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AUTOMATIC DAM GATE BASED ON PROGRAMMABLE LOGIC CONTROL (PLC)

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ABSTRACT

This paper presents the design and implementation of an automated dam gate control system using a programmable logic controller (PLC). The main objective of this system is to enhance the efficiency and safety of dam operation by automating the regulation of water flow through the dam gates. This system integrates a variety of sensors, including water level sensors and flow sensors, to monitor conditions in real-time and make informed decisions. The PLC acts as a central processing unit, executing predefined algorithms to control the opening and closing of the dam gates based on collected data. This automated system not only reduces human intervention but also reduces the risk of operational errors and improves response time through rapid execution during floods. This abstract highlights the experimental results of the system. The system has proven effective in reducing flood and flash flood risks, in addition to contributing to improved water resource management.

تُقدّم هذه الورقة تصميم وتنفيذ نظام تحكم آلي لبوابات السدود باستخدام وحدة تحكم منطقية قابلة للبرمجة (PLC). يهدف هذا النظام بشكل أساسي إلى تعزيز كفاءة وسلامة تشغيل السدود من خلال أتمتة تنظيم تدفق المياه عبر بواباتها. يدمج النظام مجموعة متنوعة من أجهزة الاستشعار، بما في ذلك أجهزة استشعار مستوى المياه وأجهزة استشعار التدفق، لمراقبة الظروف في الوقت الفعلي واتخاذ قرارات مدروسة. تعمل وحدة التحكم المنطقية القابلة للبرمجة كوحدة معالجة مركزية، حيث تُنفذ خوارزميات مُحددة مسبقاً للتحكم في فتح وإغلاق بوابات السدود بناءً على البيانات المُجمّعة. لا يُقلّل هذا النظام الآلي من التدخل البشري فحسب، بل يُقلّل أيضاً من مخاطر الأخطاء التشغيلية ويُحسّن زمن الاستجابة من خلال التنفيذ السريع أثناء الفيضانات. يُسلّط هذا الملخص الضوء على النتائج التجريبية للنظام، الذي أثبتت فعاليته في الحد من مخاطر الفيضانات المفاجئة، بالإضافة إلى مساهمته في تحسين إدارة موارد المياه.

KEYWORDS: Programmable Logic Control, PLC, Dam, Capacitive proximity sensor, Limit switch, Water flow sensor, Gate.

1 INTRODUCTION

Water is the most precious resource on Earth, and controlling it has been one of humanity's oldest challenges. For millennia, we have strived to tame rivers, store rainwater, and direct its flow to where it is most needed. Dams were the answer. Dams are water storage

reservoirs built on rivers or valleys to control water flow. They are used for various purposes, such as providing drinking water, irrigation, and generating electricity [1]. One of the most important benefits of dams is providing water and food during periods of drought and low rainfall. Dams also help prevent flooding during the rainy season and protect lives and property [2].

However, dams are not without risks. When mistakes are made during construction, or when water levels are not managed properly, the results can be catastrophic. A dam collapse is not just an engineering problem; it is a humanitarian disaster. Lives are lost, money is wasted, crops are destroyed, and entire communities are displaced [3]. The effective operation of dam gates remains a significant challenge, particularly where improper dam gate control and manual operation often lead to water wastage, inefficient resource utilization, and increased risk of flooding [4].

The collapse of the Derna Dam in Libya is a painful example. The disaster caused significant human and material losses. Many experts believe that the disaster could have been completely avoided, or the damage significantly reduced, if the dam had been managed with an automated system. If there had been sensors to measure water levels and an intelligent warning system, authorities and residents could have been alerted in time to take necessary action [5]. It would also be possible, using automated gates, to release water gradually and systematically before it reached dangerous levels.

Many dams around the world still rely on manual operation. Workers open and close the gates manually, making decisions based on observations and only responding to problems after they occur. This method of dam management suffers from serious weaknesses: water control becomes inconsistent, human error is a real danger, and there may not be enough time to respond during flash floods or sudden storms [6]. As highlighted in previous studies, manual systems are inefficient and cannot provide the real-time monitoring and rapid response capabilities necessary for effective water management [7].

Automated dams offer a better solution. They use modern technology to make dam operations safer, more efficient, and more responsive. Key components include sensors that monitor water levels and flow, motors that open and close the gates, and control algorithms that determine the actions to be taken and their timing [8]. These systems operate continuously, responding to changes in seconds rather than hours [9]. During heavy rainfall, automated gates can adapt instantly to prevent flooding in downstream areas.

A programmable logic controller (PLC) is a fundamental component of many automated dam systems. It is a small, robust computer designed for industrial environments [10]. The PLC receives information from sensors strategically located around the dam, processes it using programmed instructions, and then sends commands to actuators that control gates, valves, and pumps [11]. Its benefits include automating complex tasks and reducing the need for manual labor, providing precise control of water levels and flow rates, monitoring key parameters such as water pressure and equipment status, and triggering alarms or safety procedures in case of malfunctions [12]. Furthermore, it allows operators to remotely monitor the dam from a central control center, view real-time data, and make necessary adjustments without requiring physical presence on-site [13]. When faults occur, PLC systems help maintenance teams quickly diagnose the problem and minimize downtime. Data is also recorded over time, enabling analysis to identify patterns and optimize dam operations [14]. Perhaps most importantly, it issues alerts during emergencies, giving communities valuable time to evacuate or prepare [15].

Programmable Logic Controllers (PLCs) are fundamental to modern dam management, combining automation, accuracy, safety, and remote monitoring. Their ability to streamline

operations, detect faults, and provide actionable data makes them a cornerstone of efficient and reliable water infrastructure. As dam systems continue to evolve, PLC technology will remain vital in meeting the growing demands of sustainable and safe water management.

This paper aims to design an automated dam gate system based on PLCs that directly addresses the challenges of conventional dam operation. Its main objectives are clear: First, we seek to use a PLC to manage the dam, control water levels, and automatically open and close its gates. Second, we will use sensors to monitor water levels and warn of any hazards arising from rising water levels. Third, this project goes beyond simply solving the immediate problem; it also aims to introduce innovative concepts that can be more broadly applied to control production projects in other fields. By building this system, we hope to demonstrate that automated dam gates are not just for wealthy nations or mega-projects, but a practical and viable solution for dams of all sizes. They conserve water, save money, and, most importantly, save lives.

2 PREVIOUS STUDIES

Previous studies have extensively explored the automation of dam gate control systems, utilizing embedded systems, PLCs, and SCADA technology. Iyer et al. proposed an embedded dam gate control system using 'C' programming and Visual Basic, incorporating an AT89S51 microcontroller to monitor water levels and control dam gates for efficient water management in India. The system reduced water wastage and suggested integration with power plants for electricity generation, with future improvements involving wireless technology and centralized control integration [1]. Similarly, Bobat et al. examined the application of SCADA systems at the Yuvacik Dam in Turkey, emphasizing real-time control for managing risks such as floods and droughts. SCADA systems were deemed essential for monitoring dam and reservoir conditions, integrating decision support for water resource management [2].

In addition, Sorte et al. presented a PLC-based automation system for dam gate control, using ladder logic and real-time monitoring to automate gate operations. The system featured SCADA for graphical representation and data logging, enhancing operational control [3]. Nivedha and Magesh developed a PLC-based system using electro-pneumatic controls to autonomously manage dam gates based on water pressure and levels, aiming to prevent disasters and improve water flow management [4]. Furthermore, Mahajan and Karemore explored a smart automated door control system for dams using PLC and SCADA technology, ensuring efficient water level control through sequential operations and centralized data acquisition [5]. Lastly, Al-hadhrami and Shaikh proposed a system for remote monitoring and controlling dams, highlighting the benefits of automating dam operations through sensors and wireless communication, offering enhanced monitoring and cost-effective management [6].

Further studies explored the significance of PLC-based systems in dam automation. Sahu and Tripathi reviewed the automation of floodgates in water reservoirs using PLC, emphasizing its importance in controlling water levels for power generation and irrigation purposes [7]. Madanhire et al. presented a case study on an automated dam shutter control system, focusing on improving water management efficiency by integrating servo motors and mechanical hoist mechanisms [8]. Additional research by Sahu and Tripathi demonstrated the use of PLC for real-time control of water gates, showcasing its efficiency in managing water levels through ladder logic programming [9]. Bharatiya emphasized the role of PLC and remote control technology for enhanced monitoring and management of dam operations [10], while Pandya et al. examined the use of PLC and SCADA systems to prevent overflow

disasters and ensure water conservation through automated dam gate control [11]. Similarly, Oo and Naing focused on the implementation of a PLC-based gate control system using float sensors and relays for motor direction, emphasizing automation for irrigation and flood safety [12]. Finally, Kale et al. highlighted the importance of distant monitoring of gated dams using PLC and SCADA for improved safety, water conservation, and disaster prevention [13].

Recent studies have delved into sensor-based and microcontroller technologies for dam automation. Kommey et al. introduced an ultrasonic sensor-based automated dam shutter system that uses microcontrollers and GSM modules to automatically manage dam gates and alert nearby residents with warning messages [14]. Mahadevan et al. proposed an auto-controlled dam system with SMS warning features, which uses sensors and GSM modules for real-time gate management and resident safety alerts [15]. Similarly, Kavitha et al. discussed a low-cost flood prevention system using Arduino and RF transmitters for dam water management [16], while Kumar et al. highlighted the importance of PLC and SCADA in automating dam gate control with buzzers, sensors, and relay systems [17]. Patil et al. further explored PLC-based dam shutter control using water level sensing and HMI software, suggesting future enhancements such as GPS and wireless communication [18]. Lastly, Iribagiza et al. developed a smart system for monitoring dam water and turbidity levels using microcontrollers and GSM technology [19], while Arora proposed a PLC-based dam shutter system that incorporates level sensing, flood alerts, and future enhancements through RFID devices and PID controllers for more sophisticated control systems [20].

3 PROTOTYPE DESCRIPTION

3.1 Block diagram of Automatic Dam Gate Based on Programmable Logic Control (PLC)

Figure 1 illustrates the initial design of an automated control system that utilizes a programmable logic controller (PLC) to control the dam gates and monitor various operating parameters, including speed, flow rate, and water level. The system is designed to operate autonomously, ensuring precise water flow regulation while providing real-time monitoring and fault detection. A detailed explanation of the main components and their functions follows:

1- Input Devices:

This stage is responsible for collecting real-time data on dam conditions, including water level, flow rate, and gate position. This data is then transmitted to the control unit for analysis and processing. This stage utilizes the following devices:

- Lower and Upper Level Sensors: These sensors detect water levels at predefined thresholds, activating the PLC to initiate gate adjustments when levels exceed or fall below safe limits.
- Limit Switches (1-4): These safety devices provide dual feedback (on/off) to the PLC, ensuring that mechanical components, such as dam gates, operate within their defined ranges and preventing overstretching or mechanical failures.
- Flow sensors: Equipped to measure water flow rates in real time, enabling dynamic adjustments to gate positions for optimal water drainage.

2- Central Control Unit (PLC FX_{2n}-32MT):

The Programmable Logic Controller (PLC) acts as the brain of the system, processing input signals from sensors and executing pre-programmed logic operations to control the dam gates. The FX_{2n}-32MT model was chosen for its robustness, high processing speed, and

multiple input/output ports, making it suitable for industrial automation. PLC functions include:

- **Signal Processing:** Converting analog sensor data into operational commands.
- **Logical Execution:** Running control algorithms to determine gate movement based on water level and flow data.
- **Fault Handling:** Detecting faults (such as sensor failure or motor overload) and triggering alarms.

3- Output Devices

Output devices execute the commands from the PLC to physically adjust the gate or provide status feedback.

- **DC Motor:** Drives the dam gate's movement (opening/closing) via mechanical linkage. The motor's speed and direction are controlled by the PLC.
- **Relay:** Acts as an electrically operated switch to control high-power devices like the DC motor. It isolates the PLC from high-voltage circuits.
- **Gears:** Transmit motion from the DC motor to the gate, providing torque amplification for smooth and precise gate adjustment.
- **Indicator Lamp:** Provides visual status updates (e.g., gate fully open, alarm triggered).
- **Buzzer:** Emits audible alarms in emergencies (e.g., excessive water flow or gate malfunction).

4- **Power Supply Section:** This section provides the necessary electrical power for the entire system. It ensures reliable voltage and current distribution to the PLC, actuators, and sensors. A stable power supply is crucial for the system to maintain continuous operation and prevent dam gate control downtime.

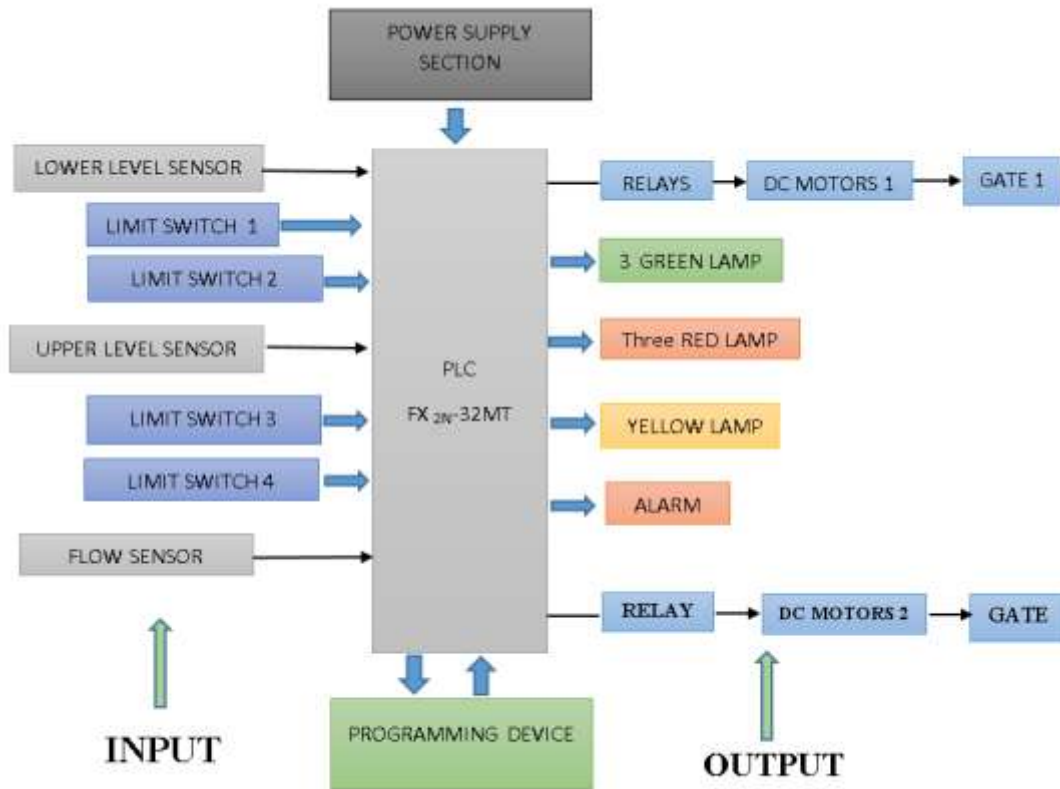


Figure 1: Block diagram of the project.

3.2 Components

The dam model and laboratory control system have been designed, and these are the main components used in building the model:-

- 1- PLC (Programmable Logic Control).
- 2- Capacitive proximity sensor.
- 3- Dc motor.
- 4- Limit switch.
- 5- Relay.
- 6- Indicator lamp.
- 7- Gears.
- 8- Buzzer
- 9- YF-S201 Hall Effect Water Flow Sensor

4 WIRING AND INTEGRATION OF SYSTEM COMPONENTS FOR AUTOMATED DAM GATE CONTROL USING PLC

Figure 2 shows the connection diagram for all the components and elements used to create the working model. The Programmable Logic Controller (PLC) appears as a basic unit for linking the different components of the model because it represents the programmed brain for controlling the dam.

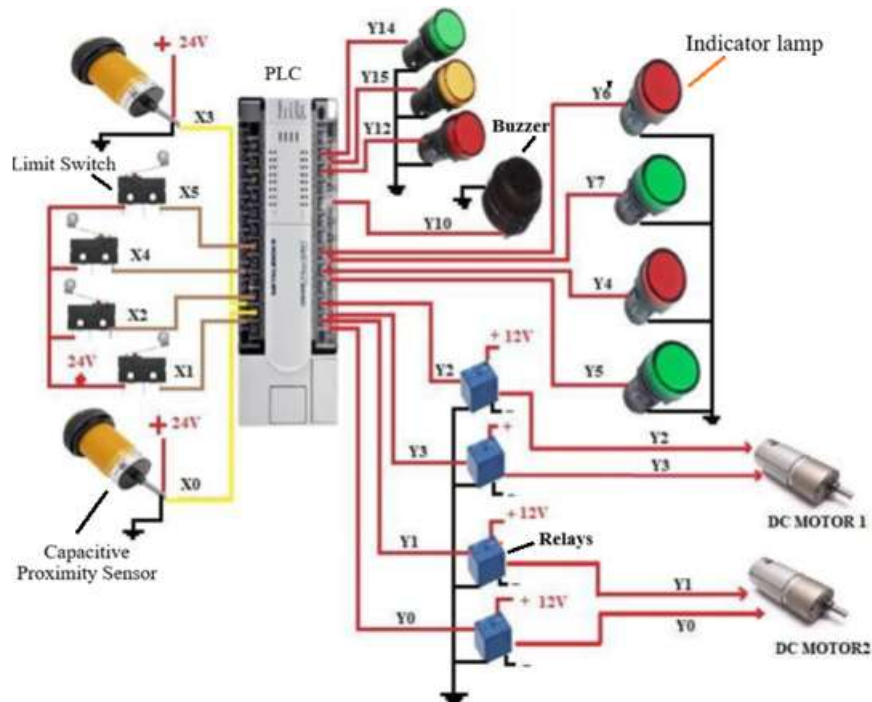


Figure 2: Connections of the basic components of the working model.

5 DAM STRUCTURE

Figure 3 shows the experimental dam structure made of acrylic, which is lightweight and shatter-resistant, making it the preferred choice for dam structures compared to plastic and glass.

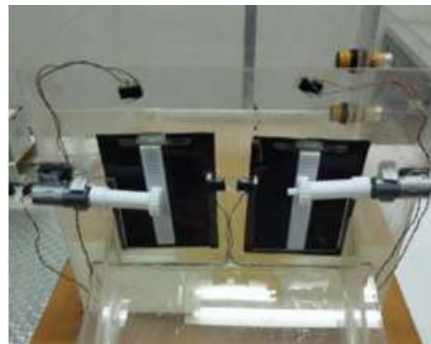


Figure 3: Shows the dam structure.

Figure 4 shows the actual dam model with the control system designed for its operation after construction is complete.

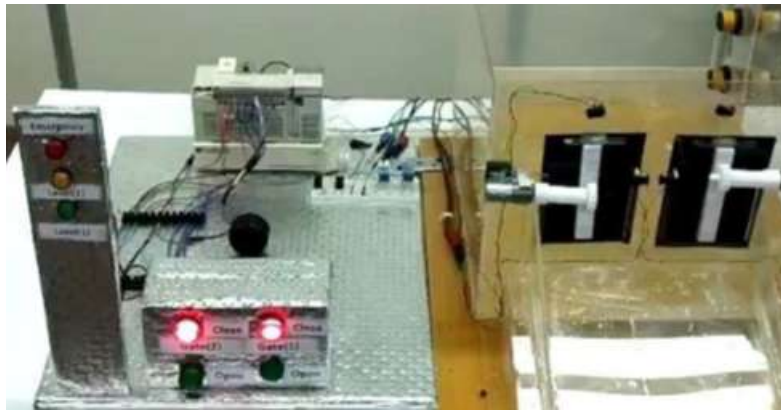


Figure 4: Final hardware configuration of the system.

6 SIGNAL FLOW GRAPH

Figure 5 shows the signal flow graph for the operation of the dam control system using a PLC.

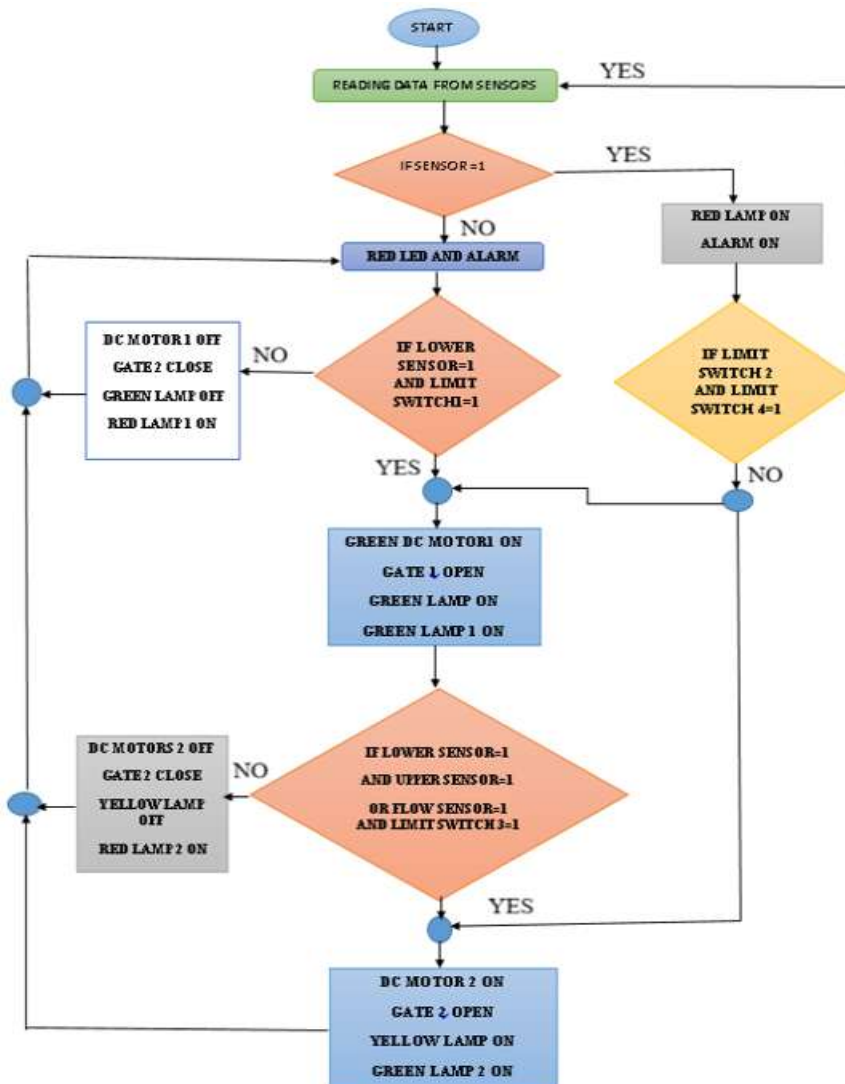


Figure 5: System Operation Flow graph.

The system starts when it receives a signal from the lower sensor, indicating that the water level in the dam has reached the first level. The PLC then activates the first motor, which

opens the gate. In the first scenario, when the water level reaches the upper sensor, the sensor sends a signal to the PLC, which then activates the second motor, opening the second gate for assistance. The first gate is for water discharge. The PLC also activates the alarm and a red indicator light to show the water level in the dam. In the third scenario, an emergency, when the flow sensor located in the water flow path of the dam sends a signal to the PLC, indicating a strong water flow approaching the dam, the PLC activates both motors simultaneously to open both gates before the water reaches the dam, thus mitigating the risk of a strong water flow. The programmable logic controller (PLC) also activates the alarm in this case to alert the user to the danger.

7 TEST AND EXPERIMENTAL RESULTS

During the testing and simulation phases of the system's operation, the most important operational steps are presented in the following paragraphs and figures.

As shown in Figure 6, the PLC ladder diagram must be simulated to verify the success of the dam management.

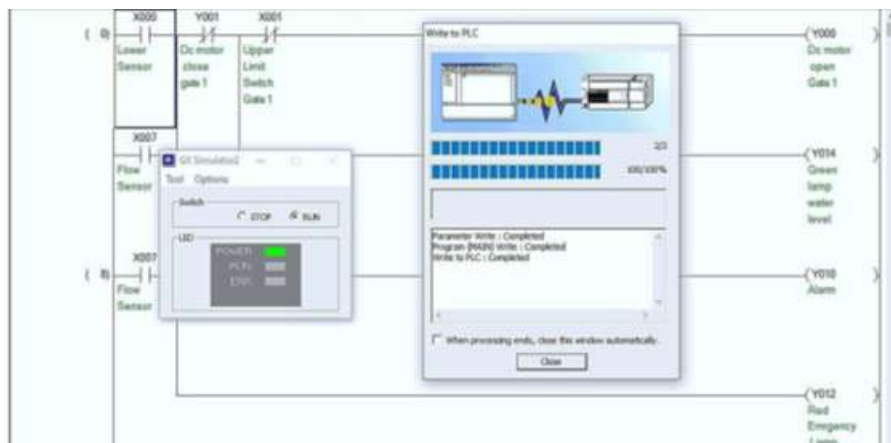


Figure 6: program running for the start of the simulation.

Figure 7 shows the state of the system before the water level reaches the lower sensor X0. We can see that both gates are closed, and the red lights Y5 and Y7 are lit.

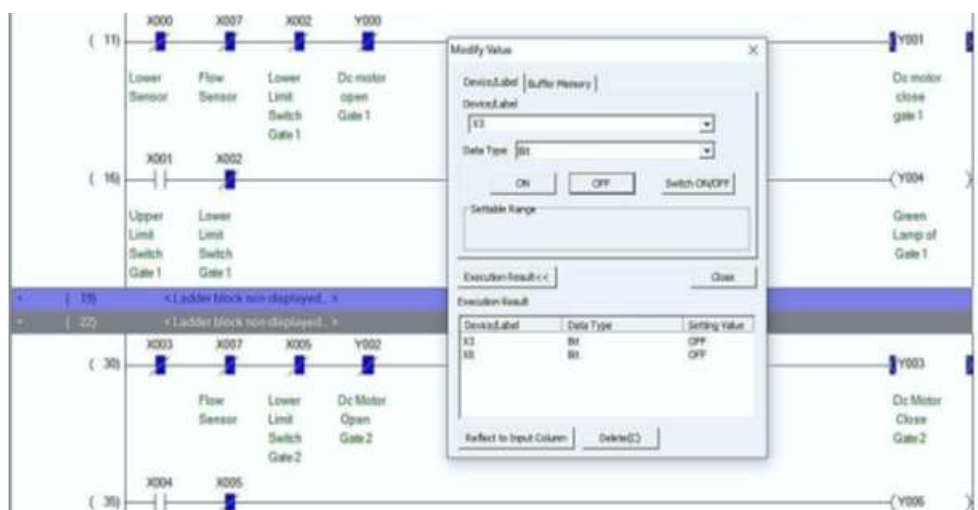


Figure 7: The state of the system before water reaches the lower sensor.

Figure 8 shows that when the water reaches the lower sensor X0, it sends a signal to the programmable logic controller (PLC), which starts the DC motor Y0 to open the gate and activates the green light Y14, which indicates the water level status in the dam.

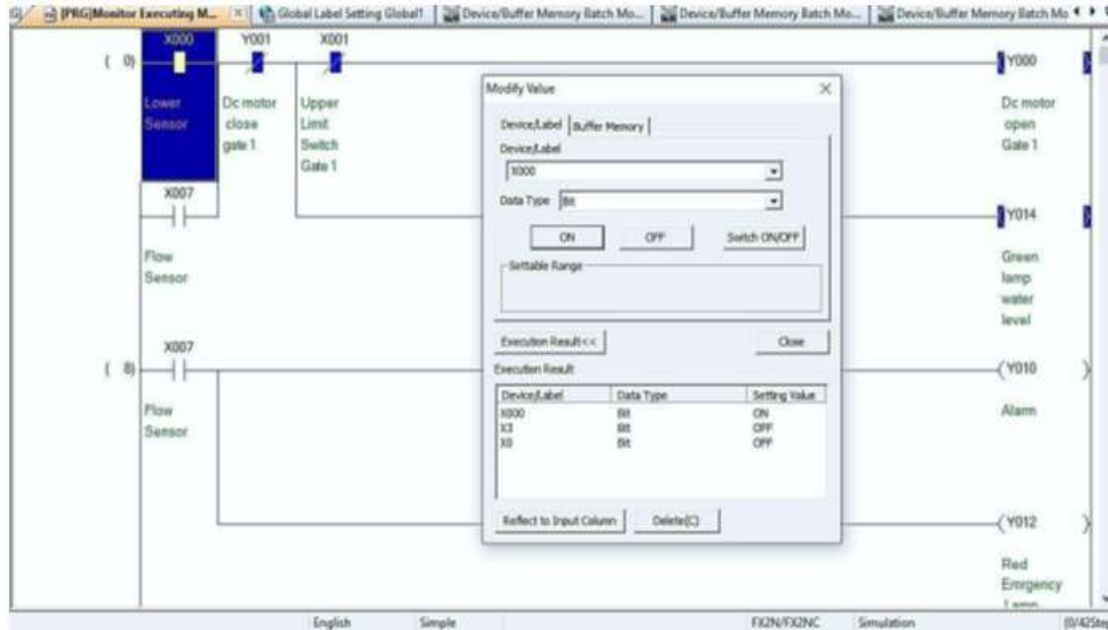


Figure 8: The state of the system when water reaches the lower sensor.

When the first gate reaches the upper limit switch X1, it sends a signal to the PLC to stop the DC motor Y0 and turn on the green lamp Y4, which indicates that the gate is in the open state. As shown in Figure 9.

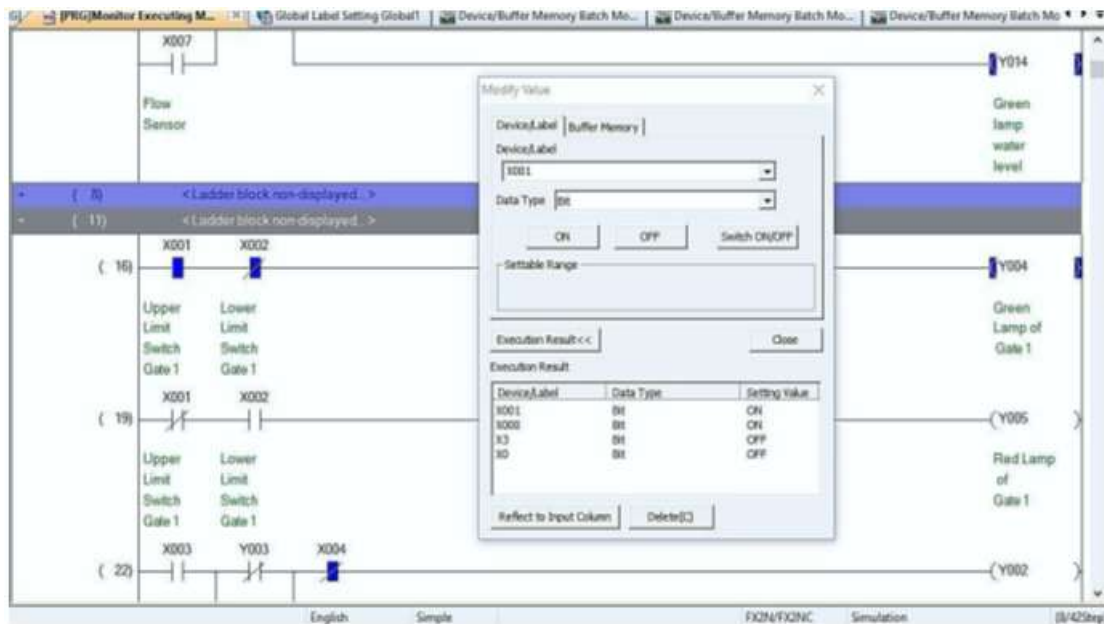


Figure 9: The system when the first gate is open.

Figure 10 shows that when the water level drops below the lower sensor X0, it sends a signal to the programmable logic controller (PLC) to give an order to the DC motor to rotate in the opposite direction Y1 to close the first gate.

And in Figure 11, when the DC motor Y1 closes the first gate and when the gate reaches the lower limit switch X2, it sends a signal to the programmable logic controller (PLC) to stop the motor and turn on the red lamp Y5, indicating that the gate is in the closed position.

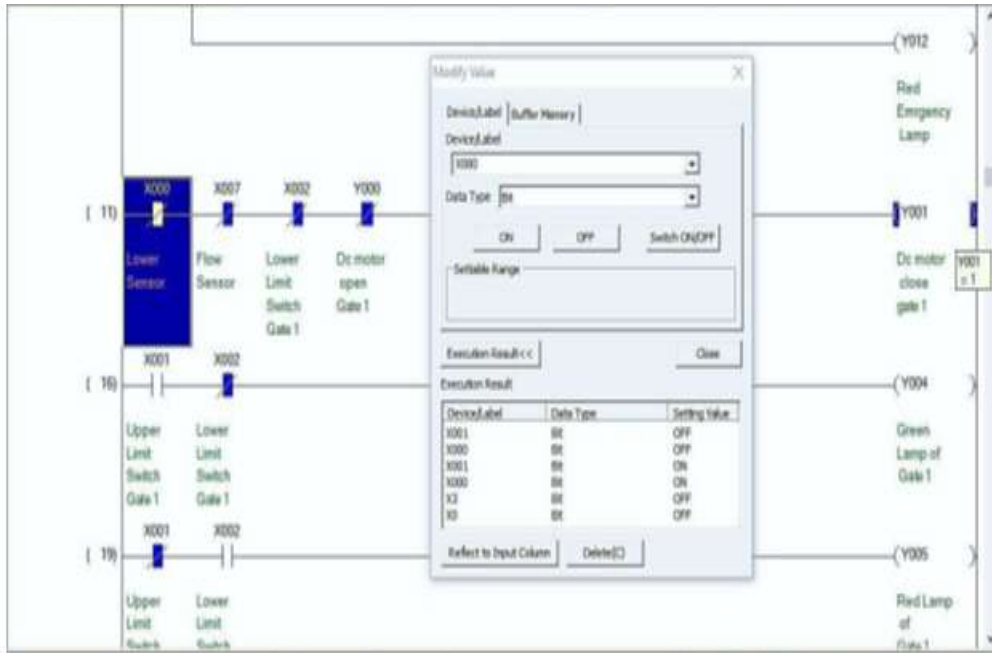


Figure 10: The motor rotates in the opposite direction to close the first gate.

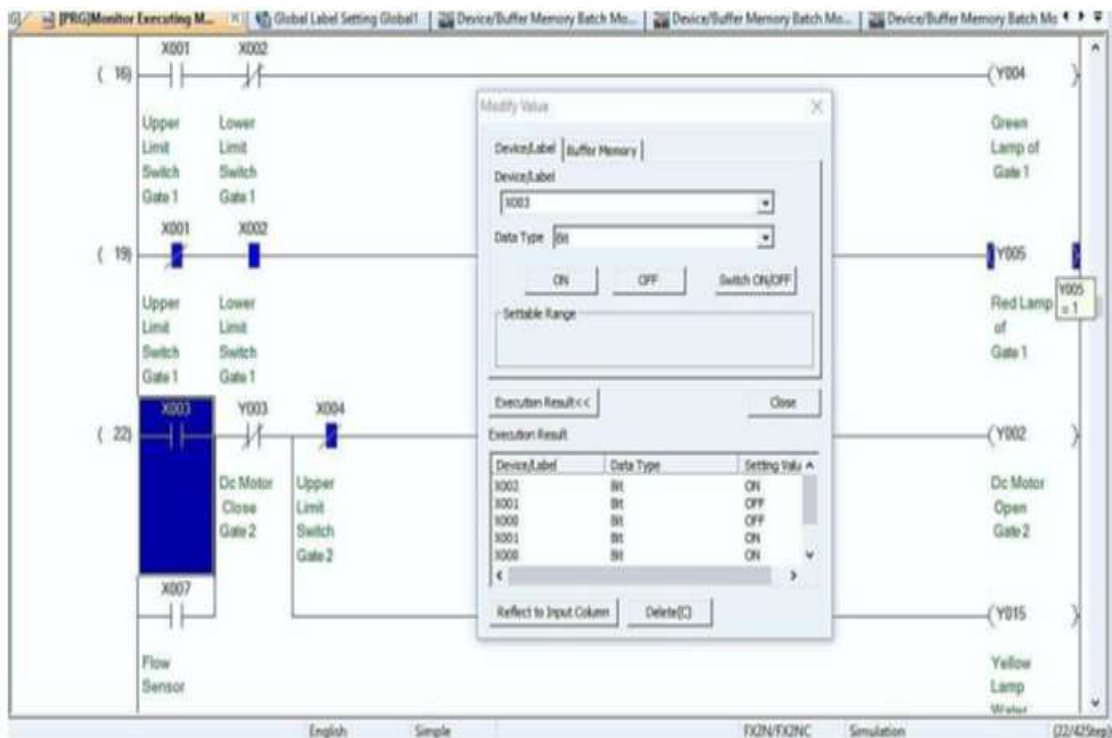


Figure 11: System when the first gate is closed.

In Figure 12, when the water reaches the upper sensor X3, it sends a signal to the programmable logic controller (PLC), which starts the DC motor Y2 to open the gate and lights up the yellow light Y15, which indicates the water level status in the dam.

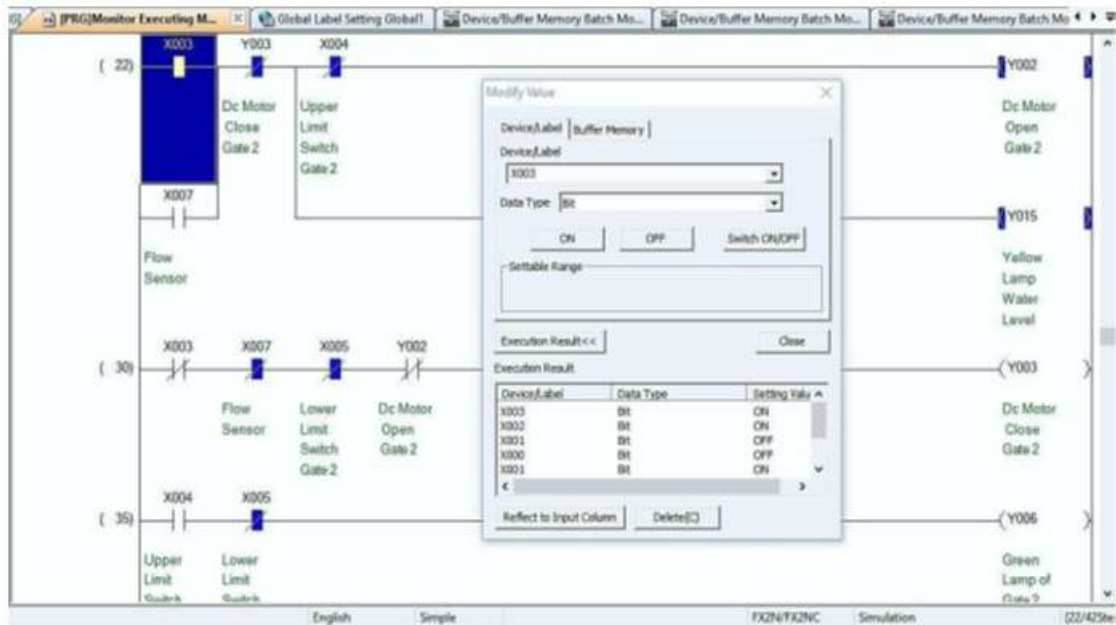


Figure 12: The system when water reaches the upper sensor.

In Figure 13, when the second gate reaches the upper limit switch X4, it sends a signal to the PLC to stop the dc motor Y2 and turn on the green lamp Y6, which indicates that gate two is in the open state.

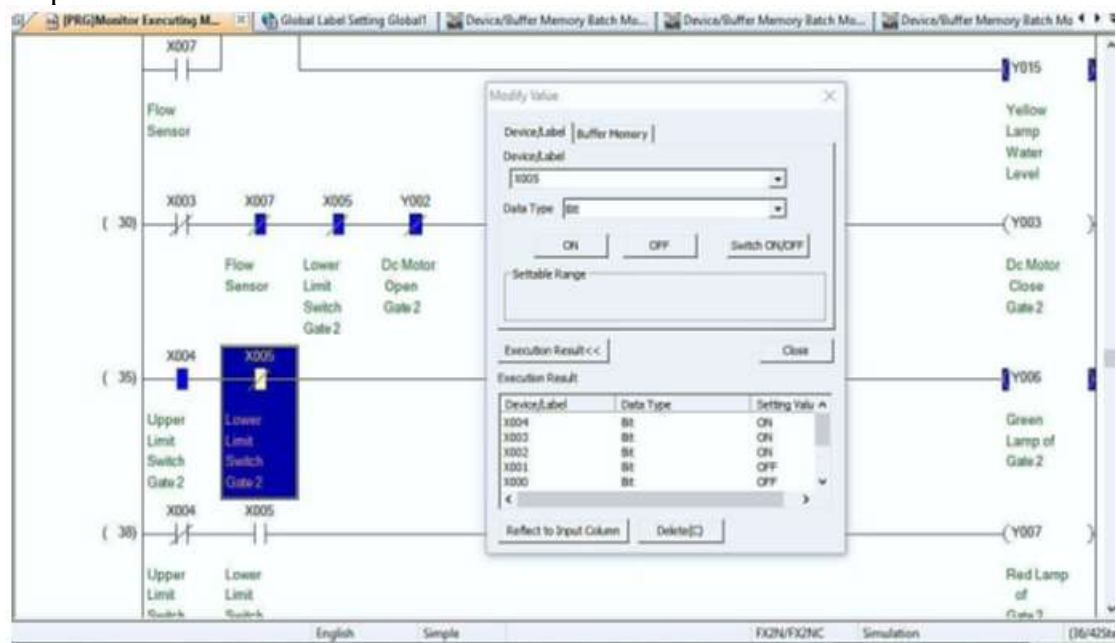


Figure 13: System when the second gate is open.

In Figure 14, when the water level drops below the upper sensor X3, it sends a signal to the programmable logic controller (PLC) to give the rotation command to the DC motor to rotate in the opposite direction Y3 to close the second gate.

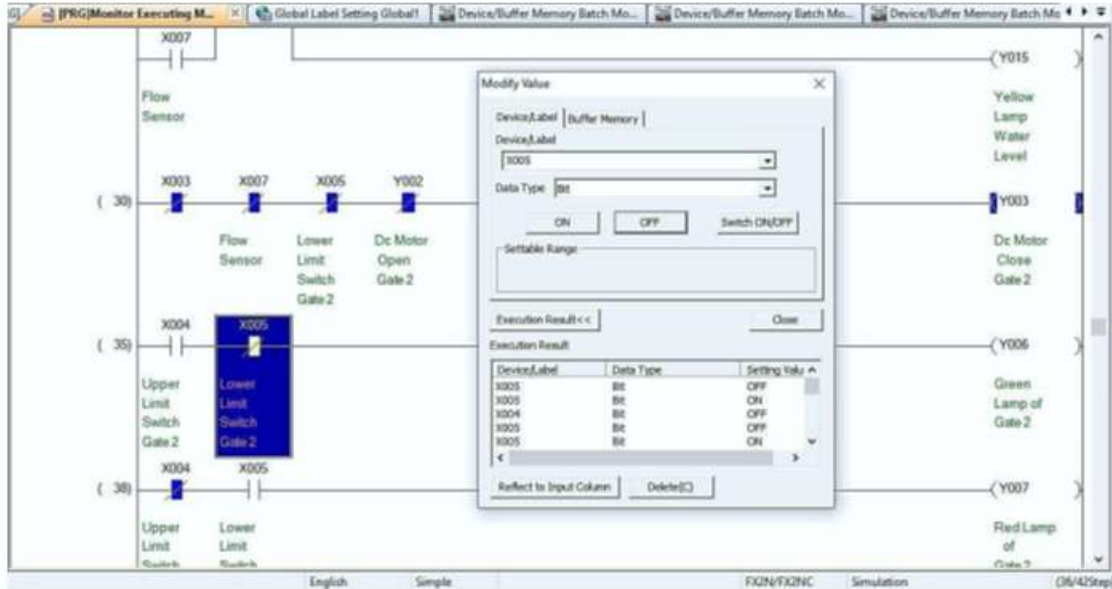


Figure 14: shows the state of the motor when it rotates in the opposite direction to close the second gate.

In Figure 15, when the DC motor Y3 closes the second gate and when the gate reaches the lower limit switch X5, it sends a signal to the PLC to stop the motor and turn on the red lamp Y7, which indicates that the second gate is in the closed state.

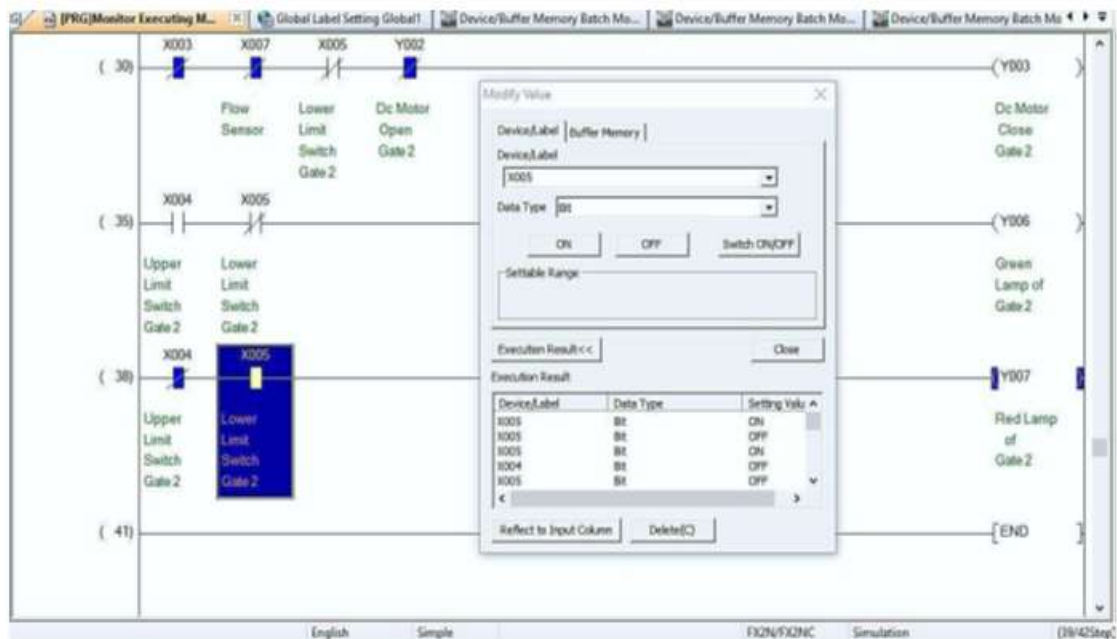


Figure 15 shows the state of the system when the second gate is closed.

In Figure 16, when the flow rate sensor X7 senses the force of the water flowing towards the dam, it sends a signal to the programmable logic controller (PLC) to issue operating commands to both motors to open the gates simultaneously. It also activates alarm Y10 and illuminates the red indicator light Y12 to signal an emergency.

The dam control system, operated by a programmable logic controller (PLC), detects faults and triggers an alarm if one of the motors stops working. The process is as follows: When the lower sensor sends a signal to the PLC, a 7-second timer starts. If the first motor does not operate in the open or closed position before the timer expires, the alarm is triggered. Figure 17 shows that the first motor has stopped working.

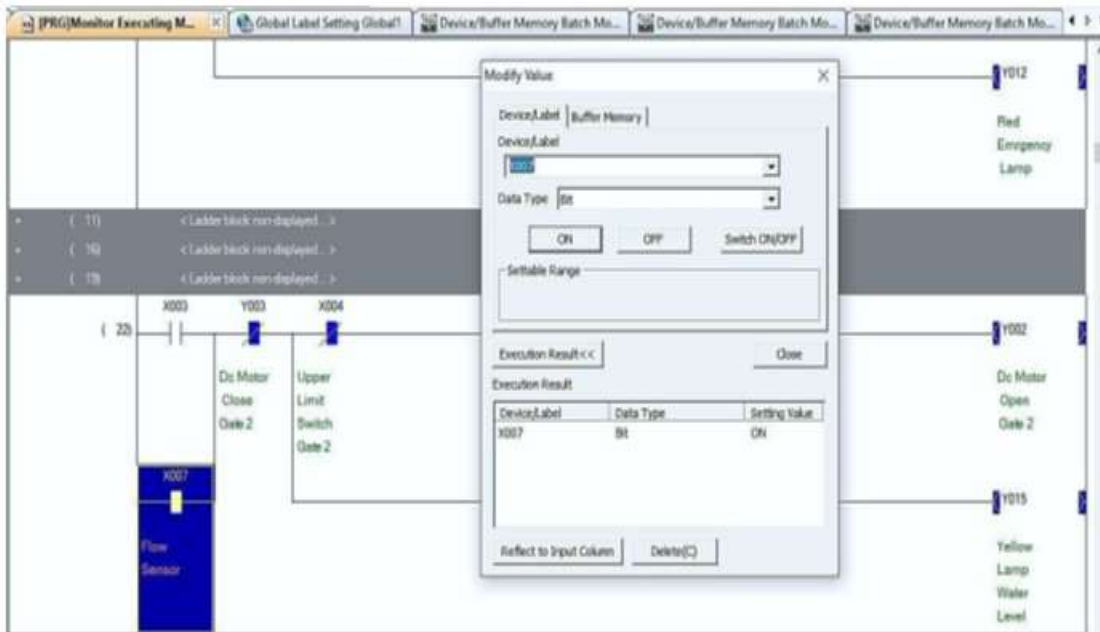


Figure 16: system when it is in an emergency state.

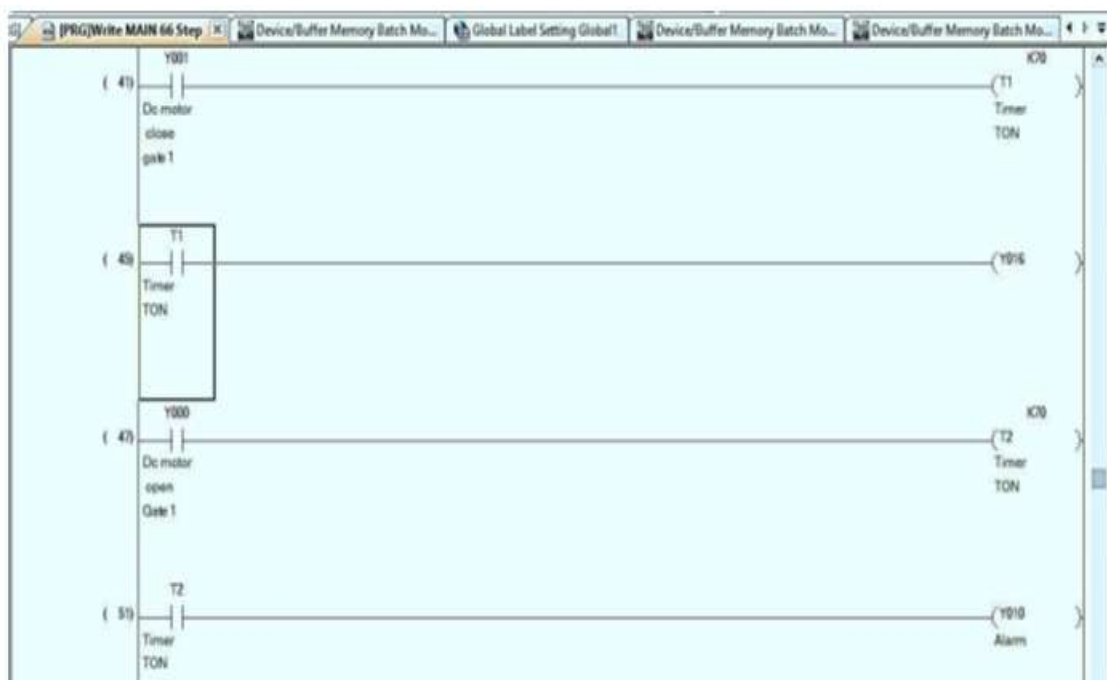


Figure 17 shows the state of the system when motor 1 does not work.

The second motor is also tested for malfunctions, specifically to check if it is not rotating. When the upper sensor sends a signal to the programmable logic controller (PLC), a 7-second timer starts. If the second motor does not engage in the open or closed position before this time expires, an alarm is triggered. Figure 18 shows that motor 2 is not in operation.



Figure 18: shows the state of the system when motor 2 does not work.

8 SYSTEM OPERATION

In this section, we explain the system's response to PLC commands for each stage of the practical design, including illustrative images for each stage.

8.1 Stage 1

Figures 19, 20 and 21 illustrate the status of the dam gates, operating lights, and alarms before the sensors detect water levels. At this stage, before the water level reaches the lower sensor X0, the lower limit switch X2 of the first gate sends a signal to the programmable logic controller (PLC) to activate the red indicator light Y5, indicating that the first gate is closed.



Figure 19: gates in stage 1.

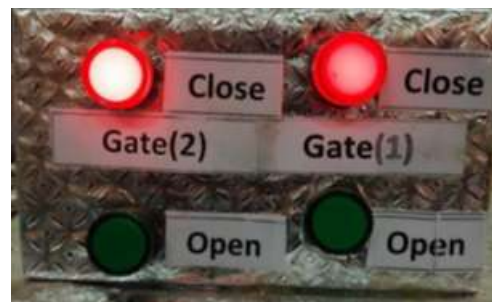


Figure 20: red lamps indicator.

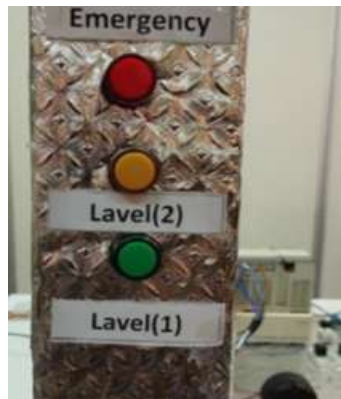


Figure 21: indicator lamps off.

8.2 Stage 2

In this stage, before the water level reaches the lower sensor X0, the lower limit switch X2 of the first gate sends a signal to the Programmable Logic Controller (PLC) to activate the red indicator light Y5, which indicates the gate's status, meaning the first gate is closed.

Once the water level reaches the lower sensor X0, it sends a signal to the PLC. The PLC activates a green light, Y14, to indicate the water level in the tank and also activates the motor, Y0, connected to the first gate to open it until the desired level is reached. Upon reaching this level, the upper limit switch X1 sends a signal to the PLC to stop the motor and activate the green indicator light Y4, which indicates the gate is open.

In Figures 22 and 23, the green light indicates that the first gate is open, while the red light indicates that the second gate remains closed.

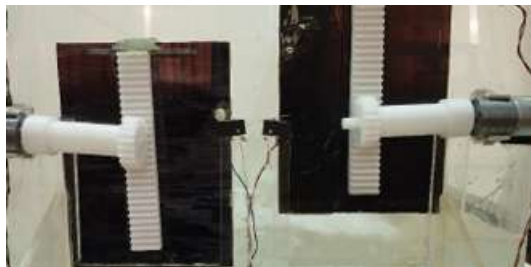


Figure 22: Opening the first gate.



Figure 23: indicator lamps for stage 2.

In Figure 24, the green light on the water level gauge panel indicates that the water level has reached the sensor's minimum threshold. The green color was chosen to indicate that there is no danger at the current level.



Figure 24: green indicator for reaching level 1

8.3 Stage 3

In this stage, before the water level reaches the upper sensor X3, the lower limit switch X5 of the second gate sends a signal to the Programmable Logic Controller (PLC), activating the red indicator light Y7, which indicates the gate's status: the second gate is closed. Once the water level reaches the upper sensor X3, it sends a signal to the PLC. The PLC then activates the yellow light Y15 to indicate the water level in the reservoir and activates the motor connected to the second gate to open it until the desired level is reached.

As shown in Figure 4.26, the yellow light on the dam's water level indicator panel indicates that the water level has reached the upper sensor. The yellow color was chosen to indicate that the water level inside the dam is approaching the danger level.

Upon reaching this level, the upper limit switch X4 sends a signal to the PLC to stop the motor Y2 and activate the green indicator light Y6, which indicates the gates are open. Figure 4.26 shows that the yellow light on the dam's water level indicator panel indicates that the water level has reached the upper sensor. The color yellow was chosen to signify that the water level inside the dam is approaching the danger level.

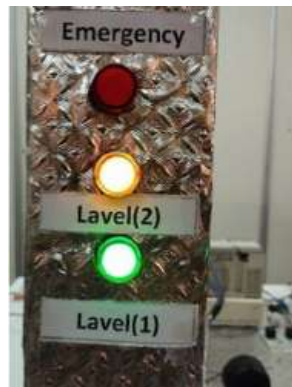


Figure 25: Level indicator lights 1 and 2 on at stage 3

When the water level in the dam reaches a level approaching danger, the upper limit switch X4 sends a signal to the programmable logic controller (PLC) to stop motor Y2 and activate the green indicator light Y6, which indicates the open gates, as shown in Figure 4.25.



Figure 26: Both gates are opened, and the indicating lamps are on.

8.4 Stage 4

This stage demonstrates how the emergency is activated upon receiving a signal from the flow rate sensor X7. Based on this signal, the programmable logic controller (PLC)

commands the two DC motors to operate simultaneously, opening both gates. It also activates the alarm device Y10 and the red light Y12 to indicate the emergency situation, as shown in Figure 27.



Figure 27: The state of the gates and indicating lamps at stage.

In Figure 28, the red light indicates that the water level in the dam has reached the danger or emergency stage.



Figure 28: level indicator lamps in the emergency state.

CONCLUSION

In this research paper, an automated dam gate system using a programmable logic controller (PLC) was implemented. The system operates automatically, taking into account several factors such as the reservoir water level, flow rate, and gate opening and closing speeds.

The system is designed to automate dam operation, control water flow and discharge, and eliminate the need for a large number of operators. A fully automated control system was successfully developed to manage the dam's discharge gates based on the reservoir water levels. Sensors monitor and measure water levels, and the data is then transmitted to the PLC. The PLC then issues commands to motors to open or close the gates according to a safe strategy for controlling water discharge and preventing flooding, thus protecting the population and surrounding areas from serious risks that could lead to death or property damage.

The automation of the dam's control and management system using a PLC proved to be effective and cost-efficient. The water level sensors proved their efficiency and accuracy in the research.

Finally, the system implemented in the practical part of the research achieved its intended objectives, demonstrating high effectiveness, accuracy, and efficiency in controlling the dam gates. The PLC automation system provides precise control to minimize human error and reduce manual intervention.

The system implemented in the research was also characterized by its ease of maintenance and control, and its low cost, making it a viable economic investment. Furthermore, it was easy to program and operate.

FUTURE WORK

The use of PLC makes the system cost-effective and easy to operate and maintain. Further extensions can be made to the system via:

- The system can be implemented on a SCADA computer to facilitate operations and control of the dam gates.
- Weather and satellite forecasts can be used to directly control gates and improve the system's response to unfavorable weather conditions.
- Integrating a system to send warning messages to the Civil Safety Authority centers to declare a state of emergency.
- Future work could focus on improving the energy efficiency of the dam's automated systems by incorporating renewable energy sources, such as solar panels or small hydroelectric turbines, to power the PLCs and related infrastructure. This would make the system more sustainable, reducing its environmental footprint.

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