© FEB 2026 | IRE Journals | Volume 9 Issue 8 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I8-1714060

Design and Implementation of a PLC-Based Automatic Liquid Mixing and Filling System

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Abstract- Designing and experimentally validating an autonomous liquid mixing and filling system based on a programmable logic controller (PLC) for small- and medium-sized industrial applications is the aim of this work. Within a single PLC framework, the suggested system combines automated filling, conveyor-based container handling, scheduled mixing, and liquid level management. Using ladder logic created in WPLSoft software, a Delta DVP-14SS2 PLC is used to coordinate sensors, solenoid valves, motors, and a pump. Stable operation, uniform mixing, and reproducible filling precision across several cycles are shown by experimental evaluation. The outcomes verify decreased human intervention and increased process efficiency. With potential for future growth through flow-based control, HMI/SCADA connectivity, and remote monitoring, the system provides a small and affordable automation solution.

Keywords: PLC, Liquid Mixing, Automatic Filling, Ladder Logic, Sensors, Industrial Automation.

I. INTRODUCTION

Automation plays a vital role in modern manufacturing by improving product consistency, operational efficiency, and workplace safety. In the food, pharmaceutical, and chemical sectors, where precise proportioning and consistent filling are essential to upholding quality standards, liquid mixing and filling procedures are frequently employed. Inconsistent mixing ratios, spillage, and a greater reliance on trained operators are common problems with conventional manual and semi-automatic processes, which raise production losses [1].

Because of its dependability, real-time execution, and simplicity of integration with industrial sensors and actuators, programmable logic controllers (PLCs) have emerged as the preferred control platform in industrial automation [8]. PLCs have better scalability, electrical noise immunity, and dependability than microcontroller-based systems, making them appropriate for challenging industrial settings [2]. In order to reduce system complexity and ensure dependable and repeatable performance, this effort focuses on creating a compact PLC-based system that combines filling and liquid mixing processes into a single automated process.

II. LITERATURE REVIEW

To increase accuracy and throughput, a number of academics have suggested PLC-based automatic liquid filling systems that use conveyors and sensor-based detection. In order to increase consistency and save manual labor, Balsaraf et al. presented a PLC-controlled bottle filling device that initiates filling based on container position [1]. In a similar vein, Suramwar et al. introduced a conveyor-based PLC filling system with a focus on modular design and timing-based control for small-scale companies [7].

It has also been observed that PLC-based liquid dispensing systems with discrete sensors and timers improve operational safety and reliability. The advantages of PLC timers and interlocks in attaining constant fill volumes while reducing human mistake were emphasized by Bhuvanesh et al. [2]. Sensor-based feedback greatly enhances process stability and prevents overflow in industrial tanks, according to research on level monitoring systems [3]. Wang has suggested a PLC-based beverage mixing method that shows how well timed mixing, solenoid valve control, and structured sequencing work to preserve ingredient ratios [5].

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The inspiration for this work stems from the fact that, despite these developments, few research combine mixing and filling inside a compact, empirically validated PLC-based architecture.

III. SYSTEM OVERVIEW

A. The Proposed Block Diagram of the System

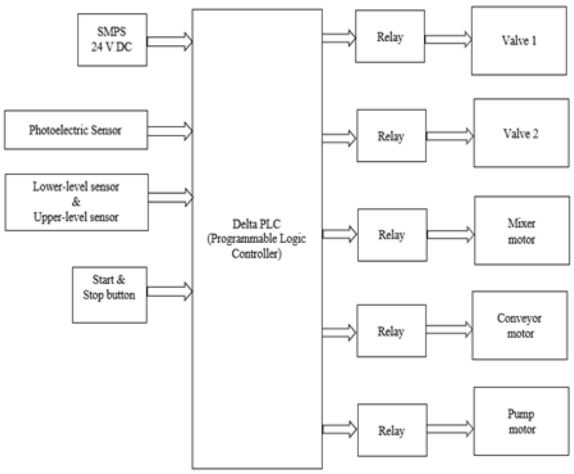

Figure 1: Overall Block Diagram of the System

Figure 1. illustrates the functional block diagram of the proposed PLC-based automatic liquid mixing and filling system. The photoelectric sensor, upper and lower level sensors, and start/stop push buttons provide inputs to the Delta PLC, which serves as the central control unit. The PLC uses relay connections to drive solenoid valves, mixer motors, conveyor motors, and pump motors based on these inputs. The PLC and field devices receive regulated power from the 24 V DC SMPS, guaranteeing steady operation. With little assistance from humans, this organized setup allows for the sequential control of liquid filling, mixing, container identification, and final dispensing.

B. The Real-time experimental setup

Figure 2: Real-time experimental setup

The real-time experimental setup created to verify the system's functionality is depicted in Figure 2. The physical configuration integrates real sensors, motors, valves, and the PLC panel and closely adheres to the logical framework depicted in Figure 2. The synchronized operation of the sensing, control, and actuation stages is confirmed by experimental findings.

The configuration exhibits accurate container placement, controlled filling, consistent mixing duration, and dependable level detection. The block diagram and experimental model work together to confirm the suggested automation system's industrial relevance, robustness, and practical viability.

IV. METHODOLOGY

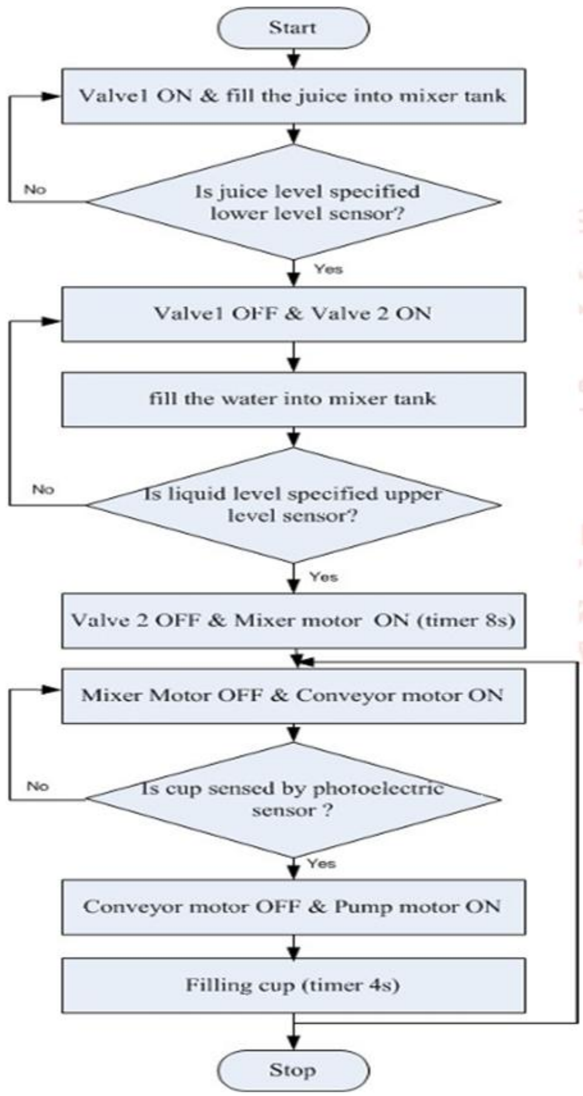

Figure 3: Overall System Flowchart

The overall flowchart in Figure 3. illustrates the proposed system's operational sequence. The start push button is used to initialize the system, allowing the PLC to start operating. To let the initial liquid into the mixing tank, solenoid valve 1 is first turned on. The tank level is continuously monitored by the lower-level sensor, and valve 1 is deactivated when the predetermined lower threshold is achieved. Then, until the upper-level sensor verifies the necessary volume, solenoid valve 2 is activated to admit the second liquid. Without the need for human supervision, this sensor-based control guarantees precise liquid proportioning.

To ensure even mixing of the liquids, the PLC uses an internal timer to turn on the mixer motor for a certain amount of time following the filling stage. After mixing is finished, the conveyor motor is started and the mixer motor is switched off. A photoelectric sensor that senses the presence of a cup at the filling position is used to track the movement of containers. The pump motor is turned on to disseminate the mixed liquid for a predetermined period of time after the conveyor motor is halted upon detection. The system is prepared for the following cycle when the pump is switched off after filling.

C. The Proposed Circuit Diagram of the System

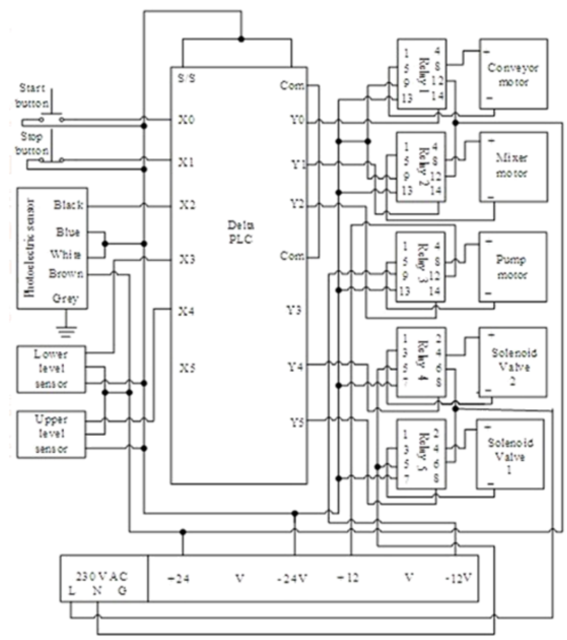

Figure 4: Overall Circuit Diagram of the System

The electrical and control connections used to implement this logic are presented in the circuit diagram shown in Figure 4. The diagram illustrates the interfacing of sensors, relays, motors, solenoid valves, and power supply with the Delta PLC, ensuring reliable execution of the programmed sequence.

V. MATHEMATICAL MODELING

The filling operation follows a time-based control approach. If Q_prepresents the pump flow rate and T_fis the filling duration, the filled volume V_fis given by

$$V_f = Q_p \times T_f \qquad (1)$$

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The liquid level rise in the mixing tank during filling can be expressed as

$$\frac{dh(t)}{dt} = \frac{Q_{in}}{A} \qquad (2)$$

where Q_inis the inlet flow rate and Ais the cross-sectional area of the tank. These relations guide timer selection and sensor placement in the control logic.

VI. RESULTS

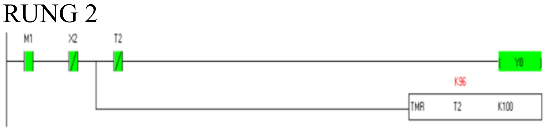
CONTROL LOGIC IMPLEMENTATION

The ladder program is divided into several rungs, each of which represents a distinct function like filling, conveyor movement, mixing, and valve control. Interlocks are used to guarantee safe sequencing and avoid overlapping actions. Timers provide consistency across operational cycles by controlling the mixing and filling times.

RUNG 1

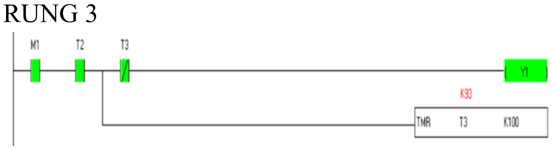
This rung represents the system start logic, where input X0 acts as the start push button. When X0 is activated, internal relay M1 is energized, enabling the execution of all subsequent control operations.

RUNG 2



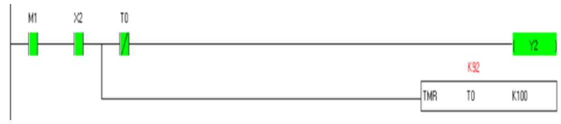
This rung controls solenoid valve 1 through output Y0 when the system is enabled by M1 and the lower-level sensor X2 indicates insufficient liquid in the tank. Timer T2 limits the valve opening duration, ensuring controlled filling and preventing overfilling.

RUNG 3



This rung activates solenoid valve 2 through output Y1 once the initial filling stage is completed and timer T2 has elapsed. Timer T3 governs the valve operation time, ensuring the second liquid is added in the required quantity.

RUNG 4

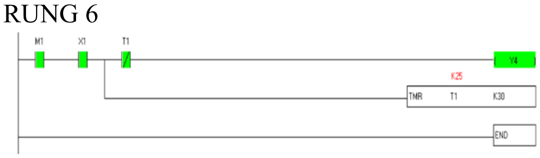


This rung controls the mixer motor through output Y2 once the required liquid level condition is satisfied and the system is active. Timer T0 defines the mixing duration, ensuring uniform blending before the next process stage begins.

RUNG 5

This rung starts the conveyor motor through output Y3 after the mixing process is completed and timer T0 has elapsed. The photoelectric sensor X1 ensures the conveyor operates only when no container is detected at the filling position.

RUNG 6



This rung activates the pump motor through output Y4 when a container is detected by the photoelectric sensor X1 and the system is enabled. Timer T1

The ladder logic's modular design makes it simple to adjust factors like filling time and mixing time, allowing the system to accommodate a variety of liquid types and container sizes. One of the main benefits of PLC-based control is its versatility.

HARDWARE RESULTS

D. Operation of Liquid Mixing and Filling Machine System

Figure 5: Result for Overview of Liquid Mixing and Filling Machine System

In Figure 5. Delta DVP-14SS2 PLC combined with level sensors, a photoelectric sensor, solenoid valves, DC motors, and a pump unit was used to experimentally evaluate the suggested PLC-based autonomous liquid mixing and filling system. A photoelectric sensor was placed along the conveyor to detect the presence of containers, and two liquid level sensors were fixed on the mixer tank to detect predetermined lower and upper thresholds. Real-time feedback and sequential process control were made possible by the sensors' interface with the PLC inputs in accordance with the ladder logic that was put in place.

E. Operation of Solenoid valve & Level Sensor

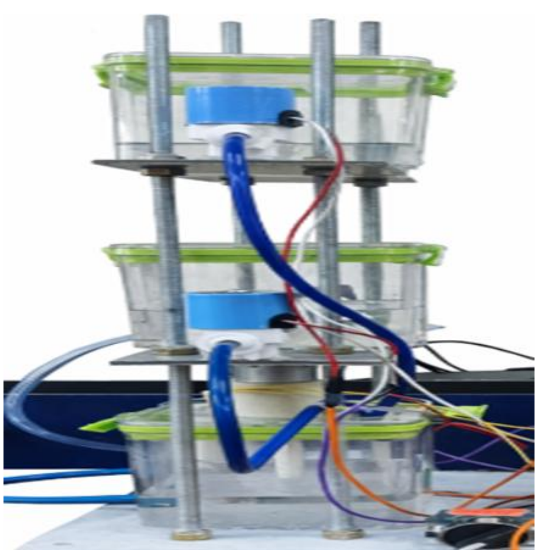


Figure 6: Result for Solenoid valve & Level Sensor

The Figure 6. Solenoid valve-1 was turned on by the PLC when the start push button was hit, allowing the initial liquid to enter the mixer tank. The second liquid was introduced by deactivating valve-1 and activating solenoid valve-2 upon reaching the lower level sensor. Accurate proportioning was ensured by the upper level sensor's successful detection of the necessary liquid level, which halted valve-2. The liquids were then evenly mixed after the mixer motor was turned on for a certain amount of time using a PLC timer.

F. Operation of Photoelectric Sensor

Figure 7: Result for Photoelectric Sensor

In Figure 7. the conveyor motor moved empty containers in the direction of the filling station after mixing. The conveyor stopped and the pump motor dispensed the mixed liquid for a predetermined amount of time when the photoelectric sensor accurately identified the presence of a container. Consistent filling and stable cyclic operation were verified by experimental observations. Effective integration of sensing, control, and actuation was demonstrated by the system's continuous and dependable operation until the stop button was touched.

VII. CONCLUSION

A Delta PLC with integrated sensors and actuators was used in the successful design and experimental validation of the suggested PLC-based automatic liquid mixing and filling system. The outcomes show correct container filling in real time, controlled mixing, conveyor movement, and dependable liquid filling sequencing. Throughout the process, human participation was reduced and accurate decision-making was ensured by the use of level sensors and a photoelectric sensor. Consistent mixing and filling times were made possible by timer-based control using ladder logic, which increased efficiency and repeatability. Operation, troubleshooting, and future extension are made easier by the structured PLC programming and modular hardware configuration. All things considered, the system shows itself to be a useful, affordable, and scalable automation solution appropriate for small- and medium-sized industrial liquid processing applications.

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