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Water Distribution Control System Using Programmable Logic Controllers (PLC)

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Abstract – With the rapid advancement in industrial automation, water distribution control has become more critical than ever to ensure optimal utilization of water resources and minimize wastage. This study aims to design and implement an automated water distribution control system using Programmable Logic Controllers (PLC). The significance of this project lies in enhancing the efficiency of water distribution and ensuring continuous flow based on water levels in different reservoirs. The system relies on modern control technologies, whereby pumps and valves are operated automatically according to water levels and consumption patterns, thereby reducing human intervention and improving operational efficiency.

Automation Studio 5.0 software was employed to simulate the system prior to its physical implementation, testing various scenarios to ensure performance accuracy and energy efficiency. The results demonstrated the system's capability for intelligent water distribution control, effective fault management, as well as improved energy utilization and reduced operational failures.

Keywords – Automatic Control, Water Distribution, Programmable Logic Controllers (PLC), Industrial Automation, SCADA, Sensing Technologies

1. Introduction – The issue of water distribution is a critical challenge faced by many countries due to the increasing demand for water and climate change affecting natural water sources. With the growing need for intelligent systems in water resource management, automated control technologies have become essential tools for optimizing water distribution and reducing losses. Programmable Logic Controllers (PLC) are effective tools in industrial control systems, offering flexible and scalable solutions for operating water distribution networks efficiently.

This study aims to design and implement a PLC-based control system to enhance the management of water flow in distribution networks. The system will automatically monitor water levels in reservoirs and control the operation of pumps and valves according to consumer demand, thereby ensuring operational efficiency and sustainable use of water resources. Additionally, a SCADA system will be integrated for remote monitoring of system performance, facilitating improved operational efficiency and rapid fault management.

2. Research Methodology

2.1. System Components – The proposed system consists of the following components:

- **PLC** for controlling the operation of pumps and valves.
- **Water level sensors** for accurately monitoring the filling levels of reservoirs.
- **Pumps** for transferring water between reservoirs and different distribution lines.
- **Electric valves** for controlling water flow between sections.
- **Automation Studio 5.0 simulation software** for testing the system prior to physical implementation.
- **SCADA unit** for remote monitoring of system operation.

2.2. Operation Method – The system operates pumps based on the water levels within the reservoirs. When the first reservoir reaches its full capacity, the pumps start transferring water to the second reservoir. Subsequently, water distribution is managed through different pipelines according to consumption rates. The system employs a **feedback mechanism** to monitor pump performance and detect faults. Operational data are also transmitted to the SCADA system for performance analysis and to enhance operational efficiency.

3.2. System Overview – The project system consists of three main sections as follows:

1. **Section 1:** The first reservoir (**Tank 1**) is filled via a **Turnout Valve**, as illustrated in Figure 2-1.

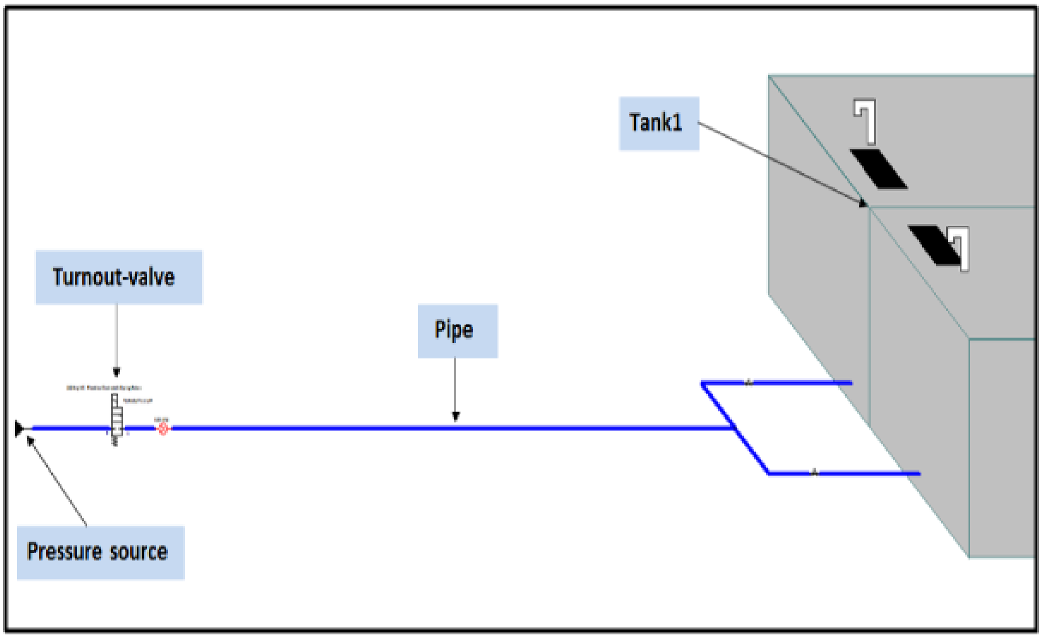

Figure 2-1: First Section of the System

2. **Section 2:** The second reservoir (**Tank 2**) is filled using the **Pump Station** from the first reservoir (**Tank 1**), as illustrated in Figure 2-2.

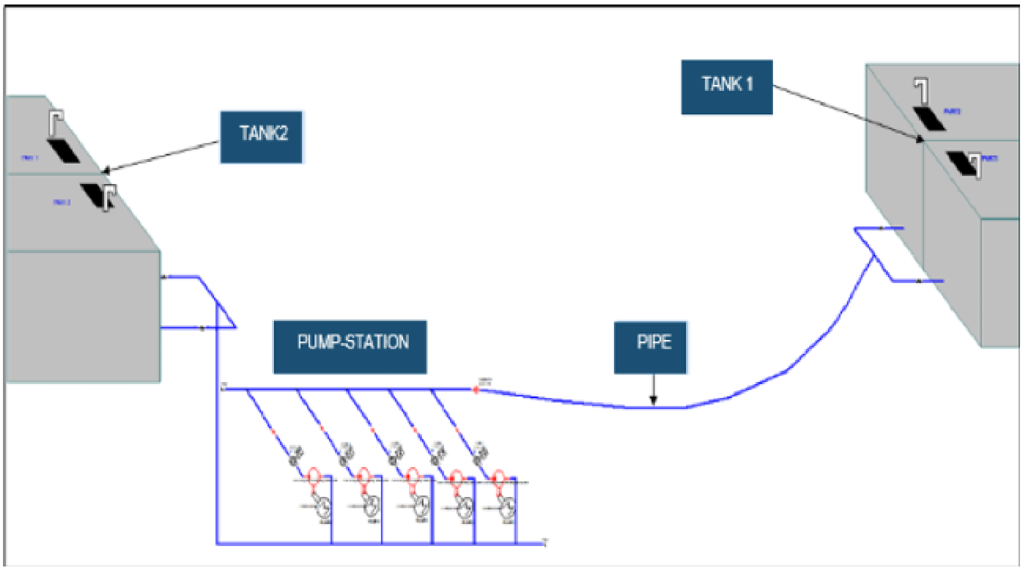

Figure 2-2: Filling of the Second Reservoir (**Tank 2**)

3. **Section 3:** Pipeline **1A** is supplied using the **Booster Pump Station**, while pipeline **1B** operates by **gravity flow** from the second reservoir (**Tank 2**), as illustrated in Figure 2-3.

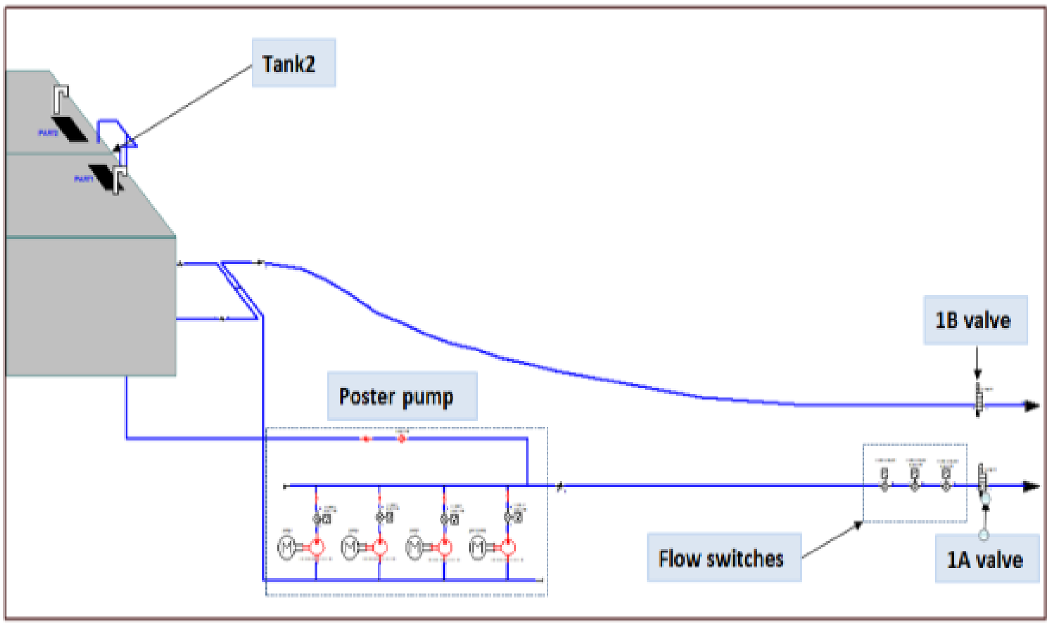

Figure 2-3: Supply of Pipelines **1A** and **1B**

Figure 2-4 illustrates the block diagram depicting the control process flow for the first and second controllers.

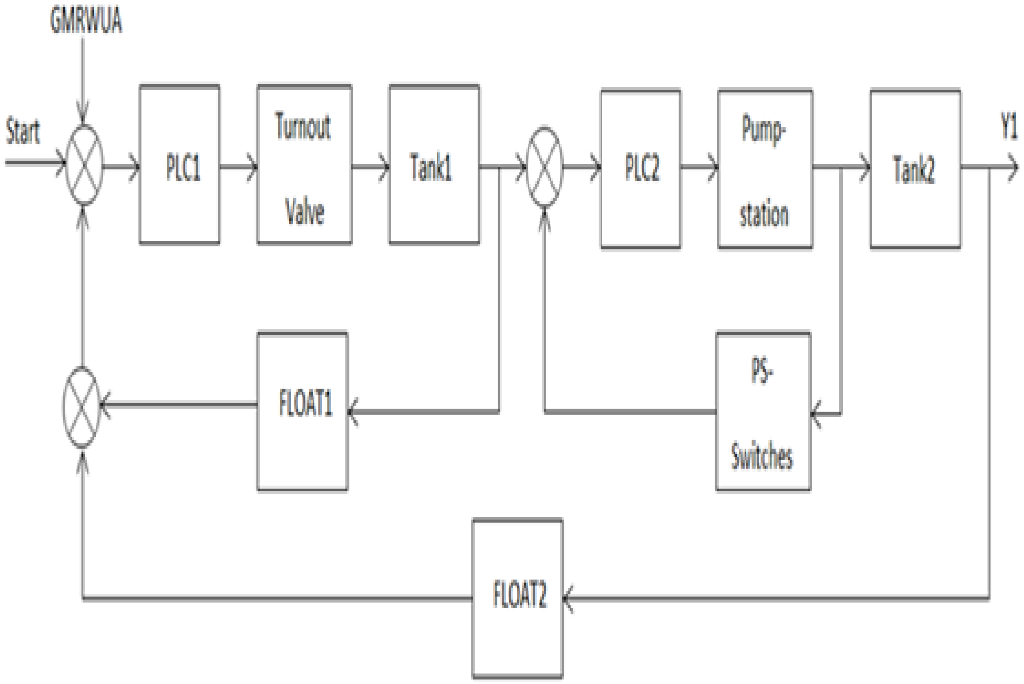

Figure 2-4: Block Diagram of Sections One and Two

The following block diagram illustrates the control sequence for the third controller.

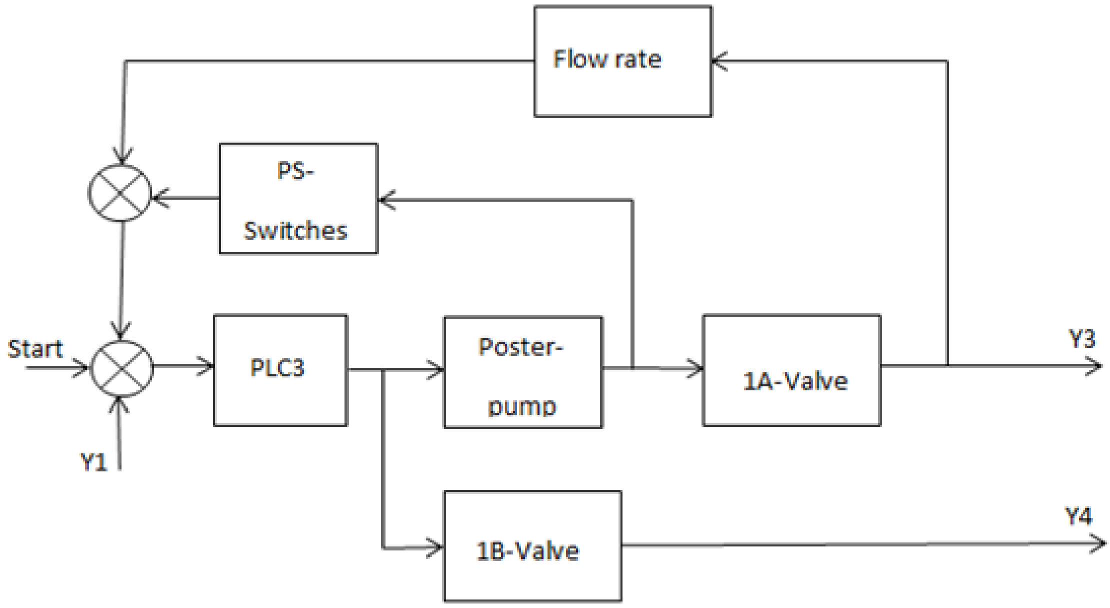

Figure 2-5: Block Diagram of Section Three

3. Experimentation and Results

3.1. System Simulation – The system was simulated using **Automation Studio 5.0** prior to practical implementation. Various scenarios for operating pumps and valves based on water levels were tested. The results demonstrated high control accuracy, as well as improved energy efficiency and reduced operational costs. Block diagrams and illustrative figures were also used to better understand the control processes.

2.3. Actual System Performance – Following the practical implementation, the results demonstrated the system's capability to:

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- Maintain stable water levels in the reservoirs.
- Automatically operate pumps according to demand.
- Detect faults and automatically replace malfunctioning pumps.
- Improve distribution efficiency compared to conventional systems.
- Monitor the system remotely via **SCADA**.

3.3. Overall System Layout

Figure 3-1: Overall Layout of the Water Distribution Control System

2.3.3. System Operation – The following provides a brief overview of the practical control process of the system:

1. **Opening the Turnout Valve** to fill the first reservoir (**Tank 1**), as shown in Figure 3-2.

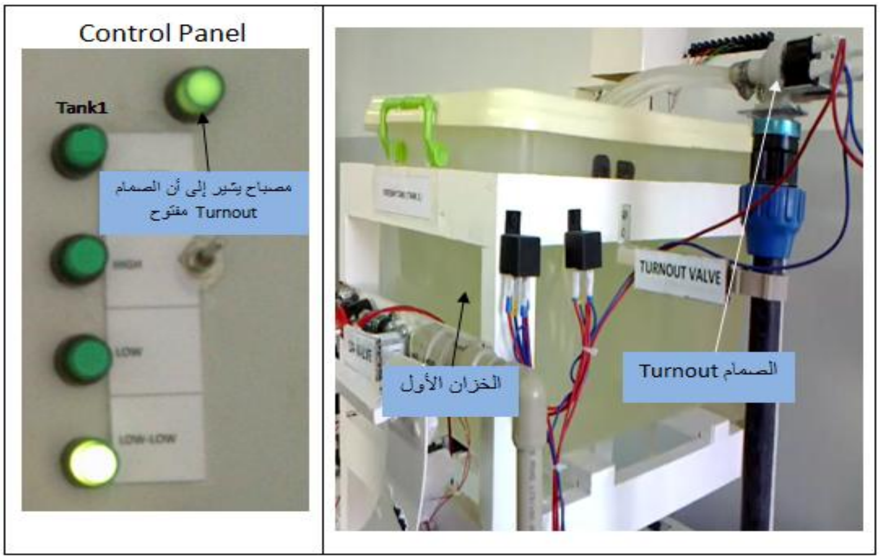

Figure 3-2: Filling of **Tank 1**

2. After **Tank 1** reaches full capacity, the **Pump Station** is activated. Since the second reservoir (**Tank 2**) is empty, three out of five pumps operate, as illustrated in Figure 3-3.

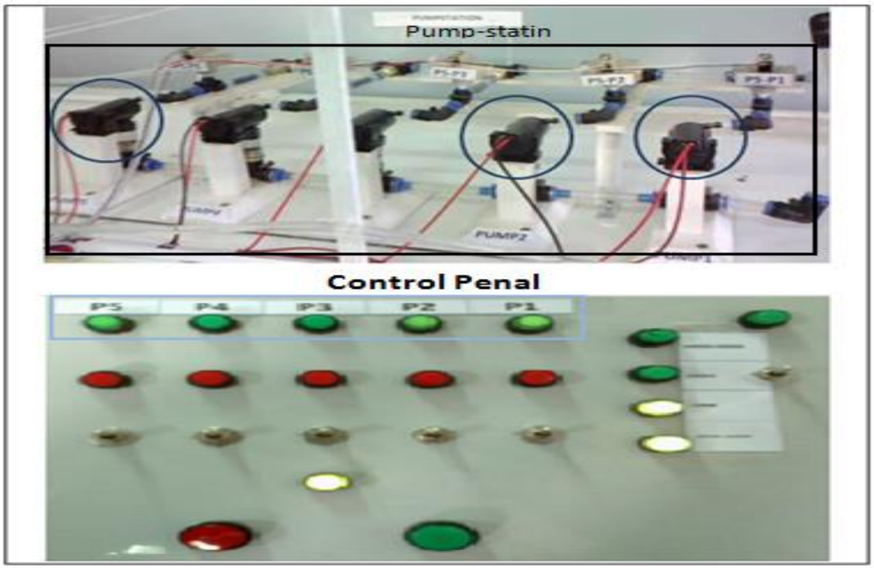

Figure 3-3: Operation of the **Pump Station**

3. When the water level in **Tank 2** reaches the **Low** level, one pump is turned off, and two pumps continue operating instead of three, as shown in Figure 3-4.

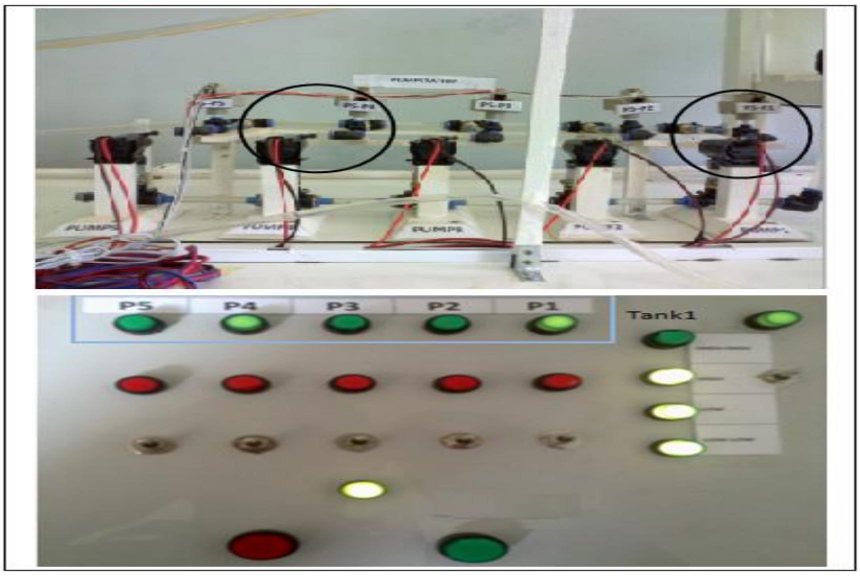

Figure 3-4: Pump Shut-Off

4. When the water level in **Tank 2** reaches the **High** level, one pump is turned off, leaving only a single pump in operation, as illustrated in Figure 3-5.

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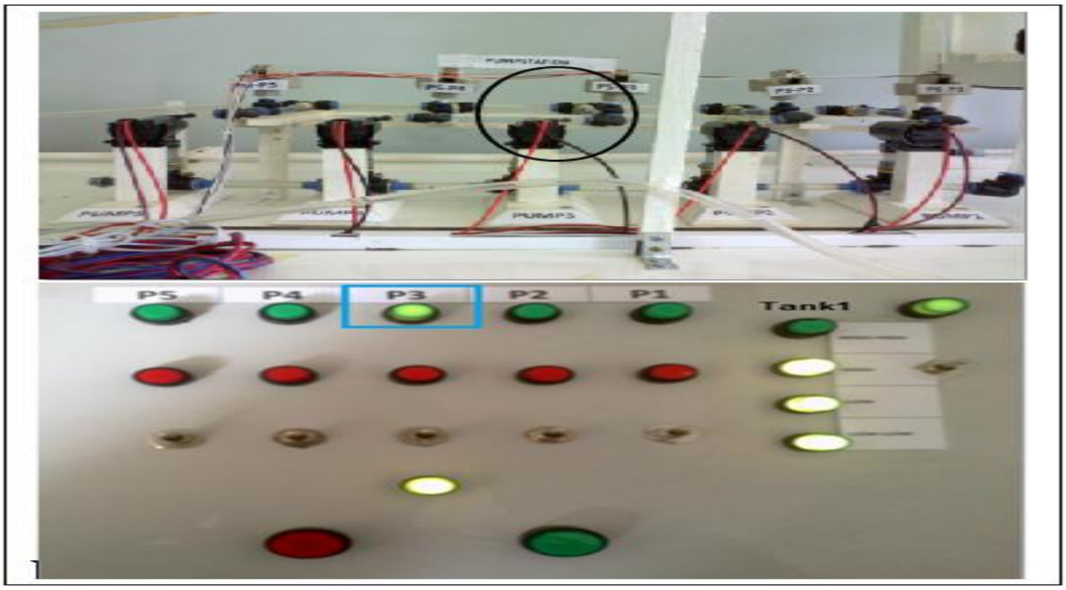

Figure 3-5: Pump Shut-Off

5. When the water level in **Tank 2** reaches the **High-High** level, all pumps are shut off, as shown in Figure 3-6.

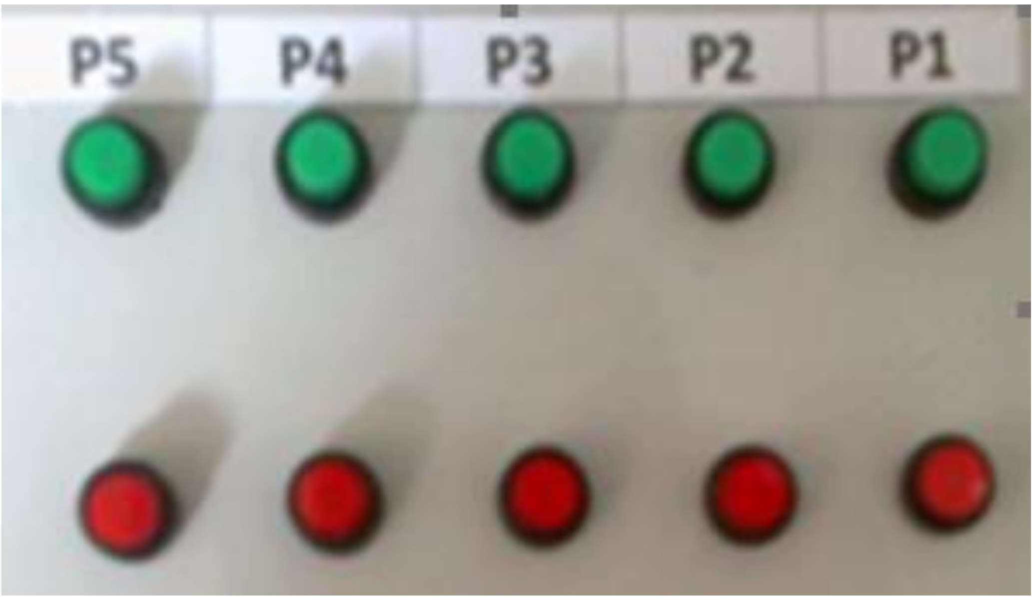

Figure 3-6: All Main Pumps Shut Off

6. When the second reservoir (**Tank 2**) is filled, the first controller (**PLC1**) sends a signal to enable opening one of the valves **1A** or **1B** by the third controller (**PLC3**). In this case, valve **1B** was opened, as illustrated in Figure 3-7.

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Figure 3-7: Opening of Valve **1B**

7. When valve **1A** is opened, the **Booster Pump** system is activated, starting with the **Jockey Pump** to fill the pipeline, as shown in Figure 3-8. It should be noted that this pump operates continuously during the valve opening as long as the consumption rate remains low.

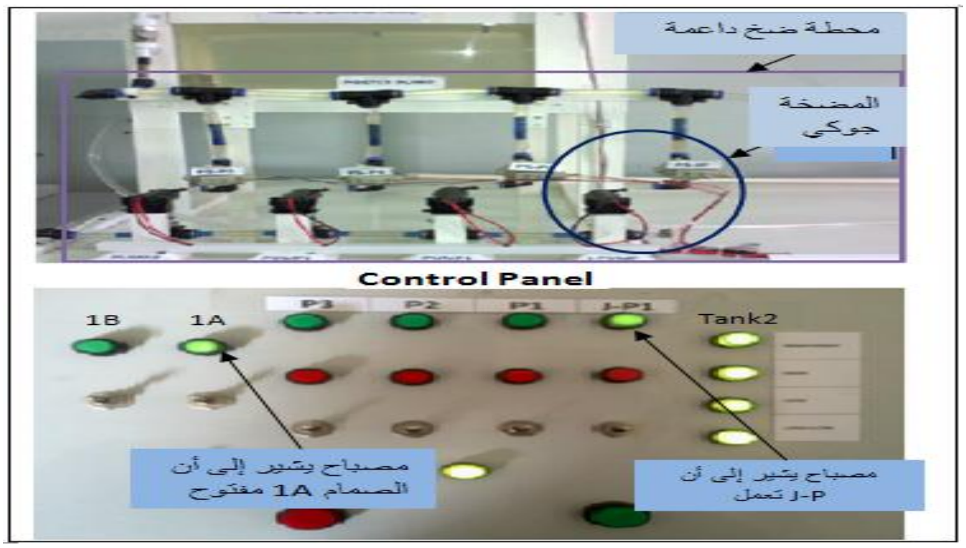

Figure 3-8: Operation of the Booster Pump (Poster-Pump) System

8. When the **flow rate** reaches a medium level, one of the three booster pumps operates, and the **Jockey Pump** is shut off, as illustrated in Figure 3-9.

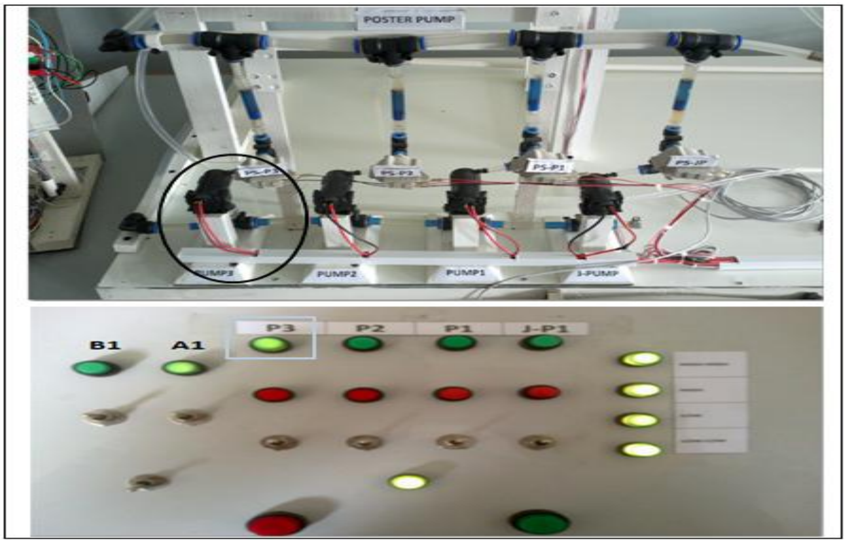

Figure 3-9: Jockey Pump Shut Off and One of the Three Booster Pumps Operating

When the **flow rate** exceeds the medium level, two out of the three booster pumps operate, as shown in Figure 3-10, with the first pump (**P1**) and the third pump (**P3**) in operation.

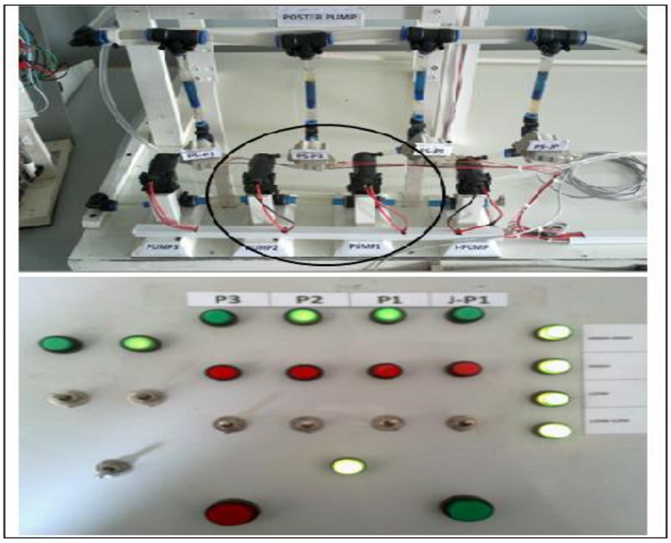

Figure 3-10: Two Out of Three Booster Pumps Operating

9. In the event of a pump malfunction, indicators on the control panel turn **red** to signal the faulty pump, as shown in the figure.

Figure 3-11: Pump Malfunction Occurred

4. Conclusions and Recommendations

4.1. Conclusions – Through the implementation of this project, several important conclusions were drawn, confirming the effectiveness of the system in controlling water distribution. The key findings include:

1. The system provides precise and efficient control over water distribution, contributing to reduced losses and improved operational efficiency.
2. It minimizes the need for human intervention, reducing the likelihood of operational errors and ensuring uninterrupted operation.
3. It allows for fault monitoring and rapid response to maintain continuous operation without affecting distribution processes.
4. Programming can be easily adjusted according to operational requirements, making the system more flexible and scalable for future developments.
5. The use of advanced sensing technologies enhances the system’s responsiveness to changes in water demand and ensures distribution according to actual needs.

4.2. Recommendations

1. It is recommended to use more **accurate analog sensors** for monitoring water levels in the reservoirs, providing continuously updated precise readings.
2. **Machine learning techniques** can be employed to analyze operational data and predict future water demand, helping to optimize distribution strategies.
3. The use of **renewable energy sources**, such as solar panels, is recommended for operating the pumps, reducing electricity consumption and enhancing system sustainability.
4. The system can be **expanded** to cover water distribution networks in smart cities and agricultural areas requiring automated irrigation systems.
5. It is recommended to **enhance the SCADA system** to include advanced data analysis and detailed performance reporting, facilitating more efficient operational decision-making.

6. **Cybersecurity measures** should be strengthened to protect the system against cyberattacks, ensuring the integrity of operational data and preventing unauthorized control of pumps and valves.

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