Advanced PLC-SCADA System for Toxic Solvent Mixing Process Control and Monitoring

Pugalarasan S.[1], Jeeva Kesavan D.[2], Arulmozhi N.[3]

[1,2]UG Student, [3]Assistant Professor, Department of EIE, Government College of Technology, Coimbatore, India

E-mail: [1]puga.71772116l13@gct.ac.in, [2]jeev.71772116l07@gct.ac.in, [3]arulmozhi6@gct.ac.in

Abstract

Industries that work with dangerous solvents struggle with control of level, flow, and consistency as a result of the high toxicity of these solvents. This study, aims to solve these problems, using a Programmable Logic Controller (PLC) equipped with SCADA. The study objective is to develop and deploy an intelligent monitoring and controlling system for toxic solvent mixing processes based on PLC and WinCC. This system is designed for pharmaceutical, chemical, food, and beverage industries. It contains sensors for flow rate measurement and temperature control, as well as actuator control, which allow managing processes with high precision while minimizing risk exposure and involvement of people. The system has both automatic and manual Clean-In-Place (CIP) hygiene procedures. The system also has visualization and alarming features that guarantee control of processes flow, and WinCC enhances product quality and process effectiveness while assuring operator safety and cleanliness of equipment. This system is designed in a way that makes it easily adaptable, flexible, and allows integration with other system.

Keywords: PLC, SCADA, Automation, Mixing Process, Process Automation, WinCC.

1. Introduction

WinCC is utilized in this workflow to plan and control the mixing activities. In this study, two materials are combined in a process tank. It has two functional modes: manual and

DOI: https://doi.org/10.36548/jei.2025.1.003
Received: 16.02.2025, received in revised form: 14.03.2025, accepted: 28.03.2025, published: 08.04.2025

automatic [1]. An agitating motor performs the mixing action and valves are used to control the flow of the ingredients [2]. The component is pumped into the process tank for mixing [3]. While the level switches monitor the tank, the flow transmitters determine the volumetric flow rate of the ingredients [4]. SCADA (Supervisor and Data Acquisition) enables the monitoring and control of the process from a remote location [5]. These industries face overwhelming challenges in the management of level, flow, and consistency because of the high toxicity of the solvents dealt with. Recent advancements in the process control technology have led to the emergence of complex monitoring and control systems employing SCADA along with PLCs. Evidence has been provided to show that the operational efficiency, safety and quality of products are enhanced when PLC and SCADA systems are employed in processes involving the mixing of toxic solvents. The systems use sensors for flow rate measurement, temperature control, and actuator control to minimize human risk exposure while providing precise regulation. Moreover, automatic and manual Clean-In-Place (CIP) functions assure the hygiene of the systems.

More recent studies have been oriented towards creating graphical interfaces based on WinCC for the automatic monitoring and control of mixing processes. These interfaces are remote supervisory systems that provide complete monitoring and controlling of the process with the help of visualization, alarms and other advanced features. This functionality increases the safety of the operators by directly reducing their contact with the hazardous materials, therefore, preventing severe health issues. The structure for modern mixing systems usually comprises several storage vessels for the different solvents and water, as well as a system of valves and pumps to control the inflow and outflow of the various materials. Flow transmitters are used for the volumetric flow rate of each ingredient, while the level switches observe the tank levels. The Process tank, refers to the central mixing chamber, uses a stirring mechanism for blending of the solvents with a motor agitator[7].Moreover, some configurations of these systems are provided with flexible operational modes. The defined capability to manually control both the mixing and cleaning processes using CIP enables the system to be user responsive and flexible to a range of operational needs. Such capability is essential when dealing with periods of research and development where parameters can change often and at short notice. The design of these systems increasingly involves security considerations. Recently, user authentication and password protection features have been implemented to improve the overall safety of the system and reduce the possibility of unauthorized access. A refined system security model has been developed that includes multi-tiered access control privileges to distinguish between operator and guest user logins [8,9]. Besides having visual alarms, the systems now have audio alarms so that the operators can be warned of issues such as overflowing of tanks. Such systems are frequently associated with automatic responders that stop activities and close valves in an effort to reduce spillage and potential harm to premises[10].

To sum up, available literature indicates that the mixing of toxic solvents with automated systems integration has greatly boosted productivity, control and safety metrics for these operations. These modern systems are flexible, adaptable, are easily and rapidly integrated into already existing systems making them useful in many industrial settings which handle dangerous substances. User of this work can transfer Mixing and CIP (Clean-In-Place) process [6]. In this operation, the user can also select to work in manual and auto modes.

Objective: To identify the specific requirement of the industrial handing of toxic solvents in term of level, flow and consistency control to address the challenges of high toxicity the study aims to

- Develop a PLC Program to monitoring and controlling the mixing process using sensors for flow rate measurement, temperature control and level measurement.
- Design a graphical interface using WinCC for real-time monitoring, alarm indication and operational control to ensure the process oversight.
- Incorporate with CIP (Clean-In-Place) process to ensure the hygiene of the process. Which is carried over in both manual and automatic modes.
- Implement user authentication and password protection to ensure the system safety and security. Also, which restrict and limit the access to prevent unwanted logins.

2. Piping and Instrumentation (P&ID) Diagram

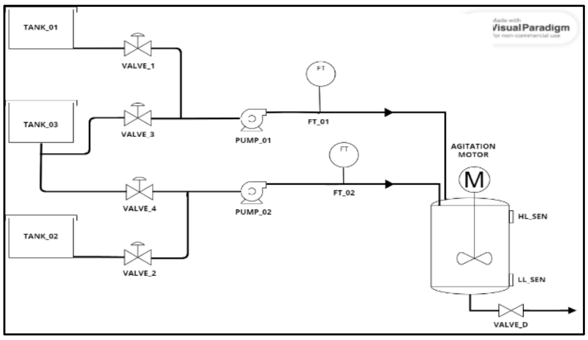

Figure 1. P&ID Diagram for Mixing Process

Figure 1 illustrates a comprehensive mixing system designed for handling toxic solvents and water. The setup consists of three primary storage containers: TANK_01 and TANK_02 for toxic solvents, and TANK_03 for water. The system's flow control is managed through a network of five shut-off valves (VALVE_1, Valve_2, Valve_3, VALVE_4, and VALVE_D), which also handle the flows of the toxic solvents during their processing. The pumping system consists of two pumps, PUMP_01 and PUMP_02, which supply the toxic solvents or water to the Process tank, where the mixing is done. There are also two flow transmitters installed to control the volume flow of the toxic solvents, which allow control and measurement of the flow.

The process tank is the core part of the system, mixing all the solvents in it by means of an agitation motor for a set period of time. The tank is equipped with limit sensors or switches to monitor the tank level which supports in process control and ensures safety. The system is flexible and gives the possibility to perform two distinct processes – the mixing of the toxic solvent and any other process. These procedures can be performed in Automatic or Manual modes. This implies that a user has control over how the tasks are completed. In essence, this system is a complete solution for mixing and managing toxic solvents with keen focus on safety, accuracy, and simplicity.

3. Ladder Design

The ladder logic program for the Automatic/Manual control system and valve operation can be expanded as shown in Figure 2.

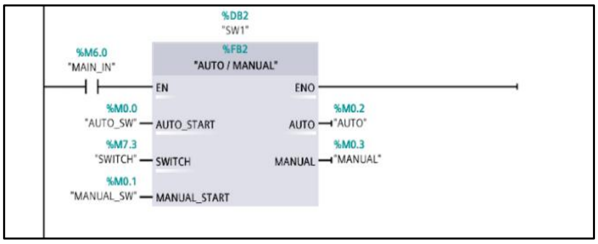

Figure 2. Auto / Manual Block

The system is designed with two primary components: The Automatic/Manual section and the Valve Function section. The Automatic/Manual enables the user to choose what operational mode to apply in the system. The section has inputs such as %M6.0 (MAIN_IN) for network activation, %M0.0 (AUTO_SW) for Automatic mode, and %M0.1 (MANUAL_SW) for Manual mode.

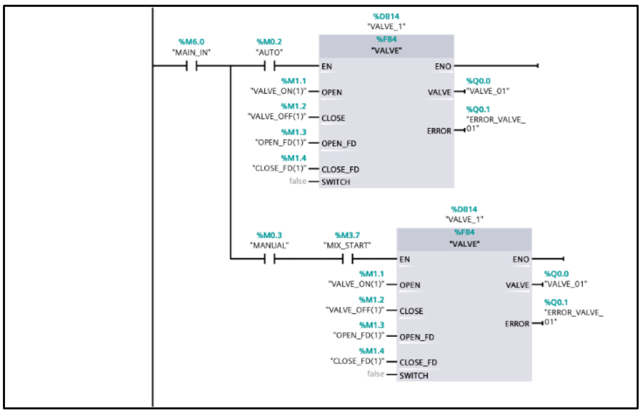

Figure 3. Function of Valve Block

Figure 3, illustrates the management of the Pump block's operation, which functions in both Automatic and Manual modes. Two Pump blocks are utilized in this process. The Pump block receives inputs such as MOTOR_ON to initiate the Pump and MOTOR_STOP to halt it. FLD_FB represents the field feedback signal from the field device. OLR_SET and OLR_RST, which are Over Load Relay Outputs, are provided as inputs to the Pump block. The outputs include Pump ON and OFF, as well as OLR_MOTOR. When the system is started, the pump awaits the field feedback signal. If present, the pump remains ON; if not, it returns to its prior state. When the system is stopped, the pump awaits the field signal. Upon receipt, it remains OFF; otherwise, it returns to its prior state. If an OLR be detected during operation, OLR Set stops the pump until OLR is Reset. The Pump Blocks are identified as follows: PUMP_01 (%DB3) and PUMP_02 (%DB4).

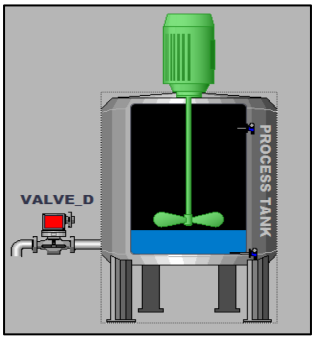

Figure 4. Process Tank

Figure 4 depicts the Process Tank, which serves as a container. In this study, the Process Tank is employed for mixing two toxic solvents. It is monitored and controlled through a WinCC SCADA Screen. A level switch is employed to monitor the liquid level. An agitation motor is used to blend the toxic solvents for the required duration. Following the completion of the mixing process, a mechanism is in place to drain the Process Tank.

4. SCADA Design

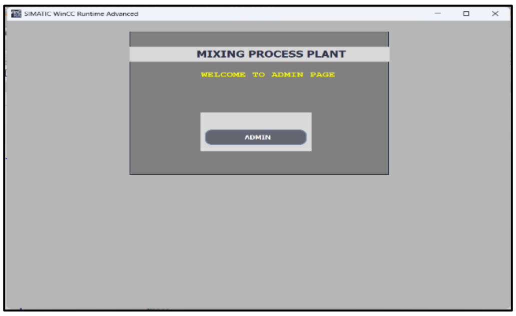

Figure 5. Admin Login Page

The admin page, as depicted in Figure 5, is where system administrators can have full control over the various components of the system. This interface is structured to allow easy control and changes to system parameters, user accounts, and other vital settings. Consequently, access to this page is restricted by a robust authentication measures, ensuring the system's integrity and security

The system employs an authentication process for access to the administrative interface. Users are redirected to a dedicated secure authentication module, where they must provide their User ID and password. The system then conducts an automated comparison against a secure, pre-defined user credential repository. This multi-layered security architecture effectively prevents unauthorized access and protects critical system functions from potential misuse.

Following successful authentication, administrators are granted comprehensive control over user management, system configuration, data analysis, and problem resolution through a centralized interface.

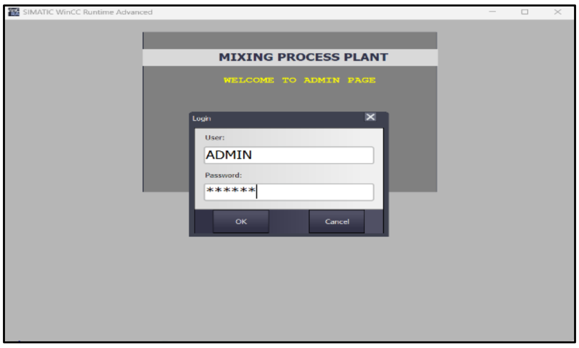

Figure 6. User Authentication Page

The system security architecture is illustrated in Figure 6 and is segmented through a multi-tiered access control system. Users or operators with higher-level privileges can perform a wider scope of functions including data editing, system setting, and sophisticated analytics. As for guest users, they are usually provided with more restricted, read-only privileges over certain portions of the system which safeguards sensitive information and critical operations. This role differentiation not only increases security but also facilitates enhanced workflow by providing each user type with a specific interface and set of features according to their roles and responsibilities.

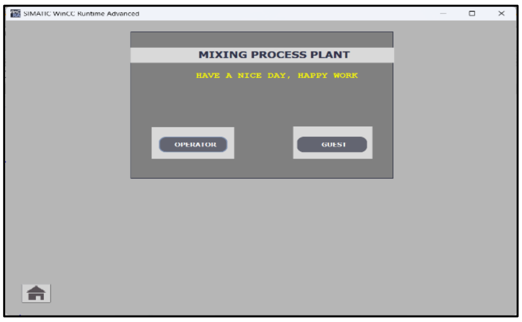

Figure 7. User Login Page

The design layout of the interface, is illustrated in Figure 7, shows that the system uses both usability and security features in the system. Since operators and guests are presented with specific login fields, chances of an unauthorized access attempt are greatly reduced, enhancing the overall user experience. Moreover, this arrangement permits the introduction of role-bound security measures, like stricter passwords and multi-factor authentication for operator accounts.

The system may also build account lockout features after multiple failed login attempts, password expiration policies, and audit logging of access attempts so that the overall security posture is further strengthened and compliance with various standards and regulations is maintained.

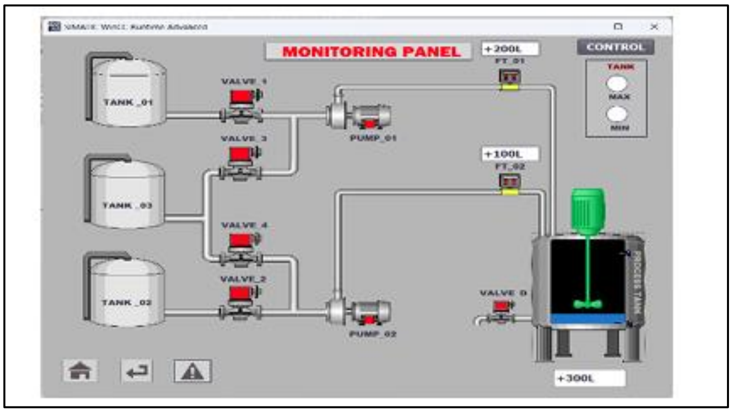

Figure 8. Process Monitoring Pane

The process monitoring page, depicted in Figure 8, offers a comprehensive view of the mixing and Clean-In-Place (CIP) operations. During the mixing process, Valve_1 and Valve_2 is activated to allow solvent flow into the process tank. Pump_01 and Pump_02 are then initiated, and flow transmitters begin measuring solvent flow. Once the flow rate reaches the user-specified quantity, the valves close and pumps stop. An agitation motor then commences mixing the two toxic solvents for the required duration. Upon completion of mixing, a drain valve facilitates tank emptying, ensuring the process is completed efficiently and safely.

The CIP process, which is essential for maintaining process and hygiene, follows a similar sequence of operations. Valve_3 and Valve_4 are opened to allow water entry for tank cleaning. After valve opening, Pump_1 and Pump_2 starts, and flow transmitters measure the water flow rate. When the required quantity is reached, the valves close and pumps halt. The agitation motor then begins tank cleaning, thoroughly removing any residual substances. Once the cleaning process is finished, as shown in Figure 8, the process monitoring page provides an overview of the mixing and Clean-In-Place (CIP) activities. During mixing, Valve_1 and Valve_2 open to let the solvent enter the process tank, after which Pump_01 and Pump_02 are turned on. Solvent flow is then measured by flow transmitters. When the user specified flow rate is attained, the valves close and the pumps stop. Next, an agitation motor starts mixing both toxic solvents for the required amount of time, after which the mix is drained. To ensure that the process is effective and safe, a drain valve empties the tank after mixing.

Like the rest of the SOPs, this unit operations processes has a very similar sequence of operations. The first step is to open valve 3 and valve 4 to allow water to enter the system to execute tank cleaning. After valve opening, Pump 1 and Pump 2 are activated, and the flow transmitters begin to register the incoming water. Once the necessary value is reached, the valves are closed and the pumps are stopped. Then, the agitation motor starts and the tank is cleaned thoroughly, removing all leftover substances in it. The last piece of the process is to open drain valve to let the water out of the tank vacuuming it in the process to prepare it for the next cycle. It is this systematic approach to both mixing and cleaning processes that maximizes efficiency, safety, and hygiene in production.

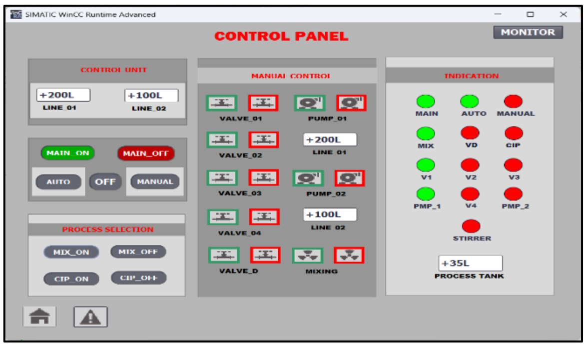

Figure 9. Process Control Panel

The control panel shown in Figure 9 acts as a mixing process software center. It enables the user to control its operation with the needed precision. One of the most useful features of this panel is the input of the exact value of the solvent to be used in the mixing step. This enables the required ratio between the solvent and the material to be preserved which is important for achieving proper mixing and good quality of product. In addition, the panel is built in such a way so that users can select different operational modes for other mixing situations. The panel also has an integrated process monitoring feature which allows the operator to observe important operating parameters and ensures that the mixing operation is done as required and adjustments can be made if something goes out of range. Another important feature of this control panel that stands out is the ability to use both Mixing and Clean-In-Place operations in one control system. This integration improves the overall process because the operators' interface controls production and maintenance activities highlighting use of the single system and eliminating unused periods of work.

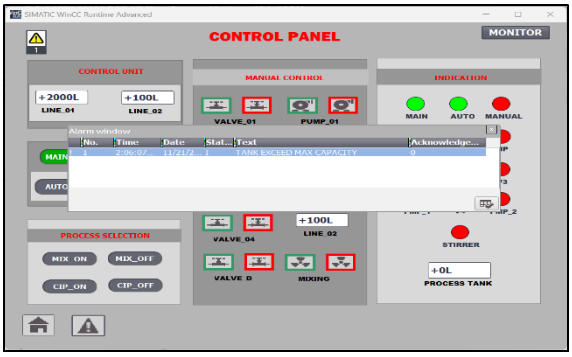

Figure 10. Alarm Indication Page

The alarm window located in the control panel is an essential part of communication for alerting operators about possible problems with the system. In the image provided in Figure 10, when the tank reaches its maximum capacity, the message that reads “TANK EXCEED MAX CAPACITY” appears in bold on the alarm window. Such extensive information is provided so as to ensure that the operators notice what their specific problem is, which they should do address immediately.

To increase the visibility of the alarm, an additional alert indicator is added in the upper left corner of the panel. This indicator uses a flashing mechanism which continues until the user takes action. This action of blinking ensures that the alarm is very much visible regardless the operator's attention. The dual notification system which is both textual and visual makes it ever more probable that operators will respond in time and prevents possible overflow cases and other associated dangers.

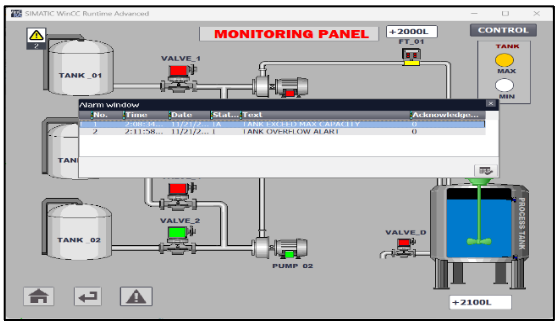

Figure 11. Process Monitoring Page

In Figure 11, the monitoring panel describes the cover alarm, which serves as an important interface for providing alerts to operators on any likely hazards to the system. The “TANK OVERFLOW ALERT” text is clearly readable meaning, which indicates urgent attention is required. A more effective visual manifestation is given by an alarm indicator which is mounted in the upper left corner of the panel. The flashing indicator will continue to flash until it is silenced by an operator; this ensures the most critical alerts are not silenced during transfer between shifts or whilst the operator is busy.

The automated intervention strategy is started at once after the overflow alarm detection. This control measure is designed to stop instantly the operation of all pumps and valves for the affected tank in use. This tank's rapid shutoff is very important in order to avert further entry of liquid into the already full tank. This greatly reduces the chance of overflowing, damages to the equipment and range of safety issues. The automation of the preventive action guarantees the safety is taken without delay in case there are no enough human operators to act quickly to the dangerous situation. This blend of visual aids such as alarms and automated responses to hazards of safety problems features on complete effort to avert danger and safety during operations in the monitored system.

5. Discussion

The advanced toxic solvent mixing process that combines the Programmable Logic Controller (PLC) and Supervisory Control and Data Acquisition (SCADA) control technologies is built in the proposed study. These systems address the problems encountered by most industries that manage hazardous solvents, particularly in controlling the level, flow, and concentration of highly potent toxins.

The integrated solutions in the system design are as follows:

1. An advanced mixing process control system through deployment of WinCC SCADA software.
2. Two operational modes of mixing and Clean-In-Place (CIP) are geared to automatic or manual control.
3. Flow rate, temperature, and level control sensor integration.
4. Control actuator for the precise control of the mixing process.
5. Graphical monitoring and control user interface.
6. Alarm systems for rapid operator notification of potential threat situations.

7. System passwords for user identification and protection against unauthorized access.

The design of the system gives importance to safety, proficiency, and flexibility which makes it ideal for the pharmaceutical, chemical, and food and beverages industries. The system minimizes the exposure to risk while ensuring quality and process standards are met by disengaging human input on unsafe situations. The combination of automatic and manual CIP operations guarantees compliance with sanitary requirements that is important for industries that handle dangerous materials. More so, the system's unique architecture is robust enough to allow connection to pre-existing systems, broadening its use for many industrial purposes.

6. Conclusion

In summary, this study has successfully developed a comprehensive toxic solvent mixing process management system that is both effective and safe. The combination of PLC and SCADA technologies, sophisticated monitoring and control features, and the proactive stance toward protecting the people and the environment greatly improve the handling of extremely hazardous materials in any industrial setting. Such a system is a great boost to productivity and at the same time protects the operators, the equipment, and the environment, which makes the system a great innovation in the problem of toxic solvents management in industrial processes.

References

[1] Ahmed, I., Roussev, V., Obermeier, S., & Sudhakaran, S. (2017). Programmable Logic Controller Forensics. IEEE Security & Privacy, 15(6), 18–24. https://doi.org/10.1109/msp.2017.4251102

[2] Bayindir, R., & Cetinceviz, Y. (2010). A water pumping control system with a programmable logic controller (PLC) and industrial wireless modules for industrial plants—An experimental setup. ISA Transactions, 50(2), 321–328. https://doi.org/10.1016/j.isatra.2010.10.006

[3] Cruz, T., Simoes, P., Panzieri, S., Lev, L., Graziano, A., Proenca, J., & Barrigas, J. (2015, May 1). Improving network security monitoring for industrial control systems. https://doi.org/10.1109/inm.2015.7140399.

[4] Fadaei, A., & Salahshoor, K. (2008). Design and implementation of a new fuzzy PID controller for networked control systems. ISA Transactions, 47(4), 351–361. https://doi.org/10.1016/j.isatra.2008.07.003.

[5] Hudedmani, M. G., Hittalamani, R., Umayal, R. M., & Kabberalli, S. K. (2017). Programmable Logic Controller (PLC) in Automation. Advanced Journal of Graduate Research, 2(1), 37–45. https://doi.org/10.21467/ajgr.2.1.37-45

[6] Ioannides, M. G. (2004). Design and Implementation of PLC-Based Monitoring Control System for Induction Motor. IEEE Transactions on Energy Conversion, 19(3), 469–476. https://doi.org/10.1109/tec.2003.822303.

[7] Vadi, S., Bayindir, R., Toplar, Y., & Colak, I. (2021). Induction motor control system with a Programmable Logic Controller (PLC) and Profibus communication for industrial plants — An experimental setup. ISA Transactions, 122, 459–471. https://doi.org/10.1016/j.isatra.2021.04.019.

[8] Valencia-Palomo, G., & Rossiter, J. A. (2010). Programmable logic controller implementation of an auto-tuned predictive control based on minimal plant information. ISA Transactions, 50(1), 92–100. https://doi.org/10.1016/j.isatra.2010.10.002

[9] Samin, Reza Ezuan, Lee Ming Jie, and Mohd Anwar Zawawi. "PID implementation of heating tank in mini automation plant using Programmable Logic Controller (PLC)." In International Conference on Electrical, Control and Computer Engineering 2011 (InECCE), IEEE, 2011. 515-519.

[10] Krupa, Pablo, Daniel Limon, and Teodoro Alamo. "Implementation of model predictive control in programmable logic controllers." IEEE Transactions on Control Systems Technology 29, no. 3 (2020): 1117-1130.