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Design of PLC control system for cascading tanks controlling

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Abstract: The article deals with the design of a PLC control system for controlling cascade tanks in the technological process of liquid mixing. The mixing process is carried out automatically according to information from individual sensors. The system also includes elements for manual control of the technological system. A human machine interface system was designed to operate the system. The simulation showed the correctness of the designed system.

1 Introduction

The system (Figure 1) consists of three storage tanks A, B, C and one master tank. Liquids from storage tanks are fed into the master tank by solenoid valves according to the chosen procedure, where they are mixed and then discharged into the main collecting tank through the outlet valve. The goal is to prepare the concept of a control system for the automatic control of the technological process of preparation of liquid mixtures with the possibility of service intervention in the process in case of emergency shutdown of the system or manual switching on of some part of the system in the event of a malfunction. The proposed reservoir management system will be used for didactic purposes for the practical education of students [1-17].

Reed switch float level sensors are designed to detect the level of liquids in each tank. Solenoid valves are designed for the discharge of liquids by gravity discharge from the tank. Low-voltage pumps are designed for pumping liquids (Figure 2). The process of mixing liquids in the master tank will take place for 10 seconds, and then the resulting mixture is discharged into the collection tank.

Options for alternative solutions to the process can be changed and set according to the selected recipe.

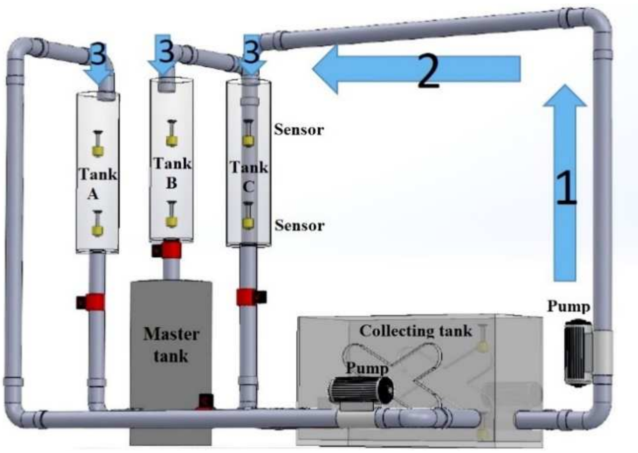

Figure 1 Educational model layout design

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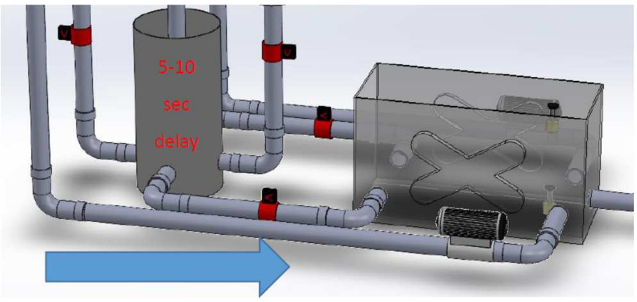

Figure 2 Simulation of fluid mixing and discharge of fluid into the tank

2 Control system design

The proposed diagram (Figure 3) shows the location of individual sensors, solenoid valves and pumps in the proposed system concept. The connection of individual components in the system is designed using transparent hoses.

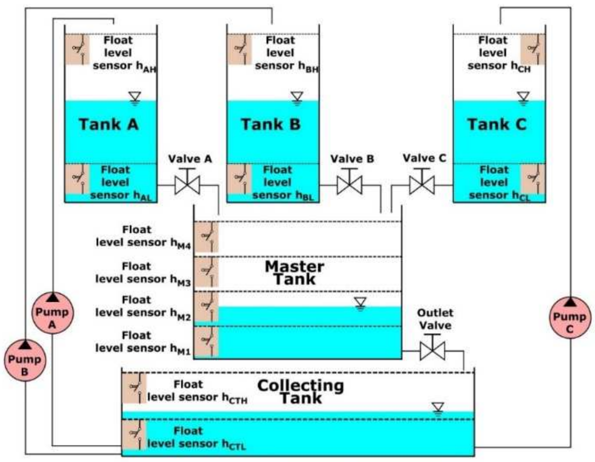

Figure 3 The diagram of the system

After solving design problems, selecting components, and describing the principle of the system, you need to choose a control element that will program the system for the work we need. The PLC will act as such a control element. Programmable logic controller (PLC) is an electronic device used to automate technological processes such as conveyor line control, pumps at water supply stations, numerically controlled machines, etc. In essence, it is a real-time hardware-software system - a computer designed to run a real-time operating system and applications that implement the necessary algorithms. Its main difference from general-purpose computers is the large number of input/output devices for sensors and actuators, as well as the ability to work reliably in adverse conditions: wide temperature range, high humidity, strong electromagnetic interference, vibration and more.

PLCs have a number of features that distinguish them from other electronic devices used in production:

- Unlike a microcontroller (single-chip computer), a chip designed to control electronic devices, a PLC is a stand-alone device, not a separate chip.
- Unlike computers focused on decision-making and operator management, PLCs are focused on working with machines through an extensive I/O system for inputting sensor signals and outputting signals to actuators.
- In contrast to built-in PLC systems, they are manufactured as stand-alone products, separate from the equipment controlled by it.

Siemens TIA Portal software (Figure 4) will be used to program the controller for our wishes. TIA Portal (Totally Integrated Automation Portal) is an integrated software development environment for process automation systems from the level of drives and controllers to the level of human-machine interface.

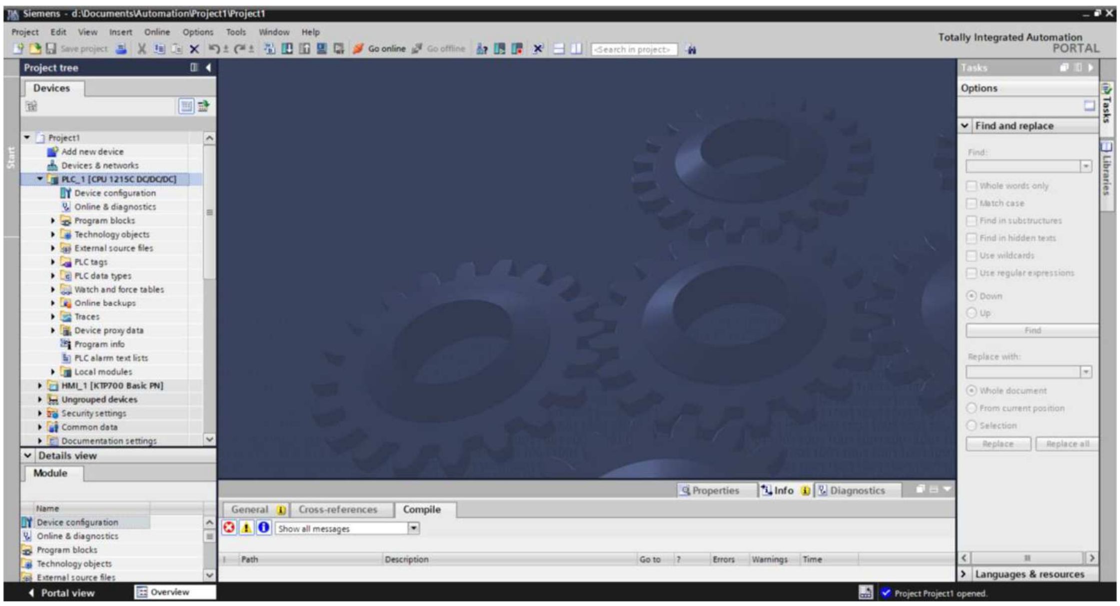

Figure 4 TIA Portal Workspace

It is the embodiment of the concept of integrated automation (Eng. Totally Integrated Automation) and the evolutionary development of the Simatic family of automation systems from Siemens AG.

Development of projects for controllers and distributed I/O devices, configuration of human-machine interface systems and SCADA systems, parameterization of network components and communication modules, debugging of software control algorithms, as well as commissioning of drives - all this is combined into a common software structure and have a unified user interface. This not only speeds up work, but also allows you to create transparent solutions that are easy to maintain and diagnose and can be easily expanded or transformed.

Variables or tags must be stored before creating the program itself. In essence, this is the identification of the actual inputs and outputs in the system that will operate the PLC. Using Image 30 you can see all the main devices that will be connected to the PLC. Sensors are inputs, and solenoid valves and pumps are outputs. Using this, you can create tags for the program.

To simulate the system before connecting it, the physical inputs must be set as memory to be able to change them and simulate possible situations in the system (Figure 5).

Level sensors are designed for the concept of this system, which generate a logic level High when the liquid level exceeds the location of this sensor and generate a logic level Low when the liquid level drops below the location of this sensor. The opening of all solenoid valves will be realized by setting the logic level High, and the closing will be realized by setting the logic level Low.

Default tag table

	Name	Data type	Address	Retain	Acces...	Writa...	Visibl...	Comment
1	Pump A	Bool	%Q0.0	☐	☑	☑	☑	
2	Pump B	Bool	%Q0.1	☐	☑	☑	☑	
3	Pump C	Bool	%Q0.2	☐	☑	☑	☑	
4	Valve A	Bool	%Q0.3	☐	☑	☑	☑	
5	Valve B	Bool	%Q0.4	☐	☑	☑	☑	
6	Valve C	Bool	%Q0.5	☐	☑	☑	☑	
7	Outlet valve	Bool	%Q0.6	☐	☑	☑	☑	
8	Float level sensor hAH	Bool	%M0.0	☐	☑	☑	☑	
9	Float level senzor hAL	Bool	%M0.1	☐	☑	☑	☑	
10	Float level sensor hBH	Bool	%M0.2	☐	☑	☑	☑	
11	Float level sensor hBL	Bool	%M0.3	☐	☑	☑	☑	
12	Float level sensor hCH	Bool	%M0.4	☐	☑	☑	☑	
13	Float level sensor hCL	Bool	%M0.5	☐	☑	☑	☑	
14	Float level sensor hM1	Bool	%M0.6	☐	☑	☑	☑	
15	Float level sensor hM2	Bool	%M0.7	☐	☑	☑	☑	
16	Float level sensor hM3	Bool	%M1.0	☐	☑	☑	☑	
17	Float level sensor hM4	Bool	%M1.1	☐	☑	☑	☑	
18	Float level sensor hCTH	Bool	%M1.2	☐	☑	☑	☑	
19	Float level sensor hCTL	Bool	%M1.3	☐	☑	☑	☑	
20	<Add new>			☐	☑	☑	☑	

Figure 5 PLC tags

After identifying the tags, you can start writing the program. FBD (Function Block Diagram) was chosen as the programming language for this project. For better orientation in the program it can be divided into networks, each of which will correspond to the tanks.

3 Concept of function block diagram networks

<u>Network 1: Total Start Stop</u> (Figure 6) is designed for total program control. The network contains the "Set/reset flip-flop" (SR flip/flop) instruction to set or reset the bit of a specified operand based on the signal state of the inputs S and R1. If the signal state is "1" at input S and "0" at input R1, the specified operand is set to "1". If the signal state is "0" at input S and "1" at input R1, the specified operand will be reset to "0". Input R1 takes priority over input S. When the signal state is "1" on both inputs S and R1, the signal state of the specified operand is reset to "0".

In this network 1, it contains two inputs, while the "START" input causes the system to be fully turned on, and the "STOP" input represents the system to be completely turned off. In other networks, the output from this block "Startup" will be incorporated so that this block of network 1 enables absolute control over all systems and enables a safe shutdown of the system and then a restart to the last known configuration. This network 1 will therefore be the superior system for other networks.

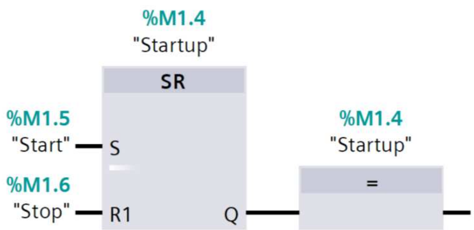

Figure 6 Network 1: Total Start Stop

<u>Network 2: Controlling of Pump A</u> (Figure 7) also contains an SR flip/flop block for switching on or off of pump A. For switching on, the signal "Float level sensor

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hAL" is used, which signals that the liquid level is below the level of this sensor and using the logic level LOW starts the SR block and turns on pump A, but only if at the same time the superior system "Startup" is in the state of logic level HIGH". Resetting the SR block and thus turning off pump A is possible when the liquid level reaches the level of the sensor "Float level sensor hAH " and that, using the logic level HIGH, causes pump A to be turned off. Or pump A can be turned off using the superior system "Startup" from network 1.

An additional block "estop pump A" was added to network 2, which is created using an RS flip/flop block for independently safely turning off pump A.

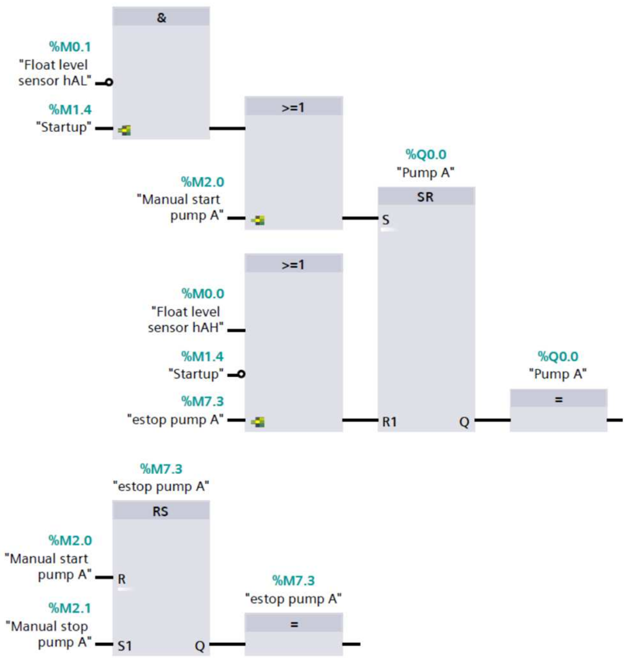

Figure 7 Network 2: Controlling of Pump A

<u>Network 3: Controlling of Pump B</u> (Figure 8) and <u>Network 4: Controlling of Pump C</u> (Figure 9): Controlling of Pump C are similar to network 2. The operation of pump B is connected to the sensor "Float level sensor hBL" and to the sensor "Float level sensor hBH". The operation of pump C is connected to the sensor "Float level sensor hCL" and to the sensor "Float level sensor hCH". Both of these networks are conditioned by the superior system from network 1 "Startup".

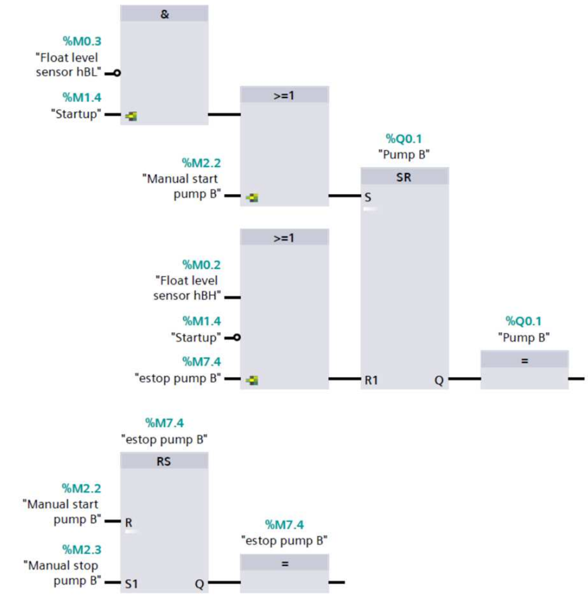

Figure 8 Network 3: Controlling of Pump B

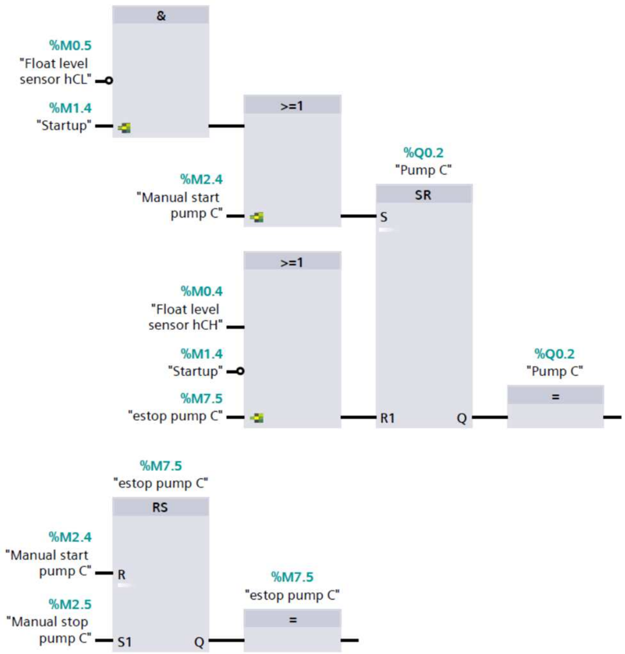

Figure 9 Network 4: Controlling of Pump C

<u>Network 5: Filling of Master Tank with fluid A using the valve A</u> (Figure 10) **-** solves the filling of the master tank with fluid from tank A, while this filling is carried out using valve A only if the fluid in tank A is between the levels of the fluid level detected by the level sensors" Float level sensor hM1" and "Float level sensor hM2". However, this process can only take place if there is at least a minimum amount of liquid level in tank A at the level of the "Float level sensor hAL" sensor. In the same way, the operation of valve A is conditioned by the superior system "Startup" from network 1. Another condition for starting valve A is that the master tank was completely emptied

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after the previous filling to below the level of the "Float level sensor hM1" sensor. Network 5 is also supplemented with another RS flip/flop block "estop valve A", which is used to create the possibility of emergency shutdown of valve A independently of other devices.

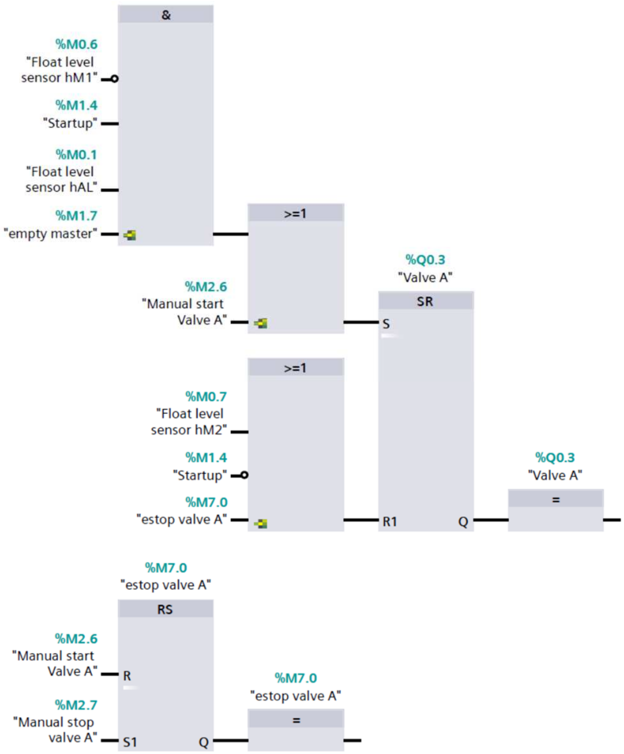

Figure 10 Network 5: Filling of Master Tank with fluid A using the valve A

<u>Network 6: Filling of Master Tank with fluid B using the valve B</u> (Figure 11) - is implemented analogously to network 5. However, in this network valve B is started for filling fluid from tank B to the master tank between the level levels detected by the sensors "Float level sensor hM2" and "Float level sensor hM3". Also, this valve B can only be started if the superior system "Startup" is active and the master tank has been previously drained. Valve B can also be started only if the liquid in tank B is at least above the level of the "Float level sensor hBL" sensor. Also in this network, an RS flip/flop block for emergency shutdown of this valve B "estop valve B" is added.

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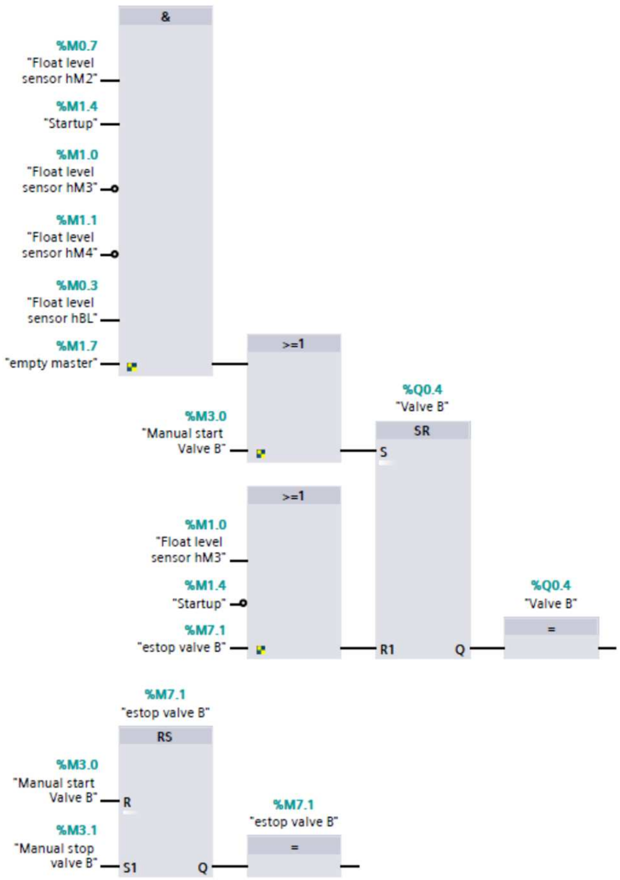

Figure 11 Network 6: Filling of Master Tank with fluid B using the valve B

<u>Network 7: Filling of Master Tank with fluid C using the valve C</u> (Figure 12) - is created for filling the master tank with fluid from tank C between the levels of the sensors "Float level sensor hM3" and "Float level sensor hM4" in the master tank. This process can only be carried out if there is at least a minimum amount of liquid in tank C above the level of the "Float level sensor hCL" sensor and the master tank volume has previously been completely emptied, which is signalled by the "empty master" tag. Also in this network, the "estop valve C" block is added for the emergency shutdown of valve C.

<u>Network 8: Empty Master tank</u> (Figure 13) - it should leave the filled mixture of liquids for 10 seconds and then the entire contents of the master tank should be drained into the collecting tank by activating the "Outlet valve". "Outlet valve is deactivated only after a time of 1 second has elapsed after the master tank is completely drained below the level of the lowest sensor "Float level sensor hM1". Just like the previous networks, in this network also the block "estop outlet valve" is added for the emergency shutdown of the "Outlet valve".

<u>Network 9: Master Tank status</u> (Figure 14) - is used to detect the status of the master tank. For the proper functioning of the entire system, it is necessary to know when the master tank was completely emptied, and this

information is stored in the "empty master" tag. After emptying the master tank, the entire filling process can be restarted again.

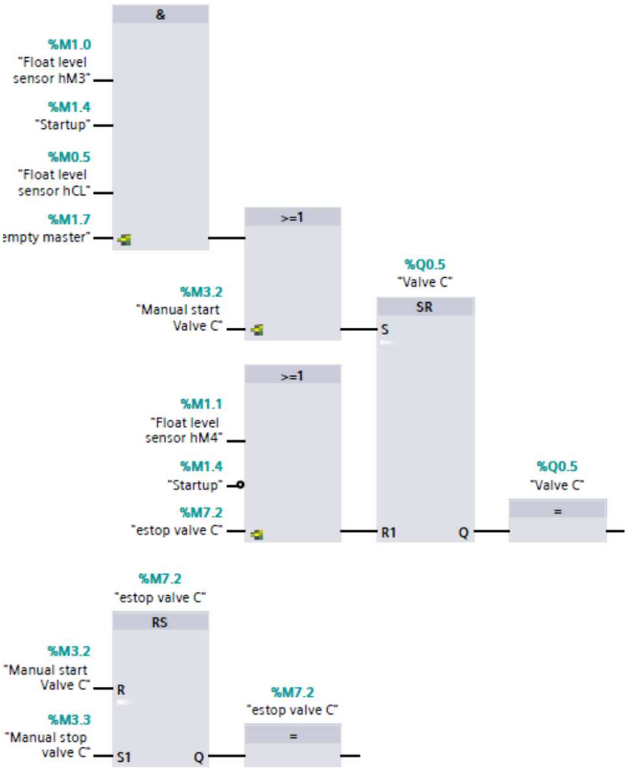

Figure 12 Network 7: Filling of Master Tank with fluid C using the valve C

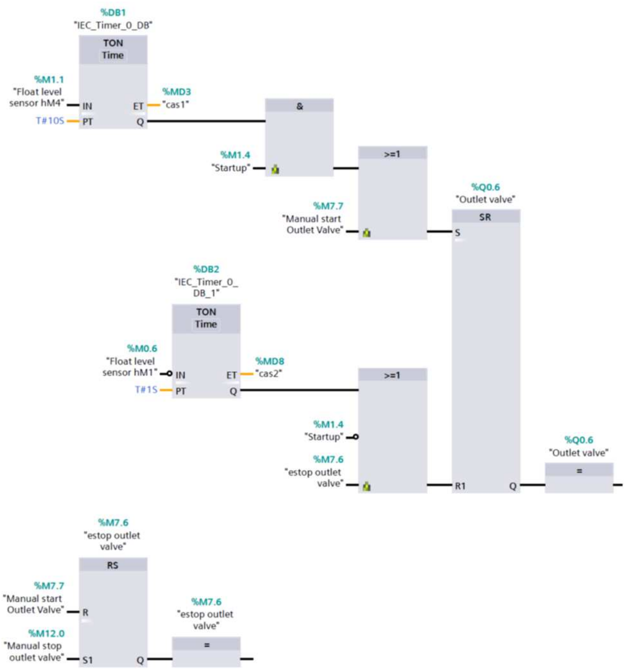

Figure 13 Network 8: Empty Master tank after 10 seconds

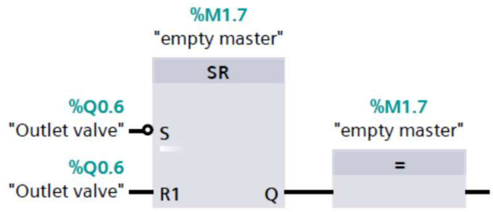

Figure 14 Network 9: Master Tank status

4 Process visualization and control using the HMI interface

The HMI (Human machine interface) interface allows you to create a user interface for controlling the system by the operator and also for visualizing the current status of all subsystems. The operator can thus fully control the system remotely and monitor all its activities. When switched off, pipes and individual valves and pumps are shown in gray (Figure 15). After the system is turned on, the active parts are displayed in blue. Active sensors also have an indicator LED for displaying the status of the sensors (Figure 16).

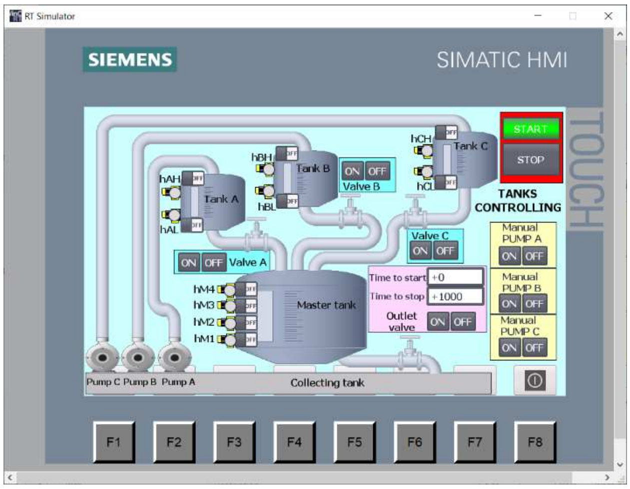

Figure 15 System in off state

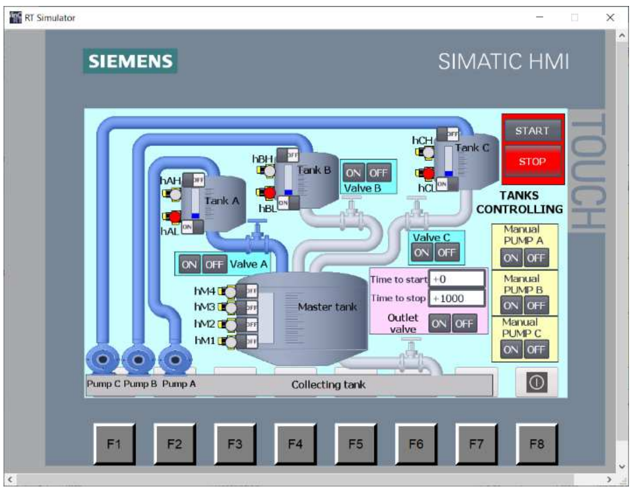

Figure 16 Filling tanks A, B, C

In addition, the HMI is supplemented with an emergency shutdown of all systems or individual systems can be shut down individually.

The filling and draining of fluids are also indicated by status indicators with a dark blue colour (Figure 17). To display the discharge progress of the master tank, a time indication of the discharge progress is also added.

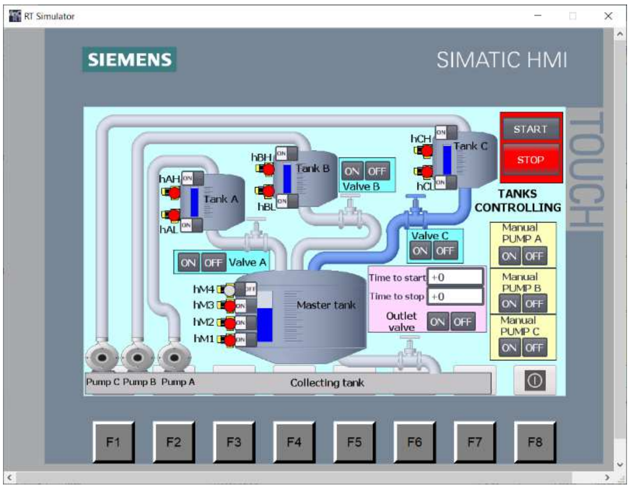

Figure 17 Filling the master tank

5 Conclusion

In this work, the concept of controlling cascading tanks for mixing liquids in the technological process according to the chosen procedure was proposed. Individual filling and emptying is controlled automatically according to the status of individual sensors. All action subsystems such as pumps and valves can be turned off in an emergency with one button or separately with special buttons. In the next work, the diagnostic network for detecting fault conditions of individual subsystems will be solved, and the possibility of flexible change of the mixing procedure of the mixture by changing the order of liquid dosing and changing the amount of liquid dosing will be proposed. This will enable a flexible change in the proportions of the mixed mixture of liquids according to the operator's current requirements.

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References

[1] LANDER, A.: *Programmable Logic Controllers: The Evolution of a Disruptive Technology*, Engineering.com, [Online], Available: https://new.engineering.com/story/programmable-logic-controllers-the-evolution-of-a-disruptive-technology [26 May 2021], 2021.

[2] SIMATIC S7-1200 *Getting started with S7-1200*, [Online], Available: https://cache.industry.siemens.com/dl/files/875/39644875/att_76194/v1/s71200_getting_started_en-US_en-US.pdf?download=false [26 May 2021], 2021.

[3] SIMATIC S7-1200 *Programming Guideline for S7-1200/1500*, [Online], Available: https://assets.new.siemens.com/siemens/assets/api/uuid:c7de7888-d24c-4e74-ad41-759e47e4e444/Programovani-S7-1200-1500-2018.pdf [26 May 2021], 2021.

[4] KELEMEN, M., SINČÁK, P.J.: Programmable logic controller training stands for educational purposes, *Technical Sciences and Technologies*, Vol. 21, No. 3, pp. 274-280, 2020.

[5] KELEMEN, M., LIGUŠOVÁ, J., LIGUŠ, J., MAXIM, V.: Additional Modules for Programmable Logic Controller Based Training Stands, *Technical Sciences and Technologies*, Vol. 22, No. 4, pp. 170-176, 2020.

[6] KELEMEN, M., KELEMENOVÁ, T., VIRGALA, I., PRADA, E., MIKOVÁ, Ľ., HRONCOVÁ, D., VARGA, M., SINČÁK, P. J.: *Training stations with programmable logic controllers*, In: Technological Forum 2021, 12^{th} International technical conference, 30.6. - 02.07.2021, Jaroměř, ČR, pp. 117-121, 2021.

[7] VITKO, A., JURIŠICA, L., KĽÚČIK, M., MURÁR, R., DUCHOŇ, F.: Embedding Intelligence into a Mobile Robot, *AT&P Journal Plus*, Vol. 2008, No. 1, Mobile robotic systems, pp. 42-44, 2008.

[8] BOŽEK, P.: Robot path optimization for spot welding applications in automotive industry, *Tehnicki vjesnik / Technical Gazette*, Vol. 20, No. 5, pp. 913-917, 2013.

[9] DUCHOŇ, F., BABINEC, A., KAJAN, M., BEŇO, P., FLOREK, M., FICO, T., JURIŠICA, L.: Path planning with modified a star algorithm for a mobile robot, *Procedia Engineering*, Vol. 96, pp. 59-69, 2014.

[10] PÁSZTÓ, P., HUBINSKÝ, P.: Mobile robot navigation based on circle recognition, *Journal of Electrical Engineering*, Vol. 64, No. 2, pp. 84-91, 2013.

[11] ABRAMOV, I.V., NIKITIN, Y.R., ABRAMOV, A.I., SOSNOVICH, E.V., BOŽEK, P.: Control and Diagnostic Model of Brushless DC Motor, *Journal of Electrical Engineering*, Vol. 65, No. 5, pp. 277-282, 2014.

[12] KONIAR, D., HARGAŠ, L., ŠTOFAN, S.: Segmentation of Motion Regions for Biomechanical Systems, *Procedia Engineering*, Vol. 48, pp. 304-311, 2012.

[13] VIRGALA, I., MIKOVÁ, Ľ., KELEMEN, M., HRONCOVÁ, D.: Snake-like robots, *Acta Mechatronica*, Vol. 3, No. 4, pp. 7-10, 2018. https://doi.org/10.22306/am.v3i4.43

[14] MIKOVÁ, Ľ., VIRGALA, I., KELEMEN, M.: Embedded systems, *Acta Mechatronica*, Vol. 3, No. 2, pp. 1-5, 2018. https://doi.org/10.22306/am.v3i2.32

[15] KELEMENOVÁ, T., FRANKOVSKÝ, P., VIRGALA, I., MIKOVÁ, Ľ., KELEMEN, M., DOMINIK, L.: Educational models for mechatronic courses, *Acta Mechatronica*, Vol. 1, No. 4, pp. 1-6, 2016.

Volume: 8 2023 Issue: 1 Pages: 7-14 ISSN 2453-7306

[16] LIPTÁK, T., KELEMEN, M., GMITERKO, A., VIRGALA, I., HRONCOVÁ, D.: THE CONTROL OF HOLONOMIC SYSTEM, *Acta Mechatronica*, Vol. 1, No. 2, pp. 15-20, 2016.
[17] KURYŁO, P., PIVARČIOVÁ, E., CYGANIUK, J., FRANKOVSKÝ, P.: Machine vision system measuring the trajectory of upper limb motion applying the Matlab software, *Measurement Science Review*, Vol. 19, No. 1, pp. 1-8, 2019.

Review process

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