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Automated Coffee Making and Bottle Filling System using S7-1200 PLC and Ladder Logic Programming

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Abstract

The development of software solutions for managing industrial processes is mostly due to modern control devices and process automation deployment. Manufacturing process developments, such as Industry 4.0, aim to replace old manual systems with completely self-controlled, reconfigurable processes in order to improve the overall production system. Automation is favoured in all production and service fields to reduce human interference and achieve high efficiency, reliability, and less human effort.
The research's objectives are to evaluate how effectively the automated solution achieves accurate and reliable coffee bottle filling as well as to examine the system's efficacy and efficiency. The idea of a smart coffee maker is realised in this study, a controller known as a Programmable Logic Controller (PLC), which serves as the brain of the entire system, is used to regulate the making of a coffee and filling of the coffee bottle. The suggested coffee machine has different modes based on the user's input.
A literature review done for different research papers, journals, etc. which helps to identify gaps in the existing knowledge and the need for further research.
The PLC has been programmed using ladder logic, which is the most popular and widely acknowledged language for doing so. The PLC regularly monitors the input, and the actuators used in the project, such as the circulating pump, various valves, and the lower-level sensors, are controlled based on the input and custom program downloaded into the PLC to achieve automation of the coffee manufacturing process.
Using the Ladder Logic Programming and PLC, an automated coffee bottle-filling system has been developed and successfully simulated. The simulation was tested and found to be quite accurate.
The PLC S7-1200 which is used in the manufacturing process is not easily scalable and is intended for small to medium-sized applications. The control system may need to be completely redesigned if a system needs to be extended.
A PLC's primary function is to automate operations by transmitting control functions that have been preprogrammed to output devices depending on signals from associated input devices.

Keywords: Industrial Automation, PLC S7-1200, Ladder Logic Programming, Coffee Making, Coffee Bottle Filling, PLC Programming Simulation

1. Introduction

A programmable logic controller (PLC) is a type of digital computer system used to automate and control industrial machinery and operations. It stores instructions in a programmable memory and executes them sequentially or concurrently. As the economy moves towards Industry 4.0 and the Internet of Things (IoT), the utilisation of PLCs is changing. PLCs are evolving to become smarter, more interconnected, and more modular, enabling more adaptable and effective control systems.

Numerous industries, including the pharmaceutical and beverage sectors, demand that bottles be filled with a specific volume of liquid. Implementing systems using relay logic control can cause them to be inflexible. PLCs are more flexible in automating various processes[7].

Filling coffee bottles is a critical procedure in the food and beverage sector that has a significant impact on customer satisfaction. To achieve uniformity in taste and quality, coffee must be filled precisely and accurately into bottles. Many businesses have turned to automation using Programmable Logic Controllers (PLCs) to improve efficiency, dependability, and consistency[1,16]. The purpose of this research is to create a coffee bottle-filling system utilising the Siemens S7-1200 PLC and the TIA Portal V13 software. The primary goals of the research are to assess the effectiveness of the automated solution in attaining correct and consistent coffee bottle filling, as well as to analyse the system's performance and efficiency.

A programmable logic controller (PLC) is a solid-state, digital industrial computer that implements control operations with integrated circuits rather than electromechanical devices[2]. PLCs consist of input modules or points, a Central Processing Unit (CPU), and output modules or points. It was developed to replace sequential circuits, which were mostly utilised for machine control. A PLC-controlled bottle-filling system allows users to fill the bottle to the appropriate level without wasting liquid. The PLC sequence is controlled by ladder logic[3].

The goal is to create a complete sorting system that performs the required categorising work by combining various sensor technology with an appropriate logic algorithm. An inductive sensor for material classification, infrared sensors for object detection, a temperature sensor for temperature detection, and an ultrasonic sensor for workpiece orientation detection are all part of the sensor system in this system.

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1.1. Literature Survey

Automation using PLC:-

It is incredibly challenging to achieve exact output with little waste and make quick manufacturing adjustments[10]. PLC and SCADA are now essential components of industrial automation[20,22]. In factories where human efforts are insufficient to operate heavy machinery, it is preferred because of durability and resistance to harsh environments, in workplaces. PLCs are a widely used gadget that will improve control education by taking a more all-encompassing approach[1,16]. In the automation sector, a bottle filling, capping, and labelling machine is introduced using a PLC-based controller. It has some benefits over the standard filling procedure and is a time-based control mechanism[12,24,27]. This suggested filling device is reasonably priced. Human labour and time are saved. It can be utilised in small-scale bottle-filling systems for the coffee and beverage sectors, including juice bars[2,23].

Bottle Filling:-

The PLC-based control system was applied and the performance was assessed. The entire system is more user-friendly, time-efficient, and reliable[3,21]. PLC-based bottle-filling systems offer the potential for faster and more efficient production, the study highlights the need for further improvement to achieve consistent performance[13,19]. In order to increase industry effectiveness and performance, sensors and control systems, including PLCs, have been intensively researched. This paper's practical research underlines the value of studying PLCs in industrial automation and shows the potential for commercial applications in the food and beverage sector[4,15]. By implementing PLC programming, the cycle time to fill a single bottle is reduced, resulting in increased efficiency. Sensors are utilized as inputs to detect the position and condition of the bottle on the conveyor, leading to improved quantity and quality of the filled product[5,25,28]. T.Kalaiselvi Paper's major goal was to design a bottle filling and capping mechanism based on a set of requirements. They added extra features, such as user-defined volume specification, and capping operations in accordance with the size, shape, and weight of the bottles. While they used SCADA for monitoring, PLC was used to control the various operations[6,29]. The demand for automatic filling systems is rising quickly because they are essential pieces of equipment in the food and beverage industry. The need for automatic production cannot be addressed by the conventional relay control approach due to its limitations in terms of automation and integration level[11,17]. With an emphasis on increasing filling precision by using a servo motor driver metering pump in the injection section, the use of PLC to control filling the beverages is essential[4,6]. Automated water-filling process, resulting in time and cost savings. The system is divided into four sections, namely loading, conveyor, path divider, and filling, with the PLC controlling the overall operation[26,30].

Smart Coffee Makers:-

Studies have demonstrated the efficiency of PLCs in delivering automatic operation and user-based decision-making. The use of a Programmable Logic Controller (PLC) in the development of a Smart Coffee Maker has grown in popularity.[18] The system may deliver hot drinks on demand and run in accordance with user preferences. The model has proven to be capable of automatically providing the necessary ingredients in large enough quantities to prepare hot drinks through experimental work.[8,9]. Some systems offer eight different modes for preparing various hot beverages, and toggle switches and limit switches are utilized to select modes and control the operation sequence. The Utilization of PLC and HMI technologies for developing an efficient and user-friendly automatic drink maker machine for Vietnamese drip coffee. The device simplifies the coffee-making process in hot conditions and can be operated by selecting coffee menu choices through touch or tap interaction.[14].

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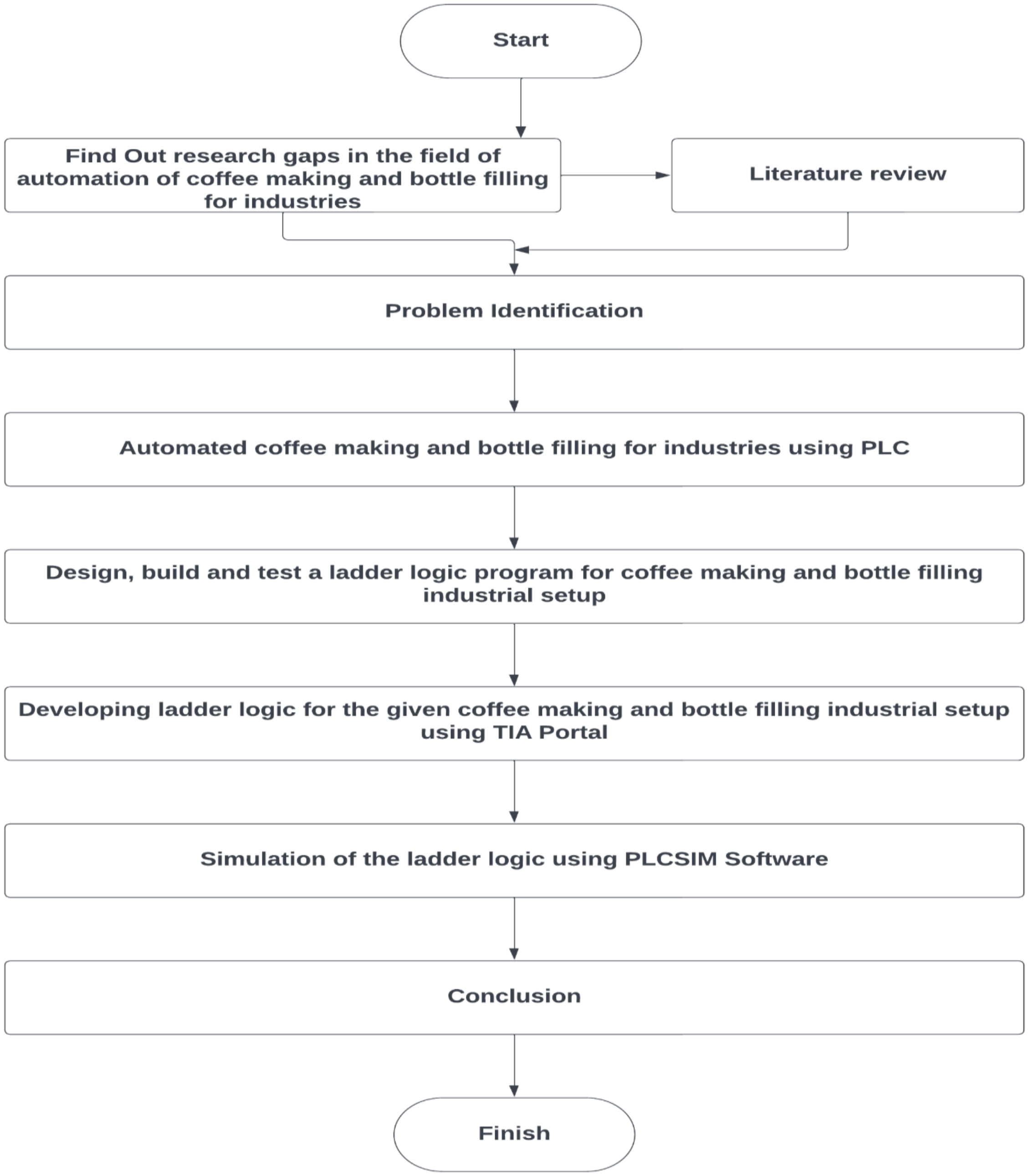
1.2. Research Gaps

1) Despite the growing interest in automation and its potential benefits, there needs to be more research into the specific application of S7-1200 PLC and Ladder Logic Programming in coffee brewing and bottling processes.
2) Although there is some research on the use of automation in the food and beverage industry, few studies have focused specifically on coffee preparation and filling, leaving significant gaps in our understanding of how using ladder logic can help in the automation of these processes.
3) While previous studies have focused on the use of PLCs in manufacturing processes, there is limited research on the use of S7-1200 PLC and Ladder Logic Programming specifically in coffee brewing and bottling processes.
4) Previous studies on automated coffee preparation have focused primarily on beverages and have not explored the potential benefits of using a programmable logic controller (PLC) and simulation software to control the process.

1.3. Research Objectives

1) Design, build and test a ladder logic program for coffee-making and bottle-filling industrial setup and analyse its performance, accuracy, and reliability using the S7-1200 PLC and Ladder Logic Programming.
2) To investigate the feasibility of automated coffee preparation and bottling using S7-1200 PLC and Ladder Logic Programming, and to evaluate the effectiveness and efficiency of the system.
3) Analyse key components and subsystems of an automated coffee brewing and bottling system, including PLC programming, sensors, motors, and valves, and evaluate their performance.
4) Develop recommendations for the design and implementation of an automated coffee brewing and bottling system based on research findings, including considerations such as system architecture, programming, and maintenance.

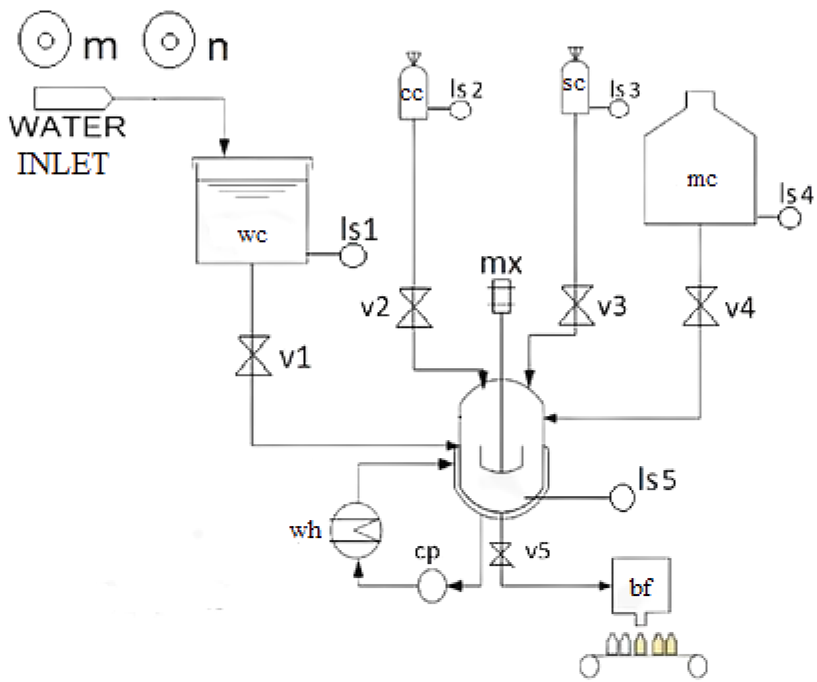
1.4. Research Methodology Flowchart



1.4. Figure 1. Flow Chart of Research Methodology

2. Setup Design

2.1 Problem Definition:-



1.5. Figure 2. Coffee Making and Bottling Plant

The water, coffee powder, sugar and milk are manually filled into their respective containers by the operator.

- m is the start button and n is the stop button.
- v represents the valve.
- mx represents a mixing motor.
- ls represent lower-level sensors.
- cp represents the circulating pump motor.

According to Figure 2, we have a water container, coffee powder container, sugar container and milk container. The lower-level sensors of the water container, coffee powder container, sugar container and cold milk container are ls1, ls2, ls3 and ls4 respectively. The valves v1, v2, v3 and v4 are the valves for water container (wc), coffee powder container (cc), sugar container (sc) and milk container (mc) respectively. The lower level sensor 5 (ls5) is used for detecting the lower level of the prepared coffee in the mixer and the valve v5 is used for the outlet of the prepared coffee to the bottle filling unit (bf),

The mixing motor (mx) is responsible for the mixing of water, coffee powder, sugar and milk to prepare the coffee. The circulating pump (cp) helps in circulating the hot water from the water heater to the mixer and vice versa.

2.2 Process Overview:-

Process:-

1. On pressing the start button (m), valve v1 will be open and water will flow into the mixer until the lower level is detected (i.e., ls1 =1). When the lower level is detected, valve v1 will be closed.

2. Now cp1 will be turned on for 30 seconds to heat the water and then turned off.

3. After that valves v2, v3 & v4 will be opened to add coffee powder, sugar & cold milk. Valves v2, v3 & v4 will be turned off when their respective lower levels (ls2, ls3 and ls4) are reached.

4. Now mx will turn on for 30 seconds and after 30 seconds mx will be turned off and valve v5 will be opened to fill the bottles.

5. When ls5 is detected, valve v5 will be closed and the process will repeat until the stop button is pressed.

Table 1: List of Components

Sr. No.	**Name of Component**	**The function of the Component**
1.	Water Container (wc)	It stores the water which is filled manually.
2.	Coffee Powder Container (cc)	It stores the coffee powder which is filled manually.
3.	Sugar Container (sc)	It stores the sugar which is filled manually.
4.	Milk Container (mc)	It stores cold milk which is filled manually.
5.	Water Heater (wh)	It helps in increasing the temperature of the water.
6.	Circulating Pump (cp)	It helps in circulating the water from the heat exchanger to the mixer and vice versa.
7.	Mixing Motor (mx)	It helps in mixing coffee powder, sugar, cold milk and hot water.
8.	Valve 1 (v1)	It controls the flow of water from the water container to the mixer.
9.	Valve 2 (v2)	It controls the flow of coffee powder from the coffee powder container to the mixer.
10.	Valve 3 (v3)	It controls the flow of sugar from the sugar container to the mixer.
11.	Valve 4 (v4)	It controls the flow of cold milk from the milk container to the mixer.
12.	Valve 5 (v5)	It controls the flow of coffee from the mixer to the bottling unit.
13.	Lower Level Sensor 1 (ls1)	It detects the lower level of the water in the water container.
14.	Lower Level Sensor 2 (ls2)	It detects the lower level of the coffee powder in the coffee powder container.
15.	Lower Level Sensor 3 (ls3)	It detects the lower level of the sugar in the sugar container.
16.	Lower Level Sensor 4 (ls4)	It detects the lower level of the cold milk in the milk container.
17.	Lower Level Sensor 5 (ls5)	It detects the lower level of the prepared coffee in the mixer.

18.	Bottle Filling Unit (bf)	It fills the prepared coffee into the bottles which are lined up on a conveyor.
19.	Pipes	They help in the transfer of raw materials (water, coffee powder, sugar, milk) to the mixer and then the prepared coffee to the bottling unit.
20.	Start Button (m)	It starts the process of making and filling the coffee.
21.	Stop Button (n)	It stops the process of making and filling the coffee.

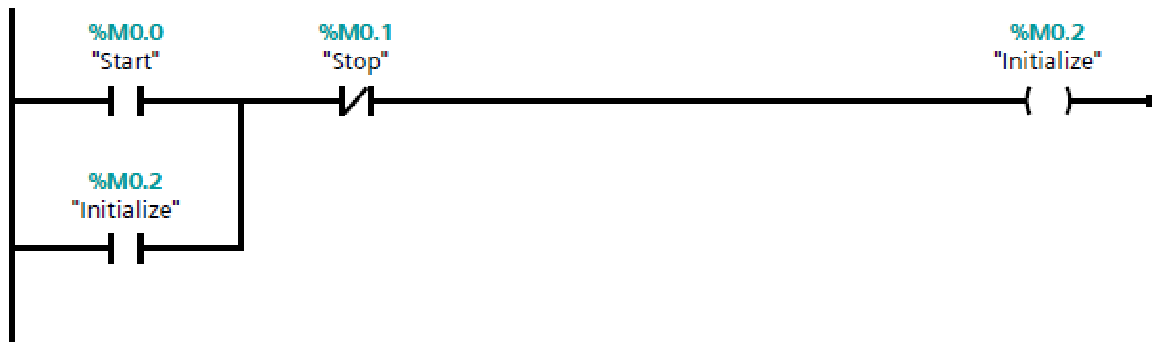
3. Ladder Logic Programming

Table 2 : List of Notations used

Sr. No.	**Notations Used**	**Meaning of the Notation Used**
1.	Start	Used for starting the program.
2.	Stop	Used for stopping the program.
3.	Initialize	It is the output of which we get on pressing the start button.
4.	Stop_V_1	Used for closing the Valve 1 (v1)
5.	V_1	Used for opening the Valve 1 (v1)
6.	V_2	Used for opening the Valve 2 (v2)
7.	V_3	Used for opening the Valve 3 (v3)
8.	V_4	Used for opening the Valve 4 (v4)
9.	V_5	Used for opening the Valve 5 (v5)
10.	Ls_1	Used for detecting the lower level of the water in the water container.
11.	Ls_2	Used for detecting the lower level of the coffee powder in the coffee powder container.
12.	Ls_3	Used for detecting the lower level of the sugar in the sugar container.
13.	Ls_4	Used for detecting the lower level of the cold milk in the milk container.
14.	Ls_5	Used for detecting the lower level of the prepared coffee in the mixer.
15.	Coffee_ON	It is the output that we get when lower-level sensor 2 is detected.
16.	Sugar_ON	It is the output that we get when lower-level sensor 3 is detected.
17.	Milk_ON	It is the output that we get when lower-level sensor 4 is detected.

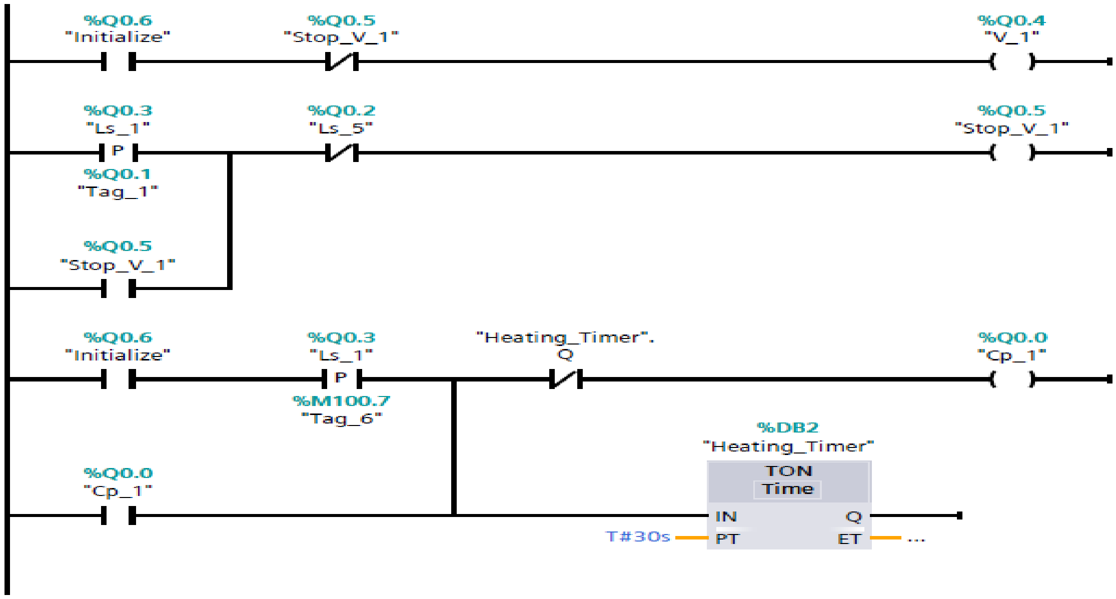
18.	MX	Used for mixing coffee powder, sugar, cold milk and hot water.
19.	Cp_1	Used for circulating the water from the heat exchanger to the mixer and vice versa.
20.	Tag_1	It is memory bit number 1 where information is stored.
21.	Tag_2	It is memory bit number 2 where information is stored.
22.	Tag_3	It is memory bit number 3 where information is stored.
23.	Tag_4	It is memory bit number 4 where information is stored.
24.	Tag_5	It is memory bit number 5 where information is stored.
25.	Tag_6	It is memory bit number 6 where information is stored.
26.	Tag_7	It is memory bit number 7 where information is stored.
27.	Tag_8	It is memory bit number 8 where information is stored.
28.	Tag_9	It is memory bit number 9 where information is stored.
29.	Heating Timer	It is the timer which indicates the time for heating of the water. The time needs to be manually entered.
30.	Mixing Timer	It is the timer that indicates the time for mixing the hot water, coffee powder, sugar, and cold milk. The time needs to be manually entered.

3.1 Network 1 - INITIALIZATION



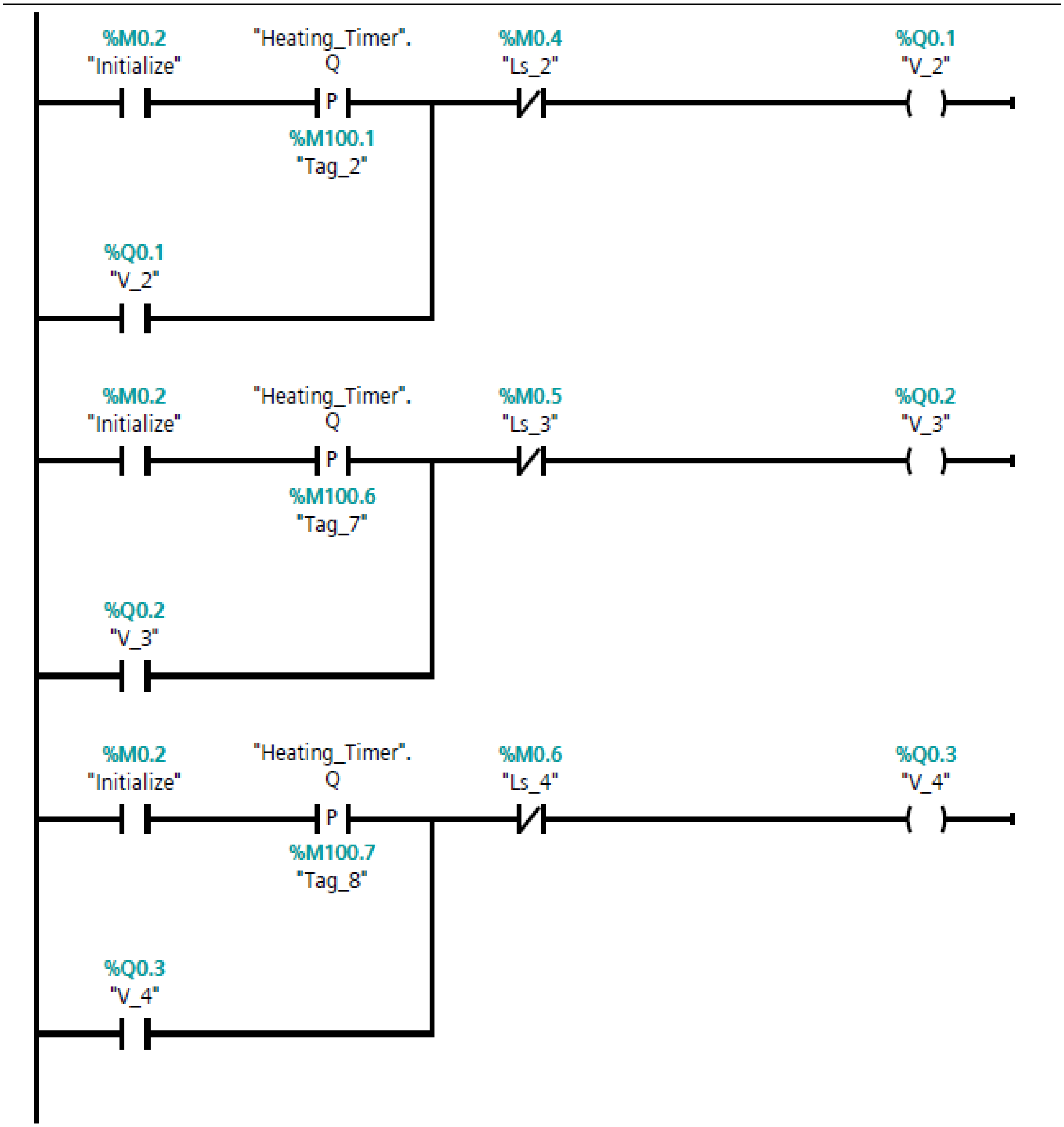
This is the first step, wherein all the processes are set to initialise upon pressing the start button. The initialised memory is latched and V_1 is opened.

3.2 Network 2 - WATER PROCESSING/WATER HEATING



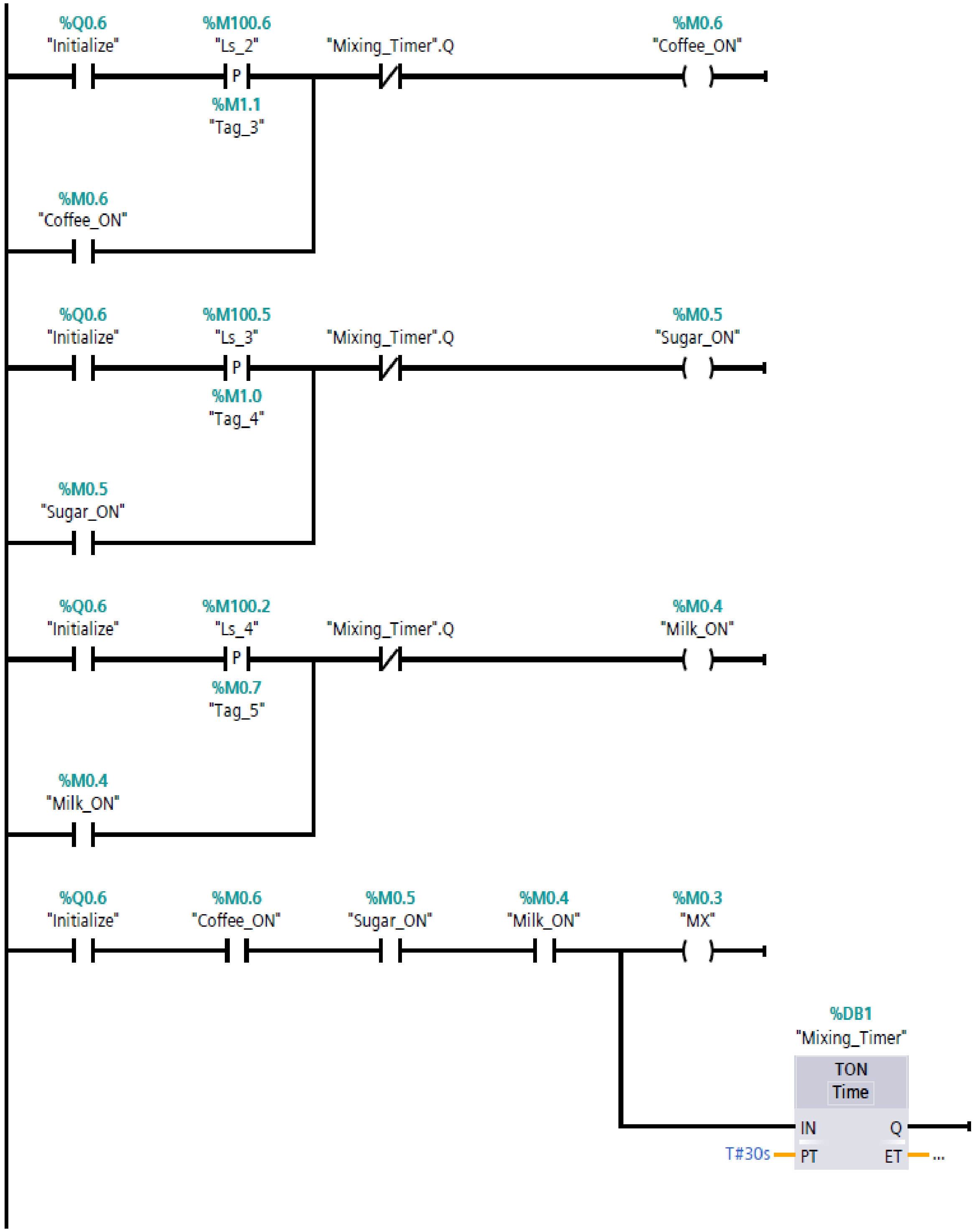
In this step, the water from the water container is sent to the mixer and then from there a circulating pump (Cp_1) is used to circulate the water from the mixer to the water heater and vice versa. The heating time limit can be set as required. For testing the program, we have set the time to 30 seconds. Ls_1 is the limit sensor of the water holding container. Ls_5 is the limit sensor for the mixer container.

3.3 Network 3 - COFFEE, SUGAR, MILK PROCESSING



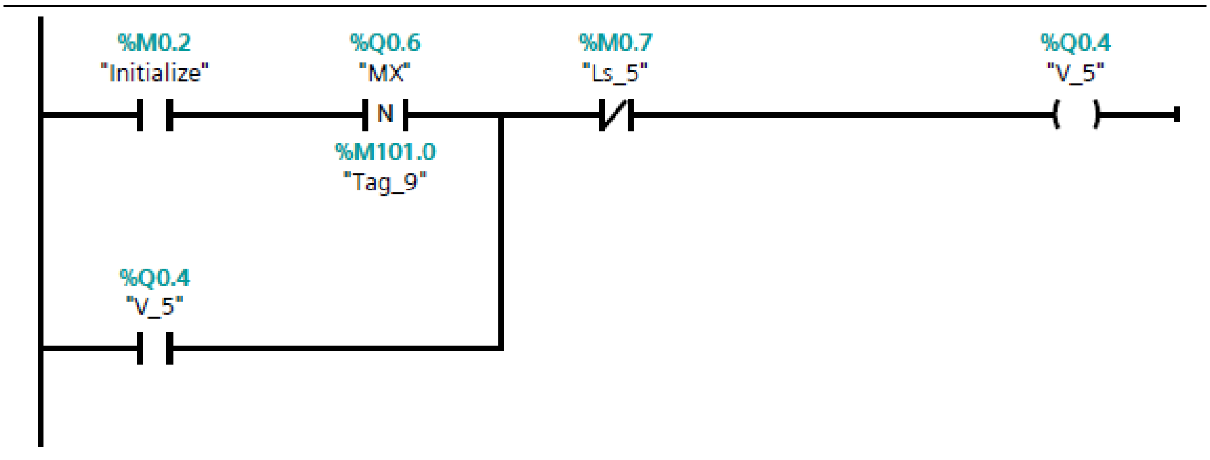
Once the heating of the water is over, only then the Coffee Powder, Sugar and Milk Container valves, V_2, V_3 and V_4 respectively are opened and they are transferred into the mixer. Ls_2, Ls_3 and Ls_4 are the limit sensors for Coffee Powder, Sugar and Milk Containers respectively. When Ls_2, Ls_3, and Ls_4 is detected, the valves V_2, V_3 and V_4 respectively are turned off.

3.4 Network 4 - MIXING



In this stage, the mixing of coffee powder, water, sugar and milk takes place. The mixer timer can be set to any desired time limit. For testing the program, we have set the time to 30 seconds. Here, MX is the mixing motor, which is turned on for 30 seconds.

3.5 Network 5 - BOTTLE FILLING

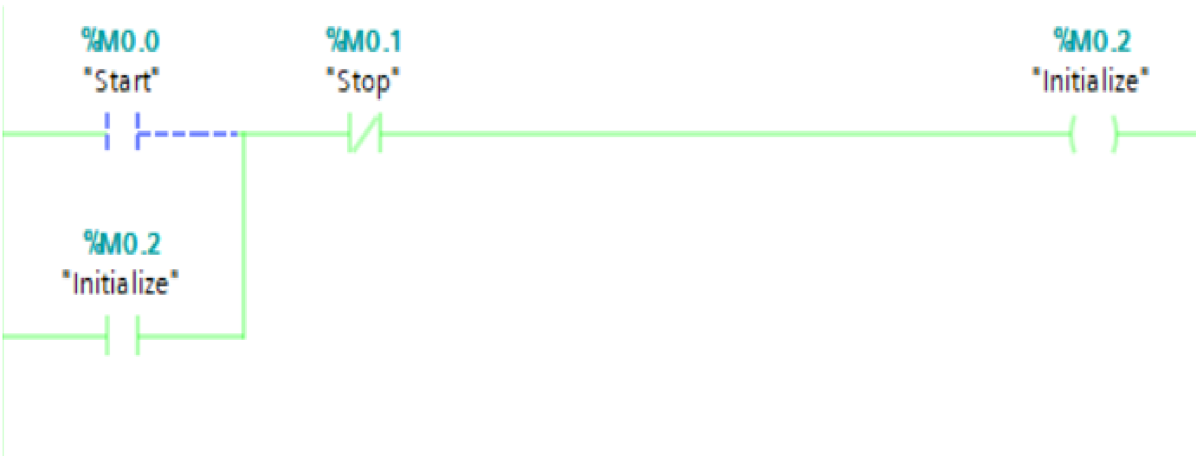


This is the last stage of the bottle-filling process. After the mixing, valve V_5 is opened and the coffee is poured into the bottles lined up on a conveyor. Ls_5 is the limit sensor for the mixing container. When Ls_5 is detected, the valve V_5 is turned off and the whole process starts once again and it continues until the Stop button is manually pressed.

4. Simulation of the Ladder Logic Program

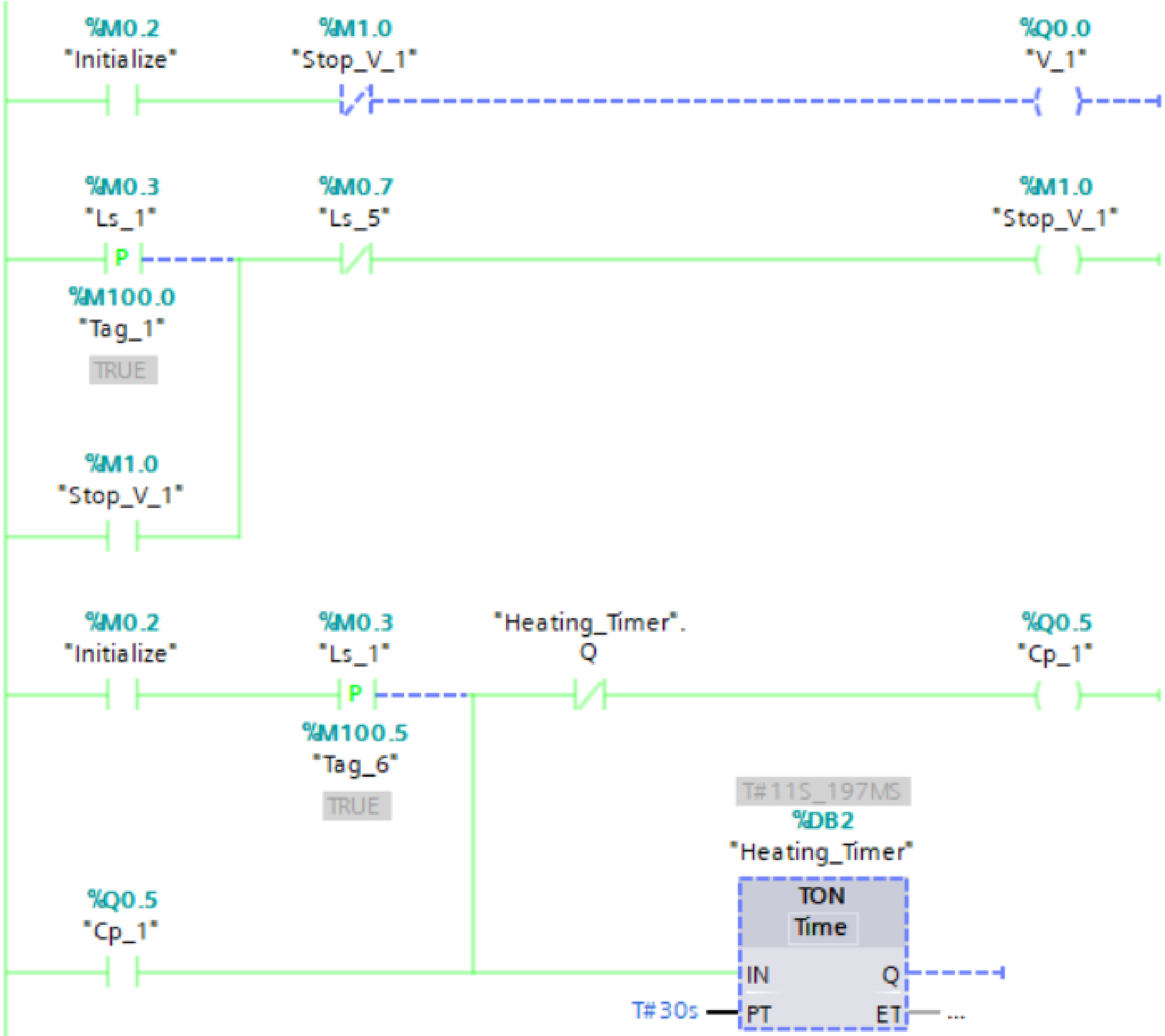
Note - The Green line indicates that the switch is on, the current is flowing and the process is on. The Blue dotted line indicates that the switch is off and the current is not flowing. However, since the switches that we have used are Push Button switches, therefore they get disconnected after being pushed once, but the process stays switched on.

4.1 Network 1 - INITIALIZATION



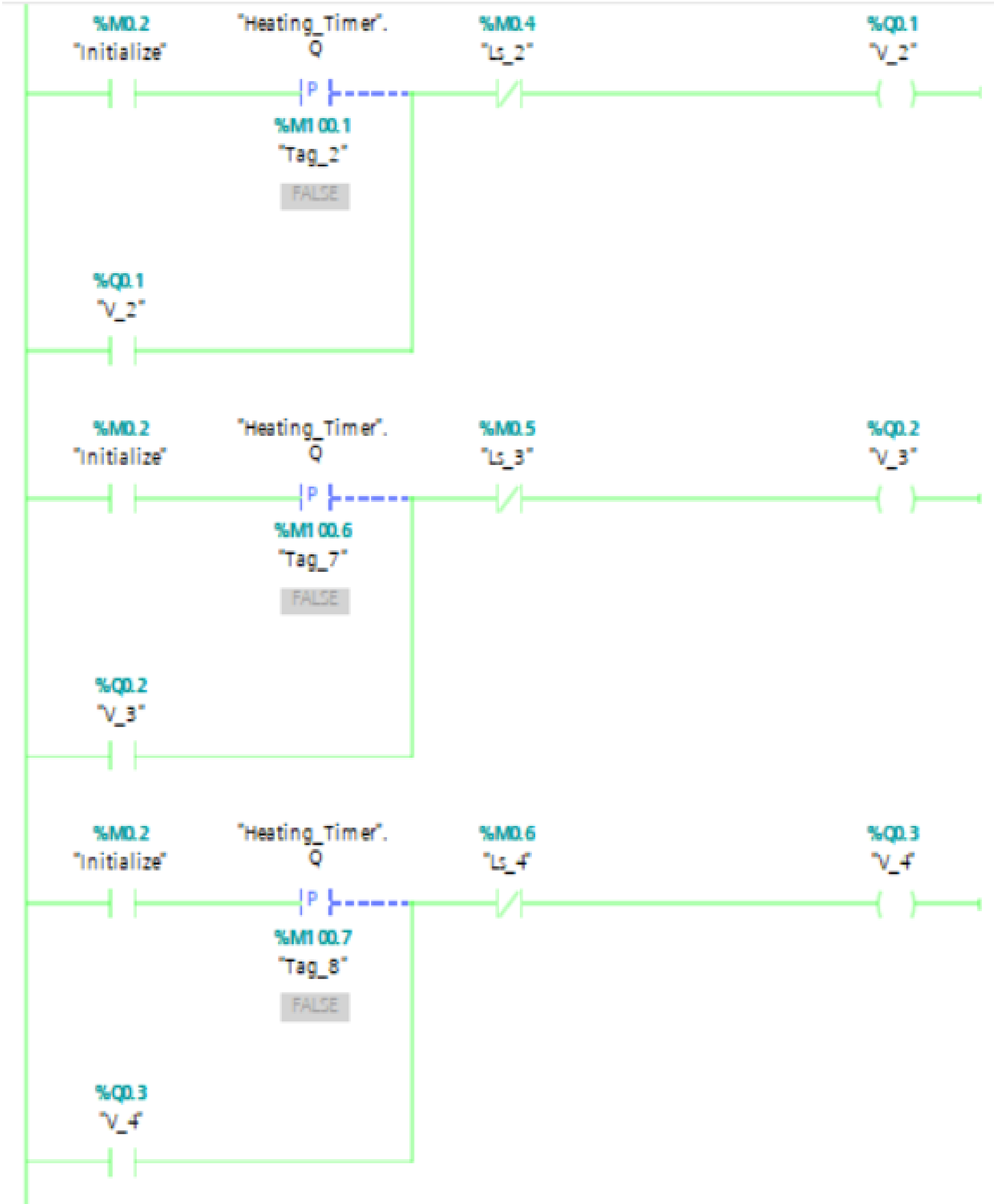
After pressing the Start Button (push button m), the memory is latched. Since it is a push button, it needs to be pressed only once and the circuit then breaks, but the machine is Initialized.

4.2 Network 2 - WATER PROCESSING/WATER HEATING



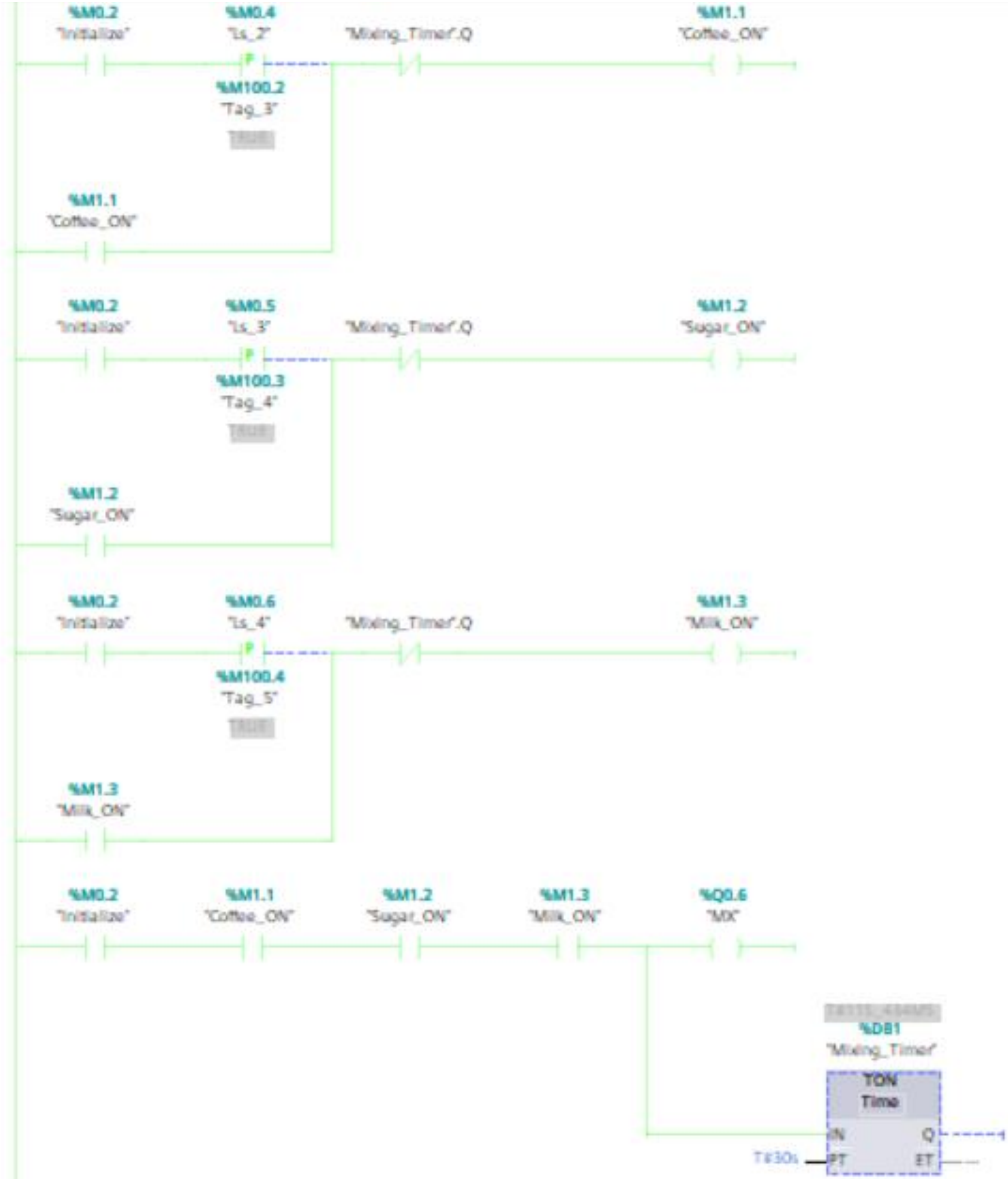
The valve V_1 is closed and the boiler is started. The circulating pump (Cp_1) pumps the water into the boiler. The heating timer is set manually to 30 seconds, during which the water gets heated. After heating, the water is transferred to the mixer.

4.3 Network 3 - COFFEE, SUGAR, MILK PROCESSING



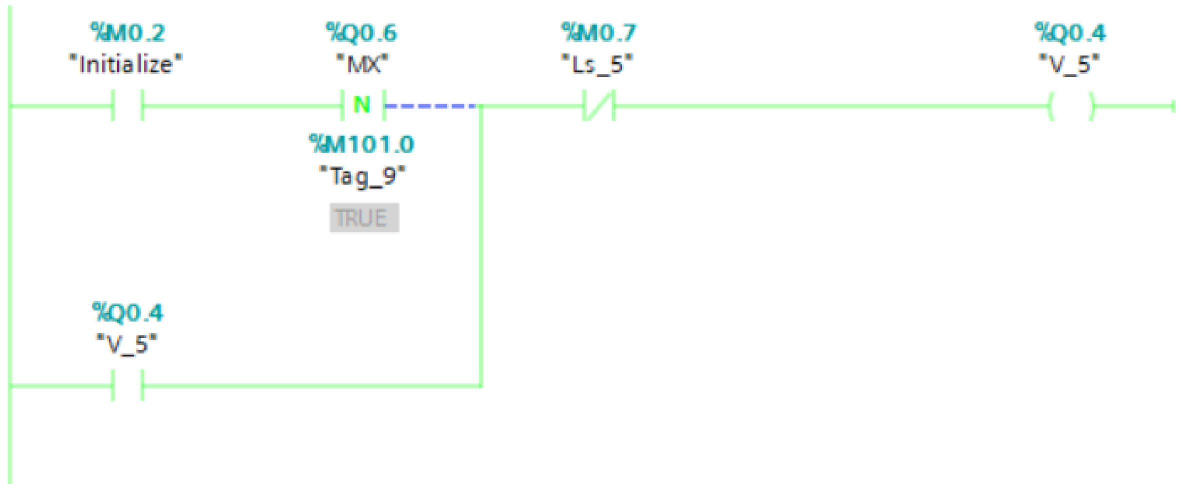
Once the heating timer of 30 seconds is over, valves V_2, V_3 and V_4 are opened to fill the mixer with coffee beans, sugar and milk respectively.

4.4 Network 4 - MIXING



Once the lower-level sensors Ls_2, Ls_3, and Ls_4 of coffee beans, sugar and milk respectively are detected, then the mixer is turned on. The MX here is the mixing motor, which is turned on for 30 seconds using the Mixing Timer.

4.5 Network 5 - BOTTLE FILLING



Once the 30 seconds of the Mixer is over, the valve V_5 is opened and the bottle filling takes place. This process continues till the lower-level sensor Ls_5 is detected. After which the process starts once again, without pressing the start button. The process continues in a loop until the stop button (push button n) is pressed.

5. Conclusion

Using the Ladder Logic Programming and PLC S7-1200, an automated coffee bottle-filling system has successfully been developed and simulated. The system was developed in compliance with thorough specifications and user recommendations. Implementing further features like user-defined volume specifications and heating times led to results that were satisfactory. It is conceivable to investigate additional advancements like filling in accordance with bottle size, shape, and weight. We believe that the information presented in this article helps promote automation and system management in the coffee bottle-filling sector. This paper has been a journey of learning about and gaining insights into the topic.

The novelty of this research paper is that it combines both (i.e. coffee making and bottle filling) processes together and uses simple and easy to understand PLC ladder logic programming to ensure the proper functioning of the industrial setup.

Appendix

List of Tables:

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Simulation of the Ladder Logic Program

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