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Solar pumps automation system using programmable logic controller for pumped hydro storage

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ABSTRACT

Pumped hydro storage (PHS) is an energy storage technology that uses electrical energy to pump water to a higher reservoir. The water is then released back into the lower reservoir to generate electricity. If the water source is limited, the pump must be stopped to prevent damage. The automation system can improve the pump's performance and protect it from damage. Therefore, a Solar pumps automation system using a programmable logic controller for pumped hydro storage is developed to avoid damage due to overheating that can damage the pump. With this automation system, the pump will automatically stop working when no water flows. The automation system at PHS will use a programmable logic controller or PLC as the controller, with a water flow sensor and an ultrasonic sensor to measure water levels. Arduino will assist in reading the analogue input on the PLC. The research shows that all the sensors work well with an error under 0.4%. The pump will turn on when the water level is less than 30 cm, while the pump will turn off when the water flow is less than 20 liters/minute. The pump can flow water stably at a water flow value level of 25-26 liters/minute.

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1. INTRODUCTION

Climate change is a global problem that threatens sustainable development around the world. Human activities, such as burning fossil fuels and emitting greenhouse gases, are the main causes of climate change [1]. The Paris agreement is a binding agreement that requires all countries to work together to combat climate change and achieve net zero emissions (NZE) [2]. One way to do this is to transition away from fossil fuels, such as coal, and towards clean energy [3]. Indonesia has pledged to achieve NZE by 2060 , as outlined in its national contribution to the United Nations Framework Convention On Climate Change (UNFCCC) [4].

The transition from fossil fuels to renewable energy in response to the Paris Agreement triggered significant research efforts, including those related to energy storage systems [5]. Pumped hydro storage (PHS) is a way to store energy generated from renewable sources, such as solar and wind power. PHS is an energy storage technology that uses excess electrical energy from nature to pump water to a higher reservoir. The water is then can released back into the lower reservoir to generate electricity. It can store energy when there is a lot of supply and release it when there is a lot of demand. This can help to integrate renewable energy into the electrical grid and keep it stable [6]. PHS is more cost-effective than batteries for large-scale energy storage [7], [8]. Indonesia has a lot of potential for PHS development, with over 26,000 potential sites with a total energy storage capacity of 800 TWh [9].

Recent advancements have led to the developing of electrical energy storage systems using pumped hydro [10], [11]. Renewable energy systems (RES) are viewed as a sustainable option for nations facing challenges in meeting their power requirements due to their cleanliness, dependability, and cost-effectiveness in ongoing operations [12]. Recent works on solar-hydro stations cover the optimal sizing of a photovoltaic or PV station operating in a complementary manner with hydropower [13], [14]. In particular, the quick response of pumped hydro energy storage systems plays an essential role in case of the high share of renewable energy systems/RESs when balancing the demand and supply gap becomes a big challenge [15].

In PHS, the pump raises water to the upper reservoir when enough water is available. However, if the water source is limited, the pump must be stopped to prevent damage. To ensure that the pump operates reliably under all conditions, an automation system can be used to control it. The automation system can improve the pump's performance and protect it from damage. In previous study [16], PHS optimization has been carried out using fuzzy based controller on human machine interface or HMI automation for efficient energy management and storage. The control carried out is only to regulate the flow of water to work better and has not been able to maintain the system from damage. For this reason, in this research, an automation will be integrated in the PHS development in order to operate in safe conditions to avoid damage. The system is designed by considering the availability of water in lower reservoir and the speed of water flow.

Automation for system monitoring and control is increasingly and intensively used to simplify work and reduce labor requirements [17], [18]. This gave rise to the concept of programmable and manageable logic controllers. A popular device currently used for these needs is programmable logic controller (PLC). The use of PLC represents a method of implementing automation systems [19]. PLC operate as control devices based on logical principles, and are widely used in industry and various other sectors where automation systems are applied [20]–[22]. Therefore, a Solar pumps automation system using a programmable logic controller for pumped hydro storage is developed to avoid damage due to overheating that can damage the pump. With this automation system, the pump will automatically stop working when there is no water to flow.

2. METHOD

The pump, fundamentally a mechanical device, is designed to transport water from low pressure to high pressure regions or elevate it from lowlands to more considerable altitudes [18]. It functions on a basic principle: the machinery applies pressure and suction to the transferred fluid. Specifically, integral components reduce the chamber's pressure on the pump's suction side. This action induces a difference between the fluid's surface pressure and that of the pump chamber, facilitating fluid intake.

In the context of this study, the pump of interest is a solar-powered variant. Unlike conventional pumps, this device operates on a DC voltage derived from sunlight. Solar panels absorb this sunlight, converting it into energy, which is subsequently stored in batteries for later use. It's crucial to underscore the significance of the pump in this research, as it plays an instrumental role in circulating water, fostering efficient energy utilization and sustainable operations.

Turning our attention to the control aspect, we've opted for the Siemens S7-1200 CPU 1211C type AC/DC/RL PLC. Central to this study is the meticulous control over pump performance, ensuring seamless water circulation from the lower to the upper reservoir. The ultimate objective is ascertaining that the pump operates optimally and incorporates mechanisms to prevent potential damage. A noteworthy element in the system's design is the Arduino Uno, leveraged to interpret readings from the water flow sensor. Working in tandem with the Arduino and an integrated circuit, the sensor's data is converted into a 0-10 VDC voltage range, ideal for PLC input [23], [24].

The empirical phase involves activating the solar pump when the lower reservoir brims with water, given that specific conditions are met. The solar pump has been designed to halt automatically once another set of predetermined conditions is achieved. Data acquisition was primarily focused on the transition state of the solar pump its shift from 'on' to 'off'. Accurate data collection is very important regarding sensor readings during system operation [25].

In the analysis phase, every reading from the sensor during system operation is recorded to gain a deeper understanding of how certain variables affect pump performance. These variables include, but are not limited to, water flow rate, pressure at various points in the system, and PLC response time to changing conditions. Understanding the relationship between these variables will provide valuable information about how to improve the efficiency of the system in the future.

Interpretation of the data indicates that there are several key factors that affect optimal pump performance. For example, the speed at which a PLC responds to changes in sensor data may affect how quickly a pump can adapt its operation to changing conditions. In addition, the data may show how variations in sunlight intensity throughout the day affect the energy output of solar panels and, consequently, pump performance. Through this interpretation, this study provides recommendations for adjusting operational parameters and improving system design for future applications.

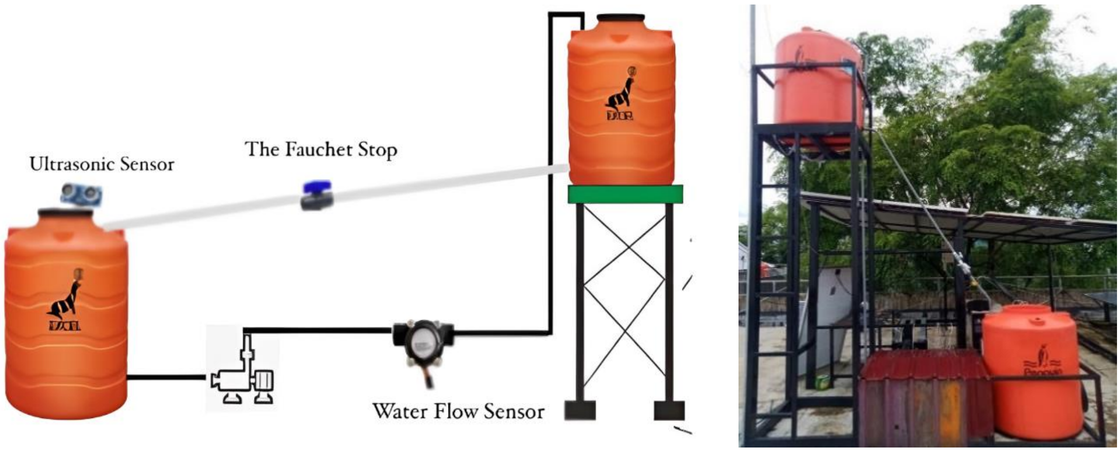
The working principle of this scheme is that the solar hydro pump will turn on when the ultrasonic sensor reads. The pump will run with the help of DC voltage sourced from the battery. When the pump is on, water will flow from the lower reservoir to the upper reservoir through the water flow sensor. The lower reservoir as a water source and the upper reservoir as a water reservoir works when the sensor detects the water level of the water surface with a small sensor of 30 cm.

The pump will turn on and drain the water when the indicator is met. When water flows through the water flow sensor, the sensor will read the value of the water flow. In this study, there is a condition that is when the water flow sensor reads a small water flow value of 20 liters/minute, the pump will stop working. The results of sensor readings using Arduino assistance will be a reference for analog input values on the PLC. Data from sensor readings will be changed with the help of the IC to form a voltage of 0-5 VDC. Analog input on the PLC in the form of the presence or absence of a given voltage. The IC input value will be processed at the PLC using the ladder diagram that is made. Automation systems are designed and work optimally by considering several factors, such as the type and efficiency of solar panels, the size and capacity of other renewable energy technologies, location and weather conditions, and energy storage capacity.

2.1. Solar hydro pump design

Solar hydro pump design is shown in Figure 1. The placement of the tool functions as shown in Figure 1(a) and the location of data collection shown in Figure 1(b). The tool consists of one lower reservoir as a water source and an upper reservoir as a water reservoir. Ultrasonic sensors are used to measure the water level in the lower reservoir. Faucet stop is used to stop water flow from the lower reservoir to the upper reservoir. The water flow sensor is used to measure water flow from the lower reservoir to the upper reservoir.

In automating the work of the solar hydro pump, it starts with reading the distance from the water surface to the sensor using an ultrasonic sensor. The pump will work when the small ultrasonic sensor reading value is equal to 30 cm. When these variables are met, the pump will turn on. If the variables are not met then a readout will be carried out again. Furthermore, when the solar hydro pump starts working, the water flow sensor will read the water flow value. The next condition is that when the small water flow sensor reading is equal to 20 liters/minute, the pump will turn off or not turn on. If the water flow sensor reading results have not been met, a reading will be carried out again.



(a) (b)

Figure 1. Pump hydro storage system (a) schematic of tool placement and (b) location of data collection

3. RESULTS AND DISCUSSION

3.1. Ultrasonic sensor testing

Ultrasonic sensor testing is carried out by uploading a program made to the Arduino software for distance reading to calculate the sensor's accuracy in detecting the height of the water surface in the reservoir. In testing, ultrasonic sensor readings were also carried out using another measuring instrument, namely a ruler. Table 1 shows the results of the sensor and ruler reading data. Based on the test results, it was carried out with 6 iterations with an average error value of 0.4 percent within reasonable limits. Thus, from the results obtained readings using ultrasonic sensors are appropriate.

Table 1. Ultrasonic sensor testing

No	Actual distance (cm)	Trial (cm)	Error (%)
1	5.5	5.58	1.4
2	10.2	10.31	1.07
3	15	15.02	0.13
4	20.8	20.84	0.19
5	25.2	25.22	0.07
6	29.4	29.41	0.03

3.2. Water flow sensor readings

Water flow sensor testing is done by comparing the sensor reading value with the water flow test results. Testing is done by calculating the time required by the pump to drain 500 liters of water. The water flow sensor works when there is flow through the sensor. Water flow sensor testing is done by uploading the program to Arduino IDE. The average flow rate as shown in (1).

$$\bar{x} = \frac{x_1 + x_2 \ldots + x_n}{n} = \frac{15208}{592} = 25.69 \quad (1)$$

From the results of the experiments carried out, the average water flow value read on the sensor was 25.69 liters/minute. In the test, the time required by the pump to drain 500 liters of water is 19.5 minutes so that the water flow is 25.64 liters/minute. Comparison between sensor readings and testing obtained an error of 0.19%. Therefore, it can be said that the sensor works well.

3.3. PLC testing

PLC testing is done by testing the ladder diagram that has been made before. Making ladder diagrams is done with the help of TIA Portal software. The ladder diagram will receive analog input from the IC and will be read in the program. Testing is carried out when input is received and not received. The ladder diagram will work and process the data into a digital output with a value of 1 and 0. Figure 2 shows TIA Portal software for program PLC with ladder diagram.

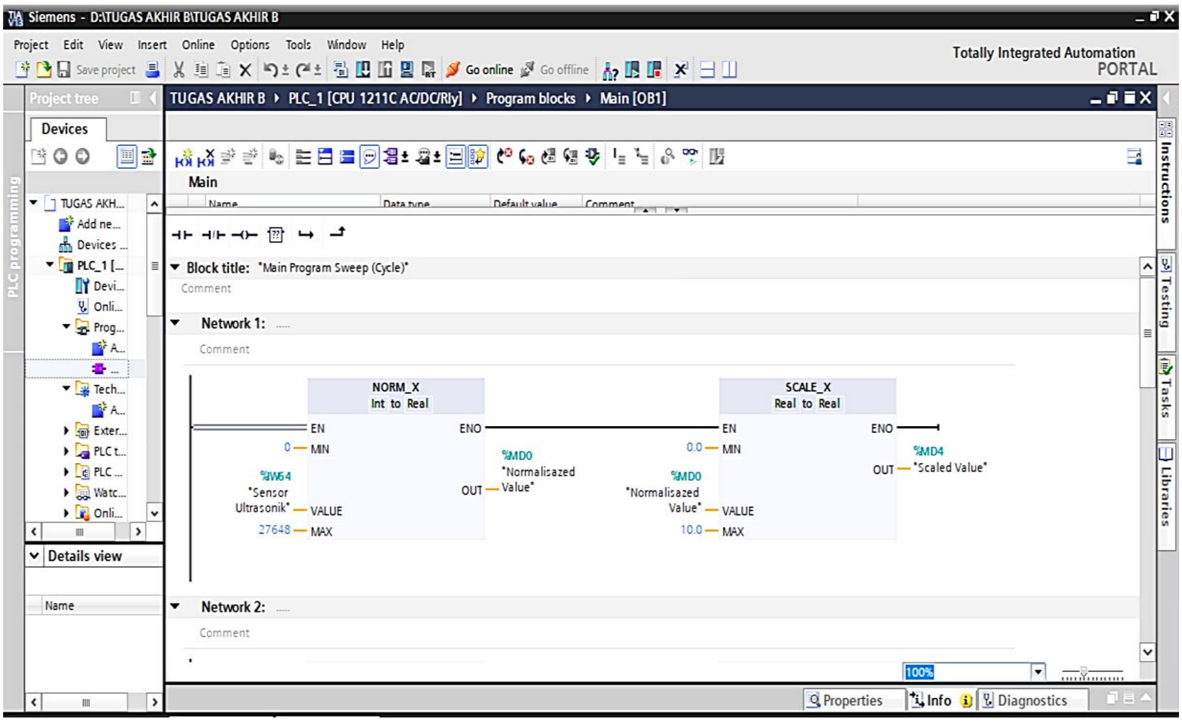


Figure 2. TIA Portal

3.4. L298N IC testing

L298N is DC motor driver module that is used to control the speed and direction of rotation of the DC motor. Testing the l298N IC was carried out measuring the value of the output voltage issued by the IC using a multimeter. Table 2 shows the explanation of the circuit pins.

The test is Carried out by looking at the output voltage, The IC outputs a voltage value in two different conditions. If the sensor reading value matches the program design, then the IC outputs a voltage, whereas if it has not been fulfilled then the IC does not output voltage. As seen in Figure 3 the performance of the IC is going well.

Table 2. Explanation of IC circuit pins

Component name	Initial pin	End pin	Information
IC L298N	VCC	VCC on the breadboard	Rated 5 V
	GND	GND on the breadboard	Polaris Negatif
	IN1	PIN 7 Arduino	Receive commands from Arduino
	IN2	PIN 3 Arduino	Receive commands from Arduino
	IN3	PIN 4 Arduino	Receive commands from Arduino
	IN4	PIN 6 Arduino	Receive commands from Arduino
	Out 1	PIN 0 analog input PLC	As analog input
	Out 2	PIN 2M analog input PLC	As analog input PLC
	Out 3	PIN 1 analog input PLC	As analog input PLC
	Out 4	PIN 2M analog input PLC	As analog input PLC

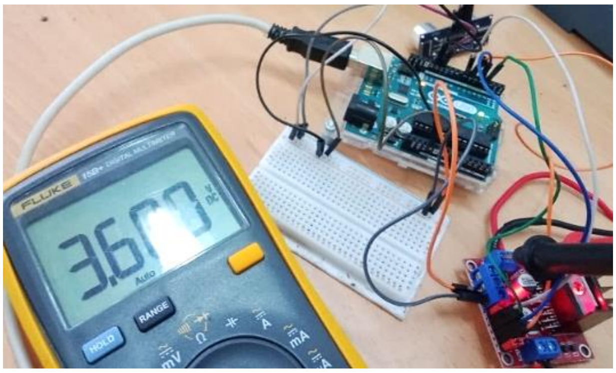


Figure 3. L298N IC experiment

3.5. Overall system testing

In the test, measurements of water level, water flow, PLC output, and ladder diagram testing were carried out. With a program on Arduino using the if command. The first if command is for ultrasonic sensor readings and for command input to the IC. Meanwhile, the second if command is for reading the waterflow sensor and the second input is for IC. In Figure 4 is a PLC ladder diagram that will be used in the system.

In the ladder diagram there are four networks, of which two networks are for reading analog inputs and two networks are for digital output. The first network is a ladder diagram for ultrasonic sensor readings, while the second network is for water flow sensor readings. Where the input is in the form of voltage to the PLC analog pin using IC L298N assistance. To use PLC analog input, the NORM and SCALE commands are used. This type of PLC can only accept a voltage of 0-10 V which will be converted into an integer of 0-27648. The input value received in the NORM command will be changed from an integer value to a real value. The real value obtained will be forwarded to the SCALE command, where the value obtained will be used as a reference for turning on the PLC digital output.

The third network is the network that receives the reading of the first analog input, namely the reading of the ultrasonic sensor. On the third network, when the reading value is equal to one, digital output 1 will turn on, and vice versa, if the value is not met, digital output 1 will not turn on. Furthermore, the fourth network is a network that receives the results of reading the second analog input, namely the results of reading the water flow sensor. When the received value is equal to 1, digital output 5 will turn on.

The data taken is the reading data of the ultrasonic sensor and water flow sensor when the system is running and the pump is flowing water from the lower reservoir to the upper reservoir. This data becomes a reference for the PLC to drive the relay. The graph in Figure 5 shows the readings of the two sensors.

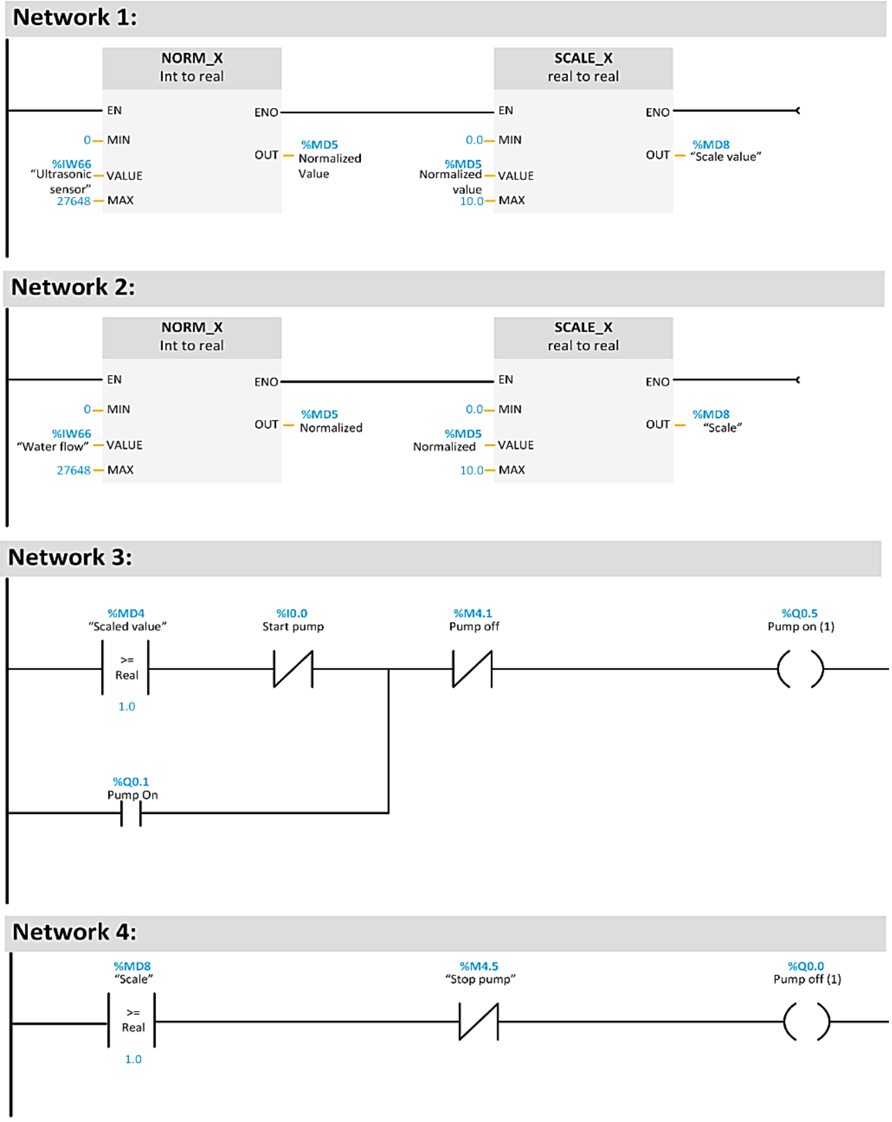


Figure 4. System ladder diagram

In this graph, it can be seen that the water pump works based on two sensors, namely an ultrasonic sensor to detect the height of the water surface and a water flow sensor to detect the speed of water flow. When the distance between the water surface and the sensor is less than 30 cm, the pump will turn on to flow water from the lower reservoir to the upper reservoir and otherwise the pump will stop working. Then based on the water flow, when the flow is less than 20 liters/minute (water from the reservoir starts to run out), the pump will stop working. The graph also shows that when the pump is not working, the water value is 0 liters/minute and bottom reservoir is filling.

In the test, when all the water from the lower reservoir has flowed into the upper reservoir, the water in the upper reservoir will flow back to the lower reservoir by opening the stop tap. In the graph, it can be seen that the value of the water flow is slowly decreasing, this indicates that the pump will stop working soon. In the graph in Figure 6 you can see the changes when the pump works, stops working and starts working again.

When the pump circulates water, the water flow sensor detects the presence of water flow. On the graph it can be seen that the water flow is stable in the range of 25-26 liters/minute. When the water level is 98 cm, you can see that the water flow continues to decrease, this indicates that the pump will stop working soon and when the flow value has been determined, the pump will stop working. Figures 6 and 7 are the results of ultrasonic sensor readings and water flow sensors against time.

The ultrasonic sensor reading results show the distance reading, the sensor reading results continue to increase, this indicates the pump is working. Furthermore, when the sensor reading begins to decrease, this indicates the pump has stopped working and the bottom reservoir is refilled with water. The results of the water flow sensor readings show that the water flow is flowing stably in a period of approximately 19 minutes once the pump is running, which shows that the pump is effective at flowing water. In this test the pump circulates approximately 500 liters of water. In the condition that the pump is flowing stable water at 25-26 liters/minute, the results of the water flow sensor readings can be said to be accurate.

At first, the water flow is zero but rapidly increases within seconds. After a while, the water flow stabilized at 25 liter, except for the last measurement, where it showed a small drop to 24. The distance initially remained at around 28.36, but there were small fluctuations in the range detected as time went on. There is a trend of increasing distance from 28.36 to 30.74 before dropping back to 29.96. Table 3 shows automation system test results in real time in two minutes.

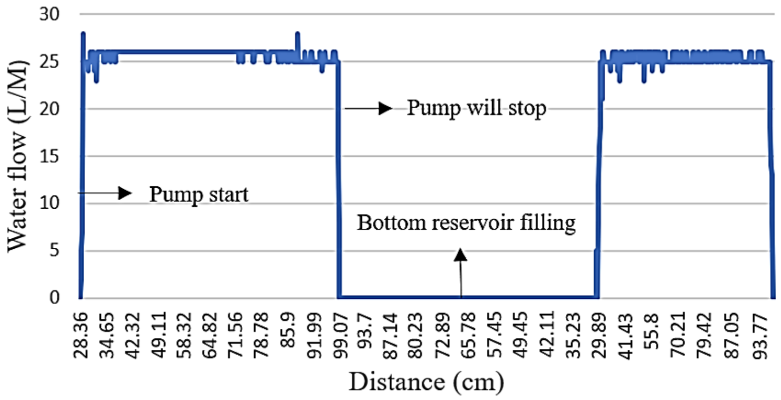


Figure 5. Graph of ultrasonic sensor and water flow sensor readings

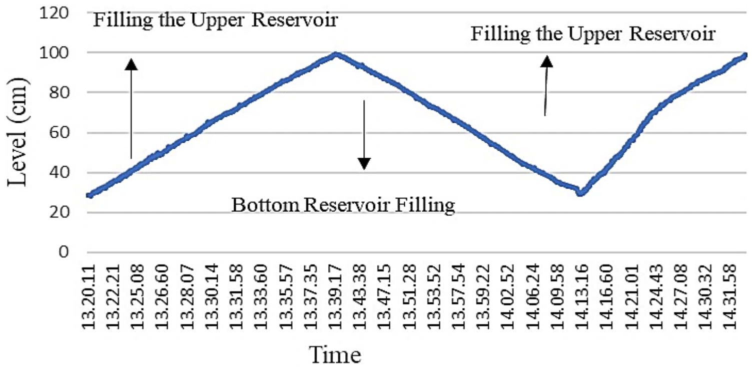


Figure 6. Graph of ultrasonic sensor readings

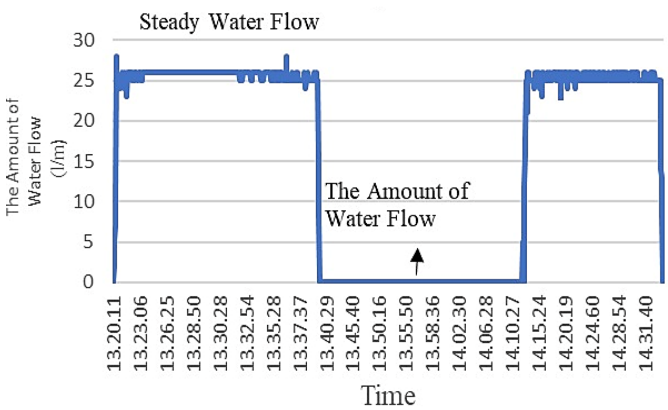


Figure 7. Graph of water flow sensor reading results

Table 3. Automation system test result

Time	Water Flow	Range	Time	Water Flow	Range
13.20.11	0	28.36	13.20.24	25	28.96
13.20.11	0	28.36	13.20.43.	25	29.01
13.20.13	2	28.36	13.20.46	25	30.21
13.20.14	5	28.38	13.20.51	25	29.96
13.20.16	7	28.36	13.20.52	25	29.7
13.20.18	10	28.38	13.20.57	25	30.23
13.20.20	13	28.07	13.20.60	25	30.74
13.20.22	18	28.65	13.21.05	24	29.96

4. CONCLUSION

The design of a solar pump automation system using a programmable logic controller for pumped hydro storage can work well and following the planning. This is obtained from a series of experiments. Experiments were carried out on each system component to the entire system. The first testing process is testing the program as a hardware configuration, such as sensors and ICs, which the microcontroller can read as input according to their respective functions. Second is the testing of ultrasonic and water flow sensors with water level parameters, and the water flow passing through the sensor can be read. The ultrasonic sensor works well with a sensor reading error of 0.4%. The water flow sensor works well, with a sensor reading error of 0.19%. Based on the research and testing conducted for this automation system, the results show that the system can turn the pump on and off based on the ultrasonic sensor reading parameters and the water flow sensor. The pump will work when the water level is less than 30 cm, while the pump will stop working when the water flow is less than 20 liters/minute. The pump can flow water stably at a water flow value level of 25-26 liters/minute. The pump will only turn on if there is excess power from the solar panels. When there is no water, motor protection aims to prevent the motor from overheating, and the motor will be activated again when the lower reservoir is filled.

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