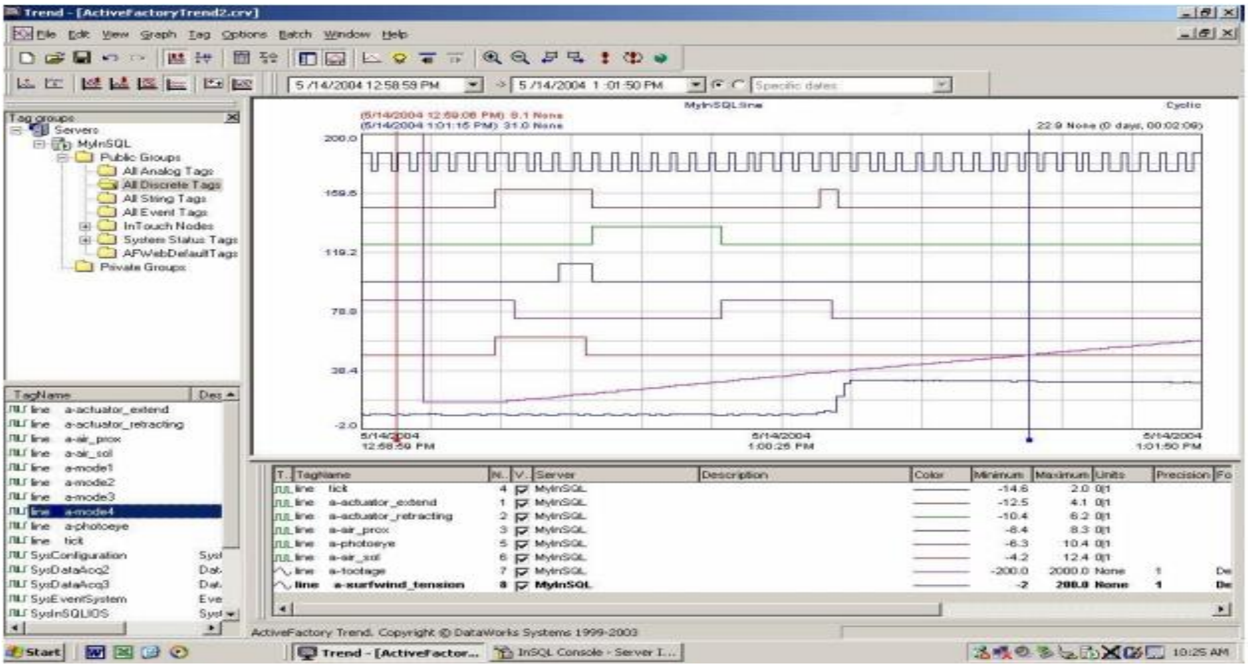
The SCADA HMI software is written to provide these services to the Operators for their day-to-day operations:

- SCADA Fundamentals
- Analog Summary
- Radio Error Analysis
- Log Report – All Data
- Detail Report
- Pump Activity – Total & Ave Run Times, Starts

- Pump Discrepancy – Excessive changes
- Flow
- Water Quality

Another very important feature of SCADA HMI software is the documentation for historical purposes. The data collected is achieved and then distributed in various formats. This information helps with maintenance as well as reporting to supervisory organizations.

A typical graphics screen allows the operator at a glance to see the status of all the critical equipment and processes in an area.

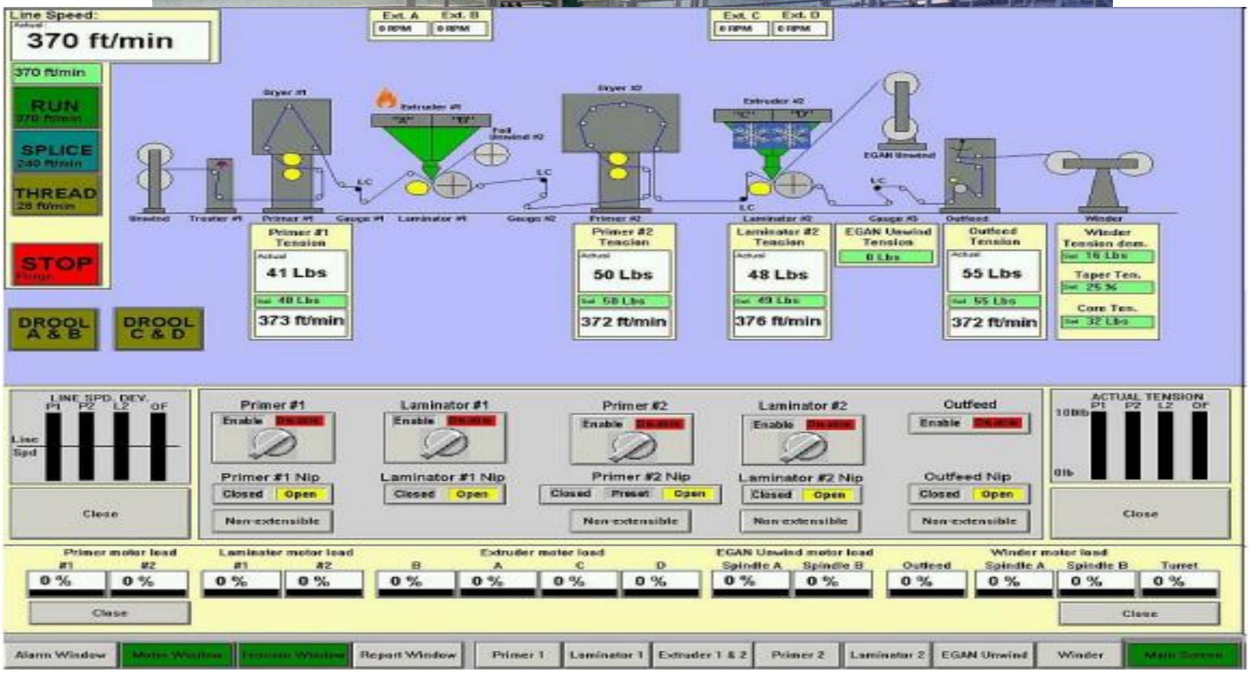


Trending is data spread over some time and presented in a graph. This is a useful tool for improving processes.

3.9 SOME APPLICATIONS OF SCADA

3.9.1 Water/Wastewater systems

SCADA systems monitor and control the water being pumped at wells and treated at water treatment plants. They are used to control flow rate sensors, contaminant sensors, etc., fill overhead storage tanks and control booster pumps to regulate the pressure of water being supplied to users, and many other tasks.



3.9.2 Food/Pharma production

This is a major SCADA application. SCADA is used to monitor and control all phases of production, control the exact mix of ingredients, and monitor the time and temperature required to process/manufacture food & beverages or pharmaceutical products. SCADA also helps to document data that proves the production process meets industry standards and governmental regulations.

3.9.3 Manufacturing plants

SCADA precisely controls all plant operations, ensuring all systems run smoothly and productivity targets are met. It tracks how many units are produced, measures values like temperature, pressure, humidity, etc. at different production stages, controls assembly-line robots, and monitor parts usage so just-in-time inventory control is implemented.

3.9.4 Oil & Gas systems

SCADA systems are used to monitor wells and pumping sites, pumping pressure, pipeline flow, and compressor stations. It detects anomalies and prevents catastrophic events from occurring – thus enhancing safety.

3.9.5 Electricity Generation, Transmission, and Distribution Systems

SCADA is used to monitor every phase of generating electricity from fuel input to electrical output. SCADA also monitors and controls electrical substations and distribution lines. SCADA is utilized to monitor and control the amount of electrical power being transmitted over long distances, and to respond instantaneously to fluctuations in demand.

The application of SCADA in power systems also serves the invaluable purpose of safety and protection, when a transmission line experiences a fault, the system will quickly attempt to clear the fault and restore power.

3.10 What is SCADA security?

3.10.1 SCADA Security Definition

SCADA security is the practice of protecting supervisory control and data acquisition (SCADA) networks, a common framework of control systems used in industrial operations. These networks are responsible for providing automated control and remote human management of essential commodities and services such as water, natural gas, electricity, and transportation to millions of people. They can also be used to improve the efficiencies and quality in other less essential (but some would say very important!) real-world processes such as snowmaking for ski resorts and beer brewing. SCADA is one of the most common types of industrial control systems (ICS).

These networks, just like any other network, are under threat from cyber-attacks that could bring down any part of the nation's critical infrastructure quickly and with dire consequences if the right security is not in place. Capital expenditure is another key concern; SCADA systems can cost an organization tens of thousands to millions of dollars. For these reasons, organizations must implement robust SCADA security measures to protect their infrastructure and the millions of people that would be affected by the disruption caused by an external attack or internal error.

3.10.2 SCADA Network Security Threats

From local companies to federal governments, every business or organization that works with SCADA systems is vulnerable to SCADA security threats. These threats can have wide-reaching effects on both the economy and the community. Specific threats to SCADA networks include the following:

3.10.3 Hackers

Individuals or groups with malicious intent could bring a SCADA network to its knees. By gaining access to key SCADA components, hackers could unleash chaos on an organization that can range from a disruption in services to cyber warfare.

3.10.4 Malware

Malware, including viruses, spyware, and ransomware can pose a risk to SCADA systems. While malware may not be able to specifically target the network itself, it can still pose a threat to the key infrastructure that helps to manage the SCADA network. This includes mobile SCADA applications that are used to monitor and manage SCADA systems.

3.10.5 Terrorists

Where hackers are usually motivated by sordid gain, terrorists are driven by the desire to cause as much mayhem and damage as possible.

3.10.6 Employees

Insider threats can be just as damaging as external threats. From human error to a disgruntled employee or contractor, SCADA security must address these risks.

3.10.7 Summary

SCADA systems are a vital tool for keeping our society going. As electronics and communications have improved, so have the capabilities of SCADA systems. SCADA systems make controlling large and small processes easier for Operators whether they are in telecommunications, water treatment, manufacturing, energy production, oil production, transportation, etc.

3.11 HMI (Human Machine Interface)

3.11.1 Introduction

An HMI system is a user interface or control panel that connects a person with a machine, system, or device. Although the term can technically be applied to any screen that allows the user to interact with a device, the HMI is most commonly used in the context of industrial processes that control and monitor production machines.

On the other hand, HMI is short for Human Machine Interface. Similarly, among professionals, its translation into Man-Machine Interface is often used to refer to this type of operator panel.

A common example is an ATM that we all use in everyday life. In this case, the screen and the push buttons allow the machine to dispense bills, and enter money, among other operations.

Human Machine Interface (HMI) systems enable reliable technology operations in every application, including high-speed trains, CNC machining centers, semiconductor production equipment, and laboratory or diagnostic medical equipment. In short, the HMI interface encompasses all the elements that a person will touch, see, hear, or use to perform control functions and receive feedback on those actions.

Thus, the operator or maintenance personnel can control or monitor the machinery from the HMI, it can include information such as temperature, pressure, production process steps, calculation of necessary materials, exact positions of the production lines, control of the levels of tanks with raw materials among many other functions.

Additionally, these control panels can be connected to PLCs and display their problem-solving behavior for maintenance technicians, saving valuable money.

3.11.2 What is an HMI for?

HMI screens are used to optimize an industrial process by digitizing and centralizing data. In this way, operators can view important information on graphs, and digital dashboards, view and manage alarms, and connect to SCADA and MES systems through a console. MES is the system-oriented exclusively to decision-making and order management of production plants, while the SCADA system is a graphical representation of the global operation: machinery, operators, facilities, maintenance, etc.

The human-machine interface communicates with programmable logic controllers (PLCs) and input/output sensors to obtain and display information for users to see. Similarly, they can be used for a single function, such as monitoring and tracking, or for more sophisticated operations, such as shutting down machines or increasing production speeds, depending on how they are implemented.

Previously, operators had to visually review mechanical progress and record it on a sheet of paper or a whiteboard. Today, PLCs can communicate real-time information directly to an HMI screen.

Consequently, this technology eliminates the need for these manual practices and therefore reduces many costly problems caused by lack of information or human error.

As data takes on an increasingly essential role in manufacturing, the future looks bright for HMI operator panels. This technology may have come a long way, but its growth potential remains virtually unlimited.

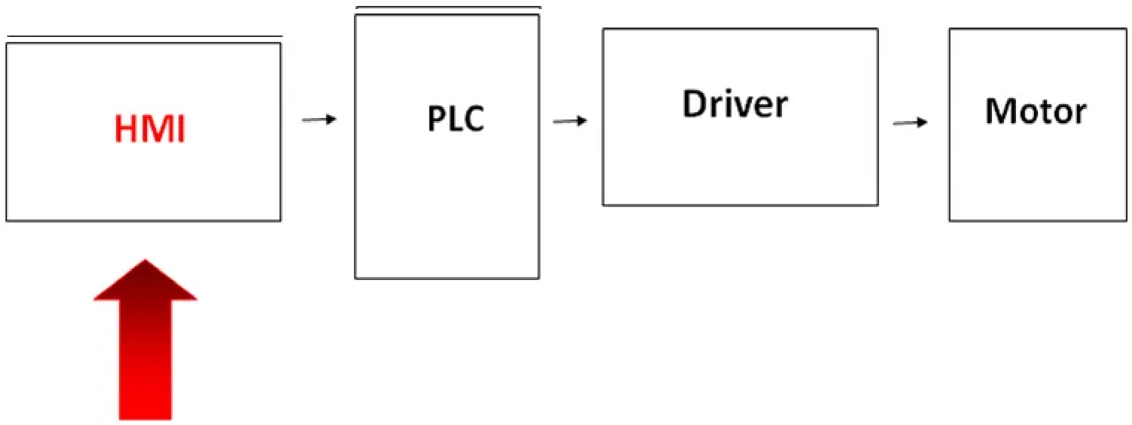
On the other hand, a well-designed HMI system does more than just present control and information functions; provides the operator with intuitive active functions to perform on the results of those actions and information on system performance.

So, another of the important concepts of its design is the usability of the control panel. In other words, its functions and handling must facilitate the life of the operator and the technicians involved in the manufacturing processes.

3.11.3 The Basic Functions of the HMI include:

- Visualize the Data
- Production Time Tracking
- Monitor KPIs (key performance indicators)
- Monitor the Inputs and Outputs of the Machines

- Basic Block Diagram of an HMI/Human Machine Interface



3.11.4 Types of HMI or Human Machine Interfaces

The Man-Machine Interface can be presented in different formats, from screens built into machines, and computer monitors, to touch screens and mobile devices, but regardless of their format or the term used to refer to them, its purpose is to provide information on mechanical performance and the development of production processes.

In the last decade, changes in business and operational needs have led to exciting developments in HMI technology. Now, it is becoming more and more common to see evolved HMI models. These more modern interfaces are creating more opportunities for team interaction and analysis.

3.11.5 High-Performance HMI

Increasingly, operators and users are moving towards a high-performance HMI, an HMI design method that helps ensure fast and efficient interaction. By drawing attention to only the most necessary or critical indicators in the interface, this design technique helps the viewer see and respond to problems more efficiently, as well as make better-informed decisions.

The high-performance HMI indicators are simple, clean, and free of extraneous controls or graphics. Other design elements, such as color, size, and location, are used discreetly to optimize the user experience.

3.11.6 Touch Screens and Mobile Devices

Touchscreens and mobile HMI are two examples of the technological advancements that have come with the advent of smartphones. Instead of

buttons and switches, modernized mobile versions allow operators to touch the physical screen to access controls.
Touch screens are especially important when used with a mobile device, which is deployed through web-based SCADA systems or an application. The mobile HMI offers a variety of benefits to operators, including instant access to information and remote monitoring.

3.11.7 Remote Monitoring

Remote monitoring allows greater flexibility and accessibility for both operators and managers. With this feature, an external control systems engineer can, for example, confirm a warehouse temperature on a handheld device, eliminating the need for on-site monitoring after work hours.
These days, testing a process at your production plant while it’s miles away from the facility may not seem like something out of the ordinary.

3.11.8 Network and Cloud HMI

Network HMIs are also in high demand because they allow operators to access data and visualization from field devices. Additionally, it is becoming increasingly common to send data from local HMIs to the cloud, where it can be accessed and analyzed remotely while maintaining control capabilities at a local level.

3.11.9 Who uses the HMI screen?

HMI technology is used by almost all industrial organizations, as well as by a wide range of companies in different sectors, to interact with their machines and optimize their industrial processes.

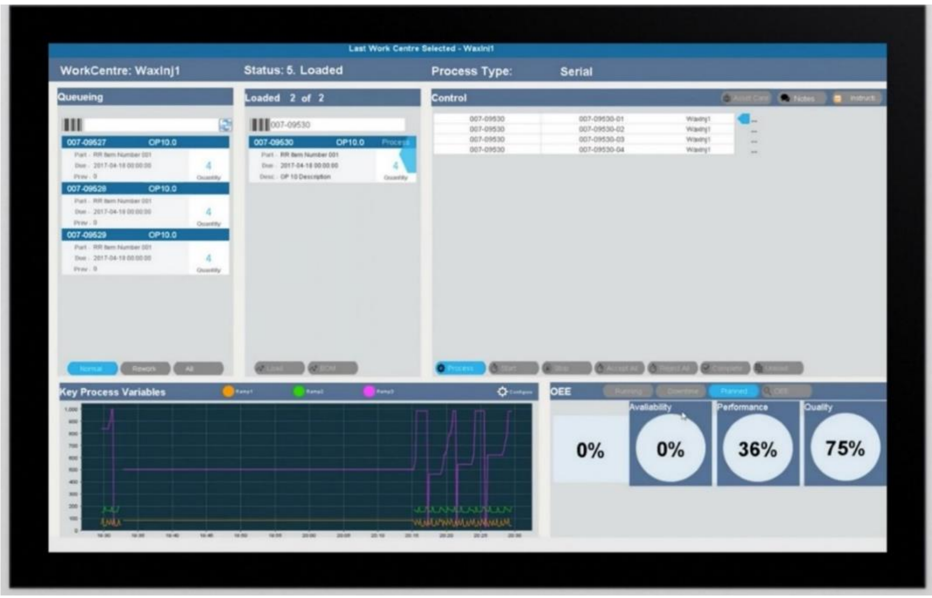
3.11.10 Industries that use HMI include:

- Energy
- Food and Drinks
- Manufacturing
- Oil and Gas
- Power
- Recycling
- Transport
- Water and Sewage

Within the production, staff interacts with HMI operators, system integrators, and engineers, especially engineers who control systems. The Human Machine Interface is an essential resource for these professionals, who use it to review and monitor processes, diagnose problems and visualize data.

For their process, they use specific software so that the engineers can program them correctly. This software allows the engineer to design what the operator will see on the screen, what they can monitor, what buttons can be pressed, and how the operator can manipulate the machine.

The systems engineer who designs the operator panel has to program each indicator and button to a specific input or output direction of a PLC, so they must be compatible and understand the same language or protocol. Consequently, the most common protocols in the industry are Modbus, Industrial Ethernet, and Profibus. These are responsible for connecting the PLC, HMI / SCADA, machinery, and other devices of the production process.



3.11.11 What is the difference between HMI and SCADA?

Supervisory Control and Data Acquisition (SCADA) and HMI are closely related, and often referred to them in the same context, since both are part of a system for industrial control wider, but each offers different functionalities and opportunities.

While HMIs are focused on transmitting information visually to help the user monitor an industrial process, SCADA systems have a greater capacity for data collection and control system operation.

Unlike SCADA systems, HMIs do not collect or record information or connect to databases. Rather, the interface provides an effective communication tool that works as part of, or in conjunction with a SCADA system.

3.11.12 What are some Manufactures of HMIs?

To ensure that your Human Machine Interface (HMI) works seamlessly with the rest of your system, it is best to choose an HMI from the same brand as your Programmable Logic Controller (PLC). Popular brands like Allen-Bradley and Siemens offer some of the best dedicated HMIs:

- Omron
- Rockwell Automation
- Mitsubishi Electric
- Schneider Electric
- Siemens
- Automation Direct

3.11.13 CONCLUSION

In conclusion, Human-Machine Interaction (HMI) is a critical field that focuses on designing interfaces for effective communication between humans and machines. With advancements in technology, HMI has evolved from basic text-based interfaces to sophisticated systems such as graphical user interfaces, touchscreens, voice recognition, and virtual reality. The development of user-centered design principles, challenges in HMI development, and its diverse applications across industries have contributed to its significance. As we look to the future, HMI trends emphasize natural language processing, wearable interfaces, and haptic feedback. However, ethical considerations must be addressed to ensure responsible and inclusive HMI development.

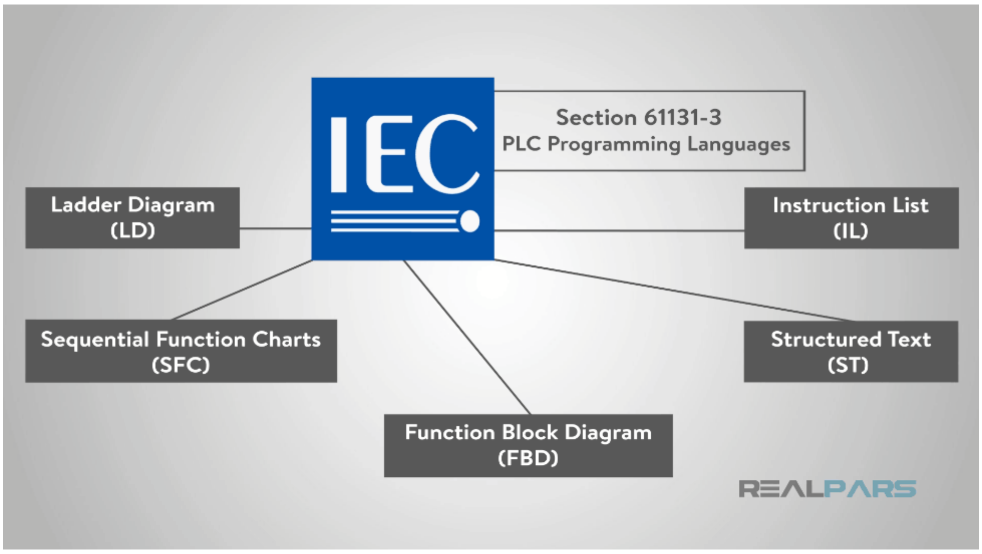
Chapter 4 PLC programming languages

4.1 Introduction

5 languages are all a part of the IEC (International Electrotechnical Commission) Section 61131-3 Standard. This IEC Standard allows some ground rules that standardize PLCs and their languages.

The 5 most popular types of PLC Programming Languages are:

1. Ladder Diagram (LD)
2. Sequential Function Charts (SFC)
3. Function Block Diagram (FBD)
4. Structured Text (ST)
5. Instruction List (IL)

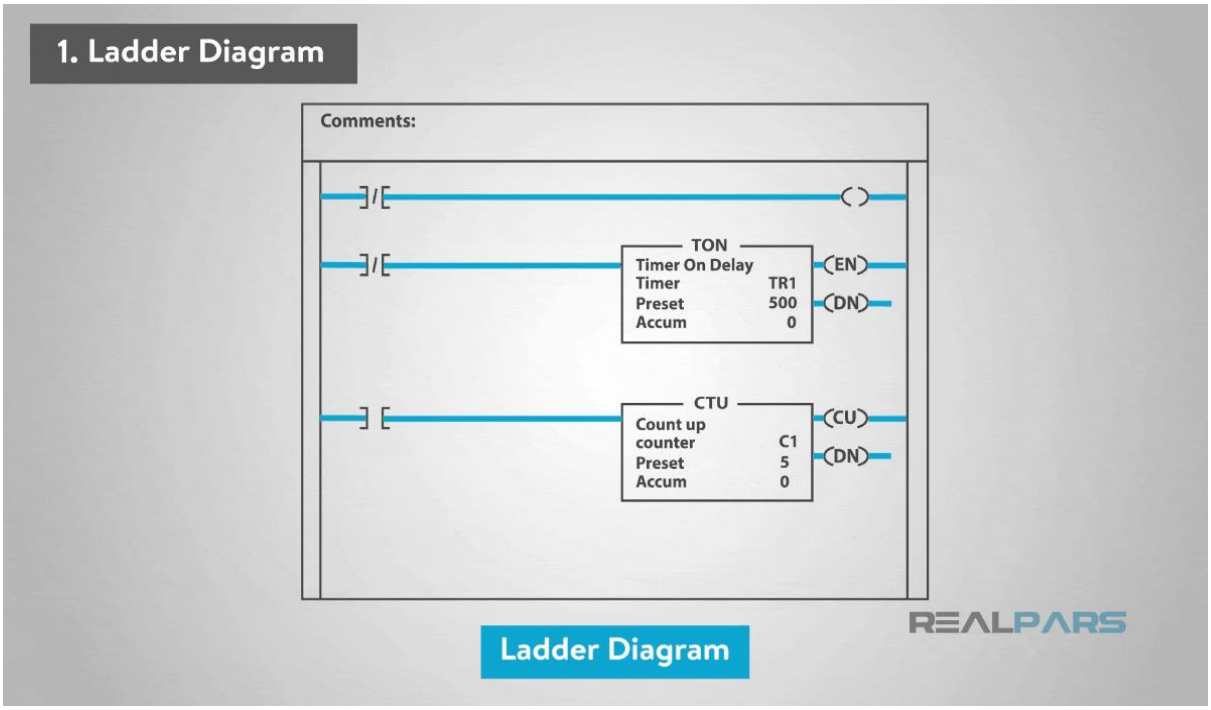


4.1.2 Ladder Diagram (LD)

The ladder Diagram was originally modeled from a relay logic which used physical devices, such as switches and mechanical relays to control processes. The ladder Diagram utilizes internal logic to replace all, except the physical devices that need an electrical signal to activate them.

The ladder Diagram is built in the form of horizontal rungs with two vertical rails that represent the electrical connection on relay-logic schematics.

You can program all the necessary input conditions to affect the output conditions, whether logical or physical.



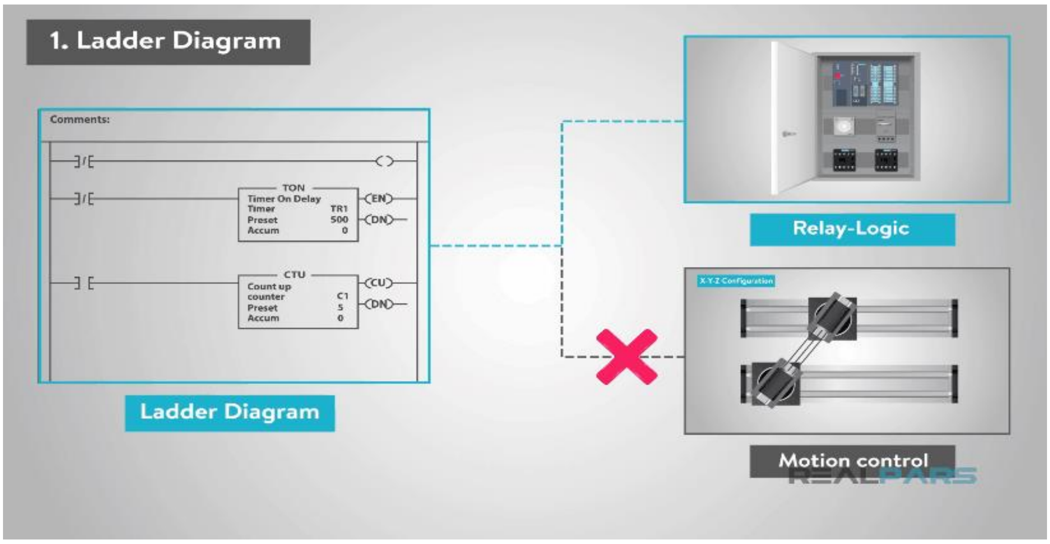
4.1.2.1 Ladder Diagram Advantages

The main advantages of the Ladder Diagram language are:

1. The rungs allow it to be organized and easy to follow.
2. It also lets you document readily visible comments.
3. It supports online editing very successfully.

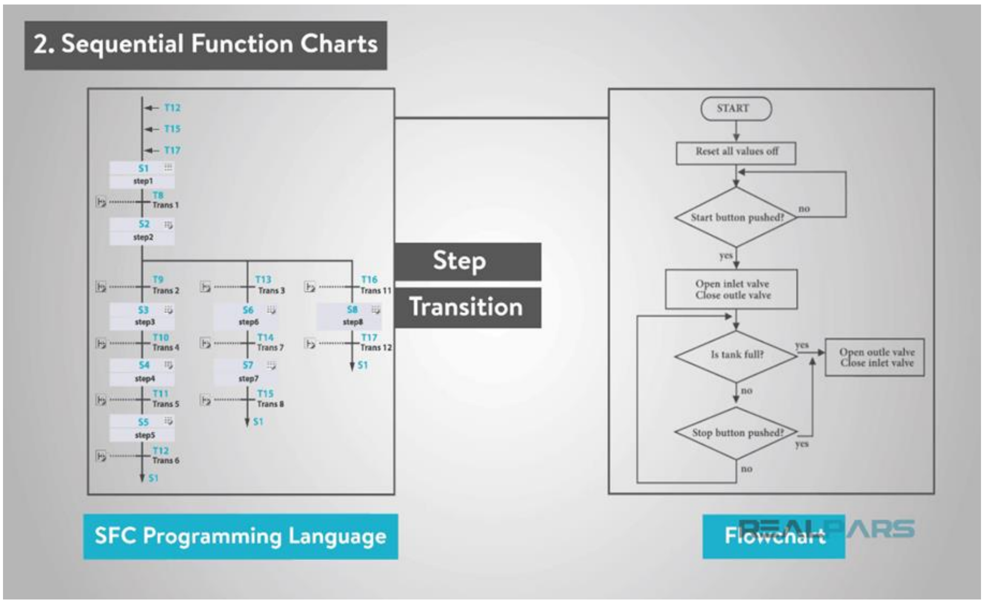
4.1.2.2 Ladder Diagram Disadvantages

The main disadvantage is that some instructions are not available, which might make it more difficult for programming such as motion or batching.

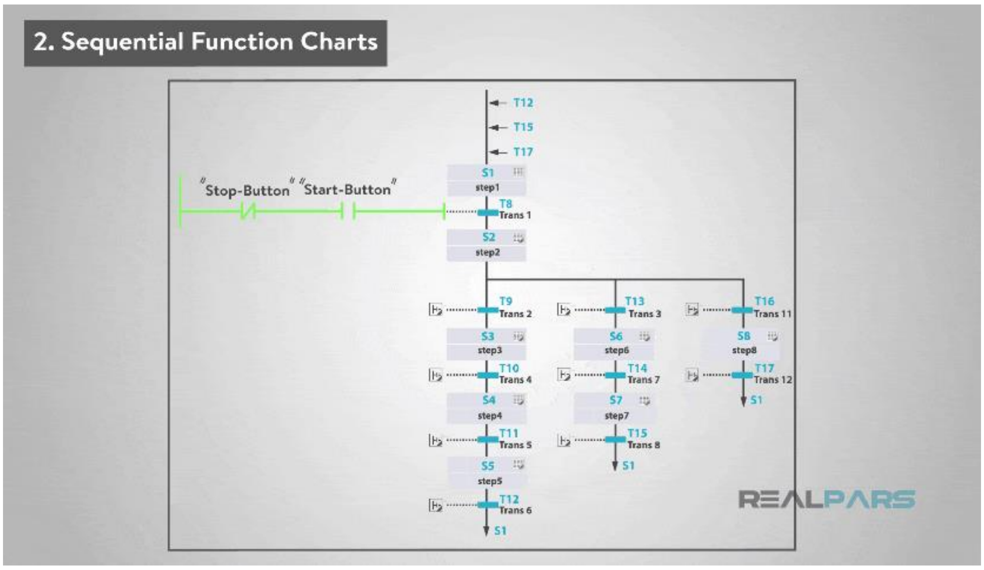


4.1.3 Sequential Function Charts (SFC)

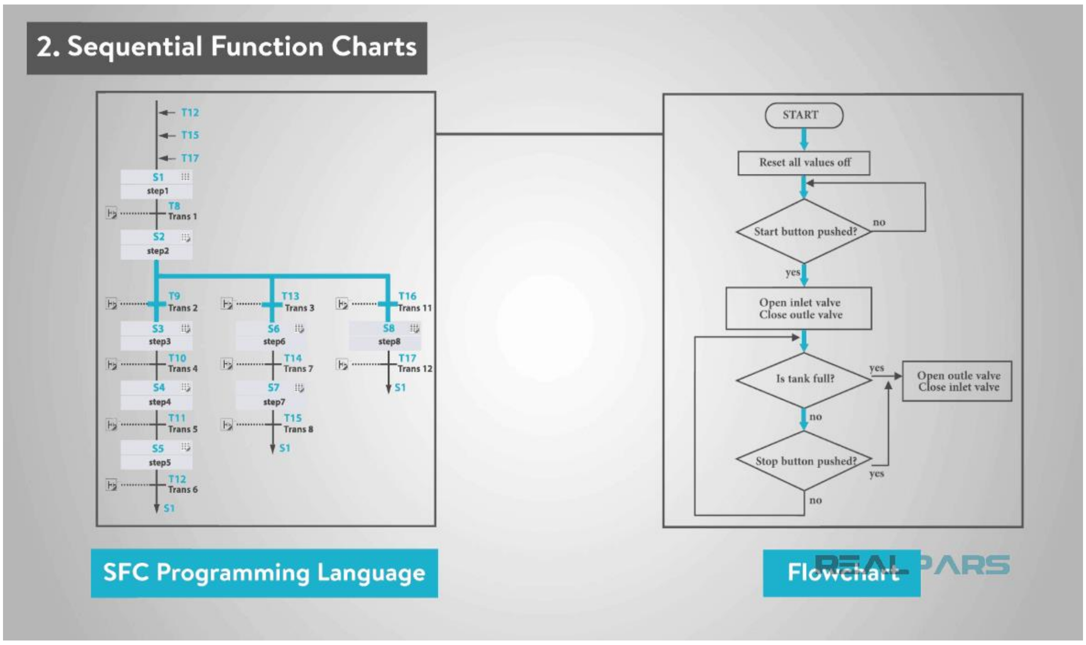
If you have any experience with flowcharts, then this PLC Programming language will feel familiar to you. In Sequential Function Charts, you use steps and transitions to achieve your results.



Steps act as a major function in your program. These steps house the actions that occur when you program them to happen. This decision can be based on timing, a certain phase of the process, or the physical state of equipment. Transitions are the instructions that you use to move from one step to another step by setting conditions of true or false.

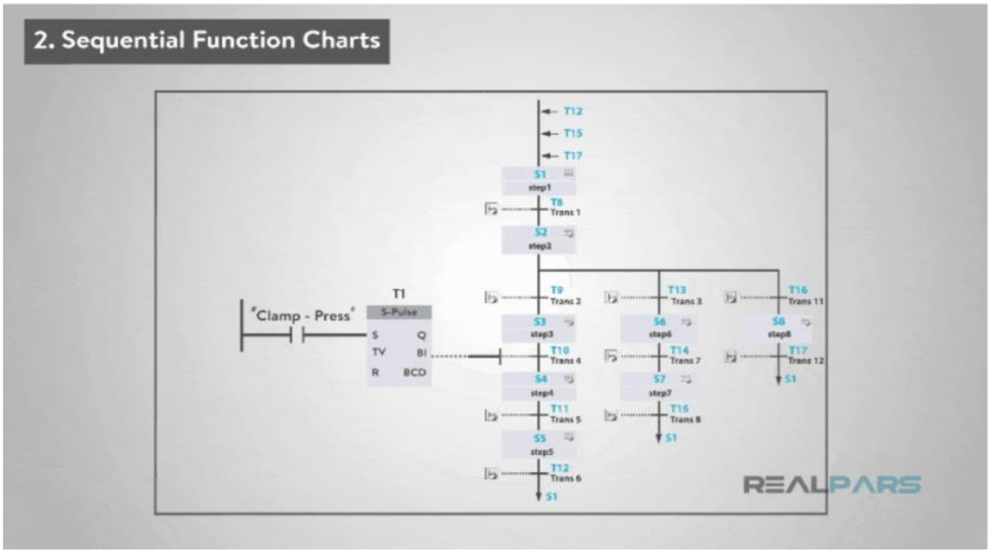


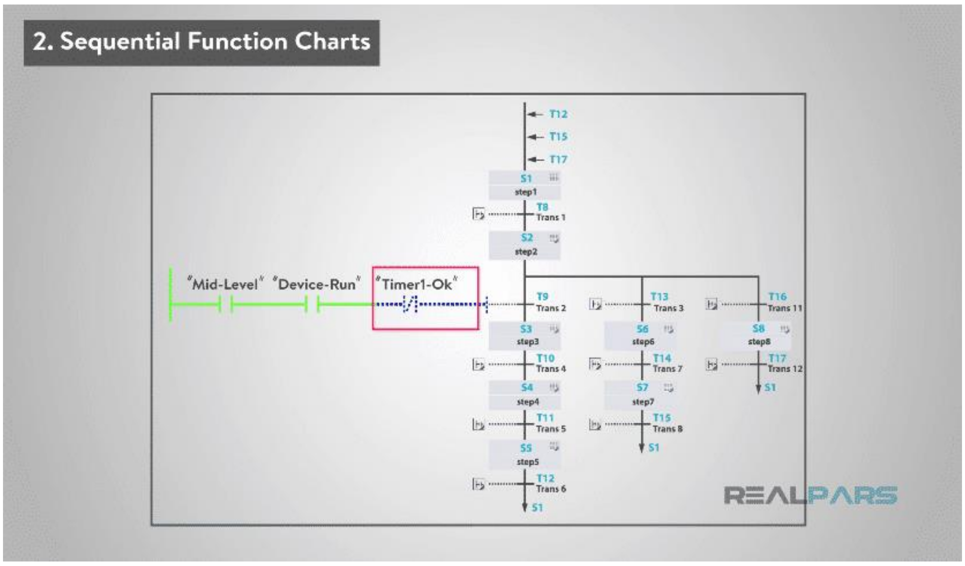
Unlike traditional flowcharts, Sequential Function Charts can have multiple paths. You can use branches to initiate multiple steps at one time.

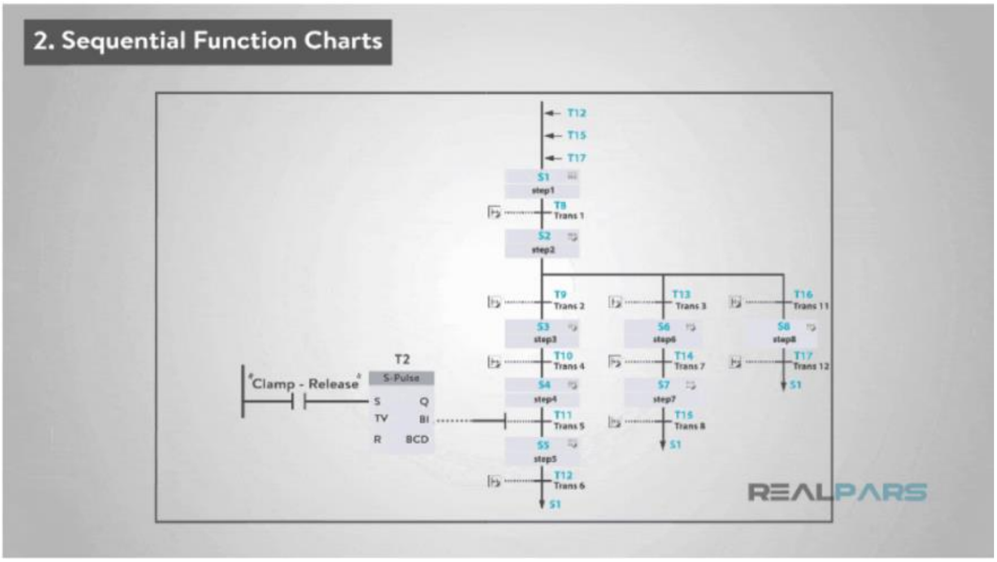


4.1.3.1 Sequential Function Charts Advantages

1. Processes can be broken into major steps that can make troubleshooting faster and easier.
2. You have direct access to the logic to see where a piece of equipment faulted.
3. It can be faster to design and write the logic due to the ability to use repeated executions of individual pieces of logic.





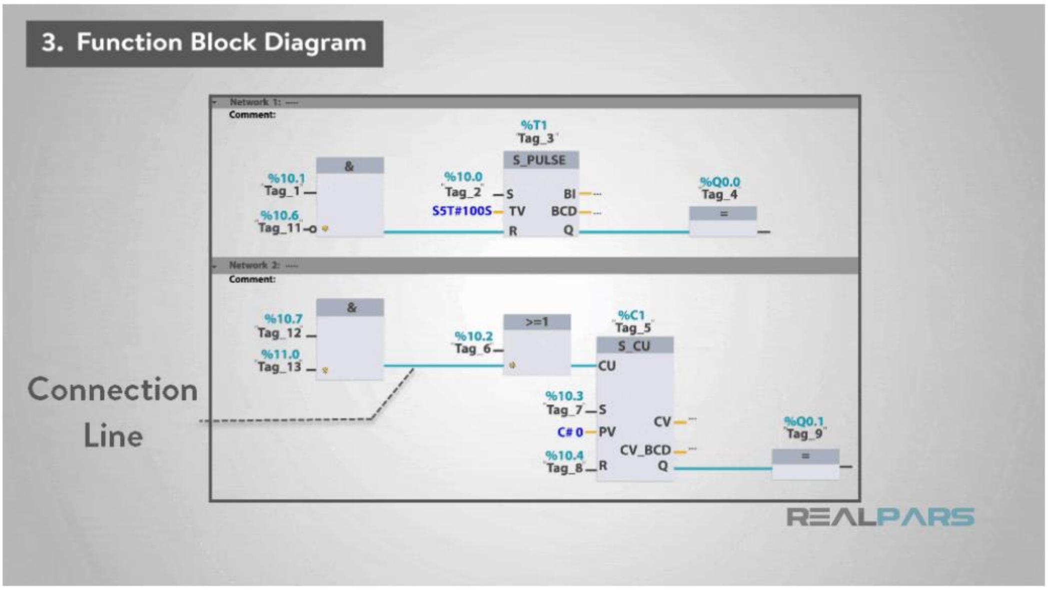


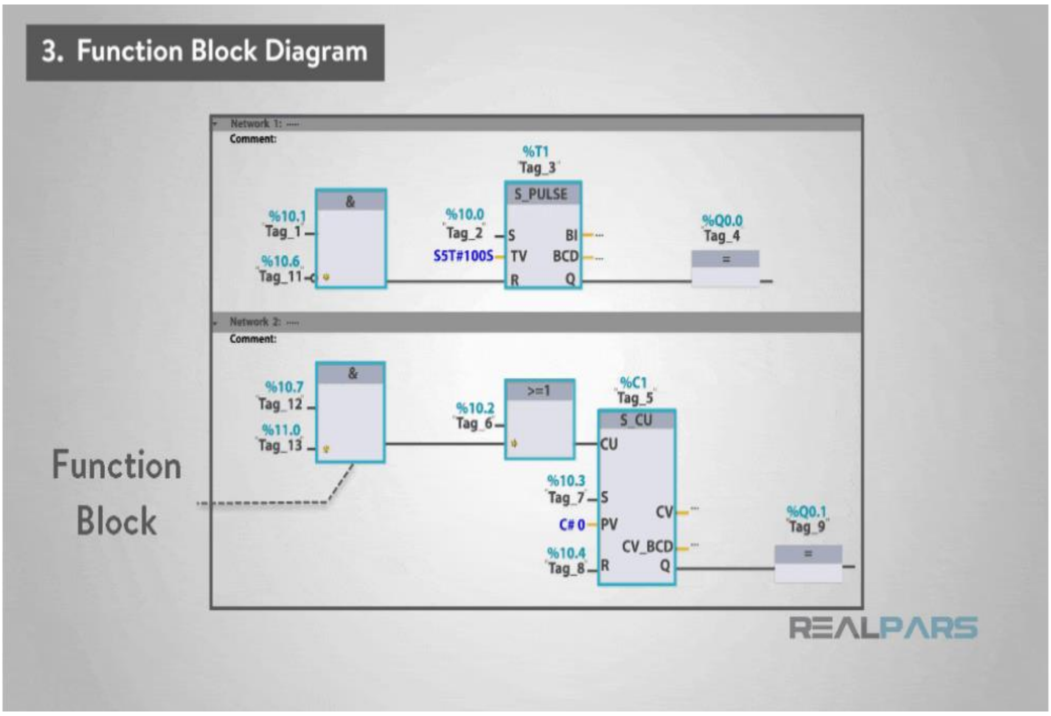
4.1.3.2 Sequential Function Charts Disadvantages

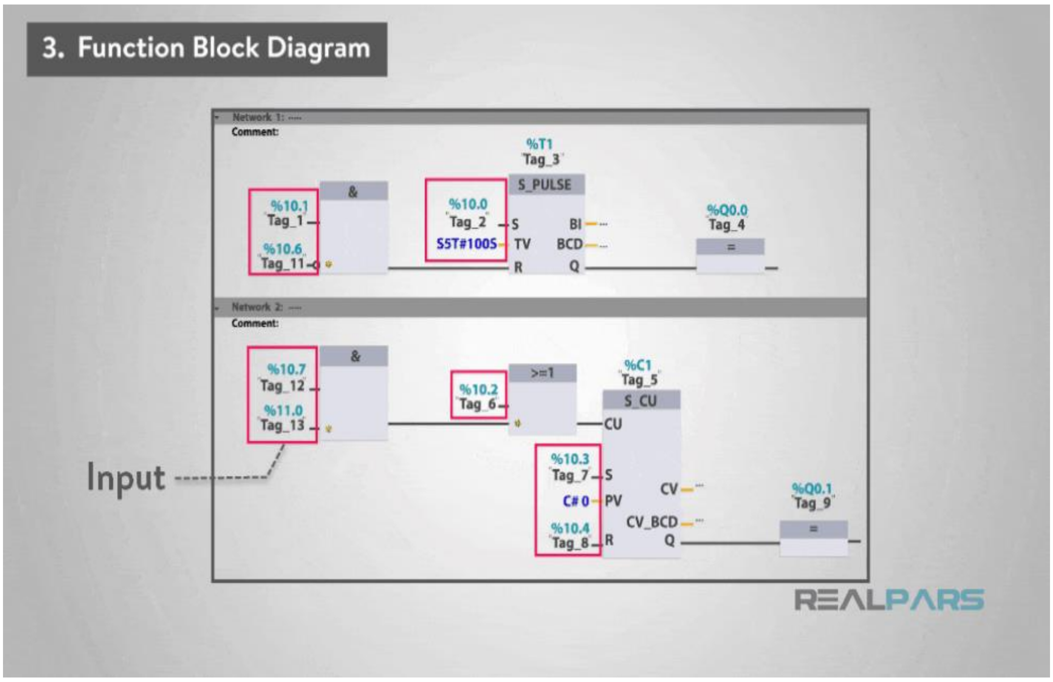
Even when you consider the advantages of the Sequential Function Charts, this PLC Programming Language does not always fit every application.

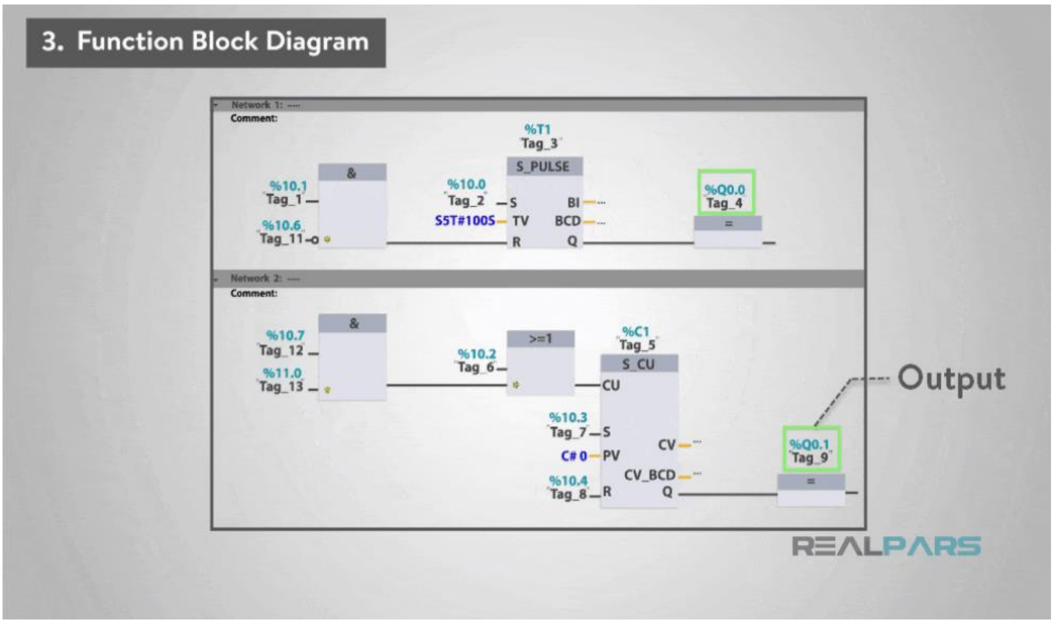
4.1.4 Function Block Diagram (FBD)

The Function Block Diagram is also a graphical type of language. The Function Block Diagram describes a function between inputs and outputs that are connected in blocks by connection lines.

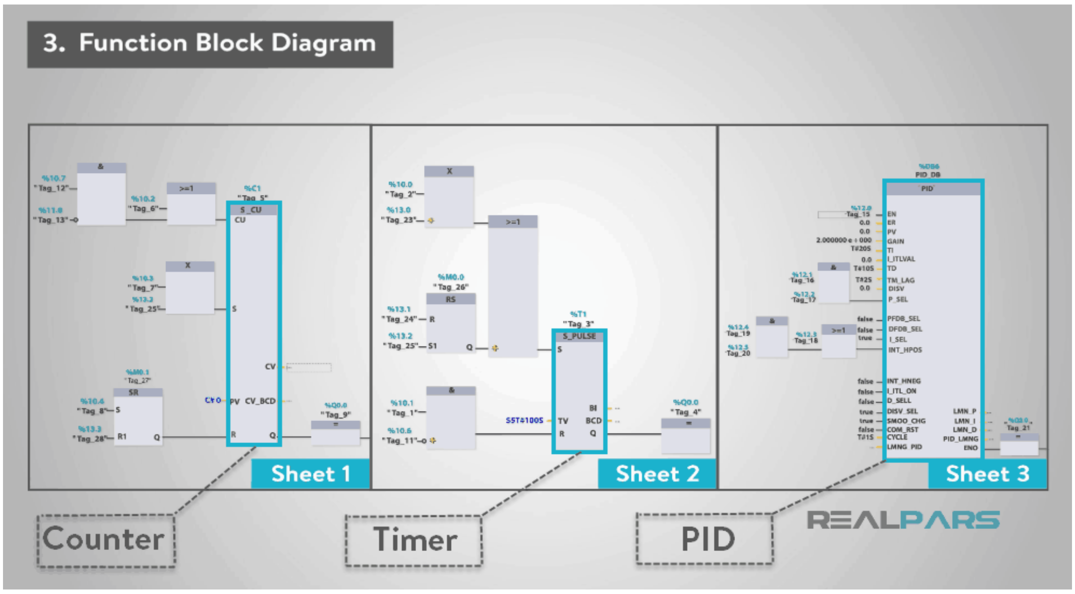

3. Function Block Diagram
Connection Line
REALPARS


3. Function Block Diagram
Function Block
REALPARS





Function Blocks were originally developed to create a system where you could set up many of the common, repeatable tasks, such as counters, timers, PID Loops, etc.
You program the blocks onto sheets and then the PLC constantly scans the sheets in numerical order or is determined by connections which you program between the blocks.



4.1.4.1 Function Block Diagram Disadvantages

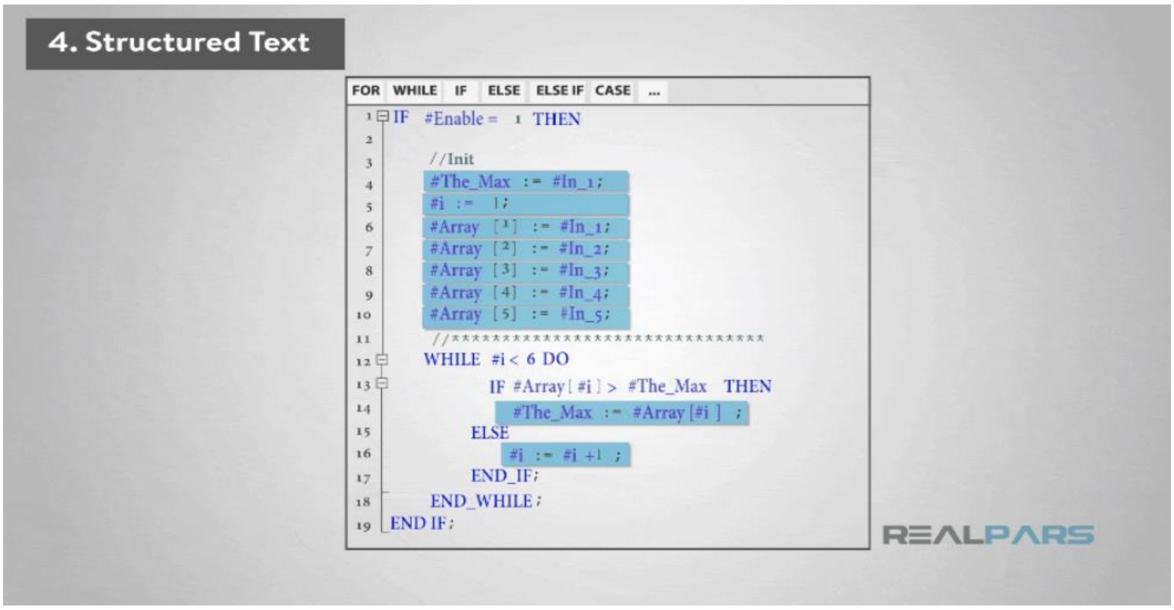
The code can get disorganized using this PLC Programming Language because you can place the function blocks anywhere on the sheet. This can also make it more difficult to troubleshoot.

4.1.4.2 Function Block Diagram Advantages

1. The Function Block Diagram does work well with motion controls.
2. The visual method is easier for some users.
3. The biggest advantage of a Function Block Diagram is that you can take many lines of programming and put them into one or several function blocks.

4.1.5 Structured Text (ST)

The 4th PLC Programming Language is Structured Text. This language is textual based.
Structured Text is a high-level language that is like Basic, Pascal, and “C”.
It is a very powerful tool that can execute complex tasks utilizing algorithms and mathematical functions along with repetitive tasks.
The code uses statements that are separated by semicolons and then either inputs, outputs, or variables are changed by these statements.
You must write out each line of code and it uses functions such as FOR, WHILE, IF, ELSE, ELSEIF, AND CASE.

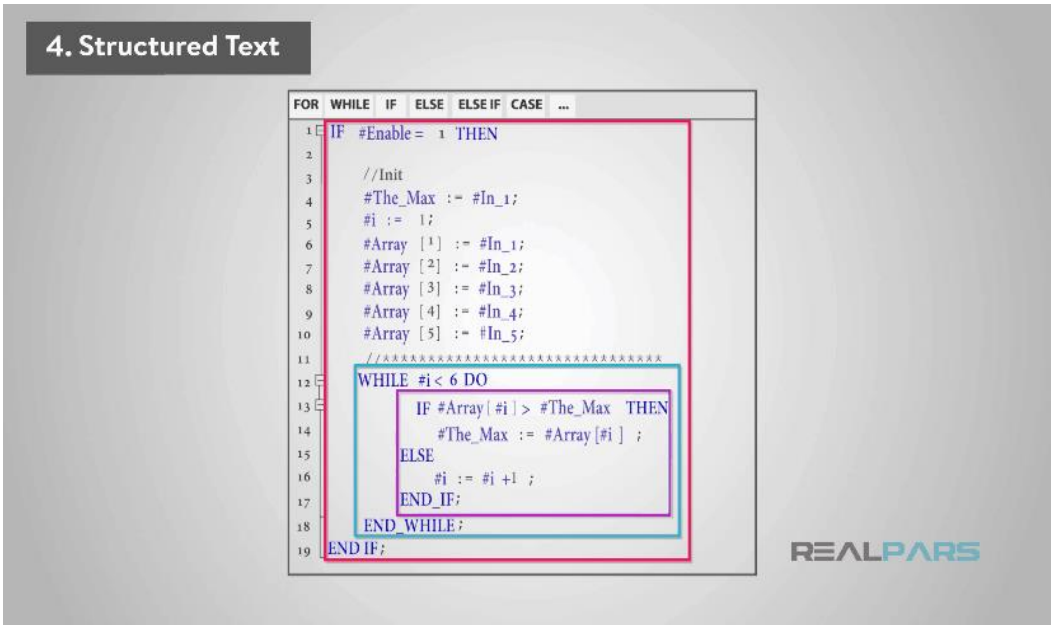


4.1.5.1 Structured Text Advantages

1. It is very organized and good at computing large mathematical calculations.
2. It will enable you to cover some instructions that are not available in some other languages like the Ladder Diagram.

4.1.5.2 Structured Text Disadvantages

1. The syntax can be difficult.
2. It is hard to debug.
3. It is difficult to edit online.

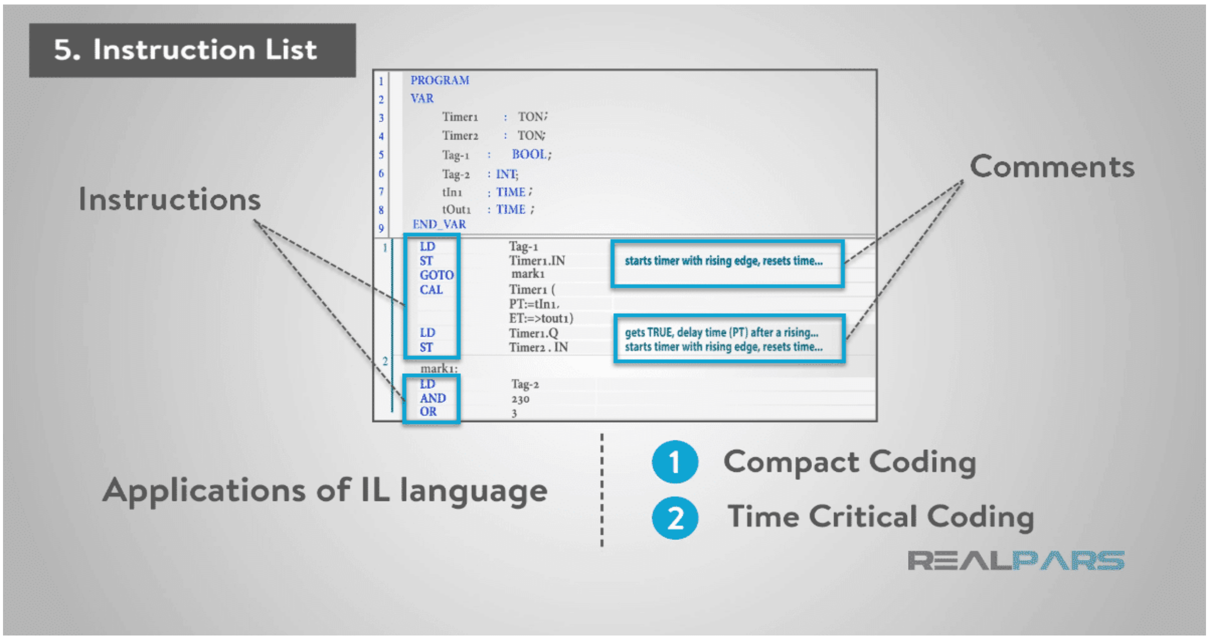


4.1.6 Instruction List (IL)

I will now show you the 5th and final PLC Programming Language which is Instruction List. The Instruction List is also a textual-based language.
The Instruction List language resembles Assembly Language. When you use this PLC Programming Language, you will use mnemonic codes such as LD (Load), AND, OR, etc.
The Instruction List contains instructions with each instruction on a new line with any comments you might want to annotate at the end of each line.

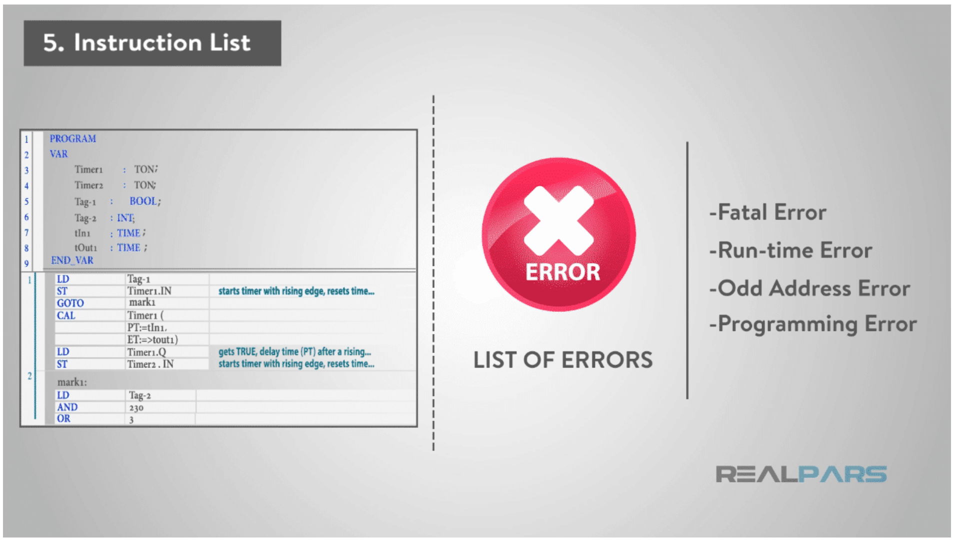
4.1.6.1 Instruction List Advantages

The Instruction List language is valuable for applications that need code that is compact and time-critical.



4.1.6.2 Instruction List Disadvantages

1. There are a few structuring possibilities with the “Goto” command being one of them.
2. There can also be many errors that are more difficult to deal with in comparison to many of the other languages that I have previously reviewed.



Note that: - The Ladder Diagram is by far the most popular PLC programing language. The main reason for this is that the Ladder Diagram language naturally followed the technological advancement from a physical relay logic to a digital and logical one. This allowed the engineers and skilled workers to follow and troubleshoot and make that transition. In summary, there is certainly a place for all the PLC Programming Languages that we have reviewed. Your background, experience, and the application you are working with are going to be the key to which PLC Programming Language you choose.

4.2 PLC Programming Software Tools

A PLC programming software is used to create a program or instructions for a PLC. The created program will be loaded into the PLC program memory; this program would contain certain instructions to implement functions such as timing, counting, etc. By using a PLC, we can control a lot of processes in an industry, we can do on/off control, sequential control, motion control, and a lot more with the help of a PLC. To program PLCs, various software tools are available from the PLC manufacturers. Common PLC programming software includes:

PLC Software	PLC Model	PLC Brand	OS Support	Programming language supported
Tia portal	S7 300, S7 1200, S7 1500	Siemens	Windows	Ladder diagram, functional block diagram, statement list, and structured text
Simatic step7	S7 300, S7 400, S7 1200	Siemens	Windows	Ladder diagram, functional block diagram, statement list, and structured text
RSlogix 5000	Compact Logix 5480,5380, and 5370	Allen Bradley	Windows	Ladder diagram, functional block diagram, statement list, and structured text
GX-Developer FX	MELSEC FX PLC series, MELSEC Q-series	Mitsubishi PLC	Windows	Ladder diagram, sequential function chart, and functional block diagram
Unity pro	Modicon m340, Modicon m580	Schneider's PLC	Windows	Functional block diagram, ladder logic, instruction list, structured text, and sequential control
Machine expert basic	ModiconM221, M100, and M20	Schneider's PLC	Windows	Ladder diagram, structured text, and instruction list
Twido suite	Twido PLC	Schneider's PLC	Windows	Ladder diagram, and Instruction list
CX programmer	Omron CJ2, CP1L,CP1H, CP2E, CP1E, and CS1D	Omron PLC	Windows	Structured text, Sequential functional block, and ladder logic.

These software tools provide an Integrated Development Environment (IDE) for PLC programming, simulation, and configuration of the PLC hardware. They also allow communication with the PLC hardware for program download and monitoring of PLC operation.

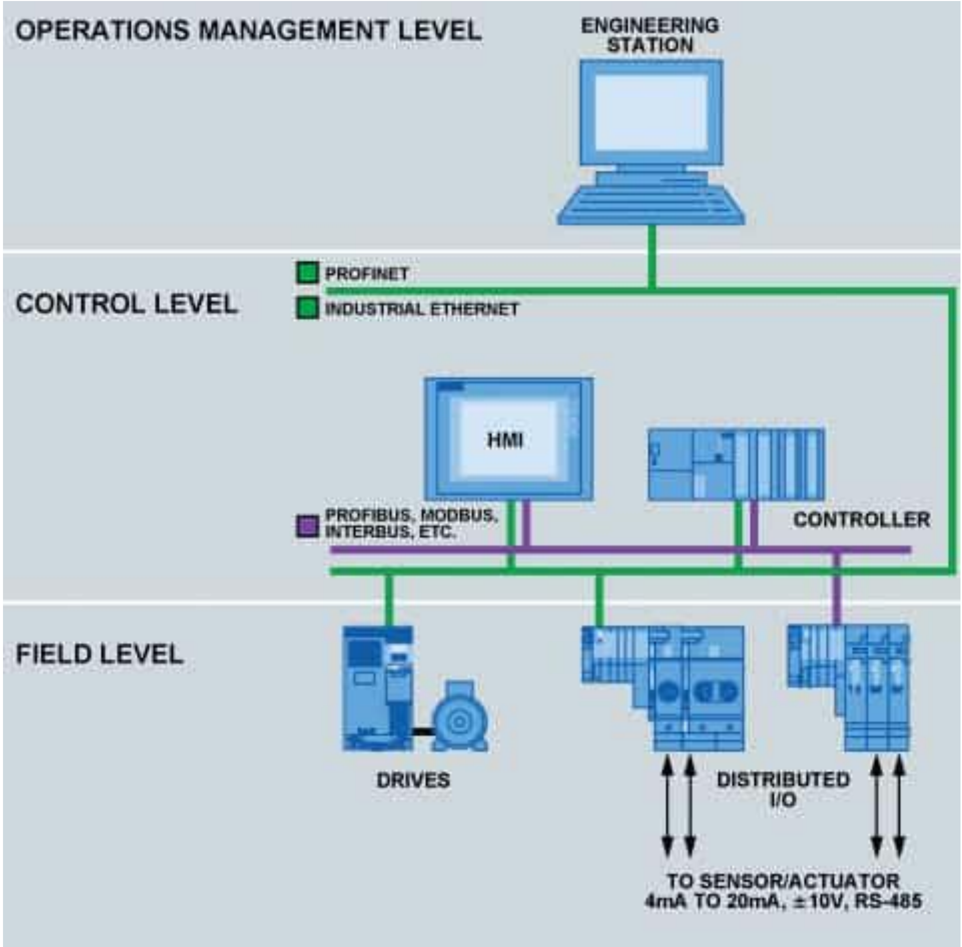
4.3 PLC communication protocols

4.3.1 What is an industrial communication network?

An industrial communication network is a backbone for any automation system architecture as it has been providing a powerful means of data exchange, data controllability, and flexibility to connect various devices.
These networks, which can be either LAN (Local Area Network, which is used in a limited area) or WAN (Wide Area Network which is used as a global system) enabled to communicate vast amounts of data using a limited number of channels. Industrial networking also led to the implementation of various communication protocols between digital controllers, field devices, various automation-related software tools, and also to external systems. As the industrial automation system becomes complex and large with more automation devices on the control floor, today, the trend is toward Open Systems Interconnection (OSI) standards that permit to interconnect and communicate of any pair of automation devices reliably irrespective of the manufacturer.
industrial communication network is a special type of network made to handle real-time control and data integrity in harsh environments over large installations.

4.3.2 Hierarchical Levels in Industrial Communication Networks

Different levels have to handle different requirements of a particular level. So it is obvious that no single communication network address requirements needed by each level. Hence different levels may use different networks based on the requirements such as data volume, data transmission, data security, etc. Based on the functionality, industrial communication networks are classified into three general levels.



4.3.3 What are networking protocols used in Industrial Automation?

We all know the typical definition of communication protocol. The communication protocol is a set of rules that govern data communication.
By using the communication protocols, two devices connect and communicate with each other.
When PLC modules are connected over the network, standard communication protocols are used. The different types of standard communication protocols support different speeds (baud rate), distances (network length), and the number of connecting devices (nodes).
The different types of communication protocols are used for the automation of processes in PLC.

1. Ethernet/IP
2. Modbus
3. Profibus
4. MPI
5. Optomux
6. DF-1
7. Interbus
8. HostLink

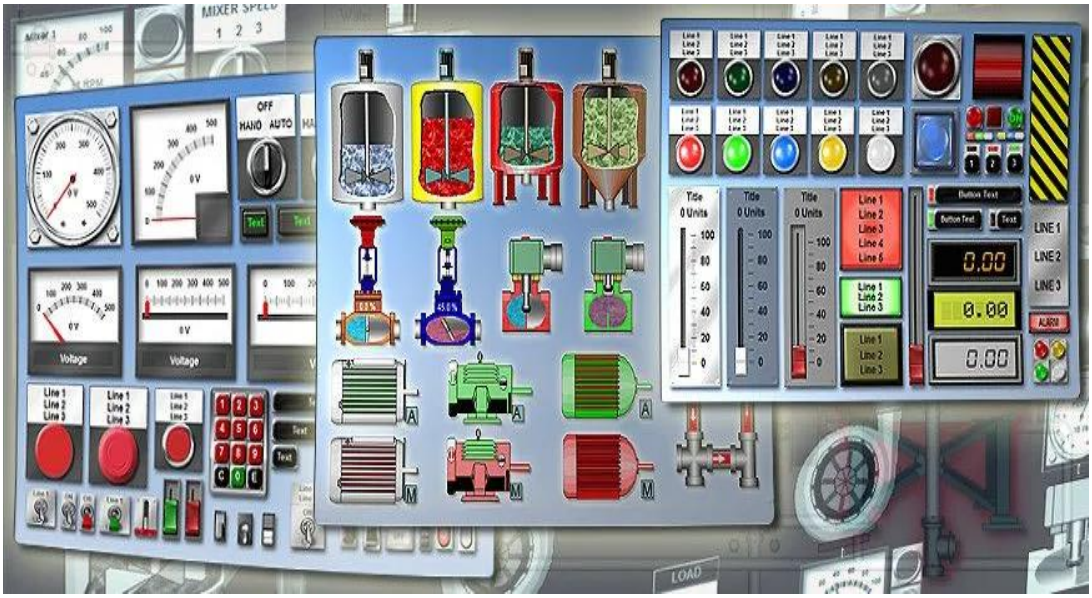
9. Data Highway (DH+)
10. Point to Point (PP)
11. Actual Sensor Interface (ASI)
12. Open Smart Grid Protocol
13. CAN (Controller Area Network) Open
14. HART (Highway Addressable Remote Transducer)

#	Protocol/Cable	Baud Rate	Length	Node
01	Ethernet	100 Mb/s	(Few Km)	255
02	Profibus	5-12 Mb/s	15 Km	127
03	MPI	19.2- 38.4 Kb/s	50 m	32
04	PPI	187.5 Kb/s	500 m	1
05	DH	230.4 Kb/s	3.048 Km	64
06	Control Net	5 Mb/s	30 Km	
07	Device Net	500 Kb/s	0.487	64
08	USB Adapter	57.6 Kb/s	10 m	1
09	PC Adapter	9600 Kb/s	15 m	1
10	RS-232	19.2 Kb/s	10 m	1
11	RS-485	10 Kb/s	1.2 Km	32

4.3.4 Which PLC communication protocol you should use?

- If you want to communicate with a more number of nodes with more speed, Ethernet is the best choice. You can read detail about Ethernet.
- If your network has a length of more than 25 Kilo-meter, you should use the Control Net protocol.

4.4 What is SCADA software?



SCADA software is an integrated development environment that allows the creation of SCADA HMI applications. Several SCADA software from various manufacturers is available, with significant differences in price and performance. The choice of the SCADA software most suitable for the application to be developed depends on several factors, as well as personal preferences, but is generally based on the complexity of the project, the required performances, any constraints imposed by the client, and the available budget.
You should also consider the learning time, which is usually higher in the case of more complex SCADA software. As a general rule, the choice of complex SCADA software is justified when the project involves a large and high-cost plant, for which software cost and learning time are no longer relevant. in the case of small-to-medium projects with a limited budget, it is advisable to move towards SCADA software that has a lower cost and requires a shorter learning time.

4.4.1 Types of SCADA Software

4.4.1.1 The first difference concerns the type of software platform:

- Dedicated platforms, consisting of software developed to supervise a particular machine or a particular plant. They can be developed by the same manufacturer which also supplies the machine to be supervised or by a software house based on specifications provided by the customer to carry out, for example, the supervision of a plant. Even if the operator can modify the configuration parameters and the process recipes, this supervisory software finds its main limitation in the impossibility of growing or adapting to the different conditions of use not initially foreseen.

- Open platforms, consisting of software that provides the user with an integrated development environment for creating SCADA applications, i.e., making available the tools necessary to manage the typical functions of a SCADA application (protocols for communicating with field devices, graphics libraries for creating templates, etc.). In this case, the software is structured in two levels: a first level, common to all users, consisting of the SCADA platform, and a second level, typical of the machine or plant to be supervised, consisting of the SCADA application created by the user. The big advantage of the open platform over the closed platform is that it gives the user total freedom to expand or modify the project.

4.4.1.2 A second difference concerns the architecture of the SCADA system:

- System consisting of a single supervisory PC connected to the field devices. It is the most common case, which is not necessarily the simplest. You can have very complex SCADA systems, with several plants to be supervised, which are distributed over geographical areas distant from each other; just as the complexity of the system is affected by the number of variables to manage (from a few units to tens of thousands of tags), the variety of connected field devices, the different communication protocols. In the simplest cases, when the SCADA system consists of a single PC connected to a single machine (usually controlled by a single PLC), we also speak of SCADA-HMI.

- Systems made up of multiple supervisory PCs connected via a local network (LAN) or a public network (Internet) and distributed on multiple hierarchical levels. The most common system is characterized by multiple PCs at the same hierarchical level connected to a central PC; second-level PCs differ based on geographical characteristics (each PC belongs to a different geographical area) or functional (each PC manages a particular function); the central PC makes all the information available from a single location.

4.4.1.3 Finally, a third difference concerns the real-time requirements:

- Classic SCADA systems without particular real-time requirements. The main function is to acquire information from the process, to provide a summary view of the status, promptly report the occurrence of alarms, record all information, and generate reports for production or quality managers. The sending of data to the field devices is usually limited to the configuration of the system or the sending of processing recipes; even when SCADA software performs process control functions, it is acceptable that delays of more than one second can occur.

- SCADA systems are characterized by strict real-time requirements. These are usually systems made up of several microcontrollers connected to the supervisory PC via a local network, with deterministic operating systems capable of ensuring response times in the order of thousandths of a second. In these cases, we speak more properly of DCS systems, much more expensive both in terms of development costs and operating costs, the use of which is justified only in the case of large plants that require exceptional performance in terms of reliability and safety.

4.4.2 Choice of SCADA Software

The choice of SCADA software to use depends on various factors, as well as personal preferences, but in general, it is conditioned by the complexity of the application to be developed, the required performances, any constraints imposed by the customer, and the available budget. It is also necessary to take into account the learning time, which is much longer, the more complex the SCADA software is. In general, we can say that the use of complex SCADA software is justified when dealing with large-scale systems, with such a high cost as to make the cost of licenses and development times almost irrelevant; in the case of small or medium-sized plants and not particularly high cost, it is better to move towards lower cost SCADA software which requires less learning time. Limiting our analysis to the case of a not particularly complex application, with a single supervision PC connected to several field devices without stringent real-time requirements, we list the points to be analyzed to choose the most suitable SCADA software:

- Dimensions of the project: the first point to establish is the number of variables to manage (tag), where "tag" means an external variable, ie a variable exchanged with the field devices. The number of tags is important because it affects license choice, system response times, and development costs.

- Interface with field devices: it is necessary to verify that the SCADA software supports all communication protocols with field devices. Alternatively, an OPC (Open Platform Communications) Server is available to be installed on the PC, to allow communication via the OPC protocol.
- Connectivity with other software: check if the application is required to interface with other software such as MES or ERP; in these cases, the interfacing is usually obtained through the OPC UA Server and OPC UA Client protocols.
- Accessibility via browser: request that remote operators can access the server application via browser from fixed (Desktop) or mobile (Smartphone) devices.
- Interfacing with external DBMS: check if the application has to interface with external DBMS (MySQL, ...) to record data tables (Datalogger function) or to interact through particular instructions (API) that allow the execution of generic queries (SELECT, INSERT, UPDATE, …)
- Remote maintenance: the possibility for the operator to access remote devices (typically PLCs) using the SCADA as a "bridge", to program the remote devices without having a direct connection (fixed IP, DNS, or other).

The choice of SCADA software must always be made by balancing the desired performance with the overall costs, both in terms of the cost of licenses and learning and development times. The points listed above are not always all necessary and the best-performing products are not always the most suitable. Sometimes a less performing product can be more reliable and easier to manage as well as cheaper. Finally, it is always advisable to check the ability and availability of the SCADA software supplier to offer prompt and appropriate technical support.

4.4.3 Advantages of SCADA Software

SCADA applications are used today in most industrial fields and are an indispensable aid for all companies, regardless of size and sector of activity. SCADA software is the most suitable development environment for the easy and intuitive creation of complex SCADA applications.

SCADA applications provide several benefits, but having to highlight one in particular, we can say that they replace the man in carrying out many routine and tedious tasks, which increases productivity, provides faster management of alarms, and reduces the risk of potentially dangerous situations for the environment. More generally, we can say that SCADA applications:

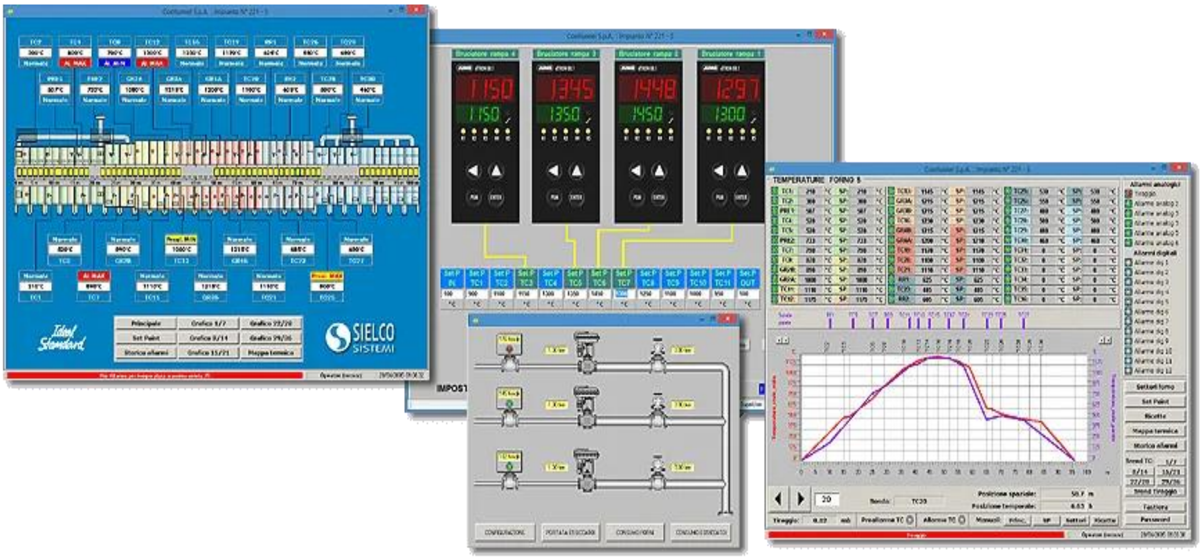
- Provide a large amount of information. All system status information, both acquired from the field sensors and provided by real-time control devices (PLC), is collected, saved, and made available for further processing, aimed at quality control, efficiency gain, and production optimization

- Provide a synthetic and clear picture of the production plant. A series of templates, that are part of the human-machine interface (HMI), provide the operator with a graphical picture of the whole process, its evolution over time, and the unexpected deviations (alarms). In this way, all information relevant to the process is translated into a visual language of easy understanding for the operator.

- Can grow and adapt easily to the growth of the company. The modular and flexible structure of SCADA software makes it possible to adapt to the different situations that arise when the company needs to grow or change, to respond to the challenges of a globalized market. The SCADA software includes, for example, all the development tools that allow modifying the SCADA application to provide communication with new devices, in a context characterized by a variety of transmission media and different communication protocols.

- Allow centralized control of remote units. Many companies, especially those that manage public service networks (water, electricity, etc.), are characterized by a structure distributed throughout the territory, which traditionally requires the fixed or programmed presence of technical staff for operation and maintenance. The SCADA application ensures remote control of peripheral units and allows technical staff to access all information with a simple browser.

4.4.4 Examples of SCADA applications



The development of SCADA applications begins within Industrial Automation, as a response to the request to centralize all the information related to the industrial process in a single control room, with special care to the aspects concerning the good operation of the industrial plant (maintenance and alarm management). SCADA applications are used in almost all sectors of Industrial Automation, from plastic to wood, from ceramics to food, and from textiles to packaging, providing a series of automatic supports aimed at optimizing the production process (quality control, compliance, returns, production reports).

In a short time, SCADA applications go beyond the boundaries of Industrial Automation and are used for remote control of public networks (electrical networks, water networks, railway networks, etc.), for building automation, and finally for home automation.

Below is a series of examples of SCADA applications; each example has a link to more information:

- **Supervision of low and medium voltage networks**: the possibility to select the most suitable contract among different energy providers make more and more convenient a supervisory system able to ensure continuous monitoring of power consumption and energy costs of low and medium voltage networks.

- **Quality control in metal heat treatment**: ensures the quality control for heat treatments in a plant division equipped with heterogeneous furnaces (multi-chamber furnaces, pit furnaces, tempering and hardening furnaces), replacing traditional paper recorders and creating production reports.

- **Wood stoves test system**: allows comparative tests on wood stoves working in different environmental conditions; temperatures are displayed as thermographic maps to provide a prompt and effective view of the thermal situation.

- **Supervisory control of a spinning plant**: makes it possible to produce polypropylene yarns in such a way as to guarantee that all product characteristics (torsions, title, tenacity, stabilization, color, ...) comply perfectly with technical specifications requested by the customer and can be reproduced even after months.

- **Monitoring of medical devices with controlled temperatures**: it has been installed in many hospitals and research facilities to ensure the continuous monitoring of local and remote equipment used for the conservation of organic tissues; the system generates periodic reports for Quality Certification, in compliance with the current laws.

- **Dust pollution level monitoring system**: it ensures continuous monitoring of the level of dust pollution, detected through triboelectric sensors, thus allowing to intervene on the plant before reaching the concentration limit values.

- **Supervisory control of a film production plant**: the system is applied to a plant for the production of films with a gas barrier, that combines the "cast film" and the "extrusion coating" technologies; it allows to control from a single point the operation of all parts of the multi-stage line, which includes a variety of machines and control equipment.

- **Quality control system in the food industry**: production and storage processes in the food industry are subject to specific laws related to quality control; the system gives the possibility to comply with the requested quality control criteria, limiting both the investment cost and the production loss during installation.

- **Supervisory control of ice cream production plant**: to comply with current rules and protect consumer safety, the system guarantees the quality of the pasteurization process, provides systematic control of the working status of the mixtures contained in the repining tanks, ensures the effectiveness of cleaning and sterilization.

4.4.5 Listed Top SCADA Software

- **InduSoft Web Studio** – The integrated development environment that allows you to design applications once and deploy them on almost any platform. Increase competitiveness and minimize costs through Portability, Mobility, and Interoperability in a cost-efficient solution.

- **Ignition SCADA** by Inductive Automation® combines an unlimited licensing model, with instant web-based deployment, and the industry-leading toolset for supervisory control and data acquisition (SCADA) — all on one open and scalable universal platform. Ignition is The New SCADA because it solves all the major pain points of old SCADA. Ignition empowers your business to easily control your processes, and track, display, and analyze all your data, without limits. Ignition SCADA software comes standard with a comprehensive set of data acquisition tools which includes built-in OPC UA to connect to practically any PLC, and the ability to seamlessly connect to any SQL database. Ignition can also turn any SQL database into a high-performance industrial historian and connects to IoT devices through MQTT.

- **Open Automation Software** -The OAS Universal Data Connector gives you unparalleled access to your industrial operations and enterprise data for connectivity, monitoring, analytics, and delivery. Connect directly to PLCs, OPC servers, files, databases, and IoT platforms to create world-class SCADA systems or industrial automation solutions. The OAS Platform offers data transport from any data source to any destination, while enabling data logging, data transformations, alarms and notifications, and cross-platform integration using SDKs for Windows, Linux, and Web applications. OAS is truly an unlimited IoT Gateway for industrial automation. Built upon a Distributed Network Architecture that enables advanced Edge Computing, reliability, and performance for IIoT, the OAS Platform can be deployed in infinite configurations to meet your needs. Interconnect OAS servers for load balancing, failover, data aggregation from remote clients, and more. Network clients, either over LAN, WAN, or the Internet can communicate directly with an OAS Platform server.

Chapter 5 System Components and Architecture

5.1 Overview

In this chapter, we will describe in detail the elements of the project in terms of mechanical development and process control of the replica

Starting with the exterior body of the replica which is made of steel that acts as the carrier of the glass tanks and the choice of steel was to provide enough solidity to carry the heavy tanks filled with water.

The side of the replica carries all of the electrical control equipment used in the process control. Wood was used to provide isolation for the electrical parts.

The last part of the exterior body is plastic fiber which is used to carry the tanks but of course, it is supported by steel.

5.1.1 The inlet tank

A 40x40 cm tank that provides the water representing the unclear water in real-life purification stations.

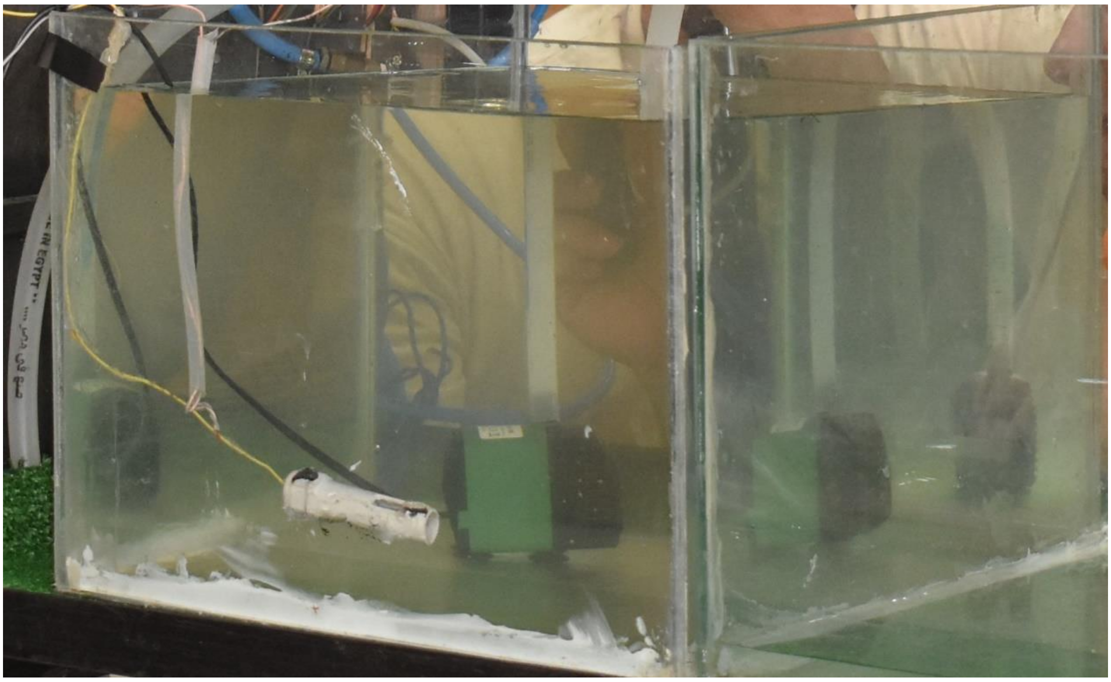
The tank contains a water pump that propels water throughout the replica.

We used a pump with the following specifications:

- Voltage:220-240V 50/60hz

- Power:10 watt
- H.max: 1.3 meter
- Q.max: 800 L/H
- Made by a corporation called SHARK.

The tank also contains a water detection sensor which is stuck to the side of the tank that is composed of a metallic bar that conducts electricity so when it is submerged in water it would send a signal to the PLC or the main controller that would be further used in the control process of the tank as it would deliver a piece of information to the PLC about the state of the water in the tank.



5.1.2 Chemical injections

When the water is propelled through the pipes on its way to the flash mixer a specified amount of chlorine is injected into the pipes, and it takes around 15-30 seconds after the injection of chlorine and before reaching the mixing phase.

Chlorine is added to eliminate living organisms like parasites or plankton.

The second injection is Alum which is used to catch non-living objects like dust and its sorts

The alum has positive and negative ions that attract and merge with all sorts of non-living unneeded objects.

To replicate the injection idea, we used to hang infusion bags for both chlorine and Alum.

The Alum and chlorine injection is controlled by liquid valves, so we could easily stop the injection when needed.

The injection process was made in the same order as a real treatment plant, since that the chlorine injection process takes around 6-8 seconds before it reaches the next phase.

5.1.3 Flash mixer pipes

The pipes connecting the raw water tank with the flash mixer where the chlorine is injected before the alum by a time difference range between (6 to 8) seconds which is controlled by water valves to control the flow of those chemicals, those valves are connected to the PLC to control them.

5.1.4 The flash mixer

The water flows through the tank from below the tank then the water is pushed to the top of the tank to be taken to the next phase of the project,

The stay time is a crucial quantity that represents the amount of time that the tank needs to be filled with water and in this time the chemicals that were added are being mixed preparing for the next step in the project.

The stay time depends on the size of the tank and the flow of the water.

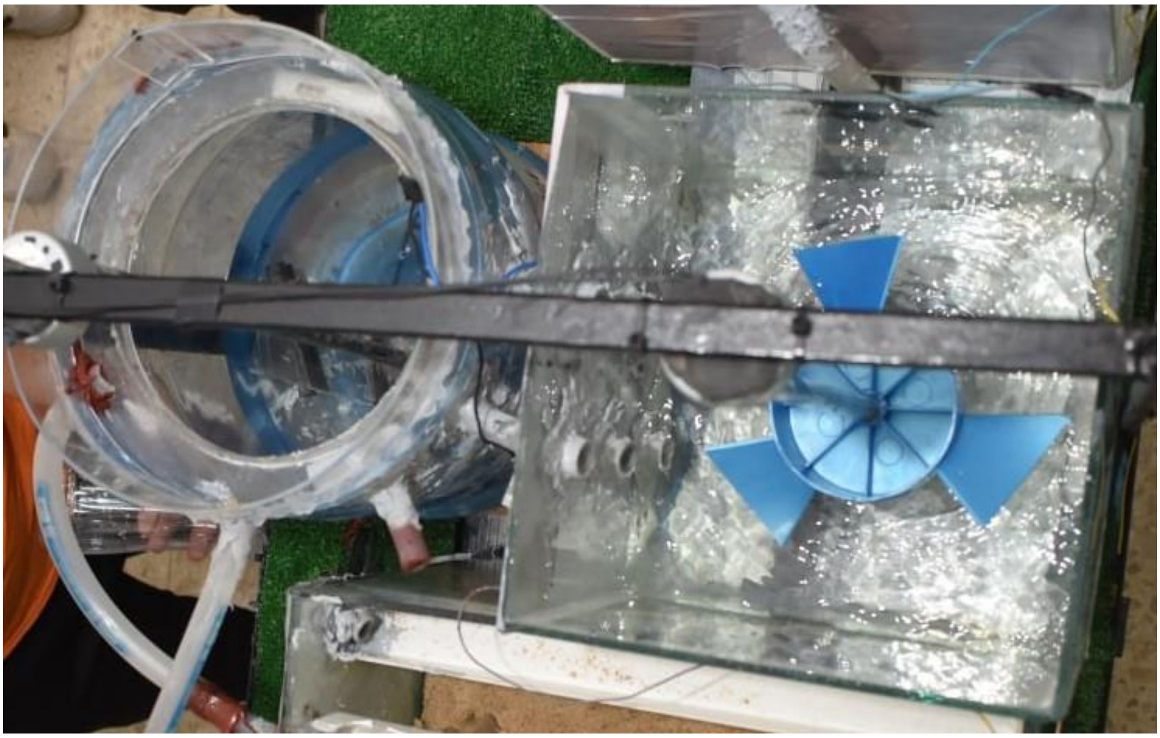
The mixer starts operation when the sensor is submerged with water indicating that the water has entered the tank, which in turn sends a signal to the PLC and then to the SCADA system, then the actuator starts functioning creating a rotation that mixes the water and the chemicals when the water reaches the top it flows through plastic conduits that have been cut in a special order shaped like a square wave-like form that allows the water to enter the conduits smoothly and drive it to a hose connected to the conduits that hose connects the water to the next phase of the project.

5.1.5 Coagulation and Sedimentation

Coagulation takes some time and needs slow mixing to be achieved. Due to the existence of Alum coagulant material is formed and precipitated in the bottom of the basin that later is driven to the sludge.

Sedimentation: The sedimentation process is known in the stages of treatment and purification of drinking water as the main procedure for the sedimentation of materials and plankton from the water and the preparation of water to enter the next stage, which is the filtration process.

Usually that basin operates about 15 minutes every 2 hours of the plant's operation.



coagulation and sedimentation

5.1.5.1 Coagulation

Coagulation is represented in our replica by using a glass tank in a lower plane than the previous tank so that water would flow smoothly to it.

The tank contains a slow mixer for the coagulation process and a water detection sensor to start the actuator when water is detected in the tank.

The tank is filled from below just like the previous one but the delivery to the next phase is different.

5.1.5.2 Sedimentation:

Through six parallel tubes, the water is driven to the sedimentation tank that contains an actuator that operates when needed to drive sediments to the sludge at a specified time, so that tank contains a water valve that opens when needed to deliver the sediments to the sludge.

The tank also contains a water detection sensor to perform the same function as the previous two sensors.

5.1.6 Filters

The filters in our project are made of glass tanks that were specially designed to handle filtering the water and washing the tank itself when it is blocked by sediment. We deployed two filters so that if one filter is being washed the other one would be working naturally parallel to each other.

Starting with the bottom of the filter where we deployed a perforate conduit that works perfectly in both directions whether it is washing the filter, or it is receiving filtered water from above.

At the same level, we deployed a perforate conduit that has the sole purpose of thrusting air through the filter when it is being reversely washed in a specified amount of time.

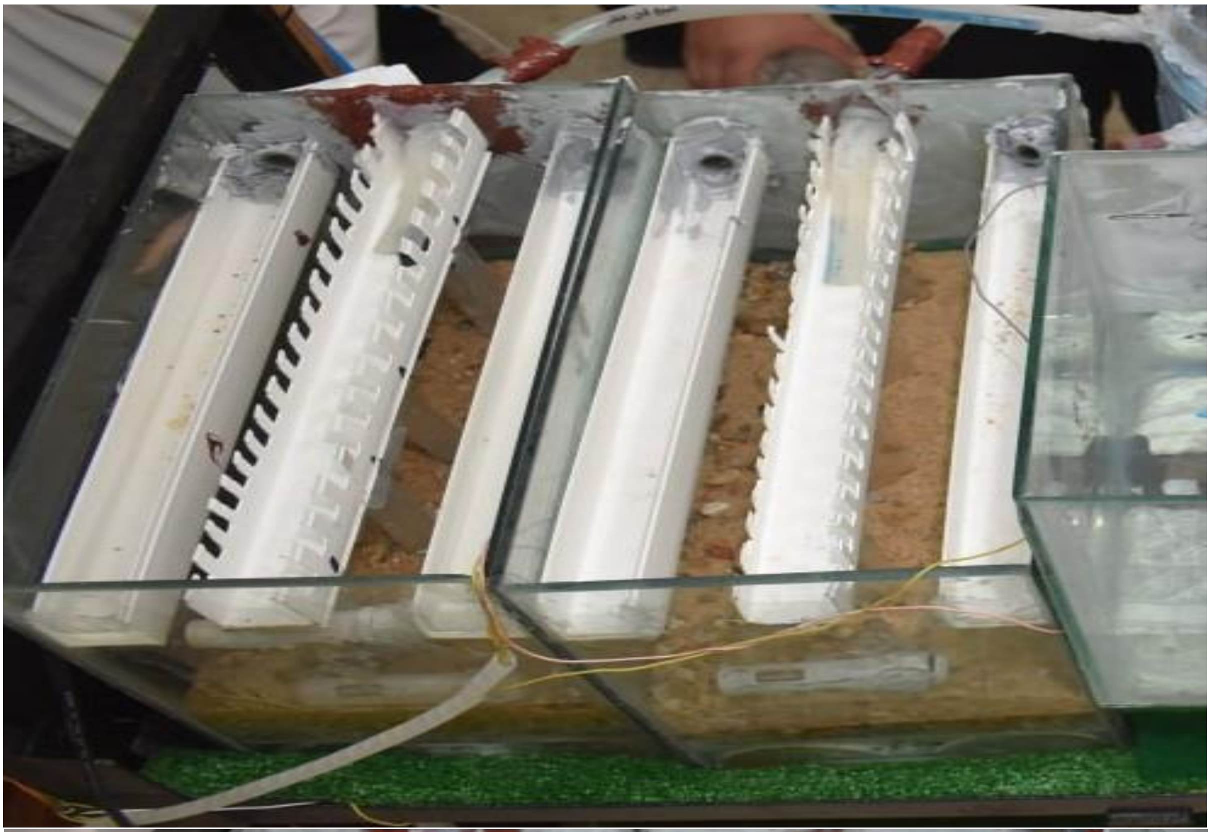
Right above those two conduits, we put two PVC shelter-like blocks that would protect the conduits from any of the filtering materials used in the process that might accidentally fall off and block the base conduits below it which is an unlikely scenario.

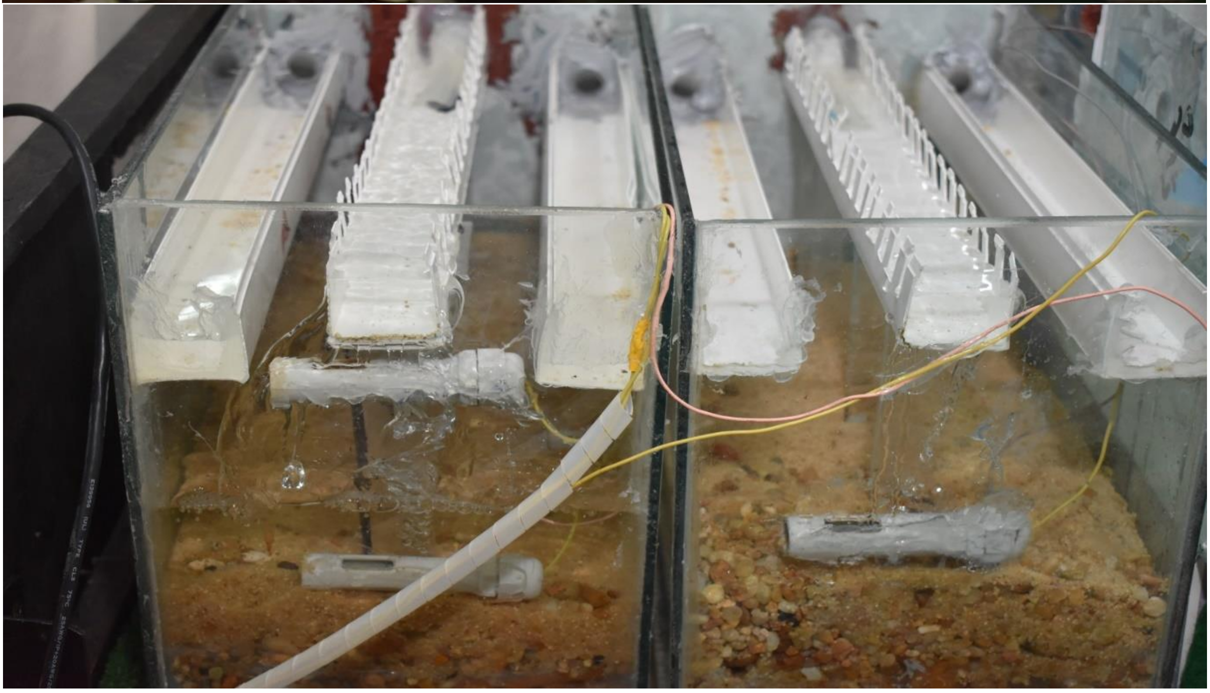
The next layer is a perforated fiber sheet that allows the water to flow through it but prevents the upper layers from falling apart.

Then comes the actual filtering layers from below we have three sizes of shingles ranging from larger ones at the bottom to smaller ones on the top and top of those shingles a layer of sand is deployed to fill all of the gaps in the shingles providing the best filtering results and a firm structure that filters and carries the water.

Right above the sand, we installed a low-level water detection sensor that delivers the indication of the water's arrival in the tank and a high-level water detection sensor that would start the reverse washing if the filters were blocked.

At the top of the filter, we installed PDS conduits designed to let the water fall in a distributed way so that it wouldn't dig a hole in the sand, and on both sides of the tank we installed conduits that would deliver the water to the sludge if the tank is being washed where both of them are merged into one pipe that drive the washing water to the sludge.





Washing the filter:

is simply done by supplying the filter with water and air from below we programmed it in a way that would let us specify the washing time from the SCADA system as we see fit.

If the high-level water detection sensor sends a signal to the controller it would then start the washing process done by both air and water.

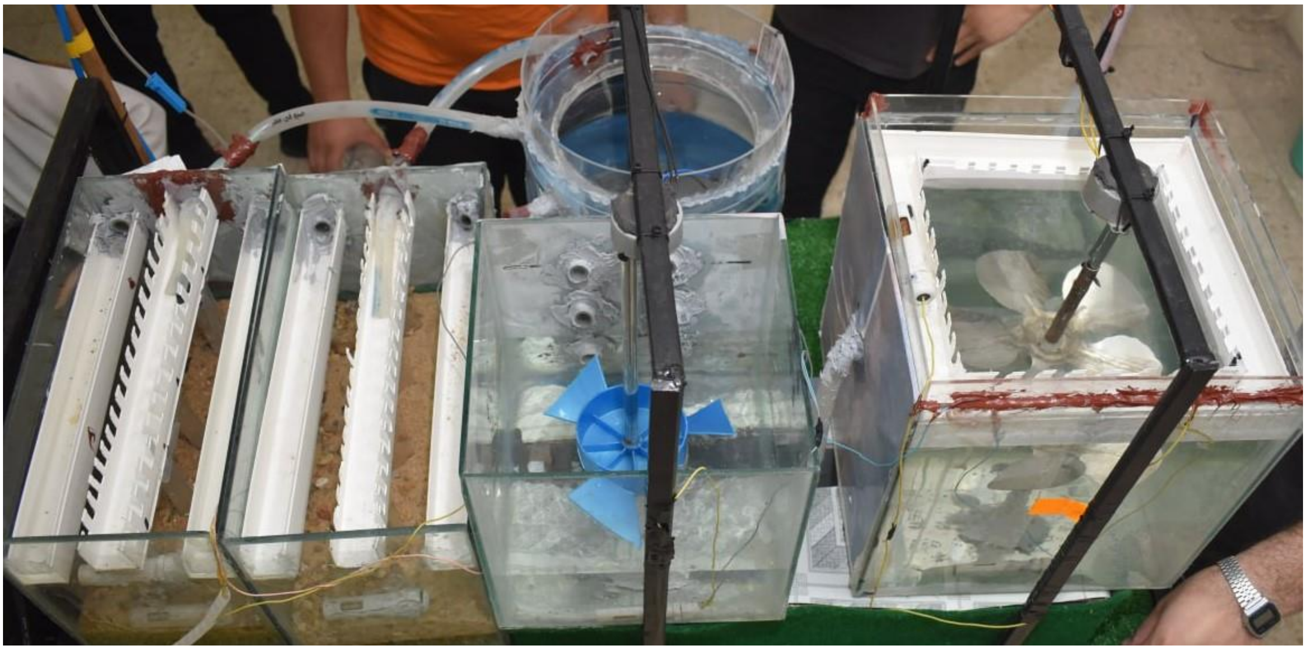
The time input to the SCADA system is divided into the following:

The first Sixth of the time is only air thrust through the water to break the layer formed by the sediment.

The second sixth is both air and water support to lift that layer and deliver it to the conduits of the sludge.

The remainder of the time is just water pushing that layer to the sludge conduits.

The water is propelled using a water pump that is submerged in the treated water tanks so that the washing would be done using treated and clean water on the other hand the air is thrust using an air compressor.



All clarifiers (Flash mixer, Coagulation, sedimentation, and filter)

5.1.7 The sludge tank

The sludge tank is considered a separate stage that doesn't have a specific order or depends on timing to operate.

The sludge tank collects all of the unneeded unclear water from either the clarifier or from the filters after they get washed.

The sludge tank has two sensors:

1- a low-level water detection sensor that indicates the arrival of water to the system.

2- a high-level water detection sensor that indicates that the sludge tank is almost full and as a result it must be emptied until the water reaches a level below the low-level water detection sensor.

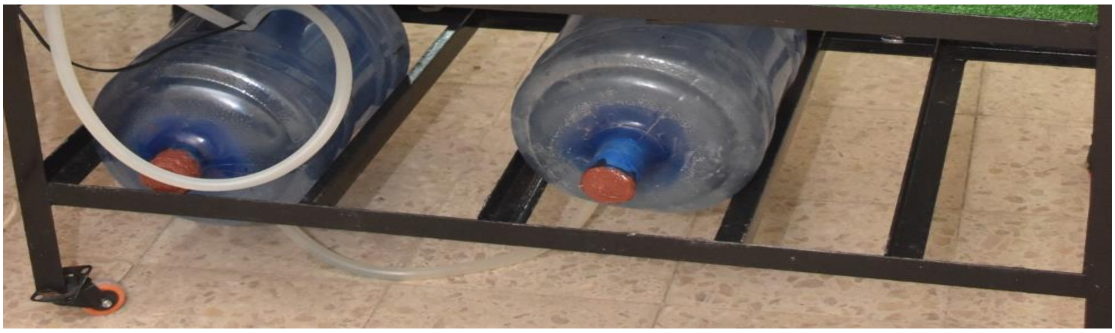
To control the operation of the emptying of the tank a water valve and a water pump are needed.

1- the valve that opens up when the water is at the level of the high-level sensor and closes when the water is below the low-level sensor which is all controlled by the PLC.
2- the water pump that would take the water away to the closest sanitation.

5.1.8 The final tank

The final tank receives the clean water that comes from the filters directly.

The very same tank contains a water pump that is used to wash the filters since the water used to wash the filters reversely must be clean.



5.2 Electrical Components

5.2.1 SIEMENS PLC 314C-2DP

Let’s start with the most important component in the system, which is the PLC.

We used SIEMENS PLC 314C-2DP.

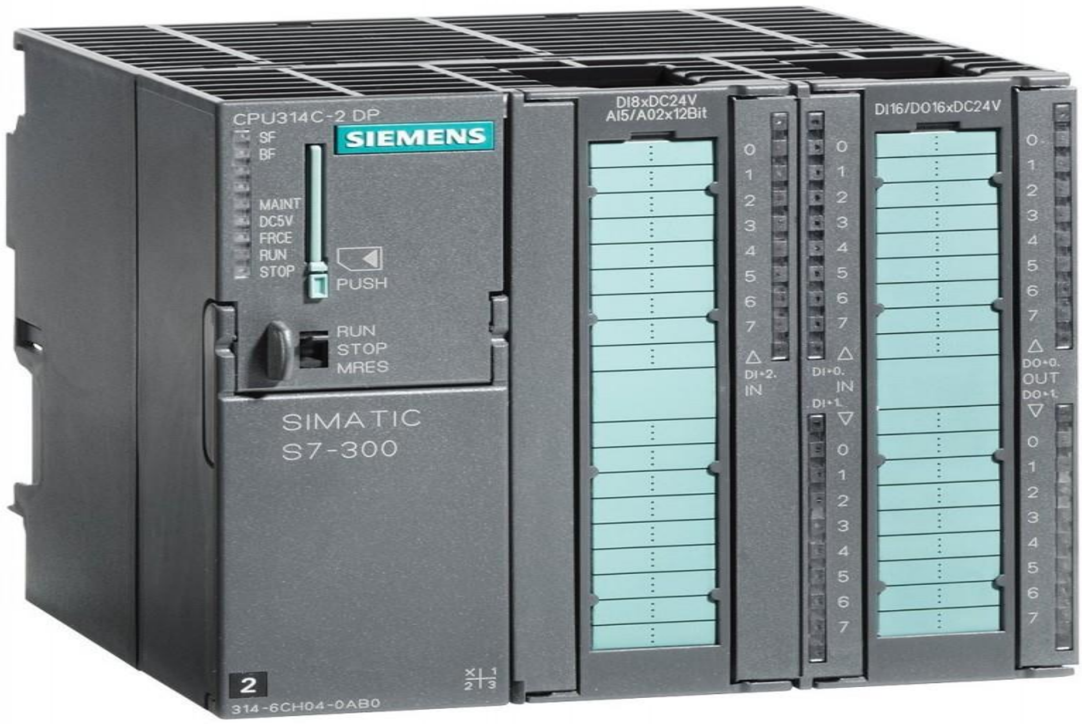
24 digital inputs – 16 digital outputs – 5 analog inputs – 2 analog outputs.

Operates on 24 DC voltage.

Contains a safety memory to protect the program loaded on it.

Contains two communication protocols:

1. MPI communication protocol which we used to connect the PLC to a computer.
2. Profibus which could be used for other communication purposes



5.2.2 The MPI communication cable

Which stands for Multi-Point Interface which is a proprietary interface of the programmable logic controller SIMATIC S7 of the company Siemens.

5.2.3 Power supply

It is a power supply that supplies 24 DC voltage after receiving 220 AC voltage so that it would supply the PLC and other 24-volt relays used.

It contains two supplying positive and negative points and line and neutral connections.

5.2.4 Panel components

5.2.4.1 relays

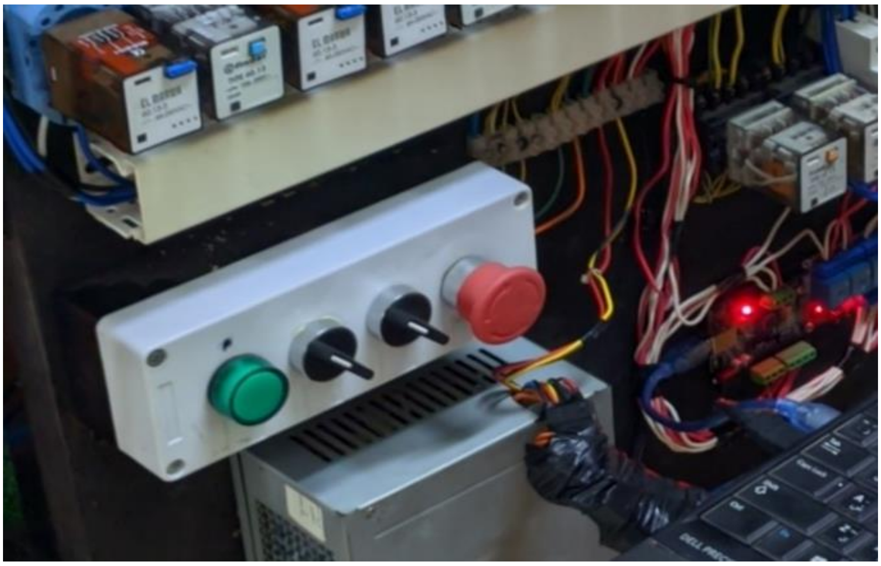
Relays are famous components in the field of industrial control, they are used as switches to control the actuators used in the system.

24-volt DC relays with 11 pins

24-volt DC relay

220-volt AC relay with 11 pins

220-volt AC relay



5.2.4.2 Buttons and switches:

1. on-off 220-volt AC switch
2. 220-volt AC emergency switch

5.2.4.3 LED lights

1. green LED 220-volt AC light as shown above
2. LED 220-volt AC light strips.

5.2.4.4 Water valves

220-volt AC water valve

5.2.4.5 Water pumps

220-volt AC water pump

5.3 Software

5.3.1 SIMATIC manager:

This software contains the Ladder program that controls the plant, and it also contains all the SCADA screens that graphically represent the plant and control it through the ladder program as well.

In the following image below, we can see the used blocks in the project:

OB1: stands for organizational block and it contains the ladder program of the project.

FC33: it is a Function block that converts the time value from the S5T#" time value in milliseconds" to an integer value

FC40: it is a function block that converts an integer value to S5T#" time value in milliseconds" which is basically the reverse operation of the FC33

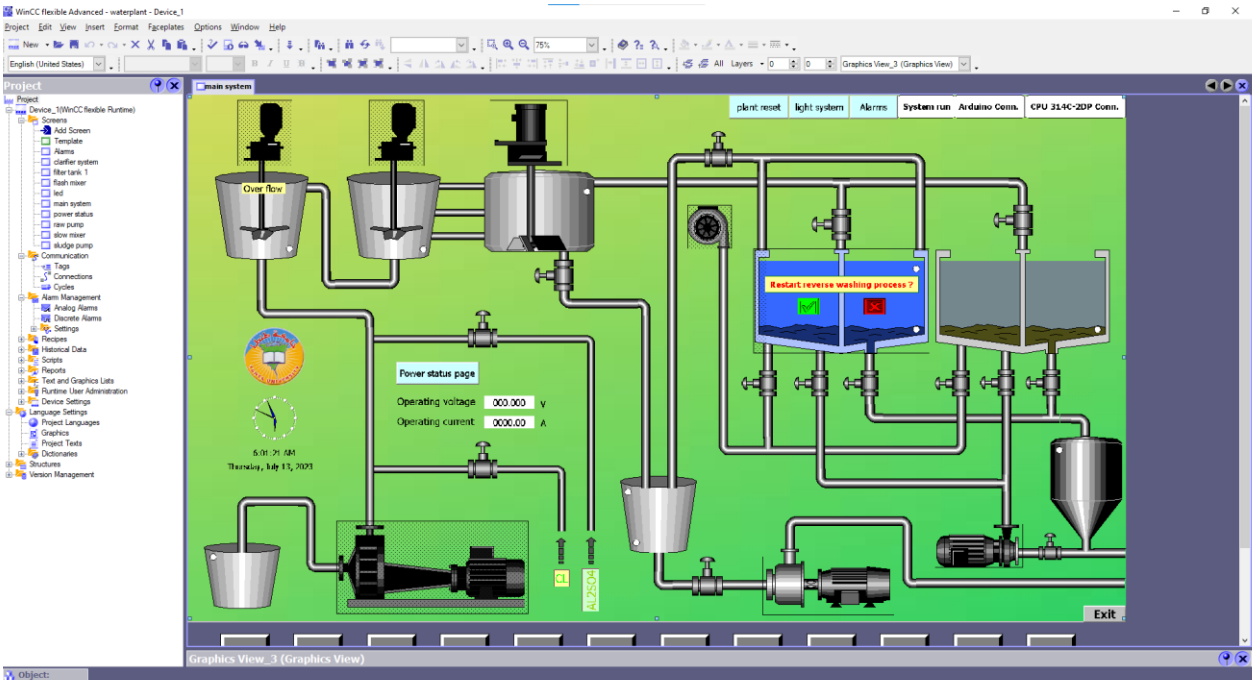
FC105: it is a function block that is used for linear scaling purposes.

That sums up all of the blocks used in the project.

5.3.2 WinCC flexible 2008 SP5:

It is the software used to develop the SCADA system as it is a graphical representation of the system and it can control the system if the PLC is connected to it.

The following image is a graphical representation of the system before running:



There are five buttons in the top right corner of the screen:

1-plant reset: this button stops the entire system and lets it operate again and only the admin is capable of doing so since there is a security password that must be entered to operate.

2-light system: this button shows the state of the LED lights in the system

3-Alarms: this button shows the state of the alarm system that we would describe in detail later on.

4-system run Arduino conn: this button shows the state of the Arduino connection that controls the ATS circuit.

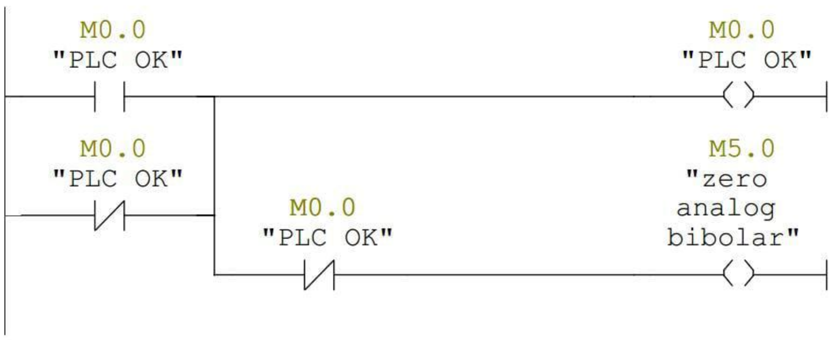
5-CPU 314C-2DP conn: that button checks the state of the PLC connection to the SCADA system

5.3.3 First Ladder Diagram

5.3.3.1 Network 1

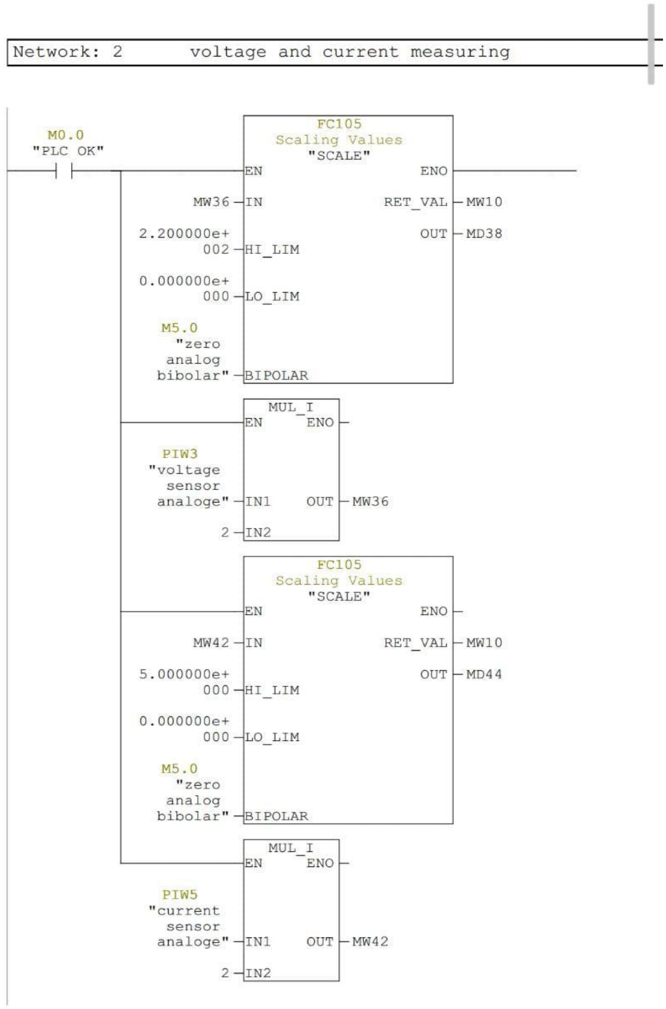
To make sure that the plc is working and connected to electricity, by recording this in the memory of the PLC M0.0, whether with a value of 1 or 0, to keep the operating state of the PLC it also activates the zero-analog bipolar.

Network: 1 PLC conn. for scada



5.3.3.2 Network 2

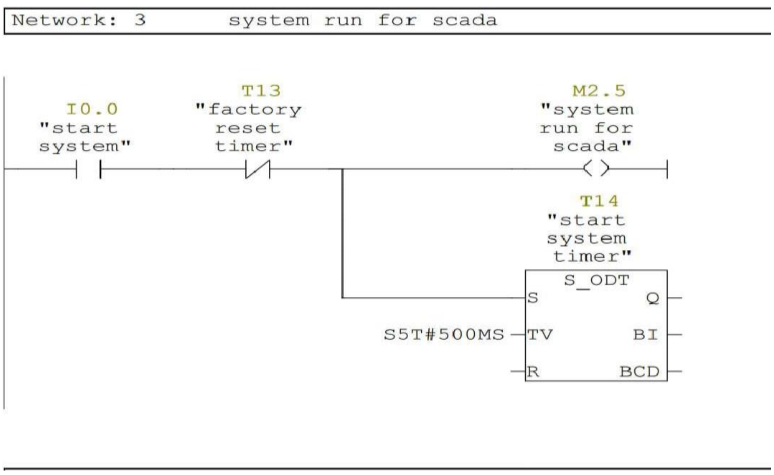
Measures the voltage and current in the project by doubling the value of the voltage read by the sensor to match the total voltage that ranges from 0 to 220 volts, and it also doubles the value of the sensor current to match the total current that ranges from 0 to 5 amperes.



5.3.3.3 Network 3

To start the system on the SCADA when it is running on the replica.

When the system "start" button is pressed and the "restart" button is not activated, the system start sign will appear on the SCADA after 5 seconds.

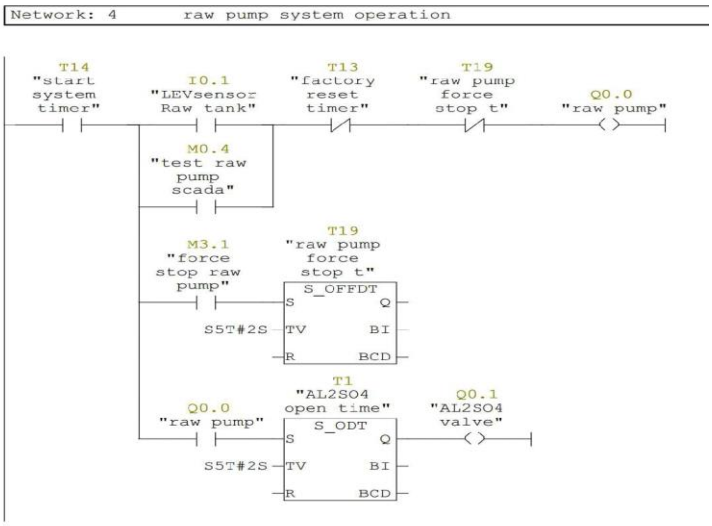


5.3.3.4 Raw pump:

- **Network 4**

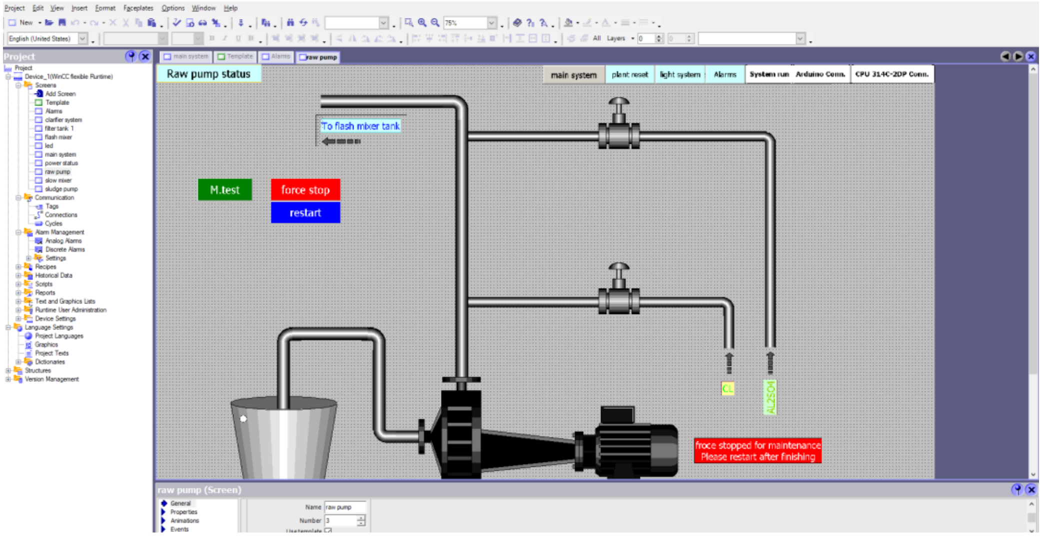
  To operate the raw water pump where the raw water pump is operated on a prerequisite if :

  - The system was started at the beginning.
  - And when the level sensor in the tank gives a signal that the water has reached it, or when a test of the raw pump occurs on the SCADA.
  - And when the restart or forced stop button is not activated
  - And the raw pump is stopped after two seconds of operating the forced stop button.
  - Then the alum valve is opened two seconds after the turbidity pump is turned on



- **In SCADA**

  the following image is a graphical representation of the raw pump in the first stage of the plant:



If the pump is not operating at any given time, its programmed color would be grey which receives zero from the memory word from the PLC ladder program.

If the pump receives the value 1 from the memory word it would be colored green, but the tank and the pipes would be colored blue, at this point the valves of the chlorine and alum would operate, and the arrows of those chemicals would be flashing indicating that they are being injected the chlorine valve and pipe would then turn light yellow and the alums would turn light green.

As we can see there are three buttons connected to the PLC using memory words which are:

M.test: that button temporarily tests the pump to check on its operational functioning which is done by sending a signal in the ladder diagram using a memory word to the pump's coil.

force stop: which stops the pump from operation and colors it yellow when the memory of that button has the value 1 that button can only be pressed by the admin since there is a needed authentication process.

Restart: which in turn starts the pump again after it is stopped by the force stop button and colors it green again.

5.3.3.5 The flash mixer:

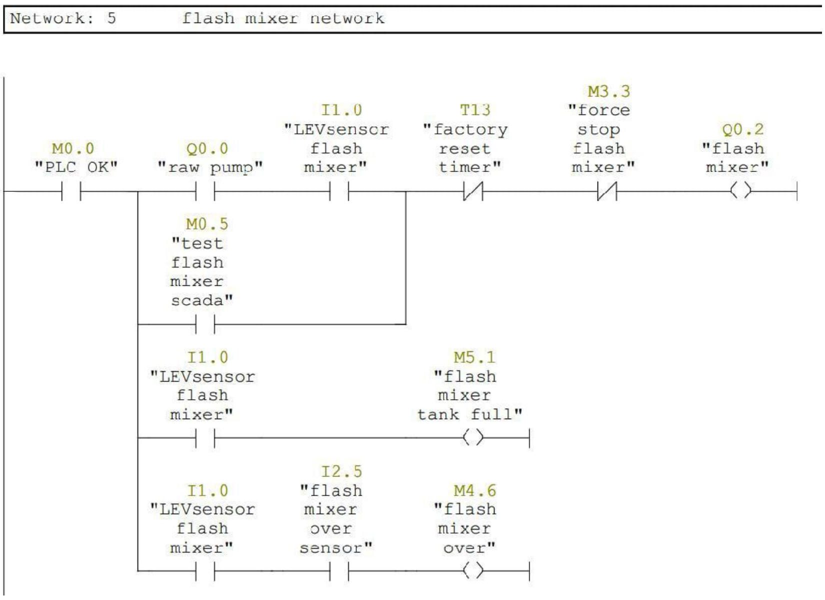
- **Network 5**

  for flash mixer operation

In the beginning, to do anything in this network, the PLC must be in its operating state.
The flash mixer operates under some conditions, including:
-The raw pump is operating and the level sensor in the flash mixer tank gives a signal that the water has reached it, or instead of both, a test of the flash mixer tank is performed on the SCADA
-Not operating both the restart and force stop buttons

•When the level sensor in the flash mixer gives a signal that there is water, a value is stored in the M5.1 memory that the tank is full, and its color changes on the SCADA

• Also, this network indicates that the flash mixer tank will overflow if both the level sensor and the high-level sensor above the tank give a signal of the arrival of water.

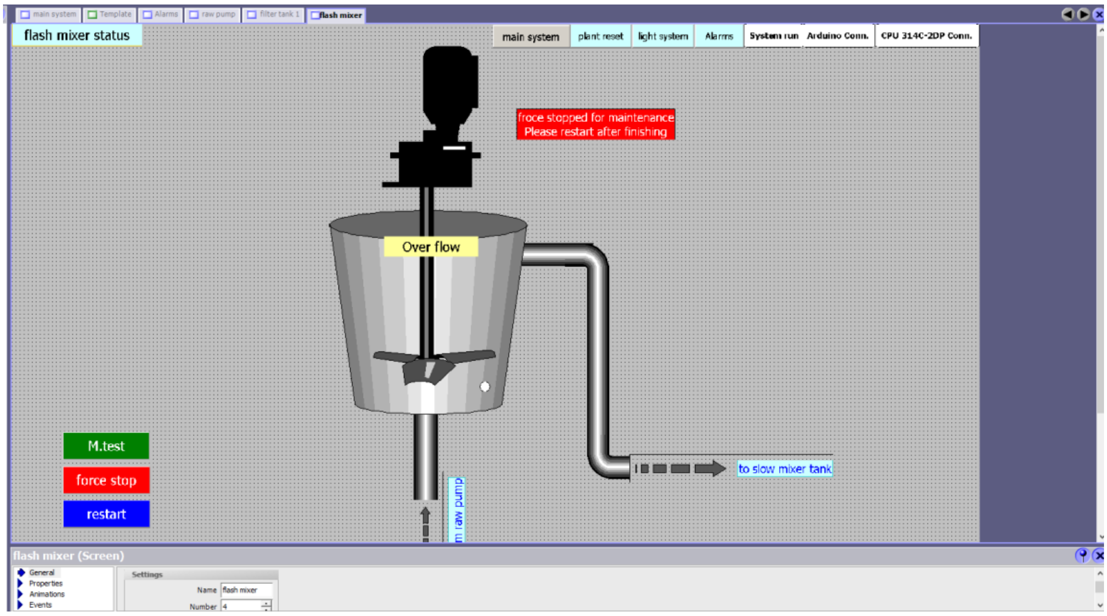


- **In SCADA**

 the following image is the graphical representation of the flash mixer

The buttons at the bottom left corner perform the same role as the previous page applying their role on the flash mixer actuator.

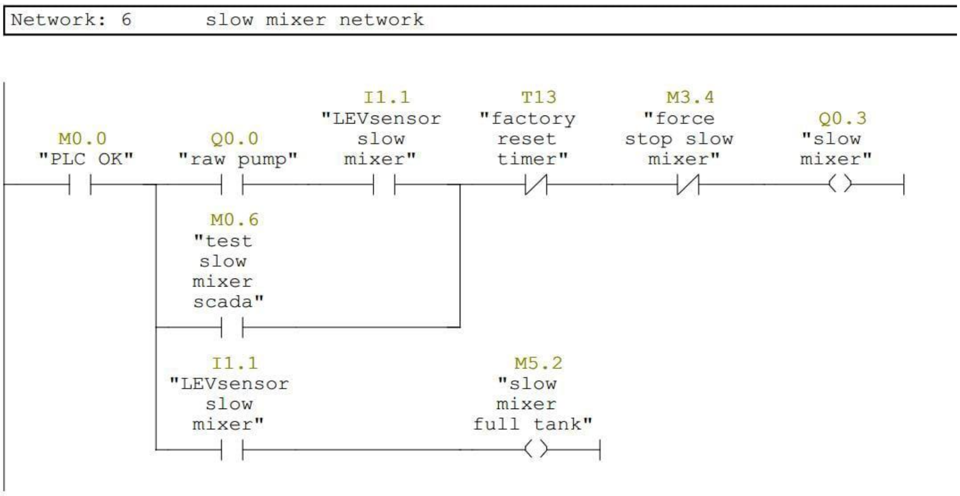
After the sensor in the tank sends a signal indicating that the water’s level has risen, the tank's color turns blue, and the arrow below the raw pump flashes indicating water flow then the actuator that operates as the mixer would be colored green indicating that the motor is functioning.



5.3.3.6 The slow mixer:

- **Network 6**

  is the same as 5

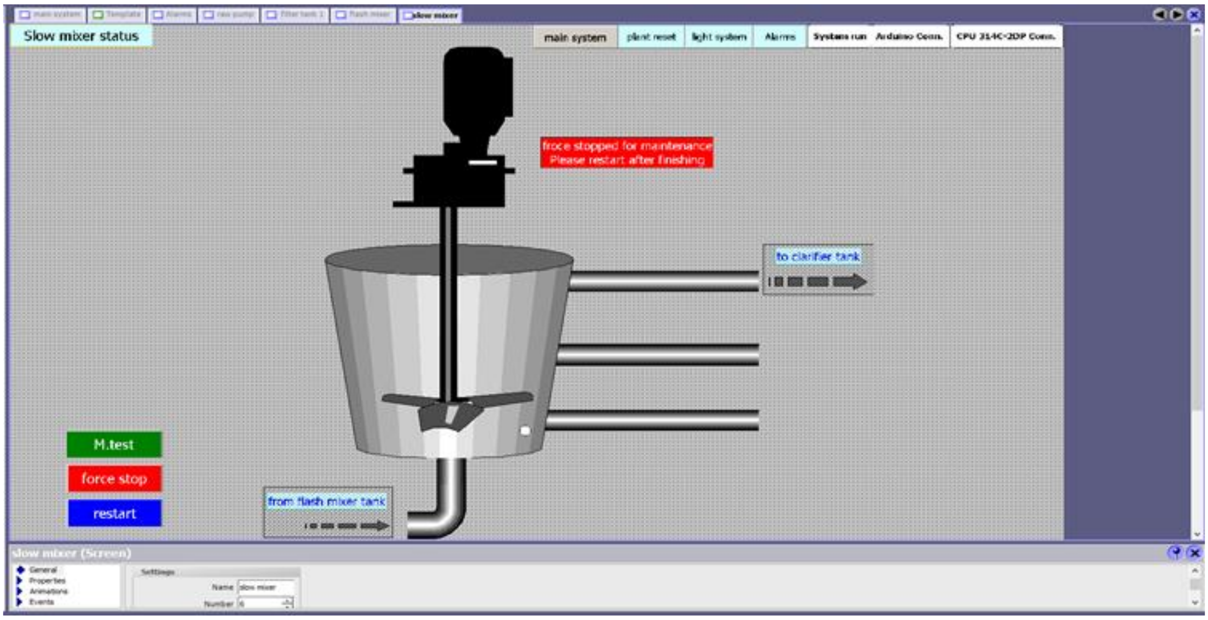


- **In SCADA**

  the following image represents the slow mixer:

Exactly like the previous filter the coloring of the actuator is the same and the buttons in the bottom left corner perform the same task where symmetry is the key to simplification.

The three pipes on the right-hand side will be colored blue when the water reaches the next tank.



5.3.3.7 The clarifier

- **In SCADA**

the next tank is the clarifier tank represented in the SCADA system:

The three pipes on the left side of the are turned blue when the sensor in the tank indicates the existence of water in it and the arrow on the left side of the tank flashes as well.

There are four buttons on the left bottom corner of the screen and three of them have the same function as the previous similar ones this leaves the last button which is the reset clarifier that stops the actuator if it is operating and resets the timers on the bottom half of the screen.

The four timers on the bottom middle half of the screen represent the following:

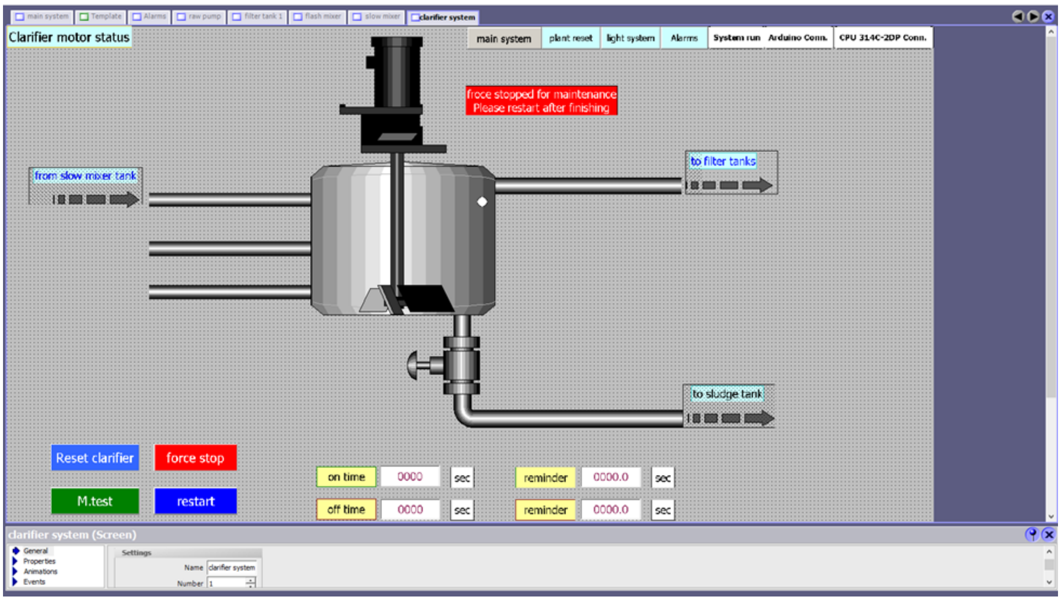
On-time: which is the time inserted by the user to operate the actuator and while it elapses it is counted backward.

Off time: this is the time inserted by the user that stops the actuator from moving while the rest of the system is operational.

Both of the previous timers have a remainder time where it counts the elapsed time forwards.

When the motor is operating the valve below opens the path for sediment to flow straight to the sludge with the water and the arrow on the right flashes indicating so and the color of the pipes turns blue.

The text that says” force stopped for maintenance please restart after finishing” flashes when the force stop button is clicked to catch the attention of the operator.



- **Network 9**

to operate the mopping motor clarifier with a stop-and-start timer

First, the raw water pump must be operating, the restart button is off, and the level sensor in the clarifier gives a signal that the water has reached it to start the operation of the clarifier motor, which works with a timer for stopping for 5 seconds, playing for 2 seconds, and repeating that.

This is done by taking the duration of the timers from SCADA and making sure that both of them are greater than zero, and at that point, the stop timer is activated for 5 seconds and converting this value stored in the memory from 58 memory words to a real value understood by SCADA

And when the stop timer ends, the on timer works immediately after that for two seconds, and also the value memory word 88 is converted to a real value that SCADA understands.

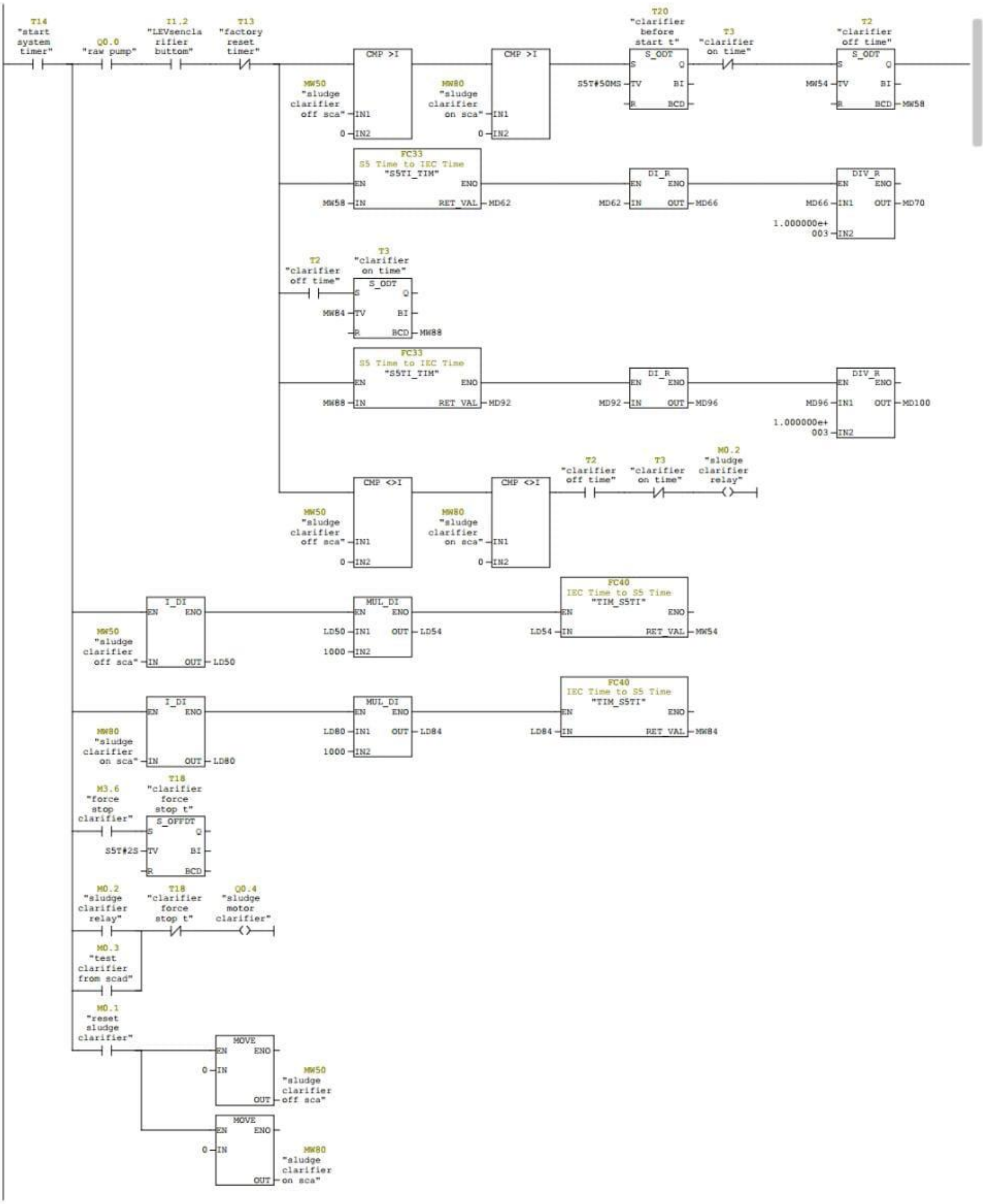
And this keeps repeating until the system stops working

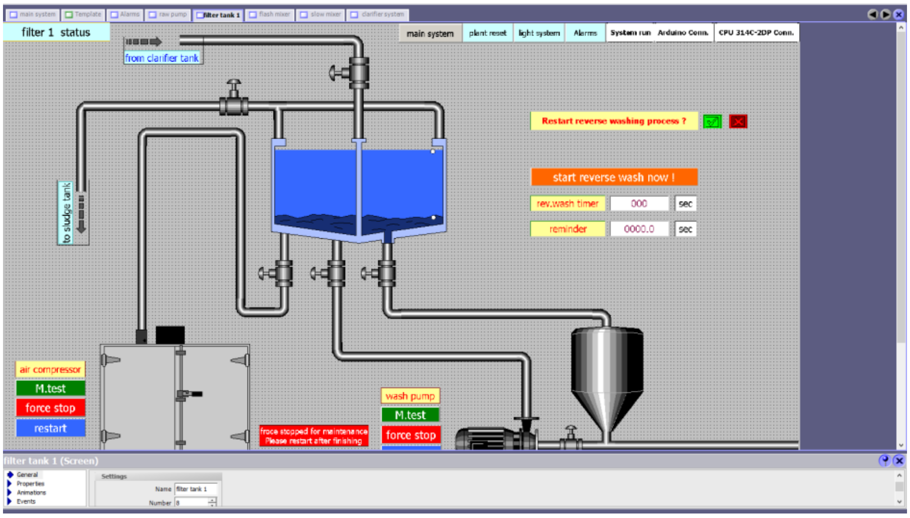
Note: - Before entering the timer values from the SCADA to the plc timer, they are converted from seconds to milliseconds, and then converted to a memory word value understood by the plc.

After that, the work of the clarifier motor starts when the clarifier motor relay works and the force stop button is not activated.

Then the timers can be restarted by entering a value of 0 into the SCADA

Network: 9 sludge motor clarifier timer operation





5.3.3.8 The Filter

The next screen represents the filters stage in our project:

At the top of the screen, we can see a pipe that turns blue when the low-level water detection sensor detects the arrival of the water in the tank, attached to that pipe is a valve that closes when the tank is being washed to prevent the water from getting in the tank and turns blue if the water flows through it.

Right below that pipe, there is another pipe that is divided into two pipes that turn blue if the tank is being washed, and attached to it is a valve that turns brown when the water flows through it.

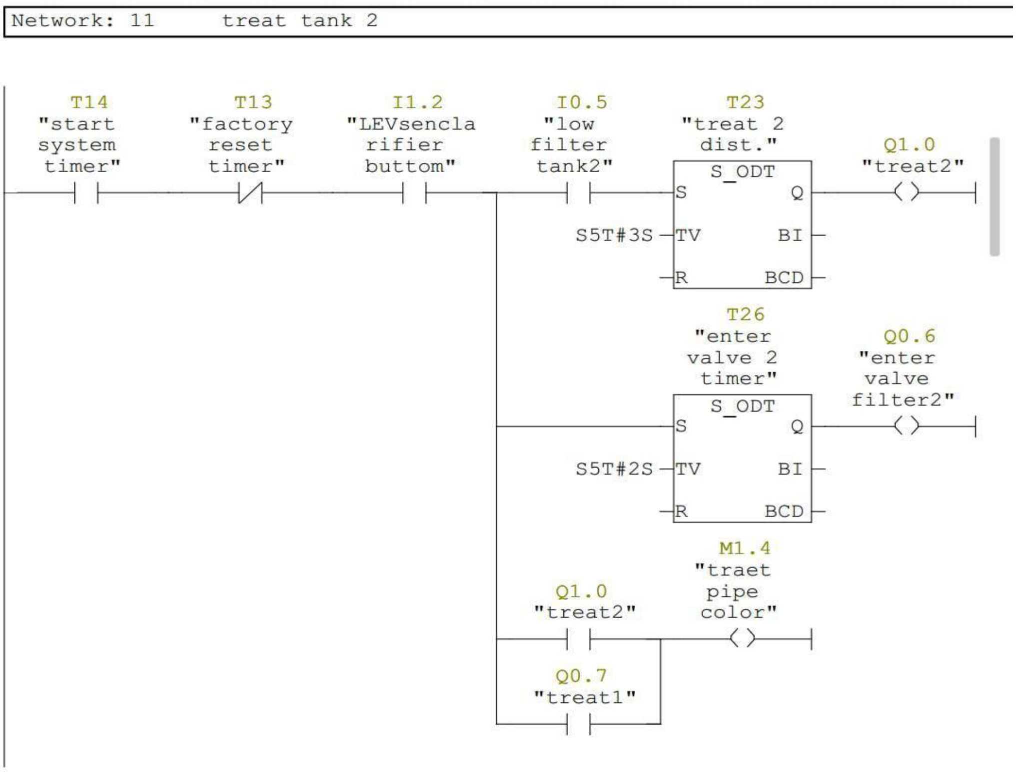
Below the tank there are three pipes:

1. the air compressor pipe that is attached to the air compressor below that turns yellow when it is operational during the washing of the filter its valve turns yellow as well.
2. the water pump turns green during the washing of the tank and the valve turns blue as well.
3. the water pipe that delivers clean water to the tank turns blue along with the valve when the water flows through it.

There are three buttons for both the air compressor and the water pump to serve the same purpose as the similar previous buttons.

As well as two buttons on the right for starting or restarting the reverse washing process.

Below them, there are two timers to track the washing process.



- **Network 11**

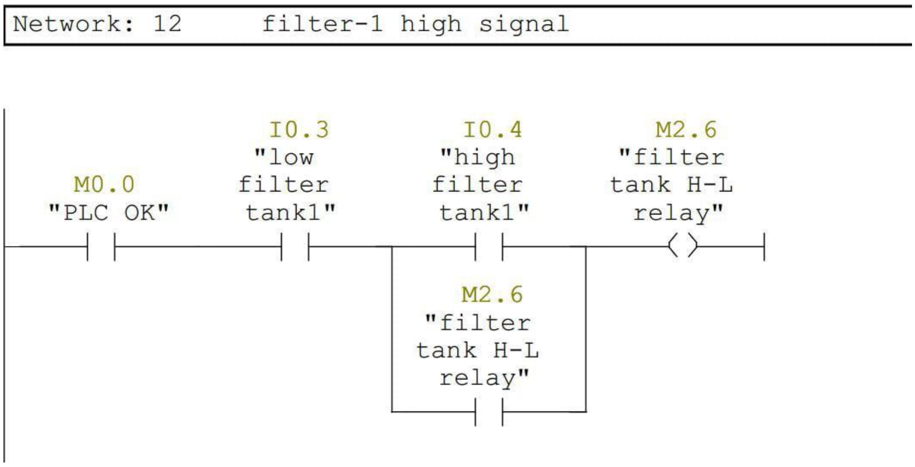
To operate the second filter.

To take any output from this network, the system must be turned on, the restart button must be off, and the low-level sensor in the clarifier should give a signal, which means that the water will go to the filter

And the following happens: -

1. The filter inlet valve opens after 2 seconds
2. And when the water enters and reaches the low-level sensor in the filter, the filter valve of the tank opens

Finally, the color of the filter pipes is changed when the first or second filter is operated.

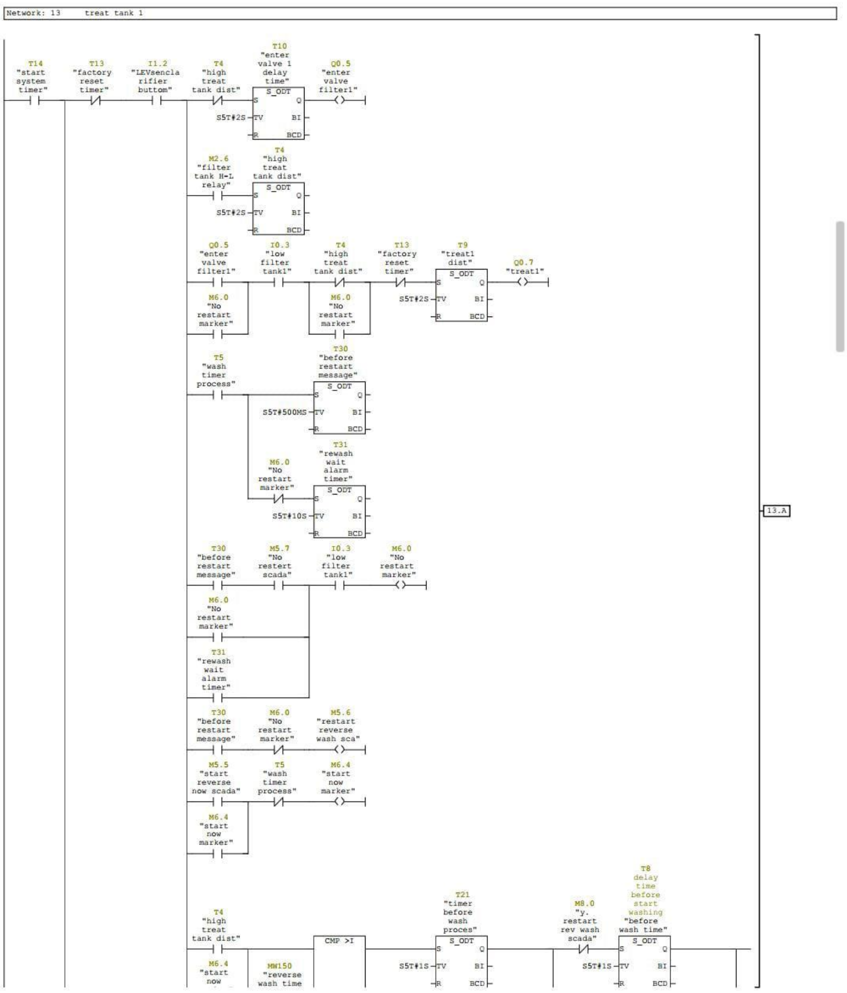


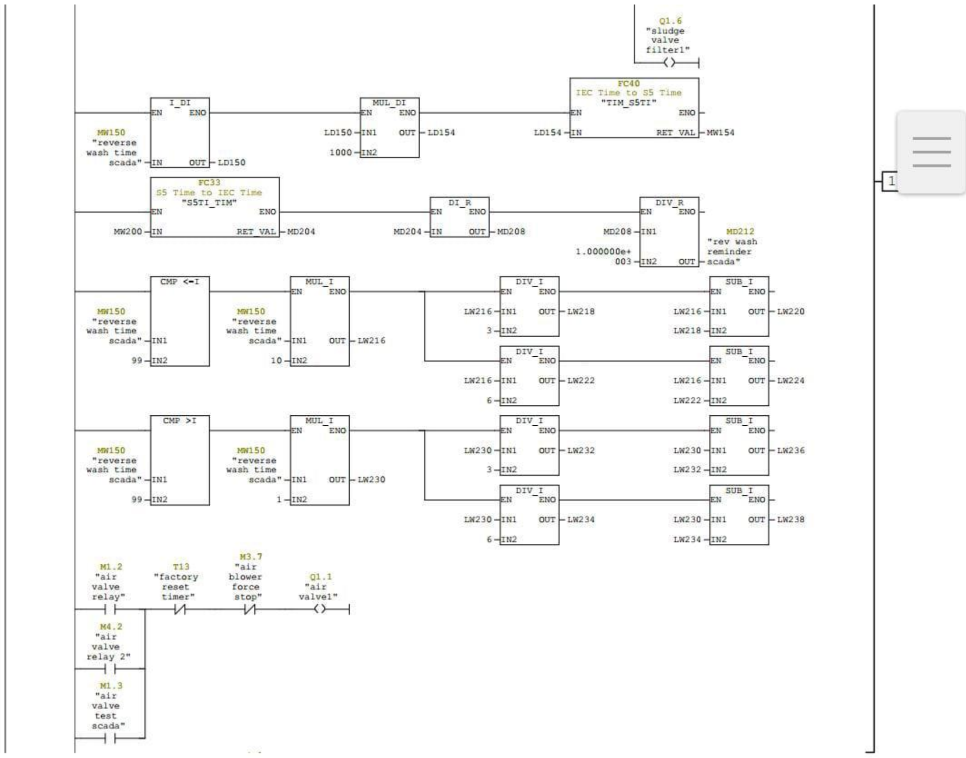
- **Network 12**

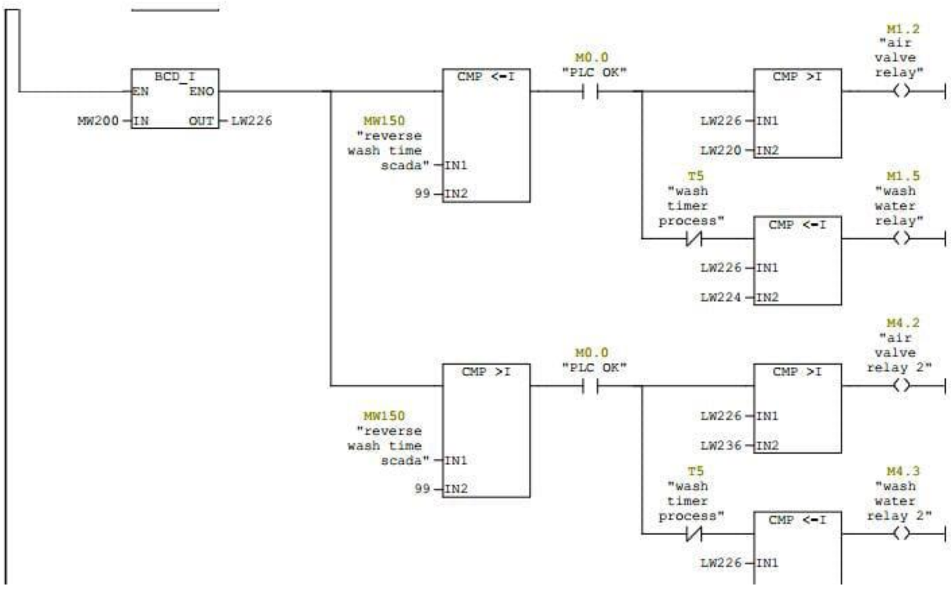
to alert the first filter tank to full

Where both the low- and high-level sensors in the filter together give a signal that the water reaches them together ،then the filter is full

Or by keeping the filter in full alert state with the first sensor signal







- **Network 13**

to operate the first filter and run the backwash process inside it

Same as the previous second filter operation where the filter inlet valve opens two seconds after the level sensor in the clarifier has given a signal

Then, after turning on the low-level sensor in this filter, the filter valve will be turned on after 2 seconds.

The backwashing process to wash the filter at a specific time and with specific timers to distribute the washing with air and water

Where air washing is used in the first third of the entire washing period

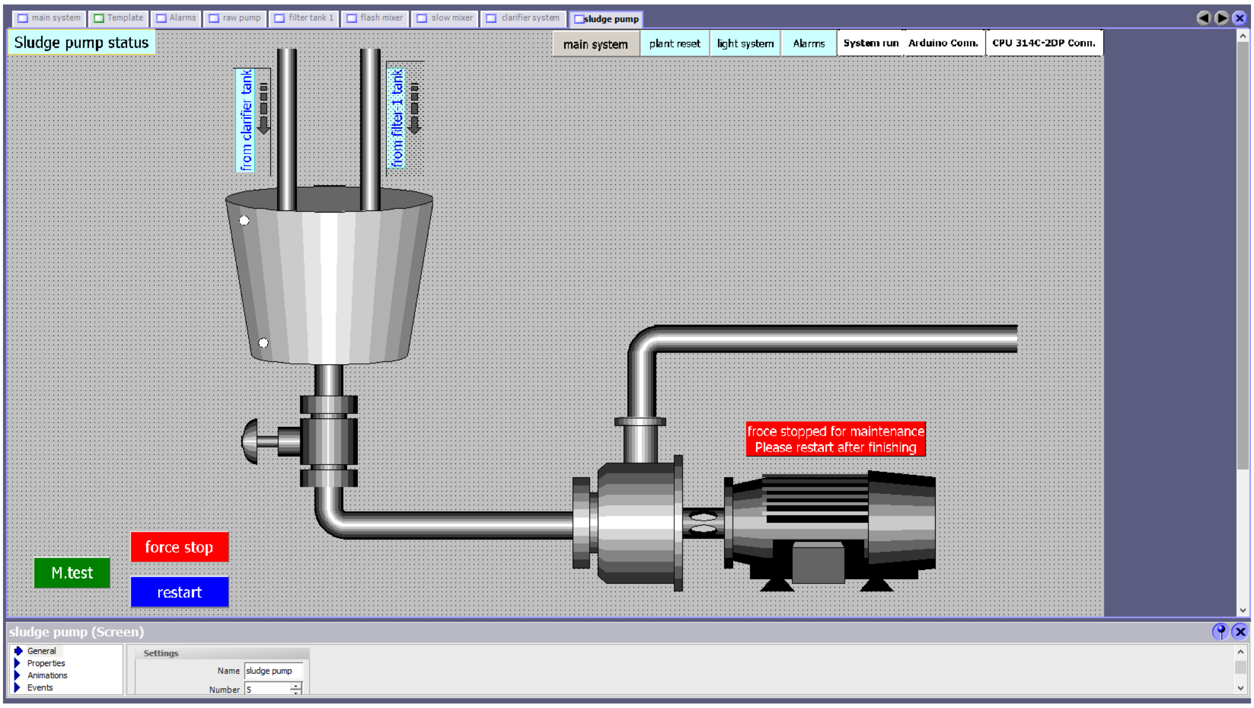
Then the washing with water begins after the end of the first sixth of the washing period and continues until the end of the washing.

The values of these timers are determined by SCADA and converted from real values to a memory word that the PLC understands and vice versa, as happened previously in the clarifier.

After the end of the backwashing process, the sludge valve in the first filter is opened

Also, after completion, a message appears on the SCADA for 10 seconds to restart the backwash, and if it is not approved within 10 seconds, it turns into a non-restart.

5.3.3.9 The sludge:



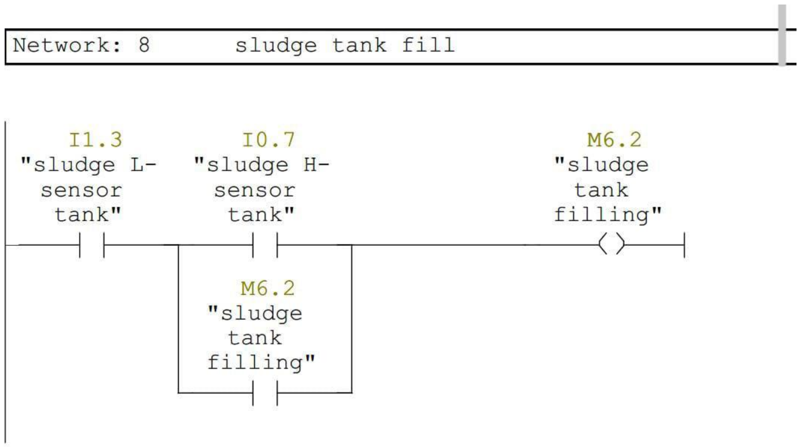
sludge tank on the SCADA system

As we can see, the top two pipes turn brown when there is water flowing through them.

Below the tank is a valve that opens when the tank needs to be emptied which is known from the sensor on the top of the tank and then that valve turns brown along with the brown.

The motor on the right turns green when operational and the three buttons in the bottom left corner of the screen control that motor as all of the similar previous ones.

If the motor is stopped the text on top of the motor appears.



- **Network 8**

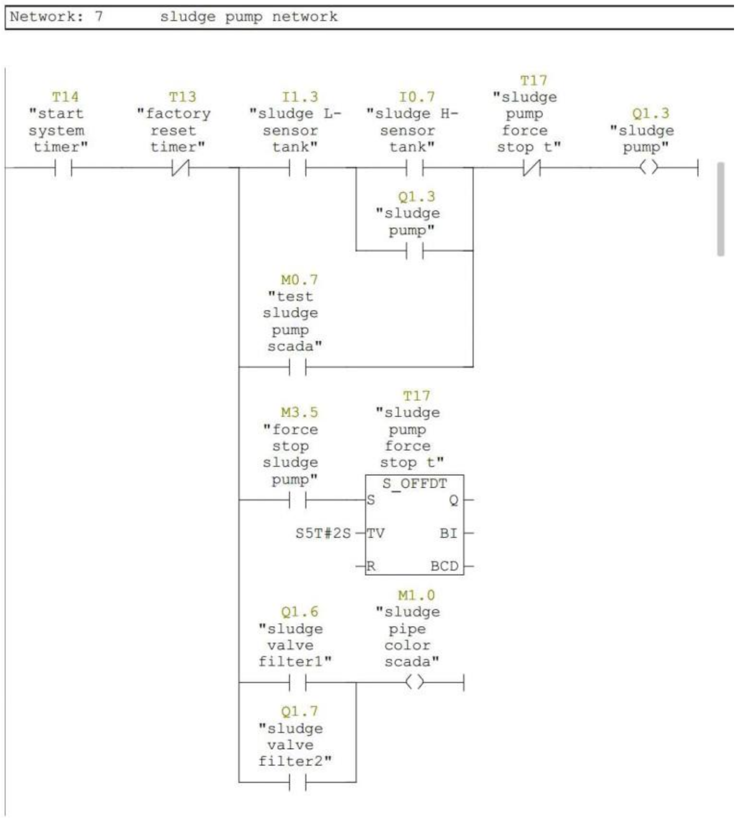
to alert you on SCADA to the fullness of the sludge tank

And this happens when both the low-level sensor and the high-level sensor together give signals that the sludge reaches them together

And when the high-level sensor stops operating due to the deterioration of the sludge, it is replaced by the memory value M6.2, which means that the tank is still full.

And it continues to discharge when the low-level sensor gives the signal with the memory value M6.2 together

And the discharge does not stop unless the low-level sensor stops.



- **Network 7**

to operate the sludge pump to withdraw the sludge from the tank to the outside.

In the beginning, to turn on any output in this network, the system must be working and the restart button is turned off or not activated.

To operate the sludge pump, some conditions must be met.

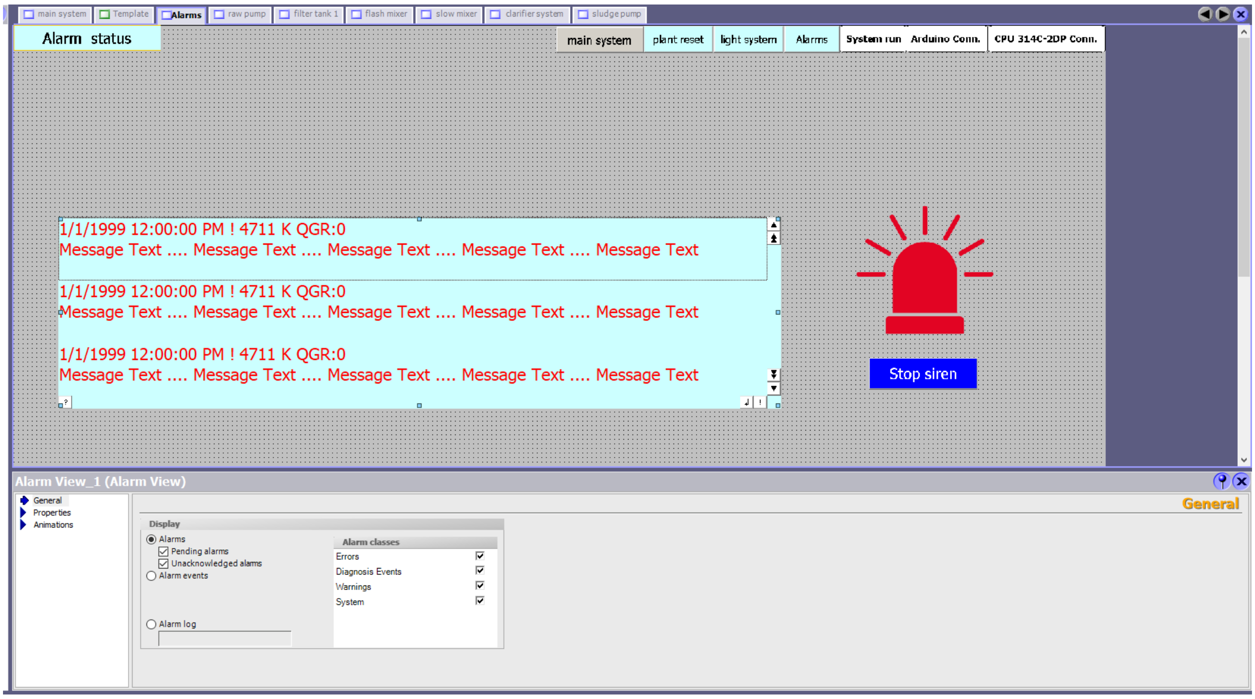
- Both the low and high sensors in the sludge tank must give a signal that the sludge has reached them
- And after operating the sludge pump for a while, the signal of the high sensor can be replaced (for the sludge to recede from it), provided that the sludge pump continues to operate.
- Alternatively, a test for the sludge pump is done on the SCADA

The operation of the sludge pump is stopped after pressing the force stop button for two seconds

The sludge tank pipe is colored on the SCADA when the first or second filter valve is turned on.

5.3.3.10 The alarms

The alarms screen is represented as the following:



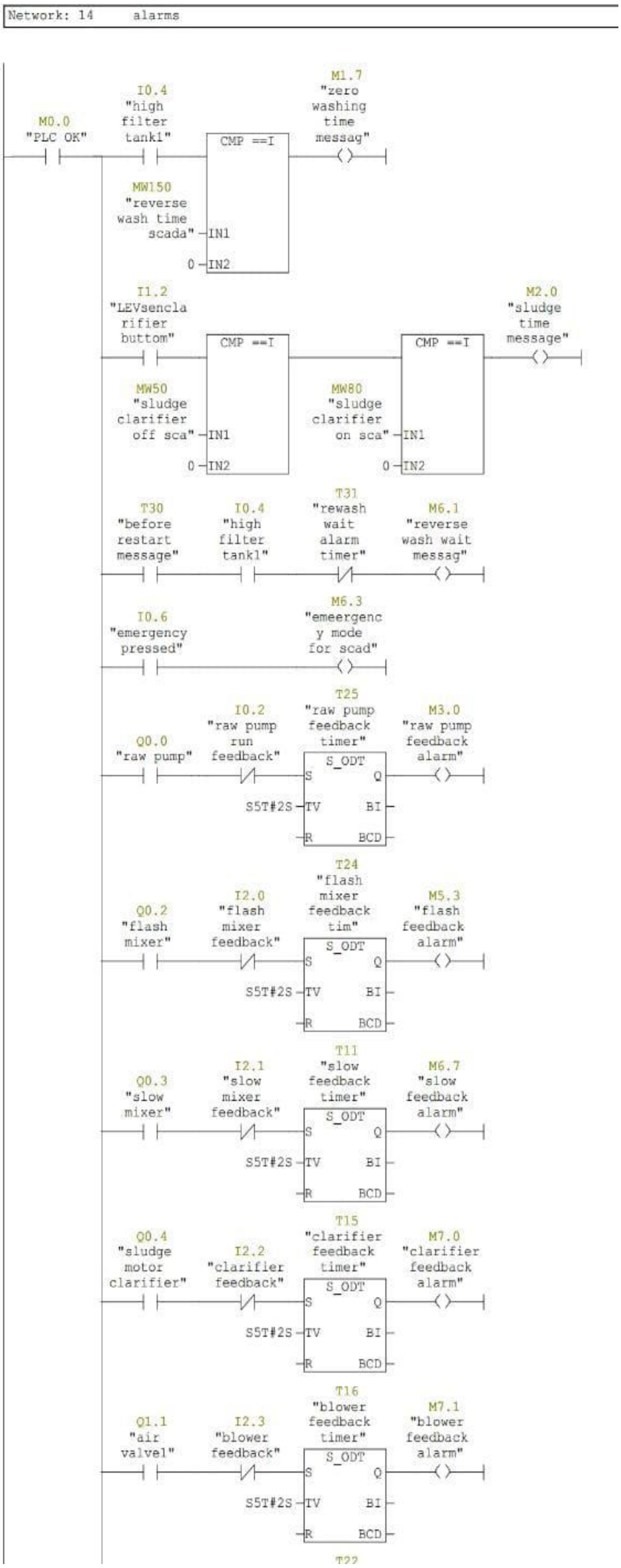
The alarms screen is accessible from anywhere within the program since any alarm could occur and rapid response is required at this point.

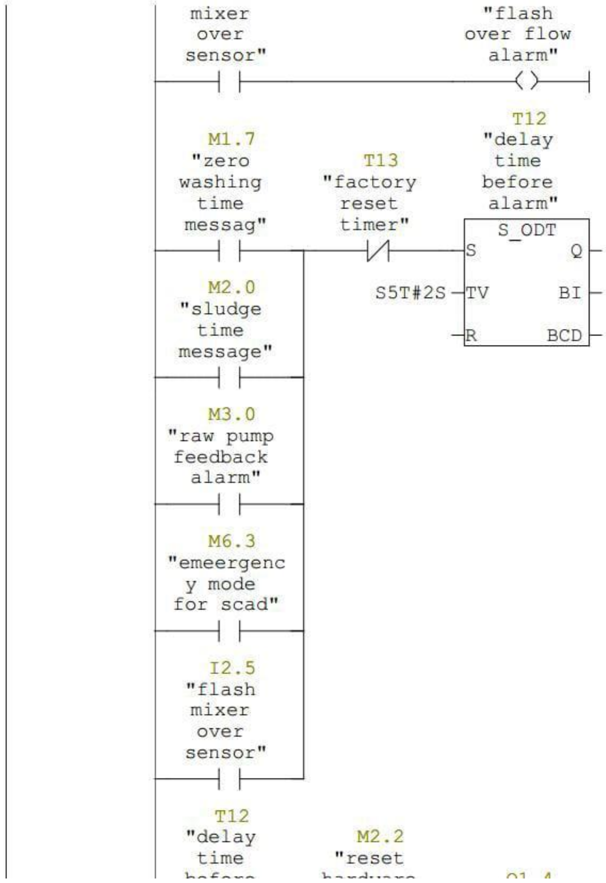
The huge rectangular text box in the middle shows the messages that appear describing the type of problem in the system, those messages could be printed later on and checked.

The bottom left corner of that text box contains a button that tells the operators more details about the pressing issue and on the bottom right corner there is a button used to dismiss error messages when they are not needed.

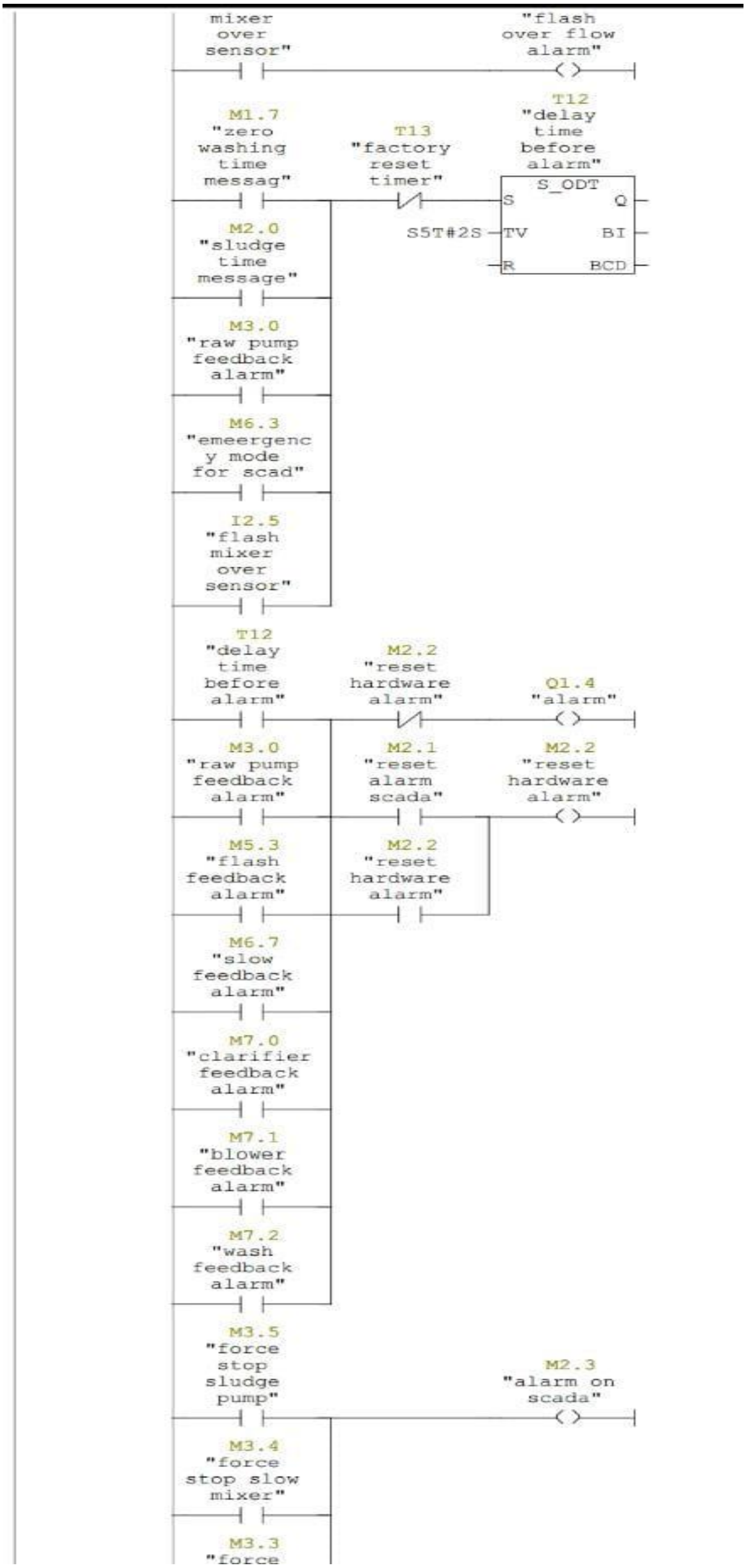
On the right-hand side of the screen, there is a button that stops the siren when clicked.

If there is an alarm due to an error in the system, the Alarms button flashes to catch the attention of the operator.


Network: 14 alarms
M0.0 "PLC OK"
I0.4 "high filter tank1"
CMP ==I
MW150 "reverse wash time scada"
IN1
0 IN2
M1.7 "zero washing time messag"
I1.2 "LEVsencla rifier buttom"
MW50 "sludge clarifier off sca"
MW80 "sludge clarifier on sca"
M2.0 "sludge time message"
T30 "before restart message"
I0.4 "high filter tank1"
T31 "rewash wait alarm timer"
M6.1 "reverse wash wait messag"
I0.6 "emergency pressed"
M6.3 "emeergency mode for scad"
Q0.0 "raw pump"
I0.2 "raw pump run feedback"
T25 "raw pump feedback timer"
S_ODT
S5T#2S
M3.0 "raw pump feedback alarm"
Q0.2 "flash mixer"
I2.0 "flash mixer feedback"
T24 "flash mixer feedback tim"
M5.3 "flash feedback alarm"
Q0.3 "slow mixer"
I2.1 "slow mixer feedback"
T11 "slow feedback timer"
M6.7 "slow feedback alarm"
Q0.4 "sludge motor clarifier"
I2.2 "clarifier feedback"
T15 "clarifier feedback timer"
M7.0 "clarifier feedback alarm"
Q1.1 "air valve1"
I2.3 "blower feedback"
T16 "blower feedback timer"
M7.1 "blower feedback alarm"

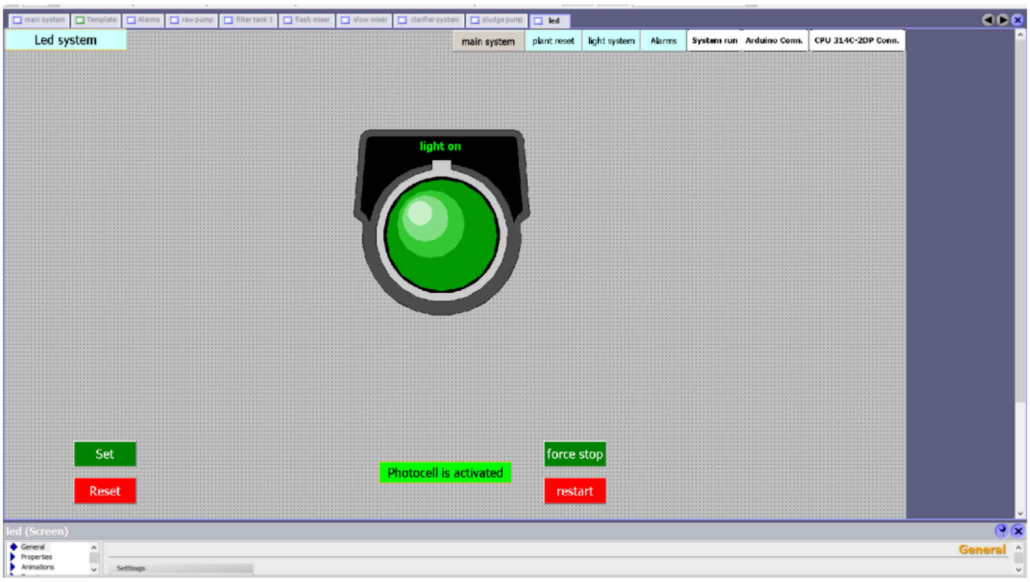


mixer over sensor"
"flash over flow alarm"
M1.7
"zero washing time messag"
T13
"factory reset timer"
T12
"delay time before alarm"
S_ODT
S
Q
S5T#2S
TV
BI
R
BCD
M2.0
"sludge time message"
M3.0
"raw pump feedback alarm"
M6.3
"emeergenc y mode for scad"
I2.5
"flash mixer over sensor"
T12
"delay time
M2.2
"reset


mixer over sensor"
"flash over flow alarm"
M1.7 "zero washing time messag"
T13 "factory reset timer"
T12 "delay time before alarm"
S_ODT
S
Q
S5T#2S
TV
BI
R
BCD
M2.0 "sludge time message"
M3.0 "raw pump feedback alarm"
M6.3 "emeergency mode for scad"
I2.5 "flash mixer over sensor"
T12 "delay time before alarm"
M2.2 "reset hardware alarm"
Q1.4 "alarm"
M3.0 "raw pump feedback alarm"
M2.1 "reset alarm scada"
M2.2 "reset hardware alarm"
M5.3 "flash feedback alarm"
M2.2 "reset hardware alarm"
M6.7 "slow feedback alarm"
M7.0 "clarifier feedback alarm"
M7.1 "blower feedback alarm"
M7.2 "wash feedback alarm"
M3.5 "force stop sludge pump"
M2.3 "alarm on scada"
M3.4 "force stop slow mixer"
M3.3 "force

5.3.3.11 The light system

The following is the light system's representation in the SCADA system:

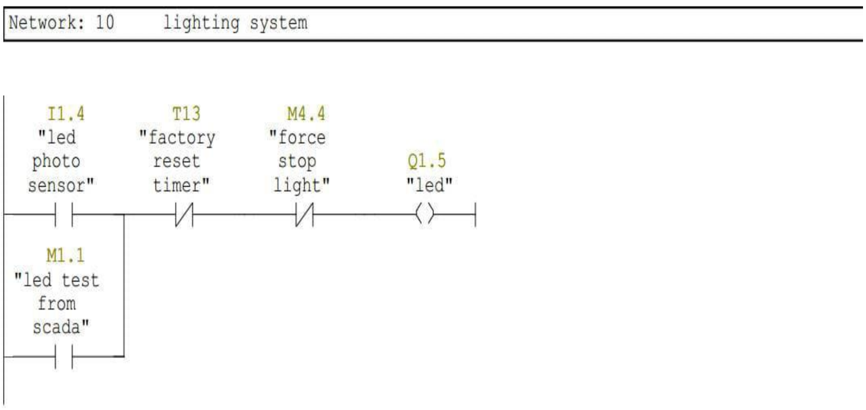


The force stop button is used to stop the light system and only the admin has access to it.

The restart button starts the system after it has been stopped.

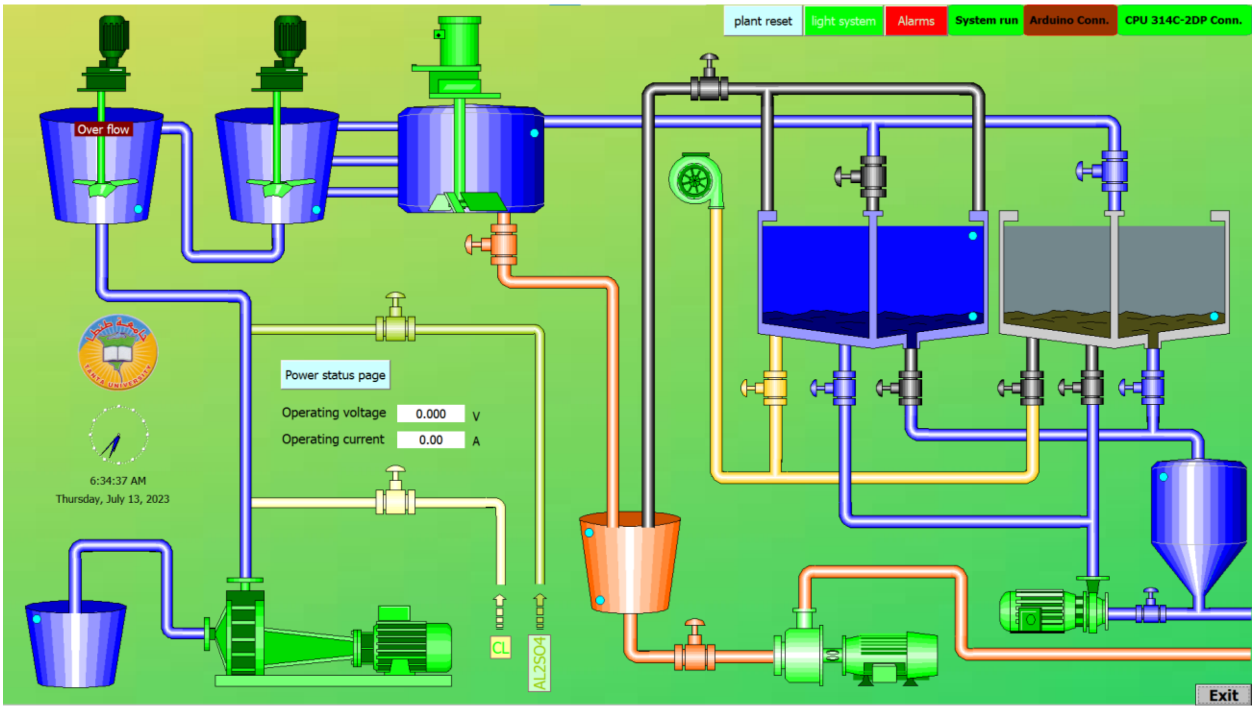
The set button is used to light the LEDs connected to the system since it sets the value of the tag in the ladder diagram to 1.

The reset button is used to turn the light system off by setting the same tag to 0.



Network 10 to operate the LED lighting system, when the LED sensor gives a signal and the forced stop button and the restart button is off, or the LED test is performed on the SCADA instead of the LED sensor signal

5.3.3.12 THE ENTIRE SYSTEM



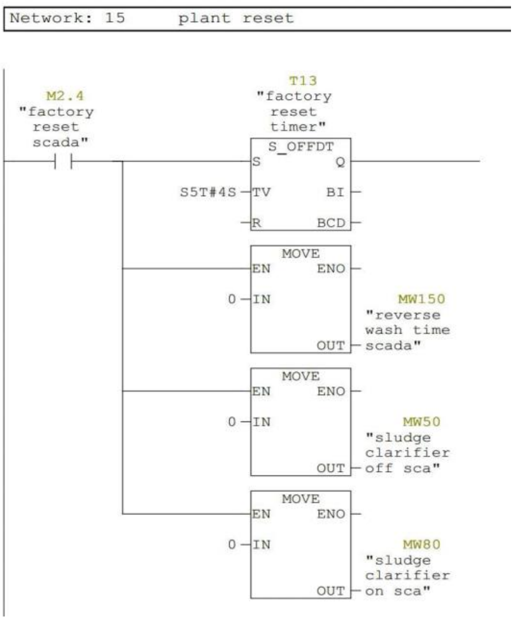
Finally, this is a picture of the entire operational system with all of the colors in the simulation mode.

- **Network 15**

  to make the entire factory restart parts

  when activating the restart button is activated this will: -

  1. Restart the entire plant
  2. Restart the backwash
  3. Restart the sludge clarifier off
  4. restart the sludge clarifier on



5.4 ATS

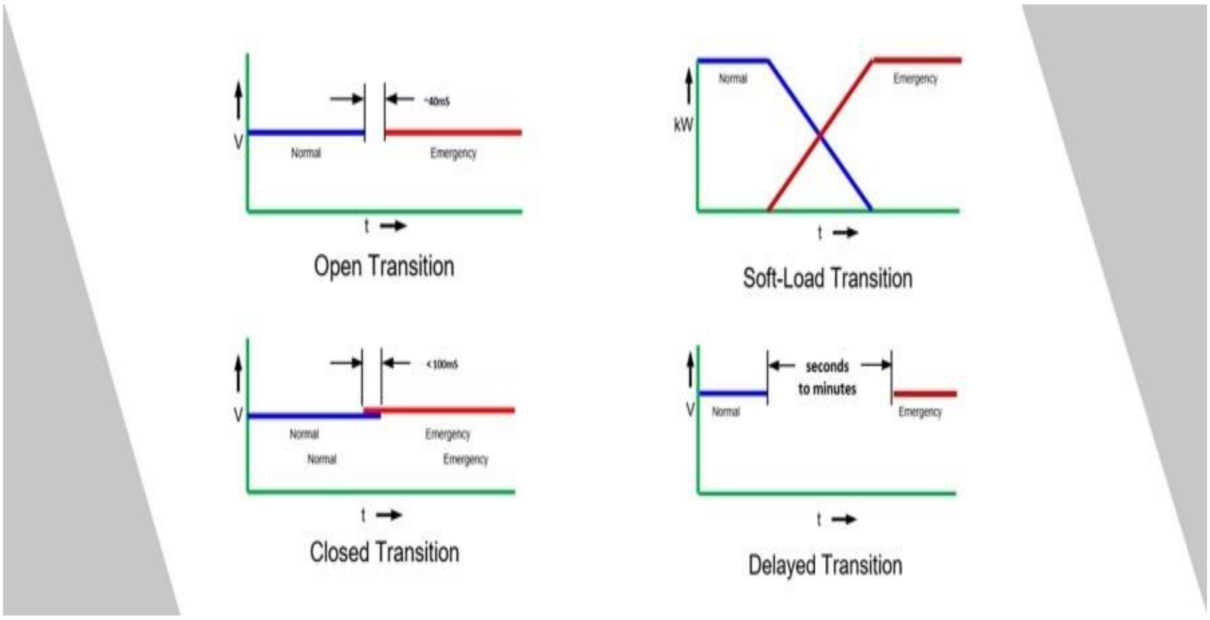
5.4.1 What is an Automatic Transfer Switch?

Low-voltage automatic transfer switch assemblies provide a reliable means of transferring essential load connections between primary and alternate sources of electrical power. Data centers, hospitals, factories, and a wide range of other facility types that require continuous or near-continuous uptime typically utilize an emergency (alternate) power source such as a generator or a backup utility feed when their normal (primary) power source becomes unavailable.

5.4.2 How does an automatic transfer switch work?

An automatic transfer switch (ATS) is a self-acting, intelligent power-switching device governed by dedicated control logic. The principal purpose of an ATS is to ensure the continuous delivery of electrical power from one of two power sources to a connected load circuit (electrical equipment – lights, motors, computers, etc.).

The control logic or automatic controller is typically microprocessor-based and constantly monitors the electrical parameters (voltage, frequency) of primary and alternate power sources. Upon failure of the connected power source, the ATS will automatically transfer (switch) the load circuit to the other power source (if it is available). As a general rule, most automatic transfer switches seek connection to the primary power source (utility) by default and will only connect to the alternate power source (engine generator, backup utility) when required (primary source failure) or requested to do so (operator command).



5.4.3 Automatic Transfer Switch (ATS) Transition Modes

5.4.3.1 Open Transition

Open transition switching is sometimes referred to as “Break-Before-Make”. This term reflects the sequence of switching mechanism operations, where the contacts for the original source are opened before the contacts for the alternate source are closed.

5.4.3.2 Delayed Transition

Delayed transition switching is primarily used where an Automatic Transfer Switch (ATS) supplies primarily inductive or motor loads. The sequence is similar to open transition switching; however, the duration of the power interruption is extended to allow residual voltages to decay and motors to slow. This avoids the occurrence of large inrush currents when the switch closes on the alternate source.

5.4.3.3 Closed Transition

Closed transition switching is often termed “Make-Before-Break” because the contacts for the alternate source are closed before the contacts for the original source are opened. This results in momentary source paralleling that provides continuous power, avoiding momentary power interruption to sensitive loads. Closed transition switching requires care to avoid extended interconnection of the sources, and should never be used without consulting utility officials.

5.4.3.4 Soft-Load Transition

Like closed transition, soft-load transition parallels two power sources. In this mode, however, the sources can be paralleled for extended periods. This highly advanced sequenced is used to decrease loading on the original source while increasing loading on the alternate source. Used only in highly specialized applications, soft-load Automatic Transfer Switch (ATS)’ can be used to avoid both power interruptions and rapid changes in power conditions. Unlike the other modes that are illustrated using voltage, soft load is best understood by observing temporal changes in power.

5.4.3.5 How Do Automatic Switches Benefit Your Business?

When you choose the right automatic transfer switches to meet the needs of your commercial building, you’ll gain:

- **Power reliability**. A generator relies on a manual or automatic transfer switch to function properly. Many businesses install an automatic transfer switch, which can save a lot of time and improve the generator’s functionality.
- **Safety**. Handling any source of power can yield detrimental results. Employees can be harmed by a sudden outage, and handling a manual generator hookup can be disastrous — especially in the dark. A transfer switch handles all your needs on its own, entirely removing the dangers associated with an outage.
- **Simplified operations**. Upon the installation of your automatic transfer switch, specific operations are chosen to be automatically powered. This can be everything from your lights to HVAC systems, industrial equipment, or refrigerators. This process drastically simplifies restoring power and improves the function of your generator.

5.4.3.6 Some types of ATS (automatic transfer switch)

- **1 out of 2**
- **2 out of 3**
- **2 out of 4**

Considering the following definitions:

Tr: Transformer

Gen: Generator

CB1: Circuit breaker one

CB2: Circuit breaker two

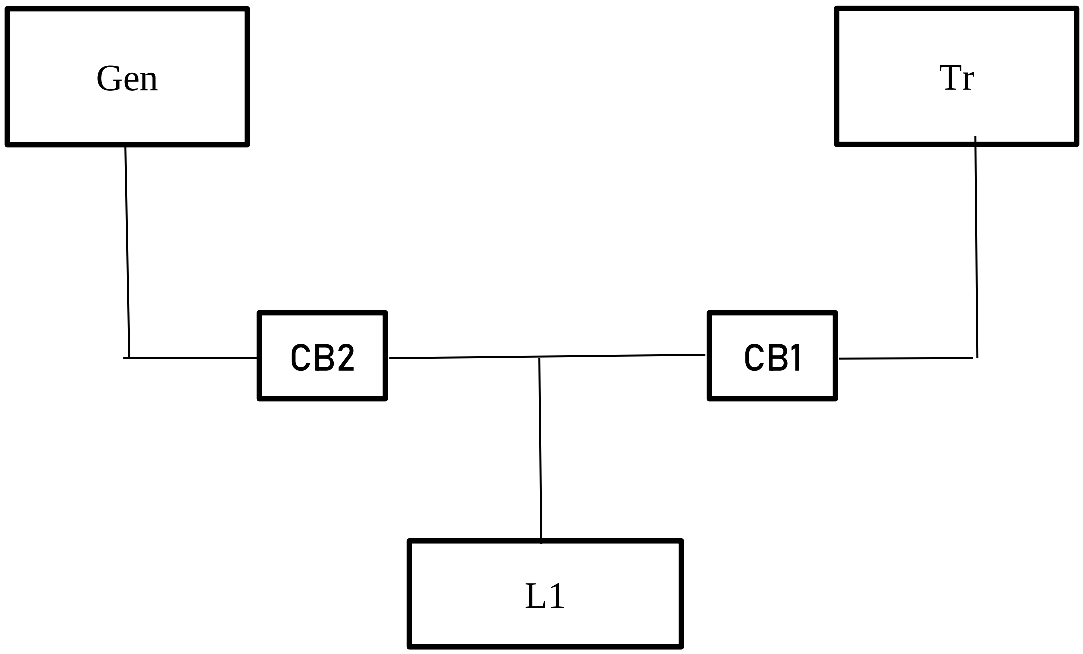
CB3: Circuit breaker three

CB4: Circuit breaker four

L1: Load one

L2: Load two

- **1 out of 2**

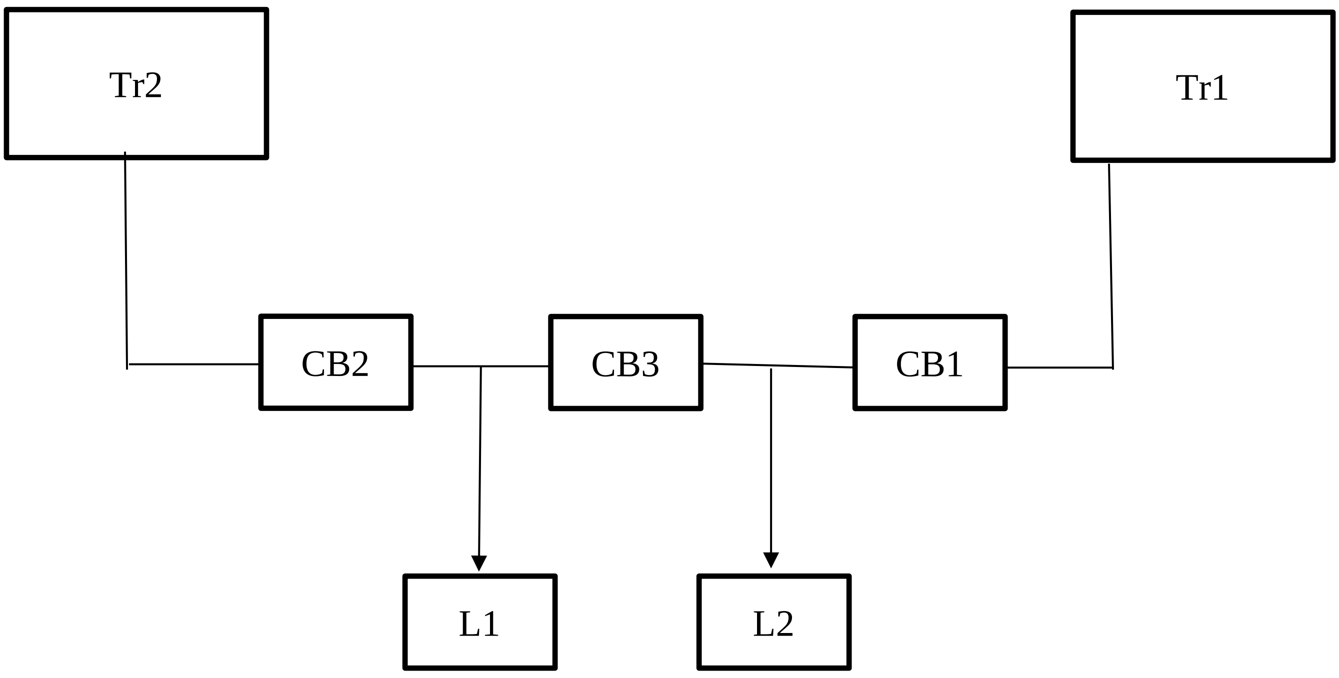


In this type, we have two cases:

Case 1: Tr is available and Gen is not available So, CB1 is closed and CB2 is opened.

Case 2: Tr is not available and Gen is available So, CB2 is closed and CB1 is opened.

- **2 out of 3**



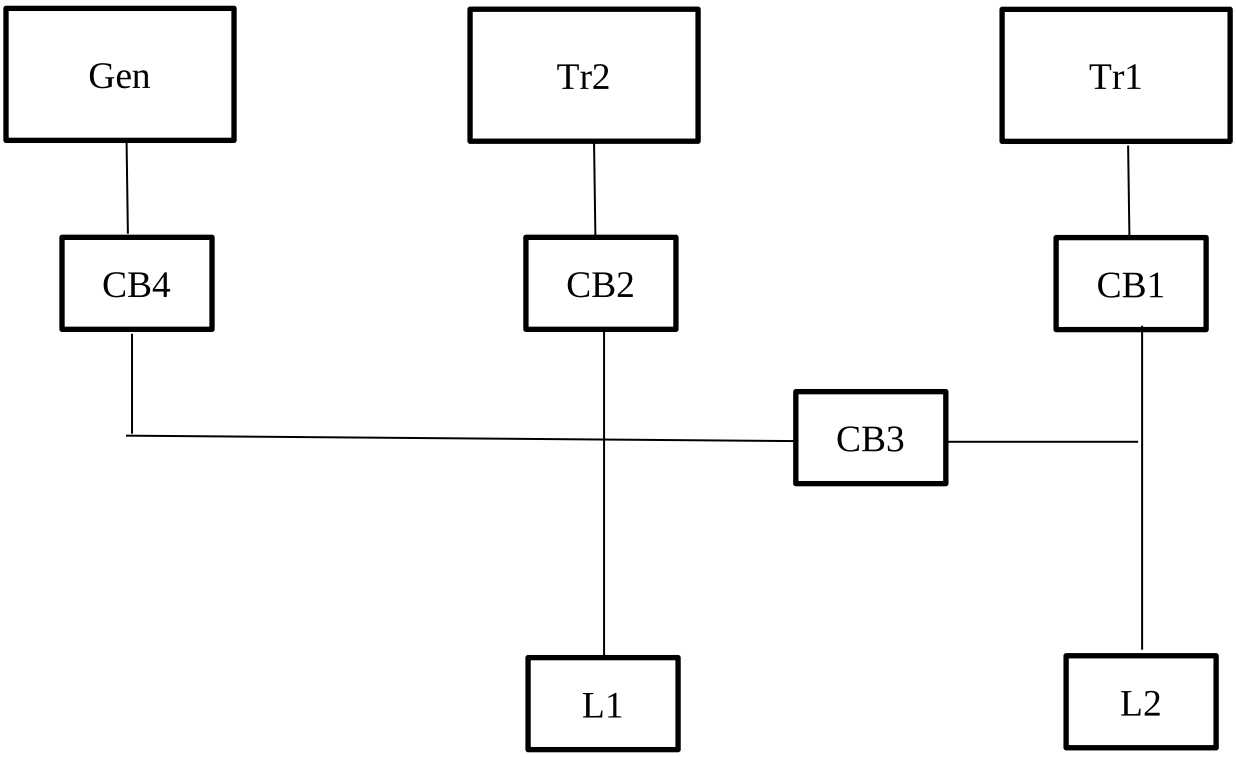
In this type, we have three cases:

Case 1: Tr1 & Tr2 are available So, CB1 & CB2 are closed and CB3 is opened.

Case 2: Tr1 is available and Tr2 is not available So, CB1 & CB3 are closed and CB2 is opened.

Case 3: Tr2 is available and Tr1 is not available So, CB2 & CB3 are closed and CB1 is opened.

- **2 out of 4**



In this type, we have four cases:

Case 1: Tr1 & Tr2 are available, and Gen is not available So, CB1 & CB2 are closed and CB3 & CB4 are opened.

Case 2: Tr1 is available, and Tr2 & Gen are not available So, CB1 & CB3 are closed and CB2 & CB4 are opened.

Case 3: Tr2 is available, and Tr1 & Gen are not available So, CB2 & CB3 are closed and CB1 & CB4 are opened.

Case 4: Gen is available and Tr1 & Tr2 are not available So, CB3 & CB4 are closed and CB1 & CB2 are opened.

5.4.3.7 Modbus Communication

Modbus is a communication protocol commonly used with input/output (I/O) data to share information at this simple device network level. It is neither necessary nor beneficial to rely on protocols that require massive packets of configuration data when only simple data transmissions are requested.

On the other hand, perhaps it is useful to adopt standardized protocols to some limited extent to take advantage of the many sockets and plugs that exist in modern equipment, such as Ethernet ports.

I/O and data exist as either discrete (Boolean) or multi-bit words (as integers or floating-point values). Therefore, if we wish to share information with I/O devices, it would seem logical to assume that all we must determine is whether the information is discrete or analog and whether we are reading or writing the information. This isn’t too far off from reality.

5.4.3.8 Modbus Function Codes

There is a small selection of codes used to identify what type of information we want to use, and what task we wish to perform.

In short, there are 4 things we can do with Modbus:

- Read bits
- Write bits
- Read words (usually words are 16-bit integers)
- Write words

In slightly longer detail, those words are called ‘registers’, and those ‘bits’ may be output coils or input contacts.

So, the slightly elaborated list of possible Modbus functions includes:

- Read Contacts
- Read Coils
- Read Registers
- Write Coils
- Write Registers

Note that you cannot write to an input contact - only the real-world device (button, sensor) can write itself. You can't force a push button to push.

5.4.3.9 Modbus Addressing for Arduino

B1	0x129	markers	S1	1x10001	ip relay	R1	0X1	op relay	I1	4x40001	MW
B2	0x130		S2	1x10002		R2	0X2		I2	4x40002	
B3	0x131		S3	1x10003		R3	0X3		I3	4x40003	
B4	0x132	M0.0	S4	1x10004	I0.0	R4	0X4	Q0.0	I4	4x40004	MW0
B5	0x133		S5	1x10005		R5	0X5		I5	4x40005	
B6	0x134		S6	1x10006		R6	0X6		I6	4x40006	
B7	0x135		S7	1x10007		R7	0X7		I7	4x40007	
B8	0x136		S8	1x10008		R8	0X8		I8	4x40008	
B9	0x137		S9	1x10009		R9	0X9		I9	4x40009	
B10	0x138		S10	1x10010		R10	0X10		I10	4x40010	
B11	0x139		S11	1x10011		R11	0X11		I11	4x40011	
B12	0x140		S12	1x10012		R12	0X12		I12	4x40012	
B13	0x141		S13	1x10013		R13	0X13		I13	4x40013	
B14	0x142		S14	1x10014		R14	0X14		I14	4x40014	
B15	0x143		S15	1x10015		R15	0X15		I15	4x40015	
B16	0x144		S16	1x10016		R16	0X16		I16	4x40016	
B17	0x145		S17	1x10017		R17	0X17		I17	4x40017	
B18	0x146		S18	1x10018		R18	0X18		I18	4x40018	
B19	0x147		S19	1x10019		R19	0X19		I19	4x40019	
B20	0x148		S20	1x10020		R20	0X20		I20	4x40020	
B21	0x149		S21	1x10021		R21	0X21		I21	4x40021	
B22	0x150		S22	1x10022		R22	0X22		I22	4x40022	
B23	0x151		S23	1x10023		R23	0X23		I23	4x40023	
B24	0x152		S24	1x10024		R24	0X24		I24	4x40024	

we used (S1, S2, … , S8) as digital inputs, and (R1, R2 , … , R8)as digital outputs.

We used (B1, B2…….) as markers and (I1, I2, …………..) as memory words.

5.4.3.10 Modbus Types

- **Modbus RTU**

  Modbus for remote terminal units (RTU) is a method of structuring a data packet so that the data transmission includes the following pieces:

  Node # (since RS-232 and 485 networks are defined by nodes), the function code, the starting address, and the ending address.

  In RTU, all data is formatted as binary equivalents of the decimal codes, but the good news is that the programmer usually doesn't need to know or care about how it does this.

- **Modbus ASCII**

  When you press buttons on a keyboard, each letter, number, and character is given a special standardized code. In the Modbus ASCII system, the same data is provided as for the Modbus RTU, except rather than using binary equivalents of the function codes, it uses the ASCII equivalents.

Again, the good news is that all the programmer needs to understand is whether the device is programmed for Modbus RTU or ASCII, and choose the appropriate format from a list.

In summary, all the programmer needs to know for both RTU and ASCII is the node #, function code, starting address, and length (if multiple).

- **Modbus TCP/Ip**

Not to sound redundant, but the programmer once again only needs to know those same basic elements as before.

However, in the TCP structure, the network communication is handled using industry-standard industrial Ethernet messaging. This means that an Ethernet port can be used as the physical connection for a Modbus TCP device. It can even be on the same network as the rest of the Ethernet devices, as long as the network parameters can be configured properly (the IP address, subnet mask, etc.)

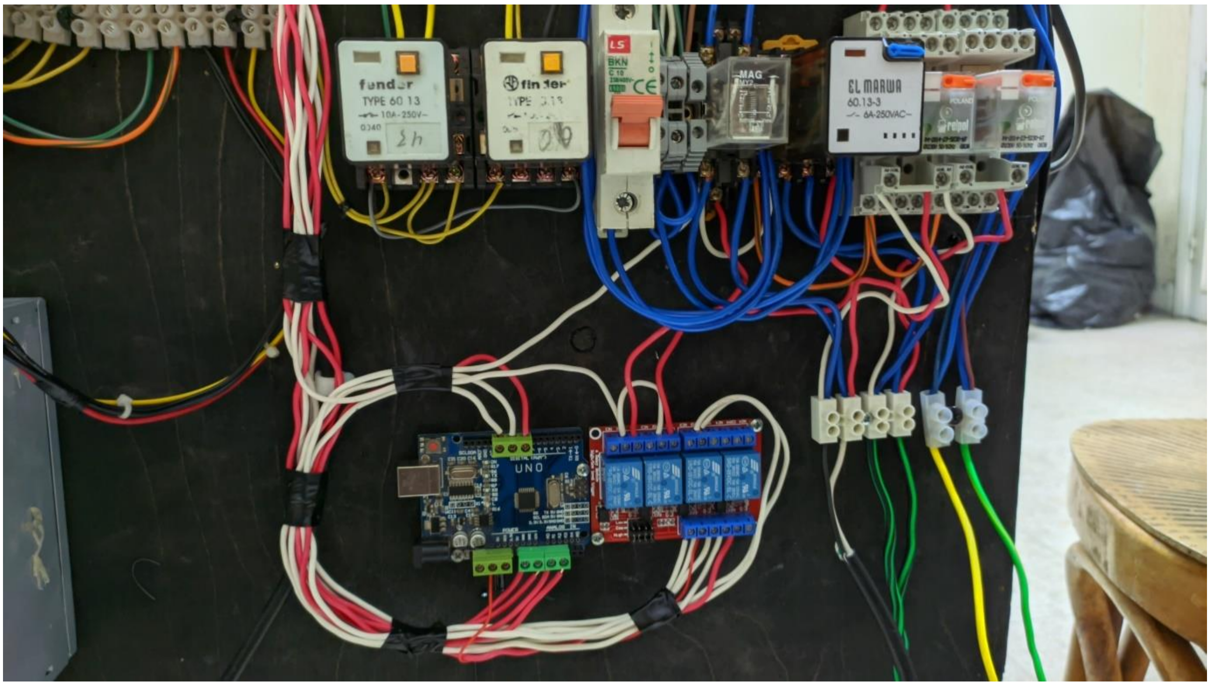
The IP address is usually able to be changed with external software, or sometimes using DIP switches embedded in the device.

How does this affect the programmer?

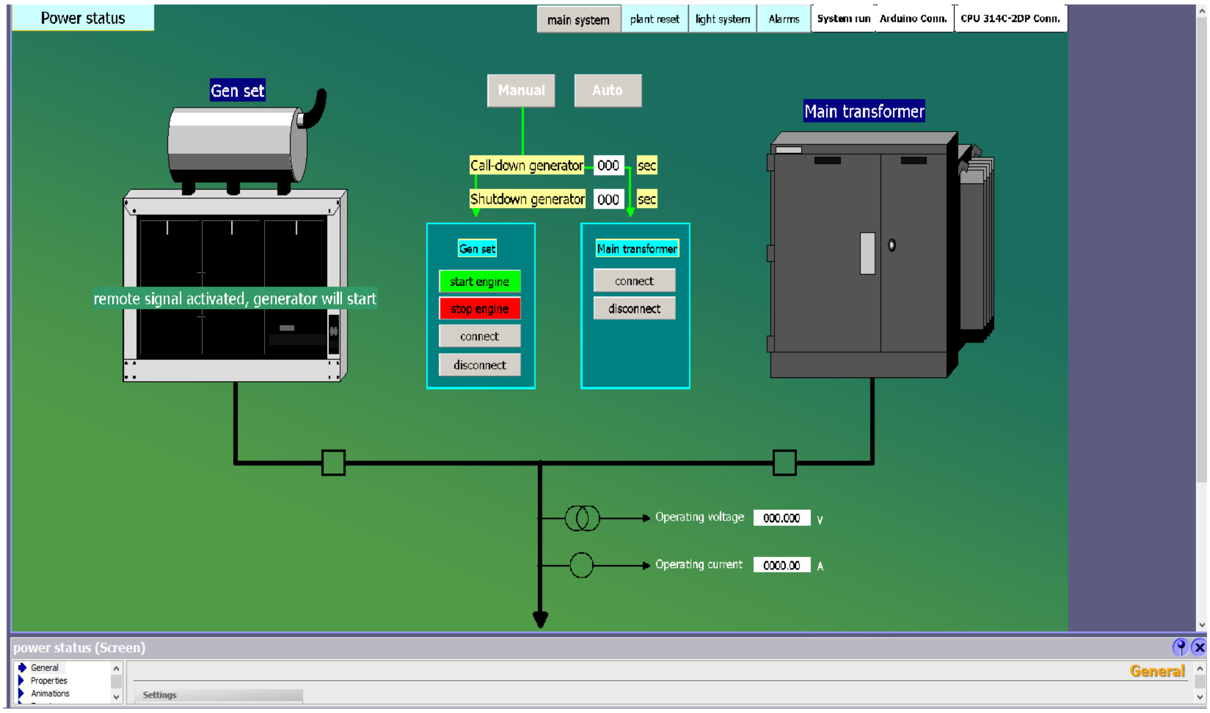
She or he must know: the device address (not called a node anymore, but the same thing), the function code, the starting address, and the length (if multiple).

In our project, we used the Modbus RTU type.

5.4.3.11 ATS in our replica

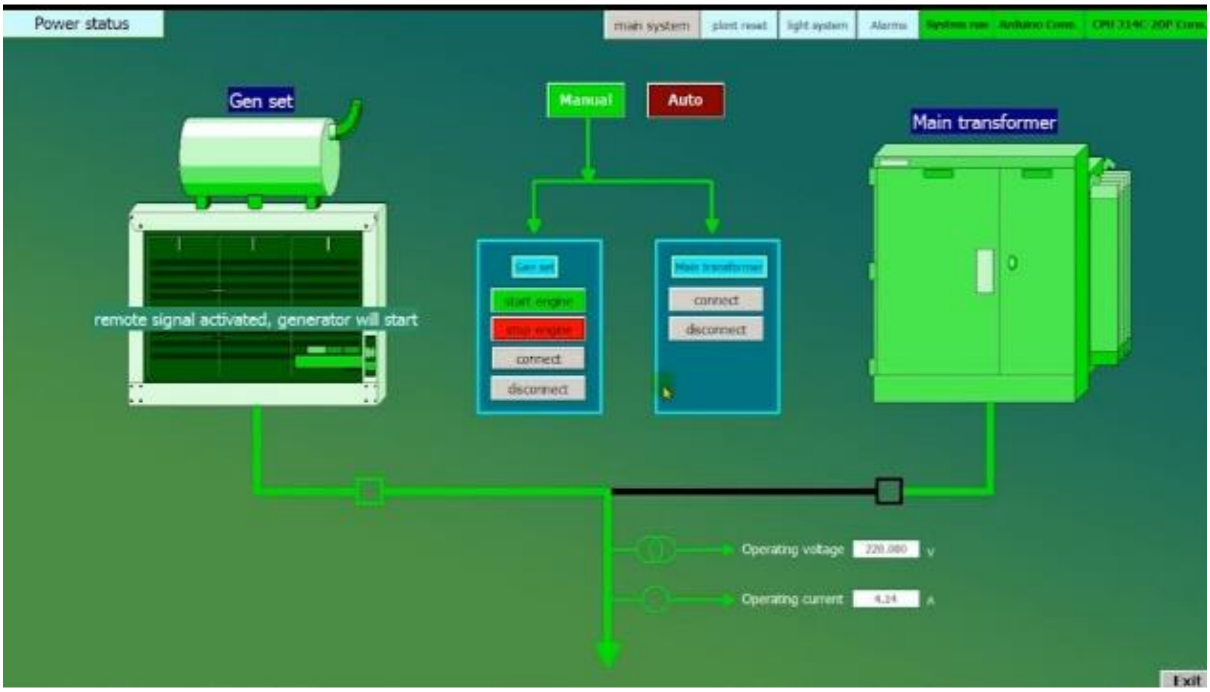


5.4.3.12 ATS in SCADA system



We have two modes of ATS in the SCADA system :

- **Manual mode:**



We have four buttons for the generator and two for the transformer

For generator

Start engine: to start the generator machine itself.

Stop engine: to stop the generator machine itself.

Connect: Connect the generator with the load.

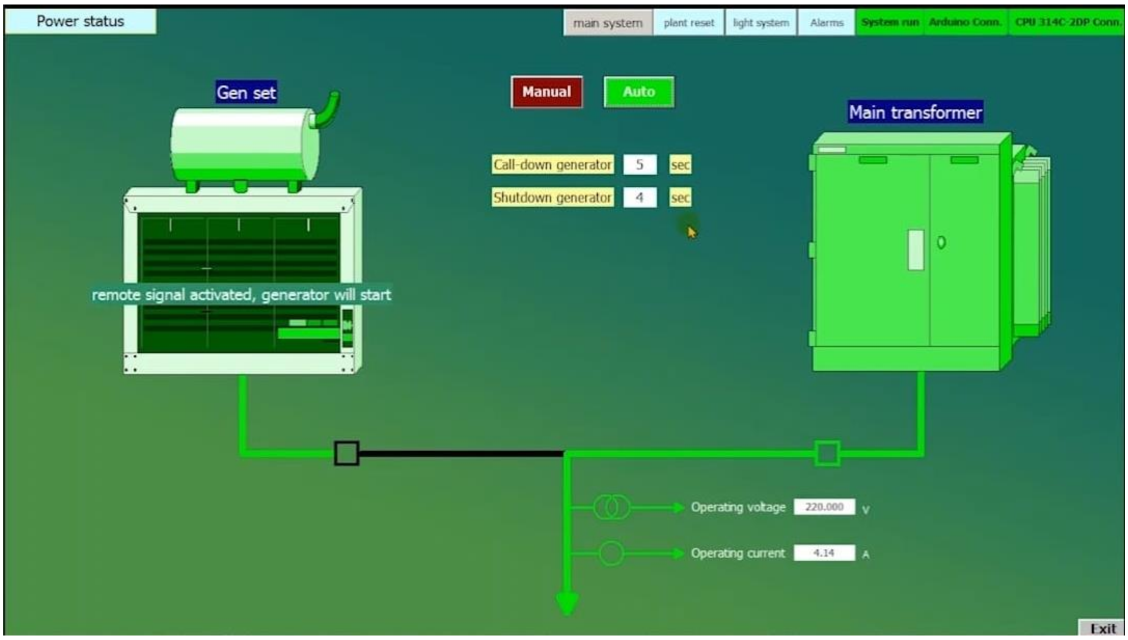
Disconnect: Disconnect the generator

For transformer

Connect: Connect the transformer with the load

Disconnect: Disconnect the transformer with the load

- **Automatic mode:**



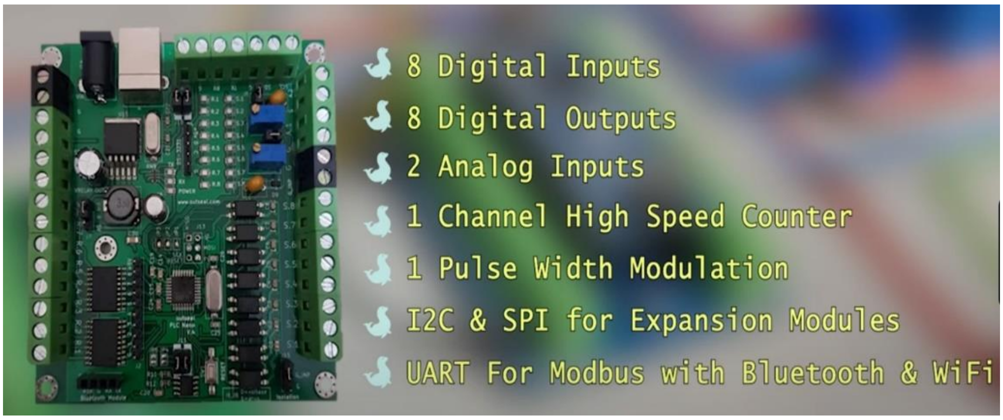
In automatic mode, only displayed two timers.

<u>Call-down generator</u>: we can set it from SCADA.

<u>shutdown generator</u>: displays the time to be shut down.

5.4.3.13 Software (Outseal studio program)

Outseal is a domestic brand of automation technology. Outseal products include PLC (Programmable Logic Controller), HMI (Human Machine Interface), and other modules. Outseal PLC is based on an Arduino bootloader, and its hardware design is open to the public, which means anyone can obtain and learn its electronic circuits freely and make them at home using Arduino microcontroller boards at an affordable price. What's interesting is that its software is in the form of a visual program (ladder diagram) and is also provided for free.



By converting the Arduino to PLC, we have 8 digital inputs:

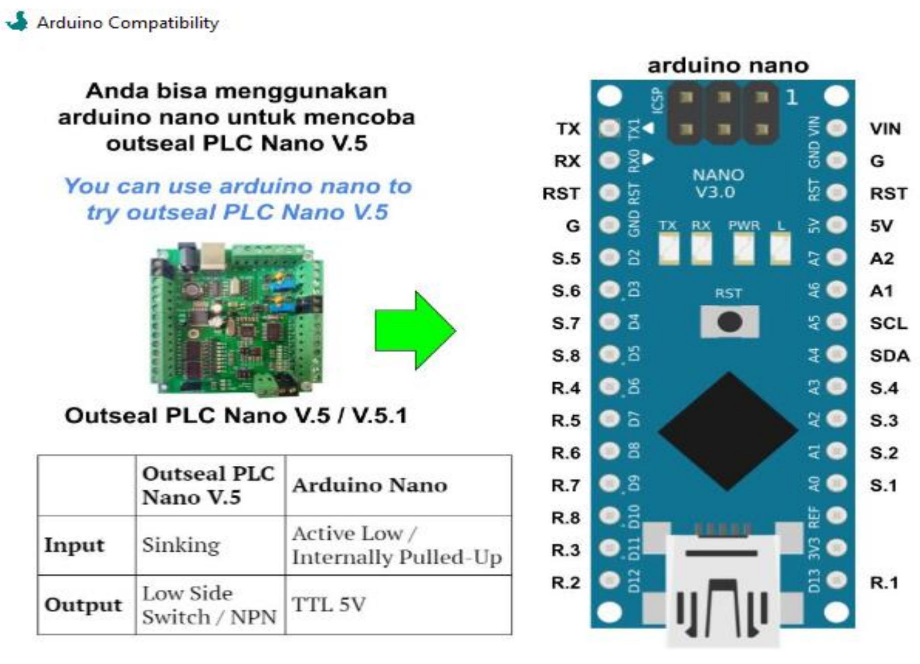
Hardware inputs mapping	Arduino pins
s.1	A0
s.2	A1
s.3	A2
s.4	A3
s.5	D2
s.6	D3
s.7	D4
s.8	D5

2 Analog inputs:

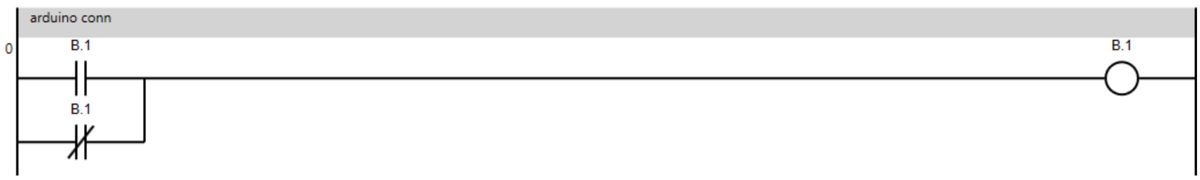
Mapping	Arduino pins
A.1	A7
A.2	A6

8 digital outputs

Hardware output mapping	Arduino pins
R.1	D13
R.2	D6
R.3	D7
R.4	D8
R.5	D9
R.6	D10
R.7	D11
R.8	D12

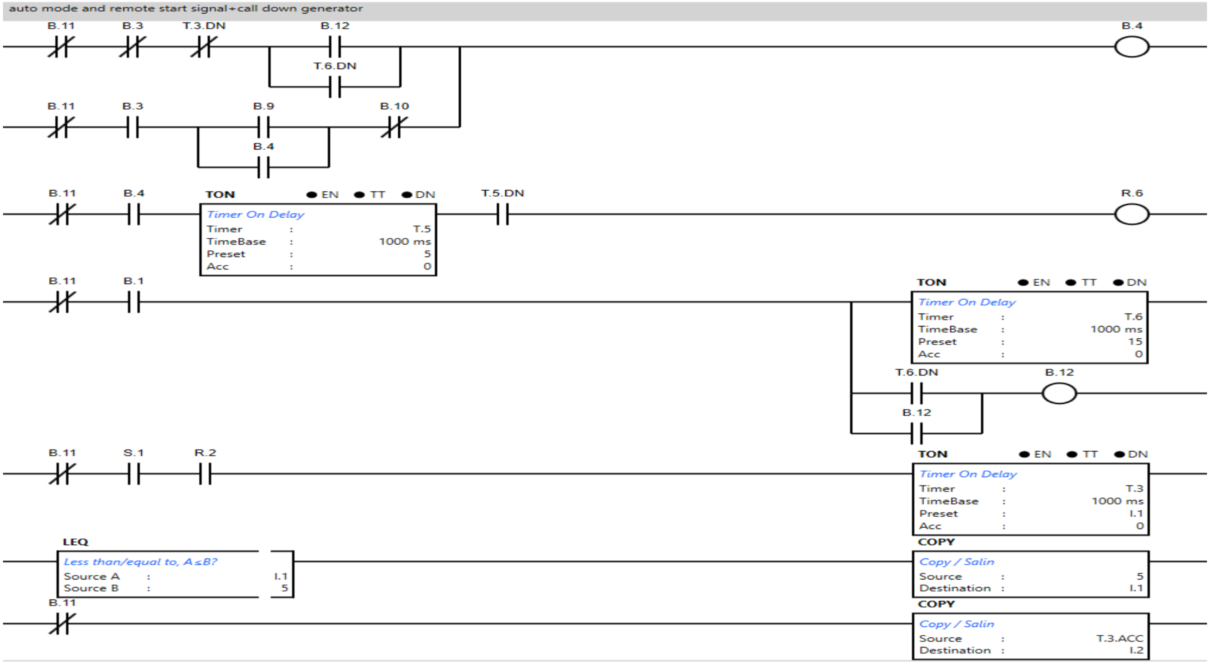


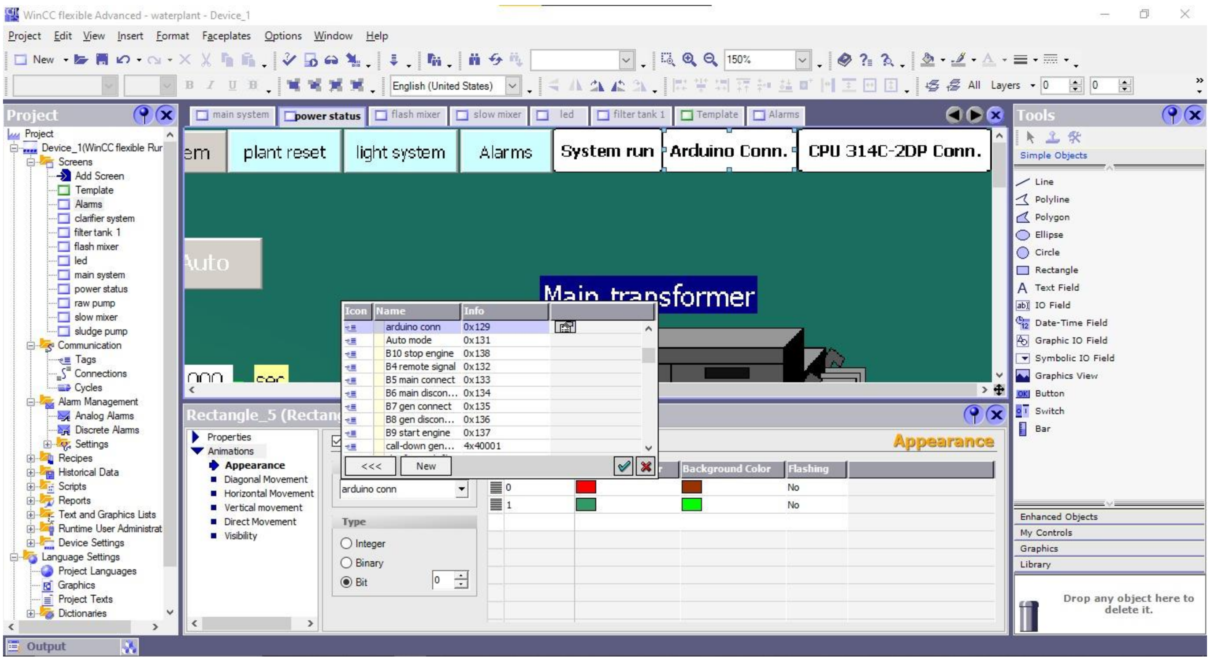
- **Ladder diagram**



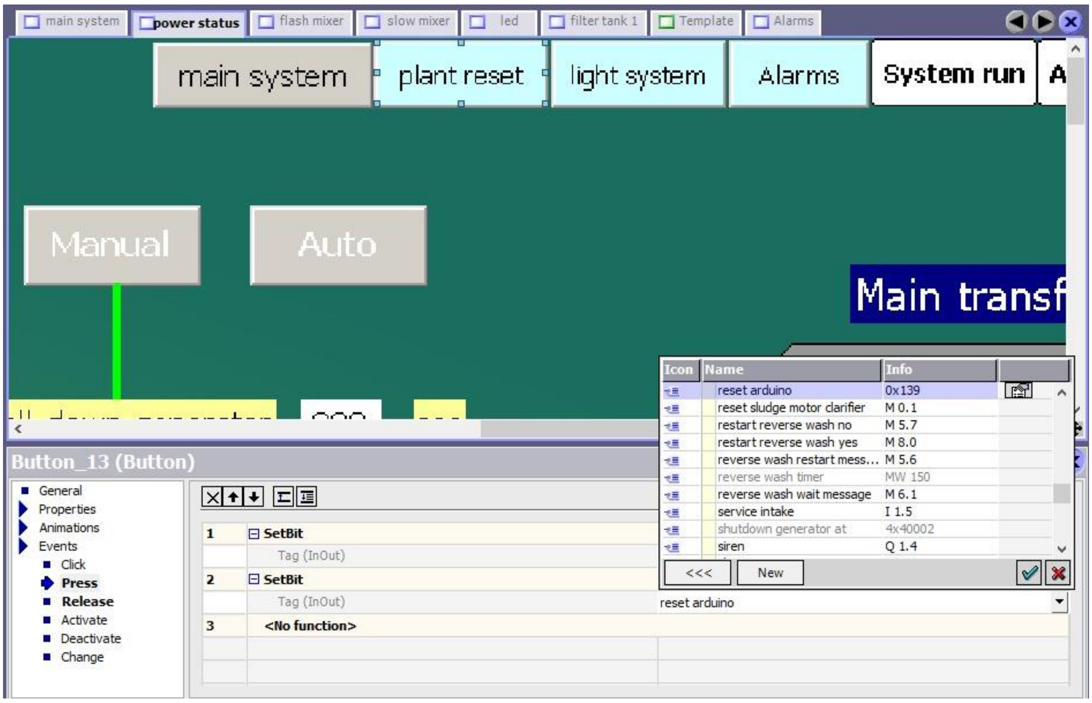
network 0 is to make the Arduino always connected to Wincc SCADA by making B1 always on.

B1 =0x129

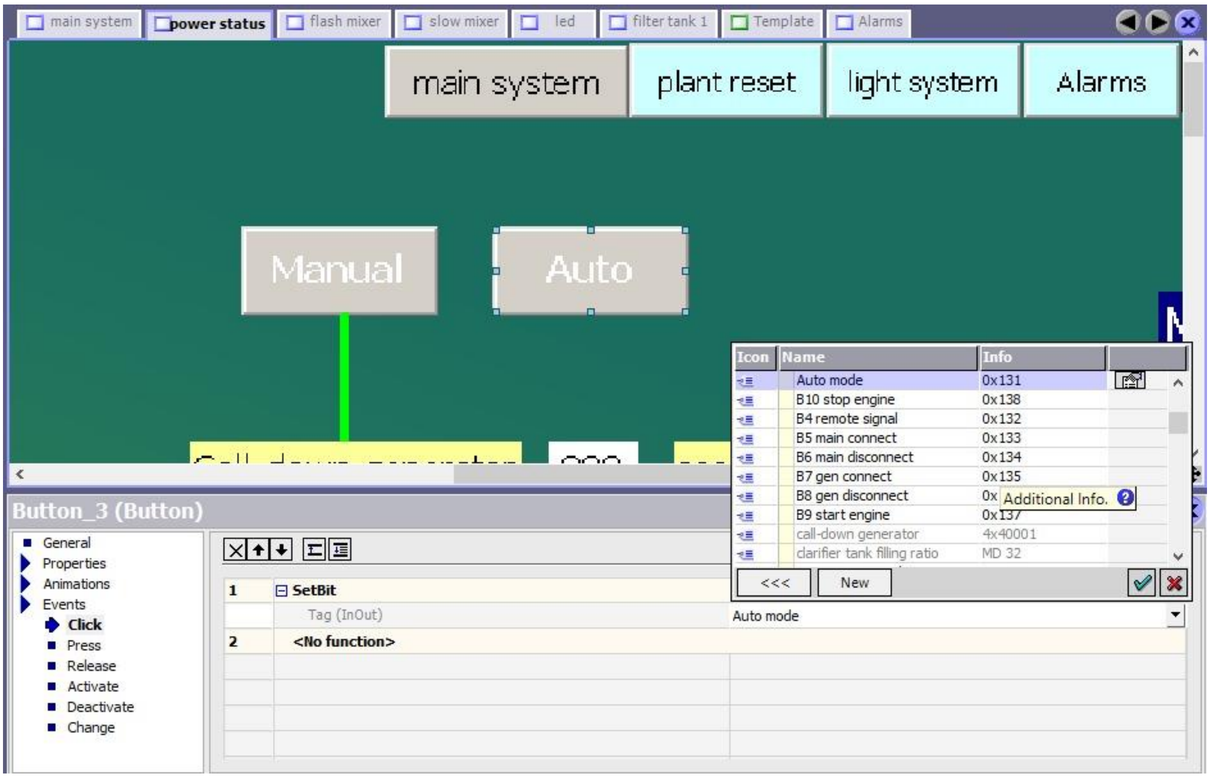


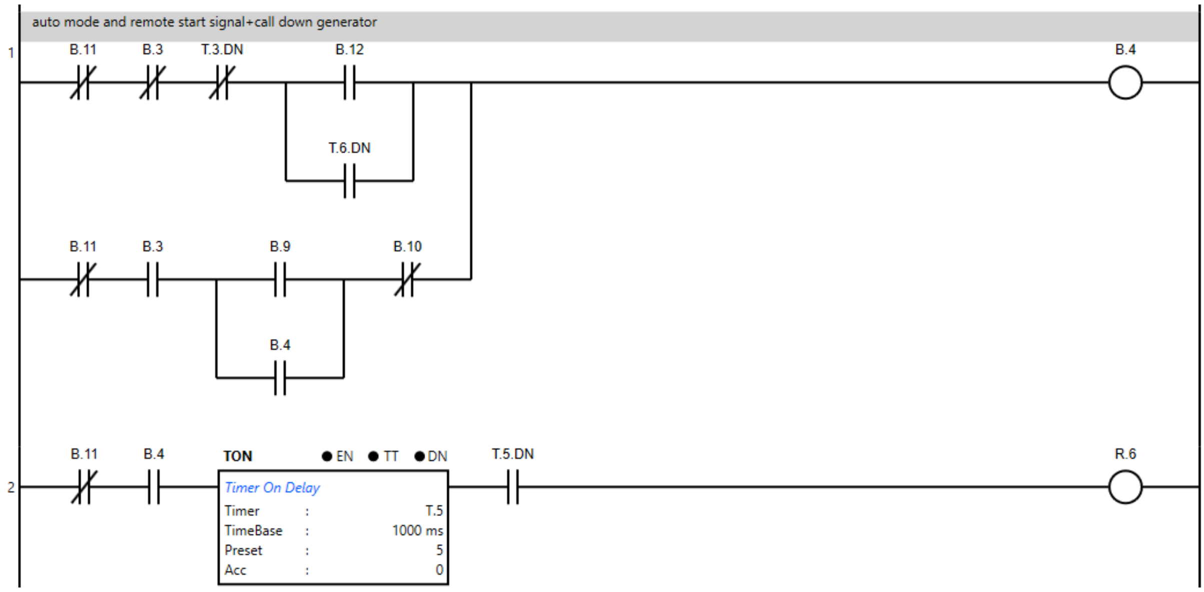


B 11 is responsible for Arduino reset from SCADA

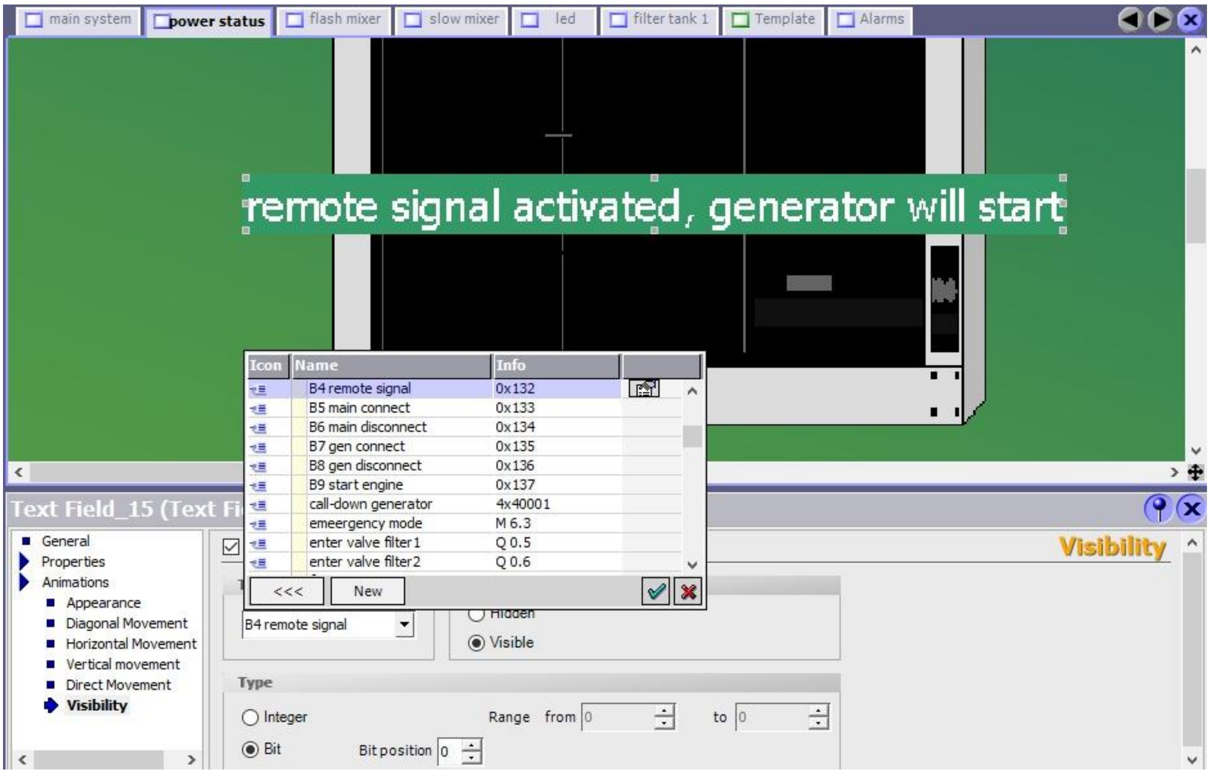


B 3 means the transition from automatic to manual mode by SCADA

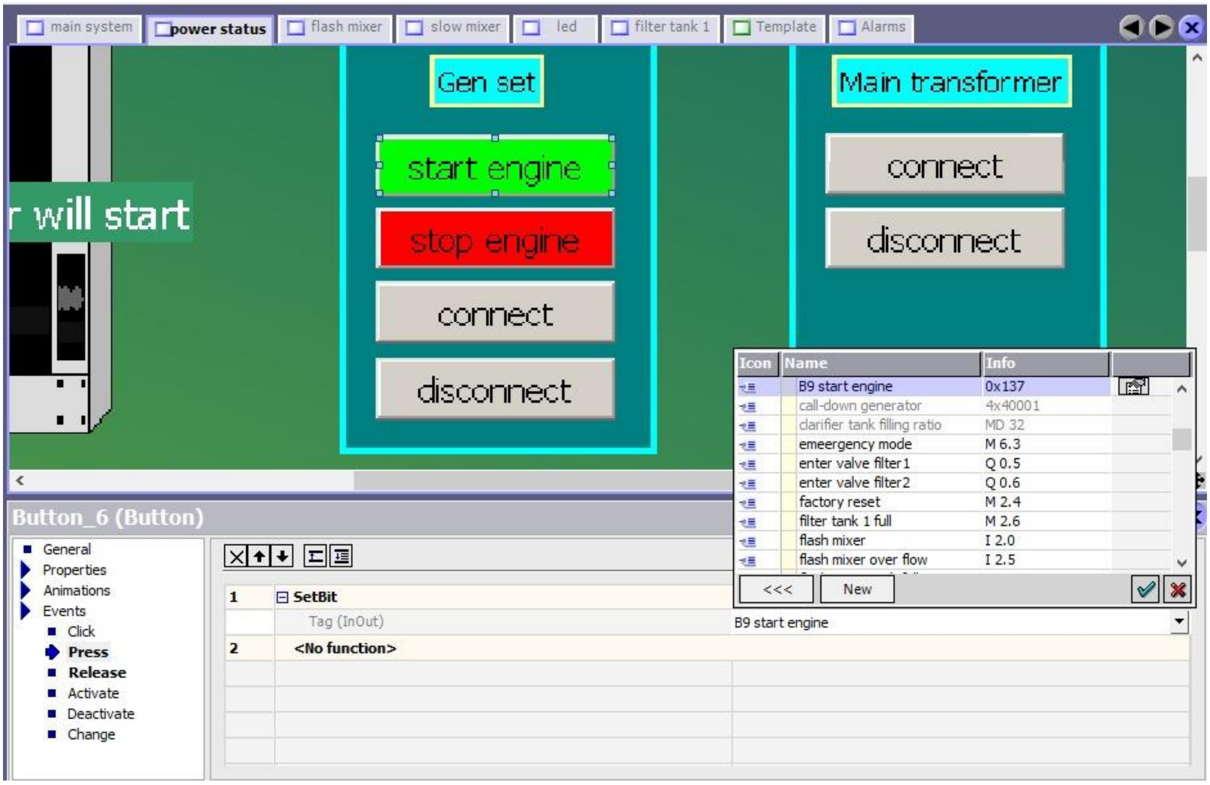




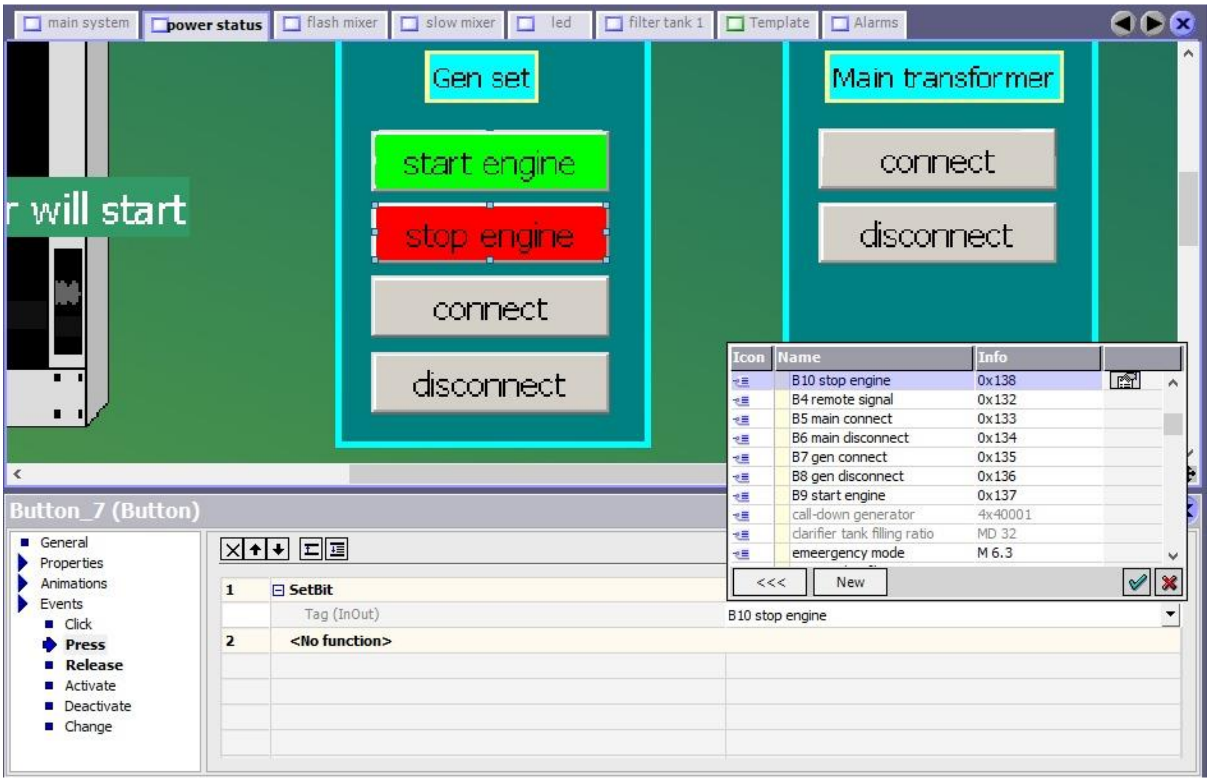
B4 means activation of remote start operation just after the transformer is down



B9 is responsible for starting the generator engine in manual mode.



B10 is responsible for stopping the generator engine in manual mode.



T5 means an on-delay timer with a 5-second delay to make sure that the main transformer is totally lost, then activates R6.

R6 means a digital output relay responsible for sending a remote start signal to the generator engine in automatic mode and manual mode.

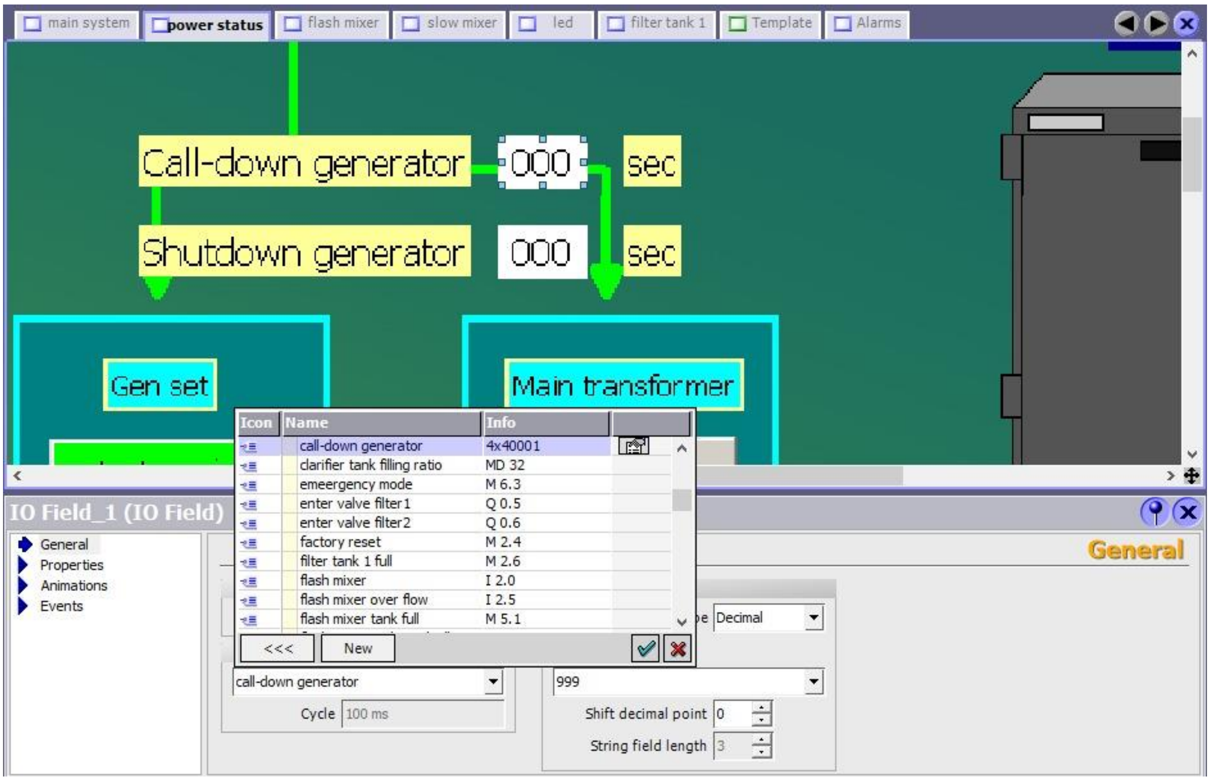
T6 means that the generator engine will not start until passing 15 seconds

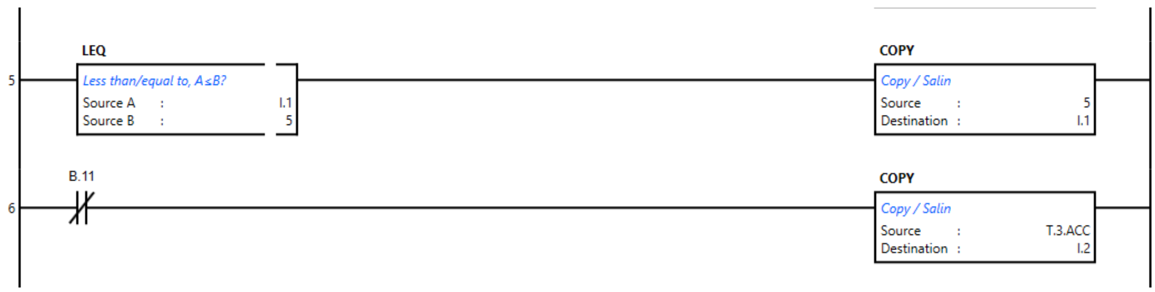
Just after the start of Arduino operation.

S1 means the transformer is available.

R2 means the transformer is connected to the plant.

T3 means an on-delay timer to call down the generator by a time specified by SCADA through I.1 (I.1 means the set value of the on-delay T3)





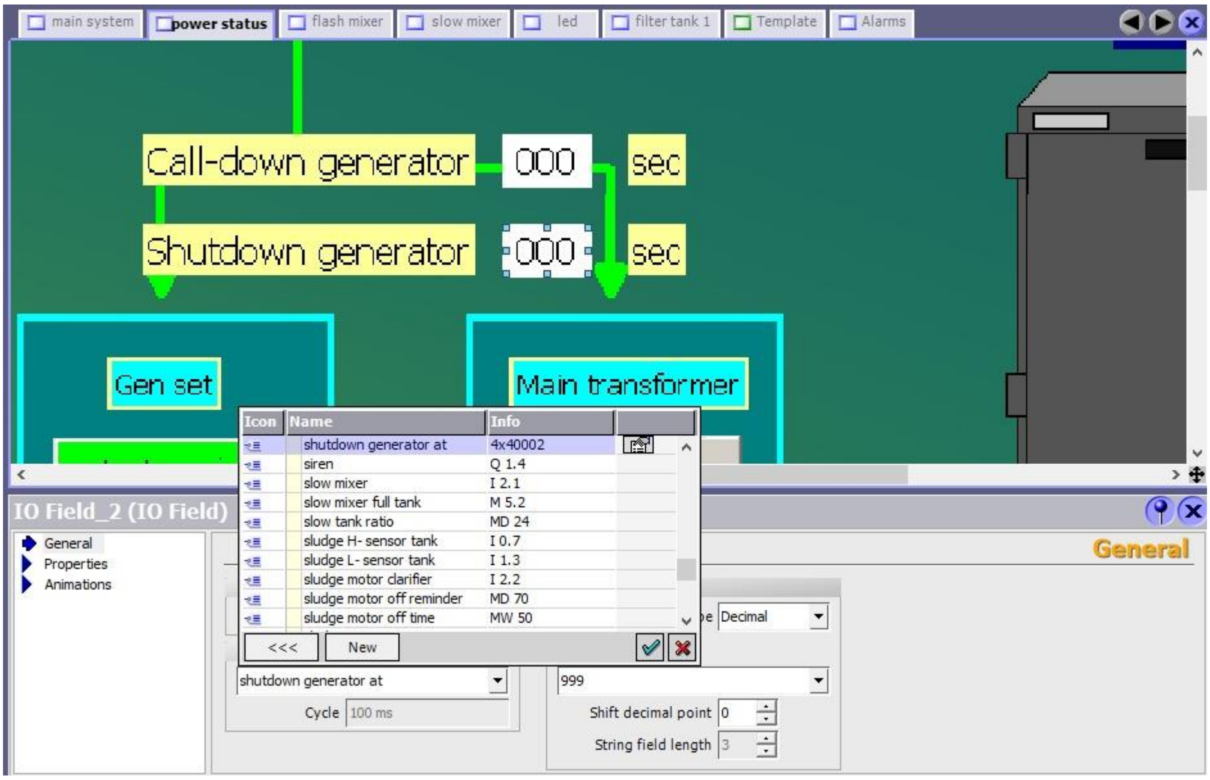
rung 5 means that the set value of T3 is equal to 5 seconds if the value from SCADA is less than 5 seconds.

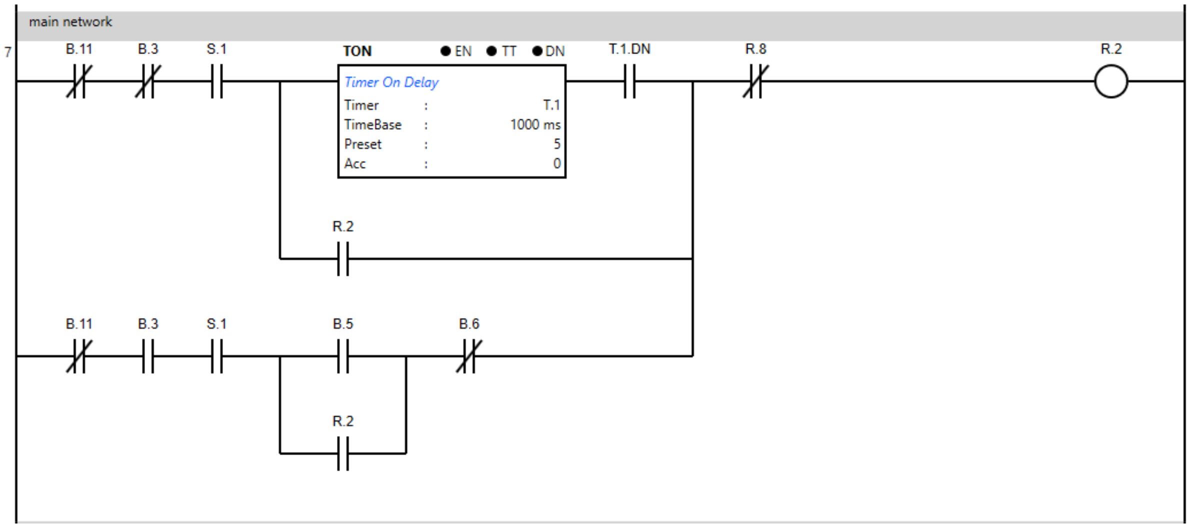
Hint, if (I.1<=5)

I.1 = 5;

Rung 6: I.2 means the output current value of on-delay T3

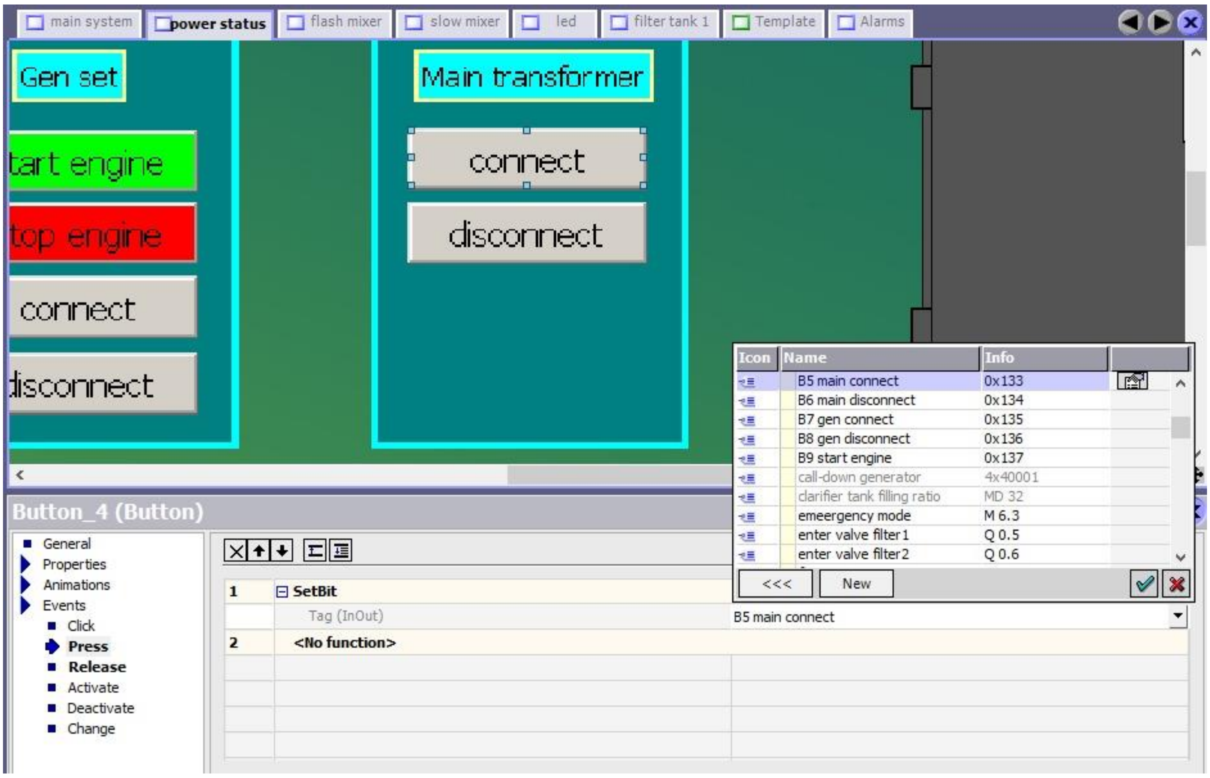
(Just to display the timer while running)



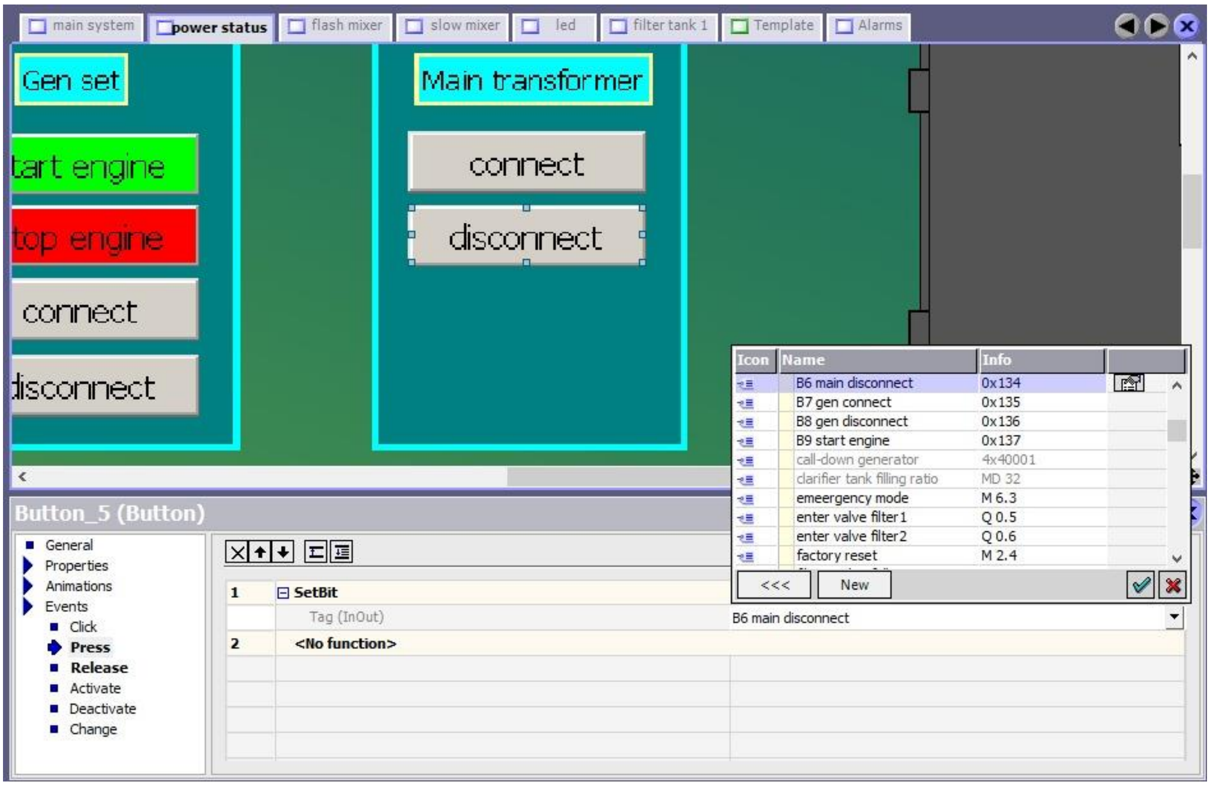


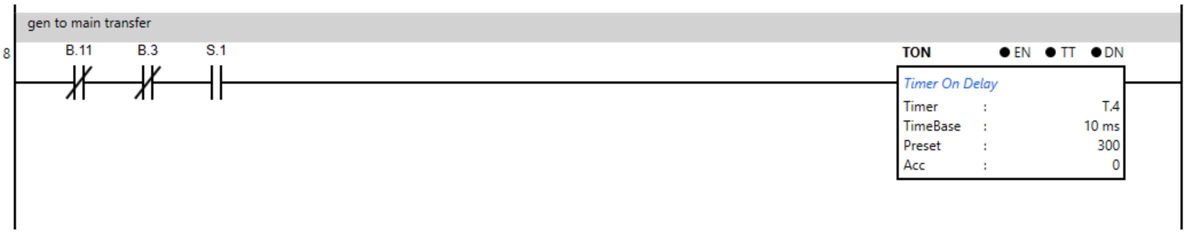
T1 means connecting the transformer to the plant after 5 seconds when the main power is restored in automatic mode.

B5 means connecting the transformer to the plant in manual mode.

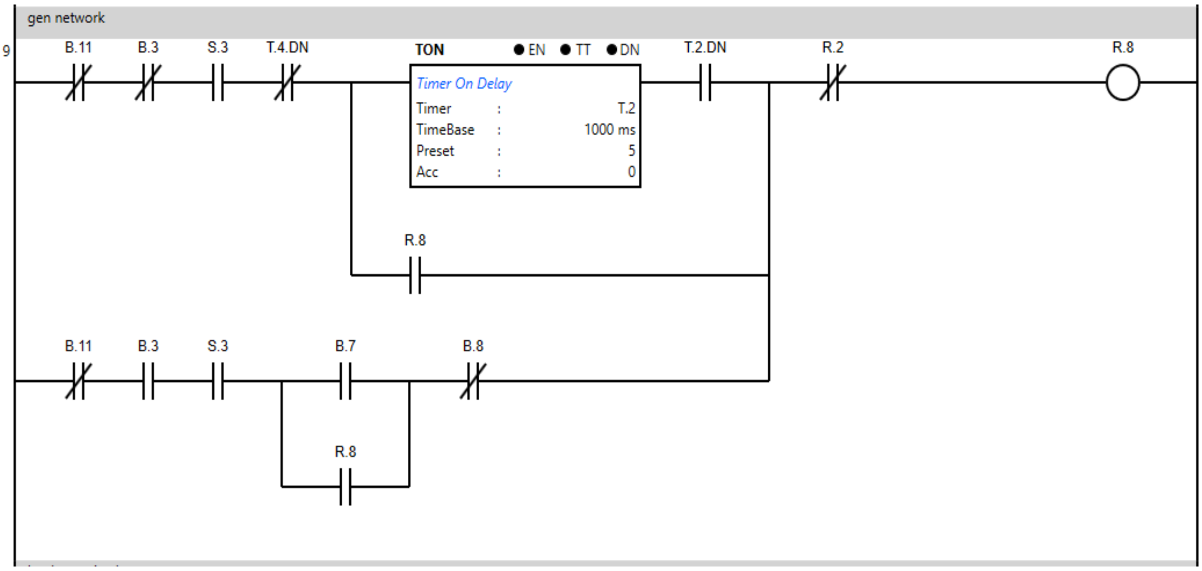


B6 means disconnecting the transformer from the plant in manual mode.



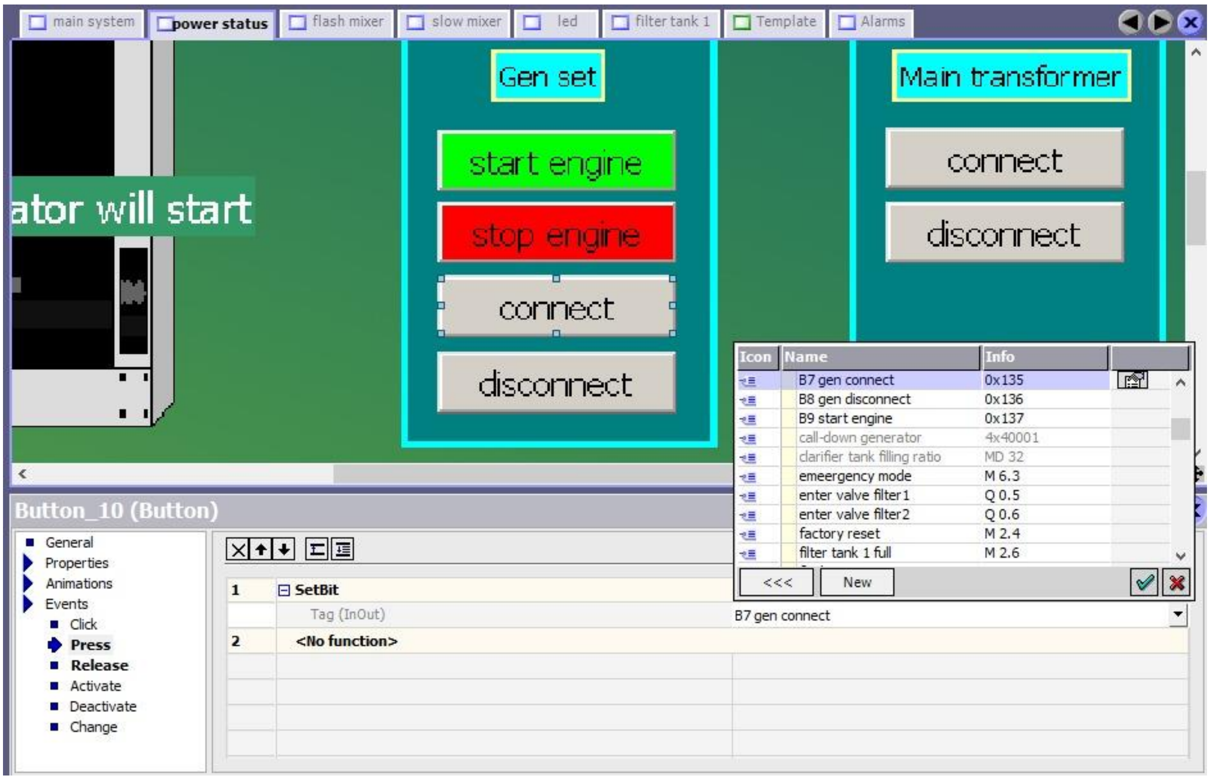


T4 whose set value is less than T1's set value transfers the load from the generator to the transformer in automatic mode by disconnecting R8 (output relay of the generator)

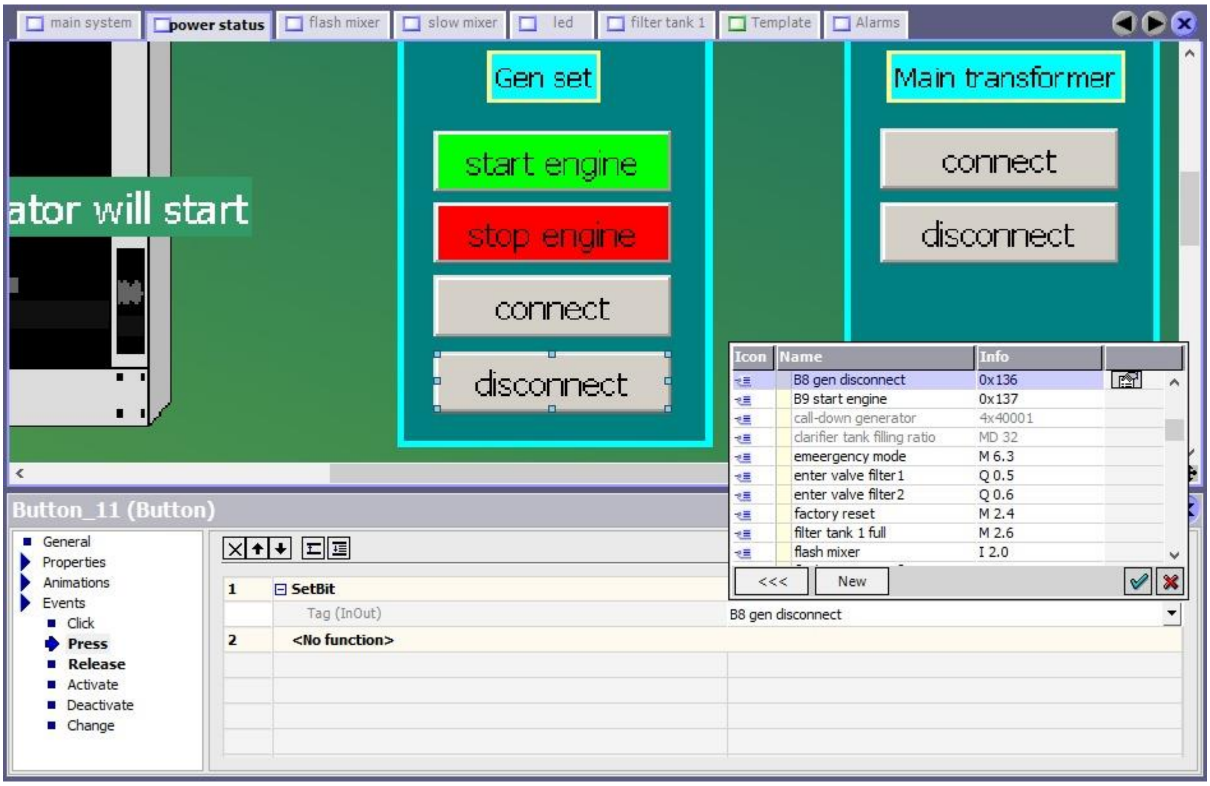


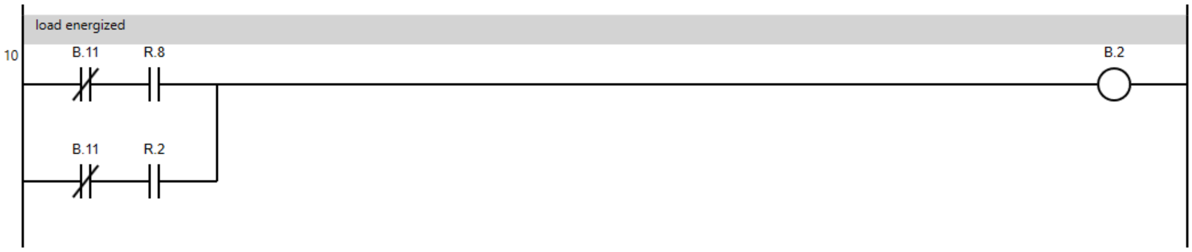
T2 means connecting the generator to the plant after 5 seconds from the generator being available in automatic mode.

B7 means connecting the generator to the load in manual mode.

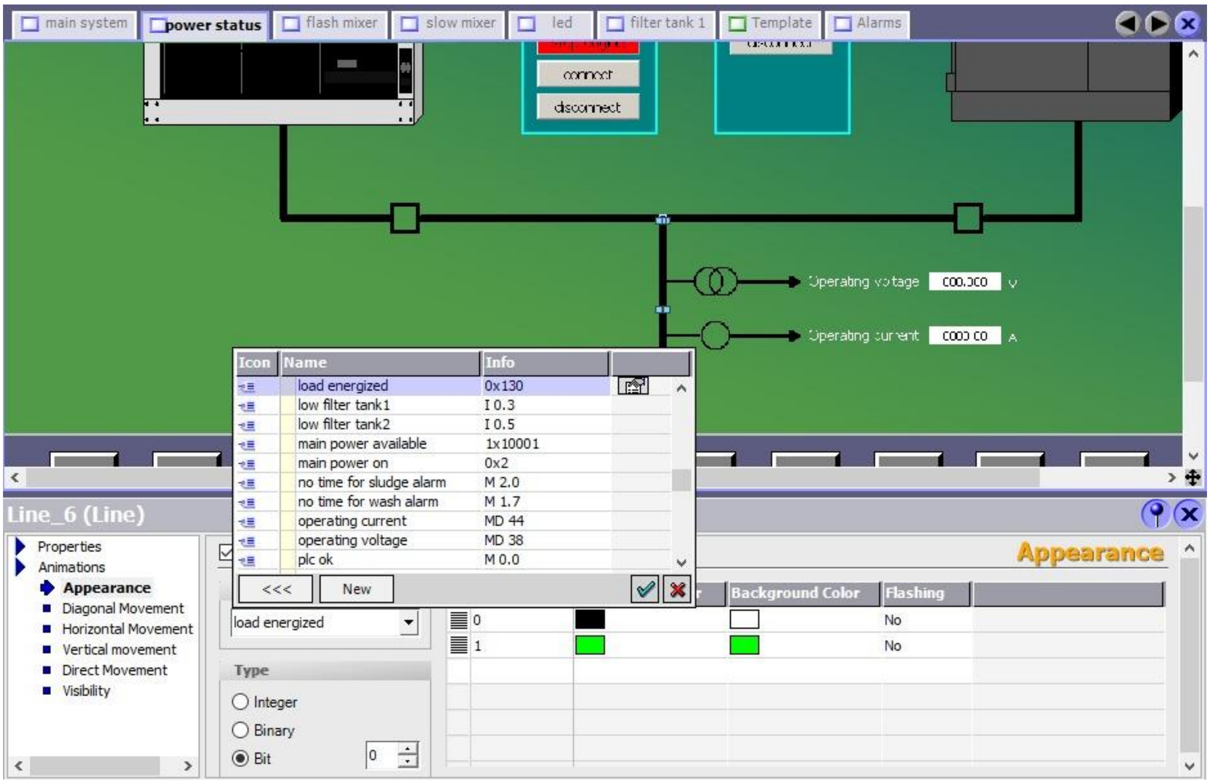


B8 means disconnecting the generator from the load in manual mode.

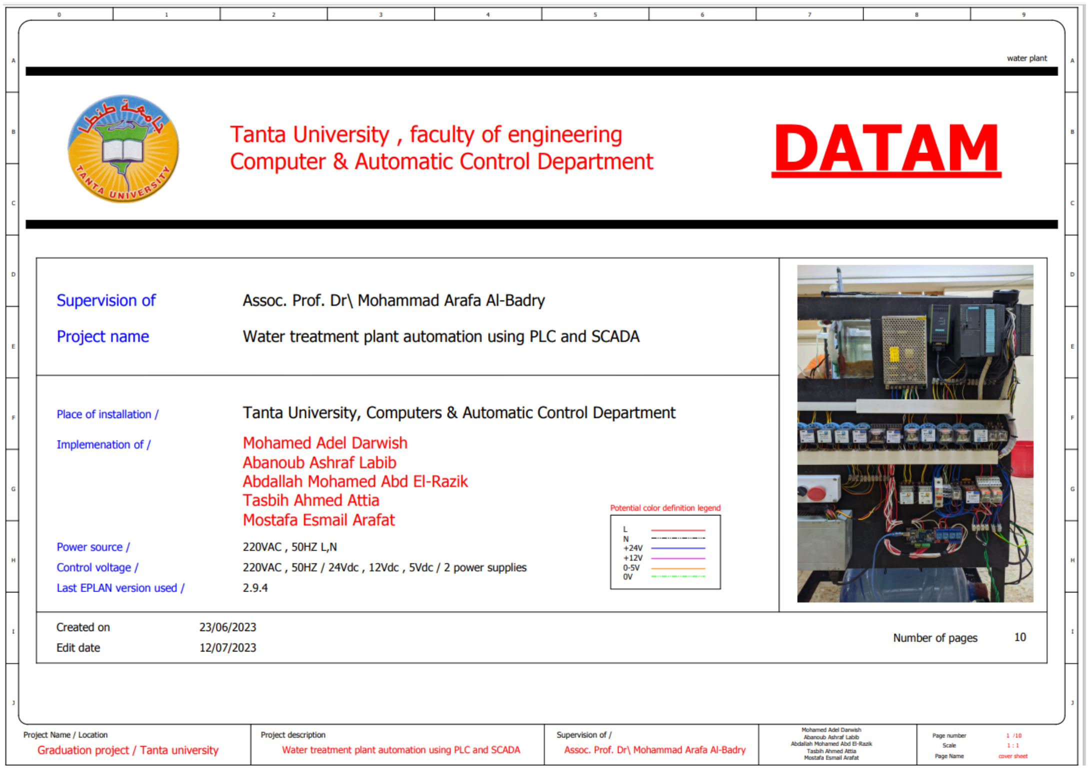


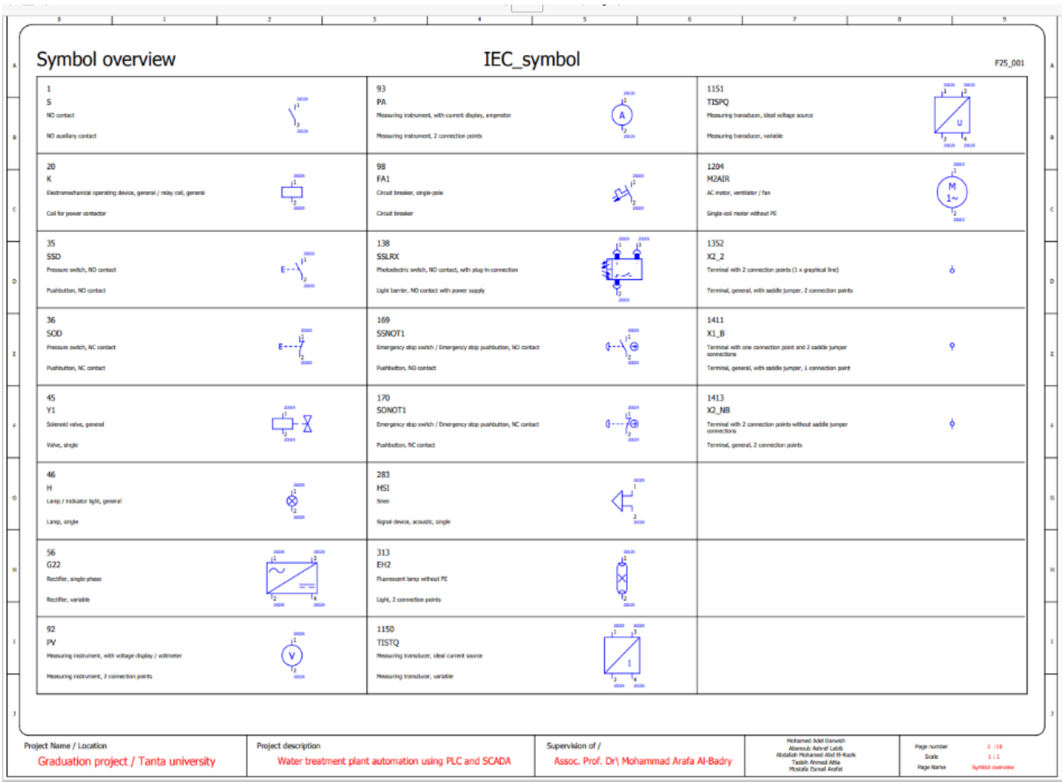


B2 shows on SCADA that the plant is connected to the transformer or the generator.



5.5 Eplan:


water plant
Tanta University , faculty of engineering
Computer & Automatic Control Department
DATAM
Supervision of
Assoc. Prof. Dr\ Mohammad Arafa Al-Badry
Project name
Water treatment plant automation using PLC and SCADA
Place of installation /
Tanta University, Computers & Automatic Control Department
Implemenation of /
Mohamed Adel Darwish
Abanoub Ashraf Labib
Abdallah Mohamed Abd El-Razik
Tasbih Ahmed Attia
Mostafa Esmail Arafat
Potential color definition legend
Power source /
220VAC , 50HZ L,N
Control voltage /
220VAC , 50HZ / 24Vdc , 12Vdc , 5Vdc / 2 power supplies
Last EPLAN version used /
2.9.4
Created on
23/06/2023
Edit date
12/07/2023
Number of pages
10
Project Name / Location
Graduation project / Tanta university
Project description
Water treatment plant automation using PLC and SCADA
Supervision of /
Assoc. Prof. Dr\ Mohammad Arafa Al-Badry


Symbol overview
IEC_symbol
F25_001
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Graduation project / Tanta university
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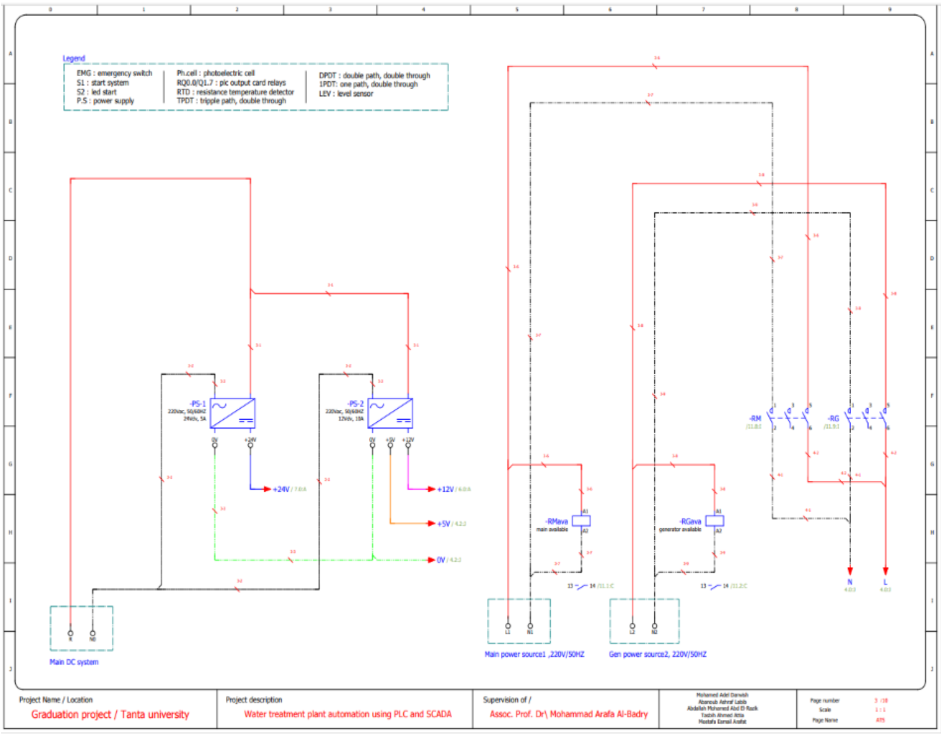

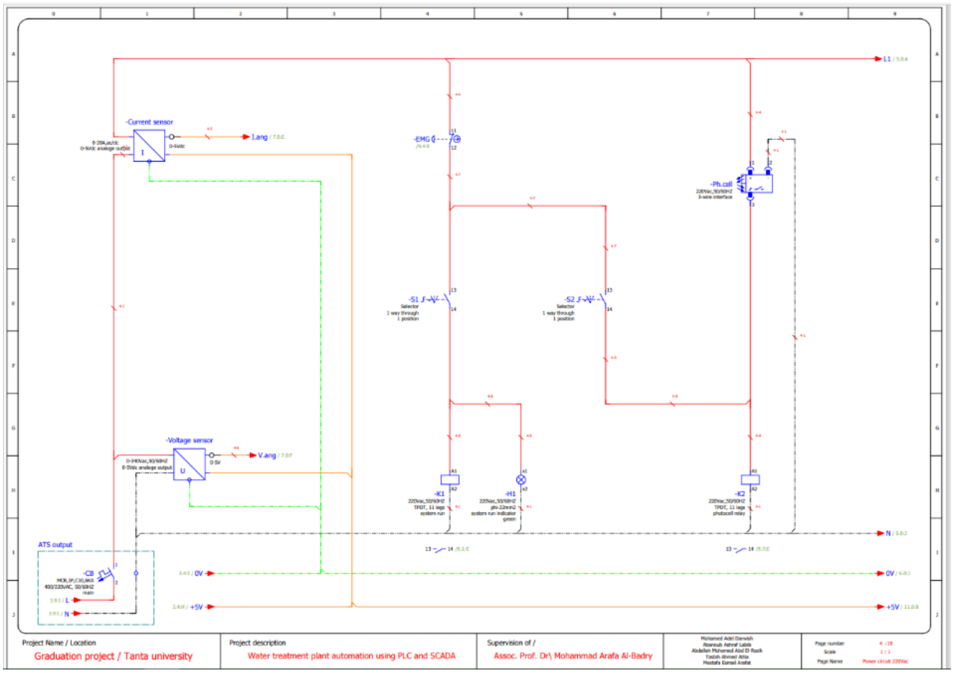

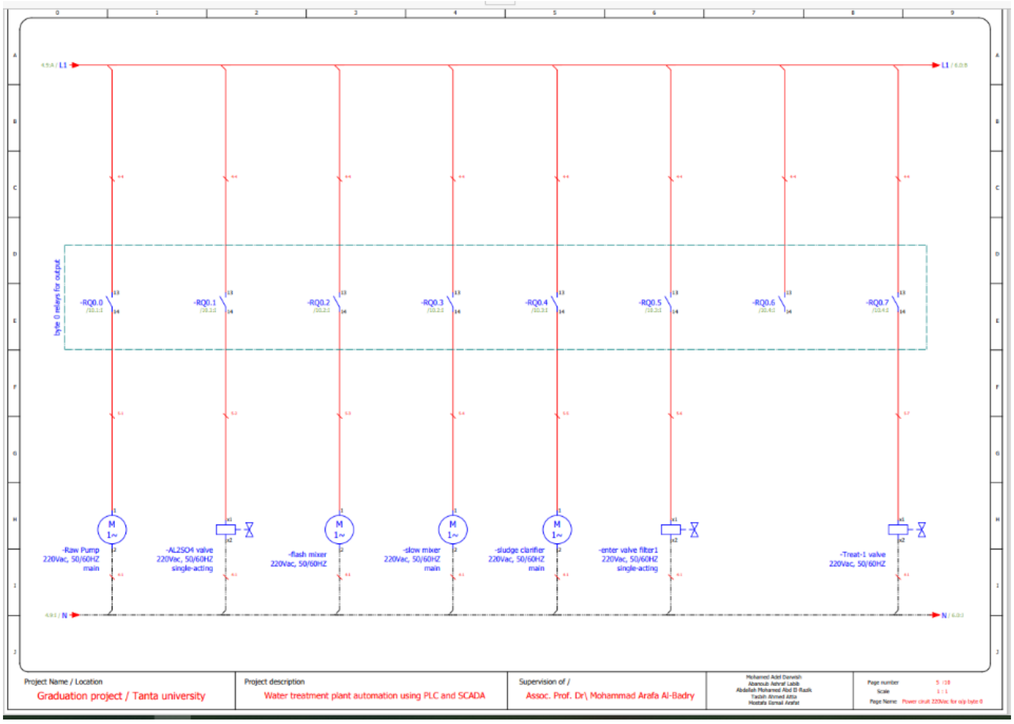
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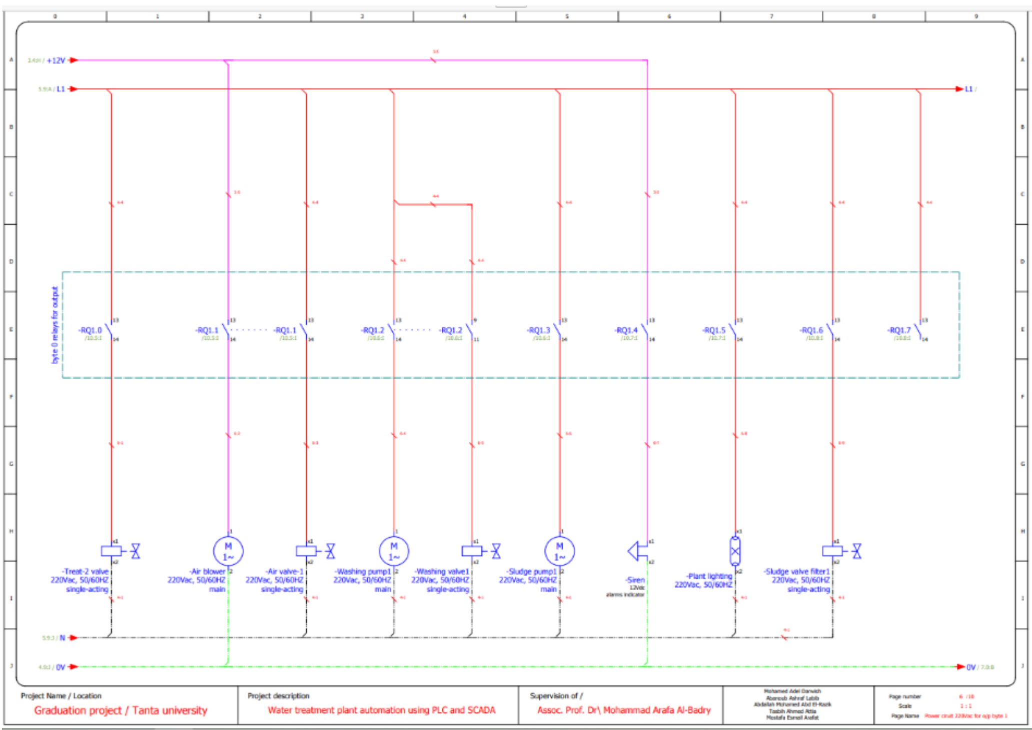
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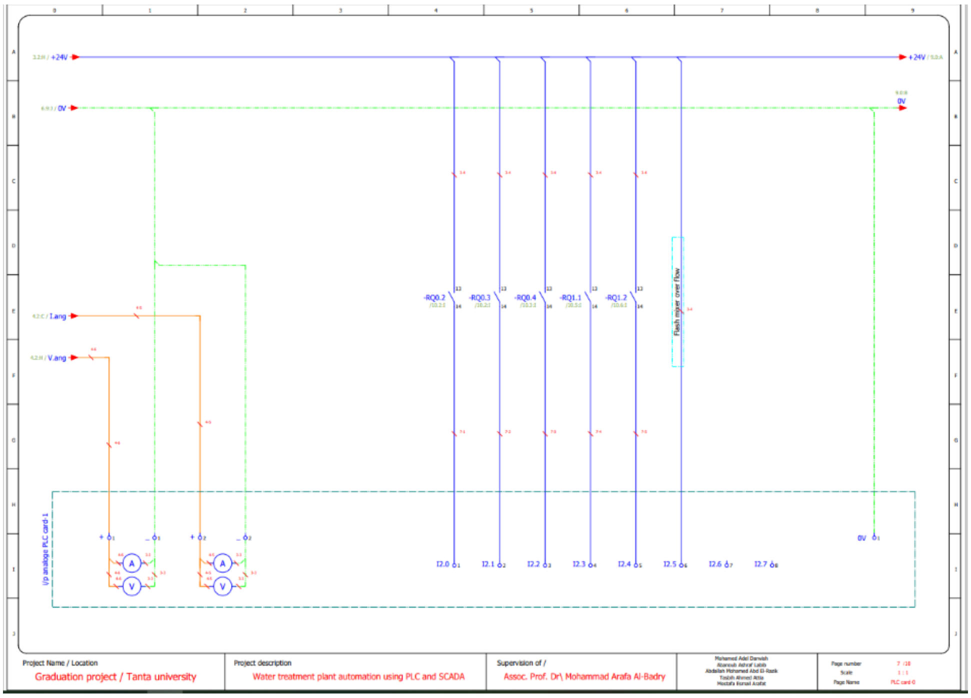
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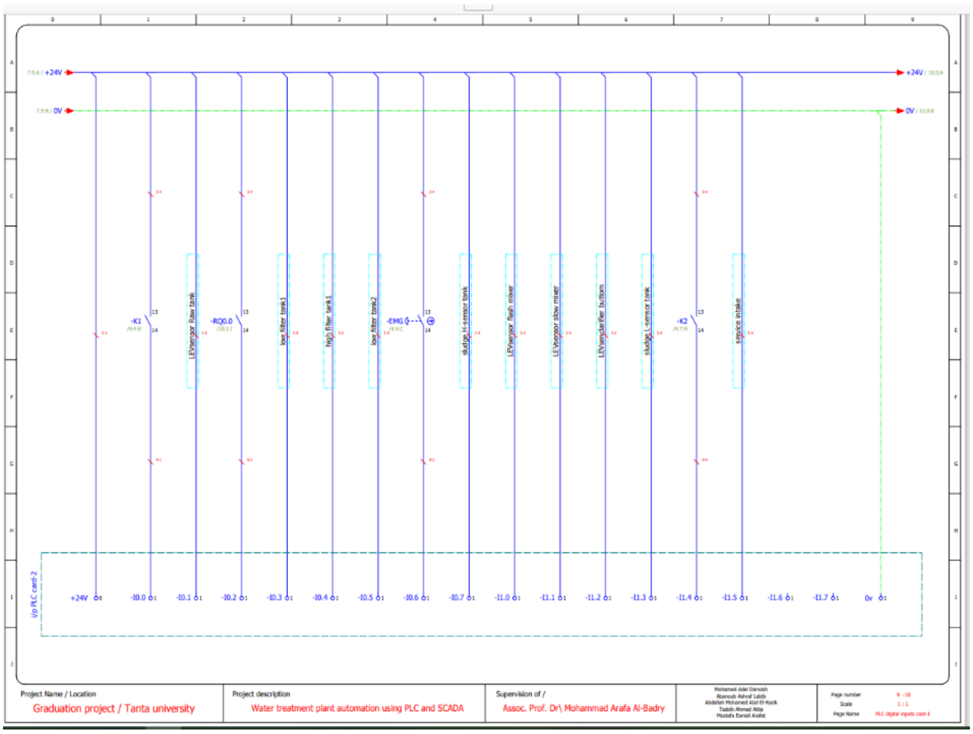
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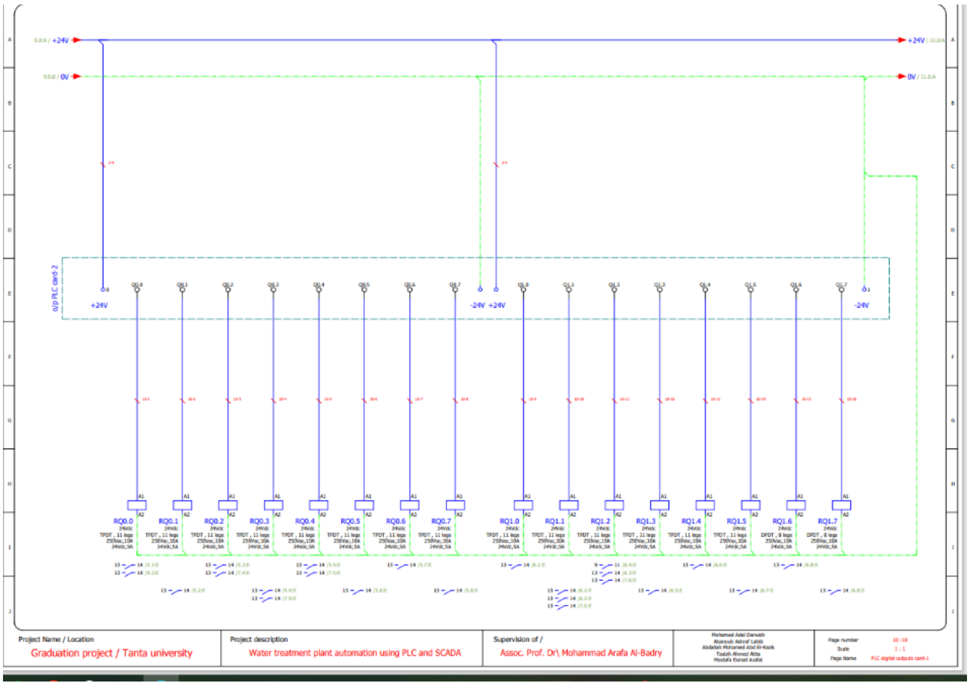
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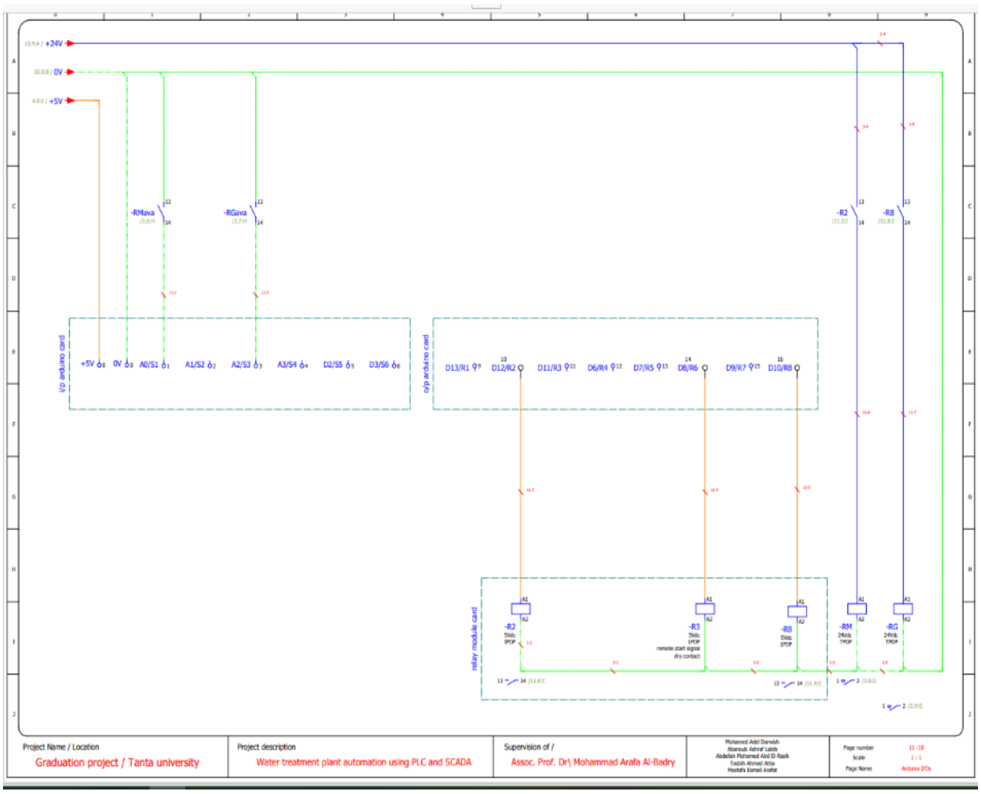
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Eplan:

Chapter 6 Future upgrades

6.1 AI-supported system

The chlorine and alum injection in our system is done manually and it is almost impossible to conduct such applications using the PLC and relays alone.

This injection could be calculated using an AI program that uses a camera to capture the color of the water after it is mixed with a specific substance that turns the color of the water into a yellowish color that varies depending on the number of bacteria in the water so based on that yellow color the AI can decide the amount of chlorine and Alum to be added to the water.

The program would be installed and stored on a raspberry pie chip that operates as the processor for the AI program and then connects it to a relay module to deliver inputs to the PLC to control the valves of the chlorine and alum.

6.2 Mobile application

We could develop a mobile application to control the plant.

Just by developing a GUI and a running program that sends signals to a WI-FI module that is connected to the same Raspberry pie chip so that it would control the plant by sending input signals through the chip to the PLC.

Monitoring the plant could be done on the mobile application as well as using relays to send feedback signals to deliver information about the status of the plant.

6.3 SCADA network

The station could be connected to a network so that it could be monitored and even controlled from a distance.

That could be done by configuring the communication settings of the SCADA system to develop it so it can be connected to a network and later be used from anywhere in the world.

Chapter 7 References

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