Mekanika: Majalah Ilmiah Mekanika

Water Pump Control System using Pulse Width Modulation Method Based on Arduino Uno R3

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Abstract

The availability of sufficient energy must support the rapid development of technology. The availability of electrical energy is decreasing. The saving of energy is one of the ways to solve this problem. One of the uses of electricity in clean water pumps, where clean water is the basic necessity of human life, therefore control system and auxiliary equipment is needed that is able to supply water according to the capacity of the need. However, often the use of the pump is not proportional to the capacity of the needs and the pump is often operated continuously, so that electricity and water are wasted. In this research, the use of water pumps is controlled, the rotation of the pump drive motor can be adjusted so that the pump output is in accordance with the water consumption load. The speed of a Direct Current (DC) motor is determined by the voltage. The higher the voltage, the faster the rotation. The focus of this research is to optimize the power efficiency of DC water pumps by using the Pulse Width Modulation (PWM) method to control the speed of the pump.

1 Introduction

Saving energy is an important part of increasing the economic value of a system by reducing the amount of energy that is used. Reducing energy use can be done by changing the way operations and maintenance are performed, investing in more efficient technology, timing operations, and performing energy conversion [1]. Water pump is one of the important devices in water management. This pump is used to drain water from the source to the point of consumption or storage, but the problem is that the pump operation still uses a conventional system so that when operated the pump cannot consider the need for water discharge flowing in the pipe [2,3]. In conventional systems or without pulse width modulation to consider the need for water discharge, the valve is opened and closed, but the voltage and current in the pump operation remain constant, there is no significant change, therefore it can make the power in the water pump still high [4,5].

The main purpose of a control system is optimizing, which is achieved through the control system's function of measuring, comparing, recording and calculating [6]. Proportional Integral and Derivative (PID) control is a control system to determine the precision of an instrumentation system with feedback on the system [7,8]. Proportional Integral and Derivative (PID) control is the development of conventional control which aims to provide optimal control performance in the control system [9,10]. For solve the problems, the previous research entitled "Controlling the Speed of the DC Water Pump Motor Using Proportional Integral and Derivative (PID) According Water debit base on Arduino" by Andreas et al. [11], which has

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designed an automatic pump control system that objective to maintain the debit or flow of water to remain constant, regardless of the valve or tap that is opened. This system uses Proportional Integral Derivative (PID) control to control the pump motor speed then the pump motor speed is controlled with a Pulse Width Modulation (PWM) driver.

In another research entitled “PID Control System for Mini Plant Water Flow Application base on Arduino" [12]. This research also focuses on controlling the water flow to remain stable based on a set point. This research makes a mini plant that regulates water flow using PID control to control the speed of the pump motor, with the speed controlled by a motor driver. By combining the two previous research, this research objective to more optimized power efficiency and stability of water flow. Therefore, this research focuses on optimized the power efficiency of Direct Current (DC) water pumps, Pulse width modulation method combined with a Proportional Integral and Derivative (PID) control system used to control pump speed so that pump operations (voltage, current, and power) follow a few of setpoint. So that to answer these problems, the author made research entitled "Water Pump Control System with Pulse Width Modulation Method Based on Arduino Uno R3"

This research uses Arduino UNO R3 as controller, BTS7960 as pump driver, potentiometer as set point input, and YF-S201 waterflow sensor to detect water flow. Other than that, this research involves a 0-25 V_{DC} voltage sensor and a 5A ACS712 current sensor, parameters such as actual water flow, setpoint water flow, pump voltage, pump current, and pump power are displayed on a 20x4 I2C Liquid Crystal Display (LCD) as a system display. By making and developing this research, it is projected that a positive step in increasing the power efficiency of water pumps is obtained, and it provides adaptive and efficient solutions in terms of resource management and contributing to efforts to use energy more sustainably.

2 Experimental Methods

2.1 Hardware design

The Figure 1 is a block diagram of how the water pump control system works with the Arduino UNO R3-based pulse width modulation method.

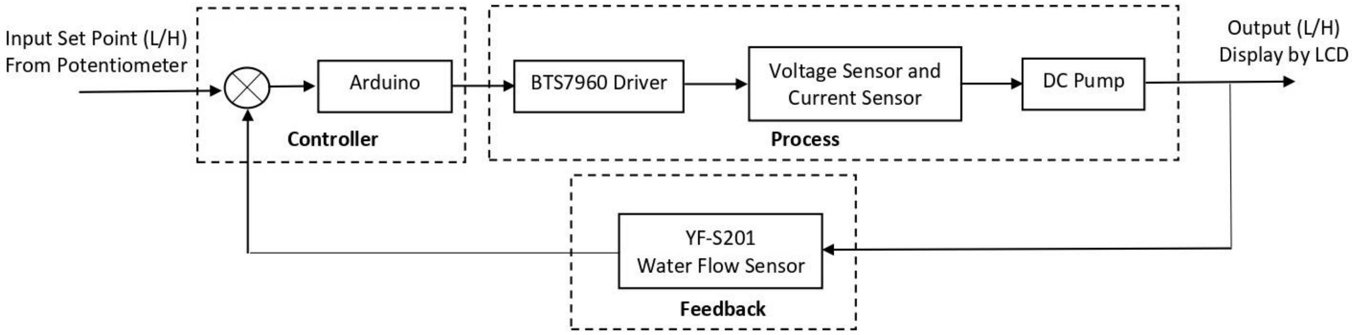

Figure 1. Block diagram of the control system

With this block diagram, the system is designed to maintain the output water flow in accordance with setpoint or input determined using a potentiometer. Arduino as the controller uses feedback from the YF-S201 waterflow sensor to generate the appropriate control signal. In the process, the BTS7960 driver is used to control the DC pump based on the control signal sent by Arduino as the controller then the 25 V_{DC} voltage sensor and ACS712 5A current sensor are used to determine the voltage and current of the DC pump whose operation is controlled by the BTS7960 driver based on the control signal sent by Arduino as the controller. Parameters in the form water flow setpoint, actual water flow, voltage, current, and power will be displayed on a 20x4 LCD as a display.

The output of this control system is the water flow produced by a DC pump, the operation of which is controlled by a BTS7960 driver based on the set point value set by a potentiometer. In addition, an electronic schematic circuit, in the form of a circuit diagram of each component and wiring, is to be made after a block diagram of the control system is made. Electronic circuit diagram is presented in Figure 2.

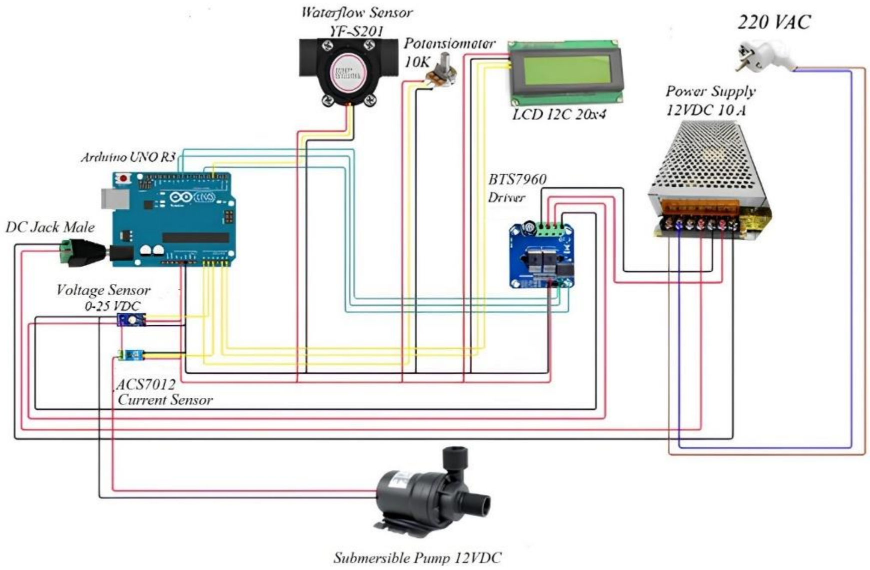

Figure 2. Electronics schematic circuit

2.2 Software design

Figure 3 is a flowchart showing the operation of the water pump control system using Arduino UNO R3 based pulse width modulation method.

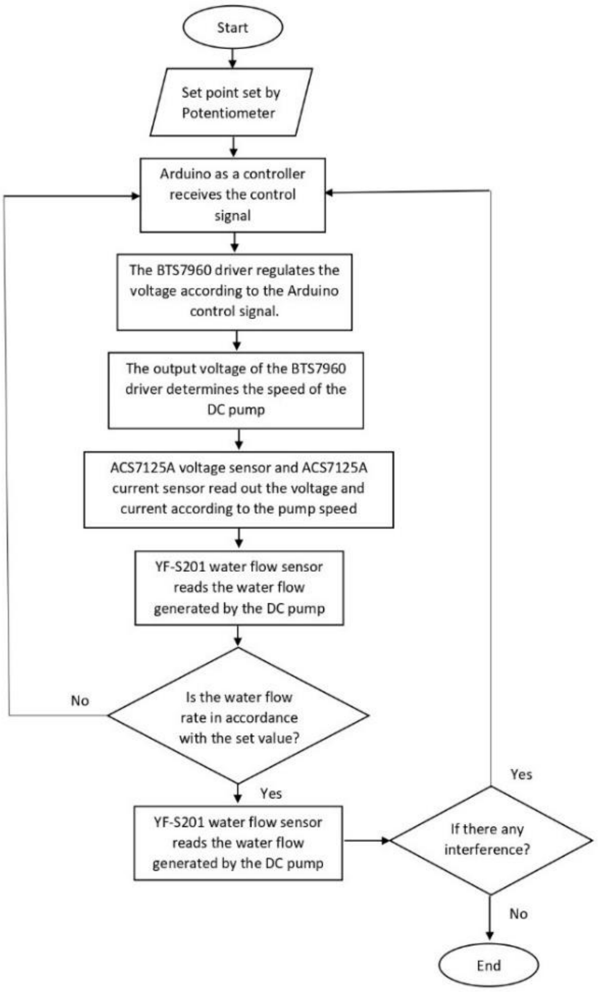

Figure 3. Flowchart of how the system works

The Figure 3 is flow chart of how the system works can be explained as follows:

1. Start is the first step of this system.
2. The set point is entered by potentiometer, the set point in consideration is the water discharge according to the data taken from the valve opening.
3. Arduino will receive a control signal sent by the potentiometer in determining the set point.
4. BTS7960 driver adjusts the output voltage according to the control signal sent by Arduino.
5. The rotation speed of the DC pump follows the output voltage of the BTS7960 driver according to the control signal sent by Arduino.
6. The voltage sensor and current sensor ACS712 5A read the voltage and current according to the speed of the DC pump, which works based on the output voltage of the BTS7960 driver according to the control signal sent by Arduino.
7. Water flow sensor YF-S201 reads the water flow produced by the DC pump whose pump rotation speed is based on the output voltage of the BTS7960 driver according to the control signal sent by Arduino.
8. The YF-S201 water flow sensor will send a control signal to the Arduino as a controller when the water flow reading does not match the initial set point, so that it readjusts according to the predetermined set point, also called feedback control.
9. However, if the flow reading is in accordance with the set point, the system will continue to operate in accordance with the initial set point.
10. If the flow is according to the set point but there is a disturbance, the disturbance being to change the water flow by changing the valve opening so that it causes a system mismatch, the Arduino will receive the disturbance signal and process it to be able to re-adjust according to the predetermined set point,
11. Finish is the last step

3 Results and Discussion

3.1 Results and discussion system that does not use pulse width modulation

First research, the Arduino is only used to read data from the YF-S201 water flow sensor, which measures different water flows by adjusting the valve opening in the range of 0 to 90 degrees, in systems that do not use the pulse width modulation method. In addition, in the systems that do not use the pulse width modulation method, the voltage and current measurements related to the operation of the water pump are carried out manually using a multimeter. The purpose of testing and analyzing the system without PWM is as a reference so that the results of testing the system without PWM are used as a reference for the system with PWM and then compared in terms of power efficiency and system response. Figure 4 system test results without using PWM.

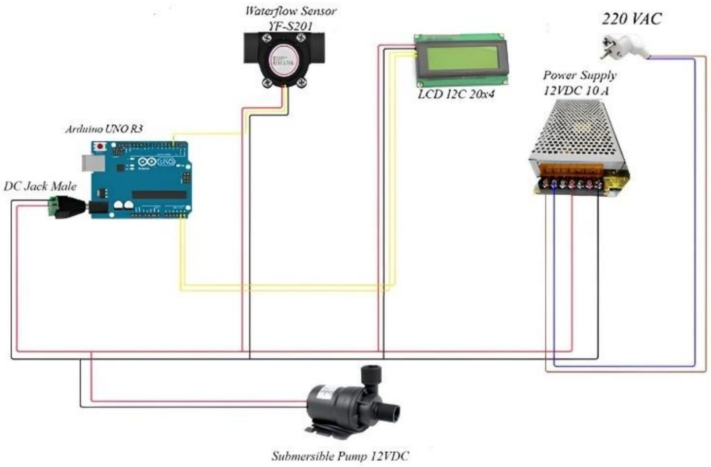

Figure 4. Testing the system without PWM with an open valve magnitude of 40°

```
Flow Rate: 678 L/h
Flow Rate: 678 L/h
Flow Rate: 678 L/h
Flow Rate: 678 L/h
Flow Rate: 690 L/h
Flow Rate: 678 L/h
Flow Rate: 678 L/h
Flow Rate: 666 L/h
Flow Rate: 690 L/h
Flow Rate: 678 L/h
Flow Rate: 678 L/h
Flow Rate: 678 L/h
Flow Rate: 678 L/h
Flow Rate: 678 L/h
Flow Rate: 678 L/h
Flow Rate: 678 L/h
Flow Rate: 678 L/h
Flow Rate: 678 L/h
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(a) (b) (c) (d)

Figure 4. *Cont.*

Figure 4 above is explained as follows:

a. Firstly, ensure the pump is connected to the power supply; the pump requires 12 V_{DC} to operate.
b. Then adjust the valve opening manually until the opening forms an angle of approximately 40°; this is done to determine the variation in flow readings from the YF S201 water flow sensor.
c. Measure flow on a pump operating with the valve opening at an angle of about 40°.
d. The water flow sensor reads the variation in flow by closing the valve at a certain angle, the readings are displayed on the serial monitor.

For more complete results of the non-PWM system test, see Table 1 for results of the non-PWM system test.

Table 1. Test results of a system that does not use pulse width modulation

Open valve **(°)**	**Pump Voltage (v)**	**Pump Current (A)**	**Pump Power (Watt)**	**Water Flow (*L/H*)**
0	12	1.92	23.04	0
10	12	1.93	23.16	36
20	12	2	24	290
30	12	2.14	25.68	545
40	12	2.24	26.88	676
50	12	2.36	28.32	824
60	12	2.43	29.16	945
70	12	2.46	29.52	969
80	12	2.48	29.76	981
90	12	2.50	30	993

From Table 1, it can be concluded that a system that does not use pulse width modulation to achieve different discharge variants must set the open valve without regard to the voltage and current of the pump, so that the average power required is rather high; to illustrate this, a graph of the power consumption of a pump that does not use pulse width modulation is shown in Figure 5.

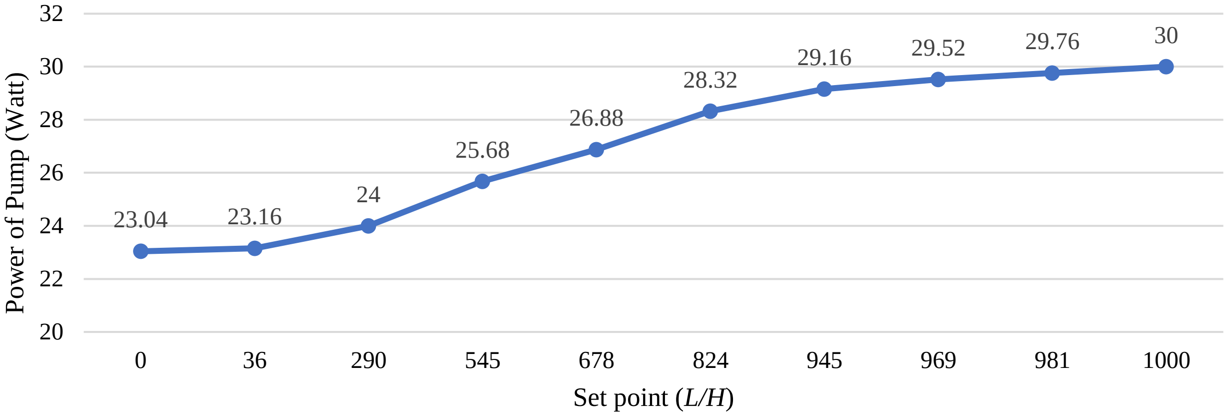


Figure 5. Graph of pump power usage that does not use pulse width modulation

3.2 Results and analysis of the system using pulse width modulation

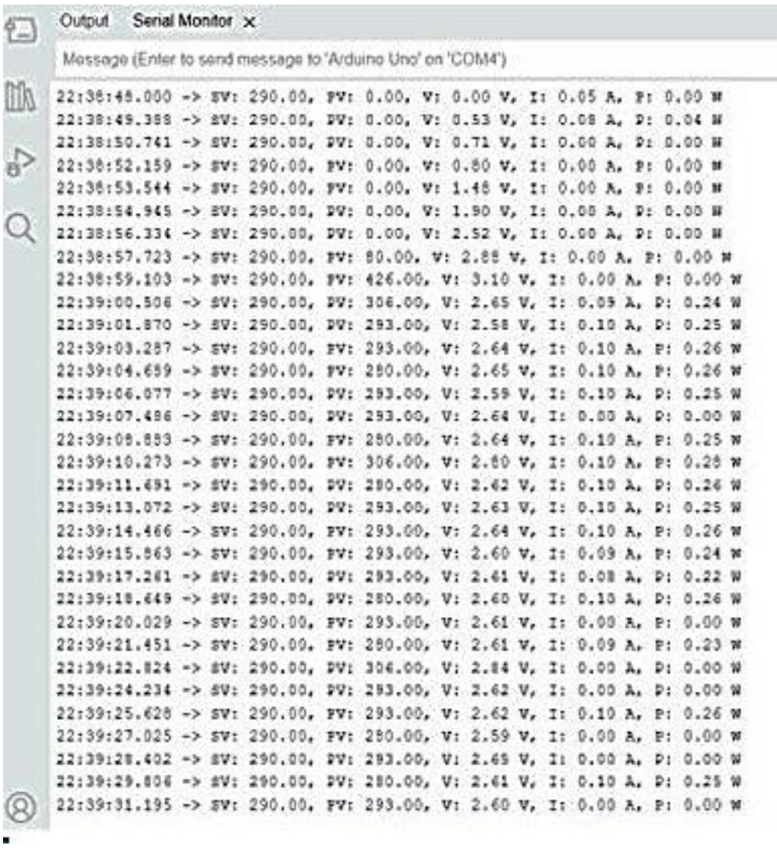
Automatic control systems can have benefits for people, in addition to speeding up the work process, Proportional Integral and Derivative (PID) control is one of the control sciences that has been widely used because of its reliability in system stabilization. In stabilizing the system, Proportional Integral and Derivative (PID) control requires a received error and converts it into a system response until the system can stabilize automatically. In the control system, there are several conditions that must be considered before the Process Variable (PV) value adjusts to Set Point (SP), there is a delayed overshoot (spike). To reduce the overshoot, the Kp needs to be increased and the PV becomes slower to respond. Control characteristics are based on Maximum Overshoot (Mp) and Settling Time (ts). These two parameters are very important in determining how the Proportional Integral and Derivative (PID) will oscillate.

Knowing the maximum overshoot and settling time allows us to determine how the best control will respond. Theoretically, maximum overshoot and settling time have an inverse relationship. In other words, if a control has a high maximum overshoot, it will usually have a short settling time. The Kp parameter is identical to the proportional control parameter. The higher the p-value, the more sensitive the controller is. The Ti parameter is identical to the integral control. The faster the controller reacts or the more sensitive it is, and vice versa, if the value of Ti is high. Parameter Td is identical to differential control. This differential control has the property that it cannot give an output when the input does not change. The output is directly proportional to the Td value, i.e., the greater the Td value, the greater the resulting output. The parameters Kp, Ti, Td in the control response using Proportional Integral and Derivative (PID) are mutually providing actions that can overcome the shortcomings of each controller P, I and D. The elements P, I, and D are each useful to accelerate the system reactions, to eliminate offsets and to obtain extra energy in the first moments of load or set point changes.

The next step is to determine if there is a difference in power consumption between not using PWM and using PWM. To be more focused, the standard is made based on water flow as the output of the pump with several set points according to the data in Figure 5. The set points to be used are 290 *L/H*, which is the flow rate when the valve is open 20°, 545 *L/H*, which is the flow rate when the valve is open 30°, 678 *L/H*, which is the water flow rate when the valve is open 40°, and 824 *L/H*, which is the water flow rate when the valve is open 50°. Water flow sensor YF-S201 to read the water flow, potentiometer as a set point input as desired as a valve substitute, use BTS7960 as a pump driver so that the pump turns according to the predetermined set point. To find out the value of voltage and current as a measuring instrument, we use a 0-25 V_{DC} voltage sensor, an ACS712 5 A current sensor, and to read the value we use a 20x4 I2C LCD.

3.2.1 290 *L/H* set point testing

The first experiment, turning the potentiometer to set the water flow set point to 290 *L/H*, will also display the system readings on the serial monitor as shown in Figure 6. Also, as shown in Figure 7, the results of system response measurements that have been processed from the readings displayed on the serial monitor to produce a system response graph for a set point of 290 *L/H*.



```
22:38:48.000 -> SV: 290.00, PV: 0.00, V: 0.00 V, I: 0.05 A, P: 0.00 W
22:38:49.388 -> SV: 290.00, PV: 0.00, V: 0.53 V, I: 0.08 A, P: 0.04 W
22:38:50.741 -> SV: 290.00, PV: 0.00, V: 0.71 V, I: 0.00 A, P: 0.00 W
22:38:52.159 -> SV: 290.00, PV: 0.00, V: 0.80 V, I: 0.00 A, P: 0.00 W
22:38:53.544 -> SV: 290.00, PV: 0.00, V: 1.48 V, I: 0.00 A, P: 0.00 W
22:38:54.945 -> SV: 290.00, PV: 0.00, V: 1.90 V, I: 0.00 A, P: 0.00 W
22:38:56.334 -> SV: 290.00, PV: 0.00, V: 2.52 V, I: 0.00 A, P: 0.00 W
22:38:57.723 -> SV: 290.00, PV: 80.00, V: 2.88 V, I: 0.00 A, P: 0.00 W
22:38:59.103 -> SV: 290.00, PV: 426.00, V: 3.10 V, I: 0.00 A, P: 0.00 W
22:39:00.506 -> SV: 290.00, PV: 306.00, V: 2.65 V, I: 0.09 A, P: 0.24 W
22:39:01.870 -> SV: 290.00, PV: 293.00, V: 2.58 V, I: 0.10 A, P: 0.25 W
22:39:03.287 -> SV: 290.00, PV: 293.00, V: 2.64 V, I: 0.10 A, P: 0.26 W
22:39:04.659 -> SV: 290.00, PV: 280.00, V: 2.65 V, I: 0.10 A, P: 0.26 W
22:39:06.077 -> SV: 290.00, PV: 293.00, V: 2.59 V, I: 0.10 A, P: 0.25 W
22:39:07.486 -> SV: 290.00, PV: 293.00, V: 2.64 V, I: 0.00 A, P: 0.00 W
22:39:08.883 -> SV: 290.00, PV: 280.00, V: 2.64 V, I: 0.10 A, P: 0.25 W
22:39:10.273 -> SV: 290.00, PV: 306.00, V: 2.80 V, I: 0.10 A, P: 0.28 W
22:39:11.691 -> SV: 290.00, PV: 280.00, V: 2.62 V, I: 0.10 A, P: 0.26 W
22:39:13.072 -> SV: 290.00, PV: 293.00, V: 2.63 V, I: 0.10 A, P: 0.25 W
22:39:14.466 -> SV: 290.00, PV: 293.00, V: 2.64 V, I: 0.10 A, P: 0.26 W
22:39:15.863 -> SV: 290.00, PV: 293.00, V: 2.60 V, I: 0.09 A, P: 0.24 W
22:39:17.261 -> SV: 290.00, PV: 293.00, V: 2.61 V, I: 0.08 A, P: 0.22 W
22:39:18.649 -> SV: 290.00, PV: 280.00, V: 2.60 V, I: 0.10 A, P: 0.26 W
22:39:20.029 -> SV: 290.00, PV: 293.00, V: 2.61 V, I: 0.00 A, P: 0.00 W
22:39:21.451 -> SV: 290.00, PV: 280.00, V: 2.61 V, I: 0.09 A, P: 0.23 W
22:39:22.824 -> SV: 290.00, PV: 306.00, V: 2.84 V, I: 0.00 A, P: 0.00 W
22:39:24.234 -> SV: 290.00, PV: 293.00, V: 2.62 V, I: 0.00 A, P: 0.00 W
22:39:25.628 -> SV: 290.00, PV: 293.00, V: 2.62 V, I: 0.10 A, P: 0.26 W
22:39:27.025 -> SV: 290.00, PV: 280.00, V: 2.59 V, I: 0.00 A, P: 0.00 W
22:39:28.402 -> SV: 290.00, PV: 293.00, V: 2.65 V, I: 0.00 A, P: 0.00 W
22:39:29.806 -> SV: 290.00, PV: 280.00, V: 2.61 V, I: 0.10 A, P: 0.25 W
22:39:31.195 -> SV: 290.00, PV: 293.00, V: 2.60 V, I: 0.00 A, P: 0.00 W
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Figure 6. System readings at set point 290 *L/H* on serial monitor

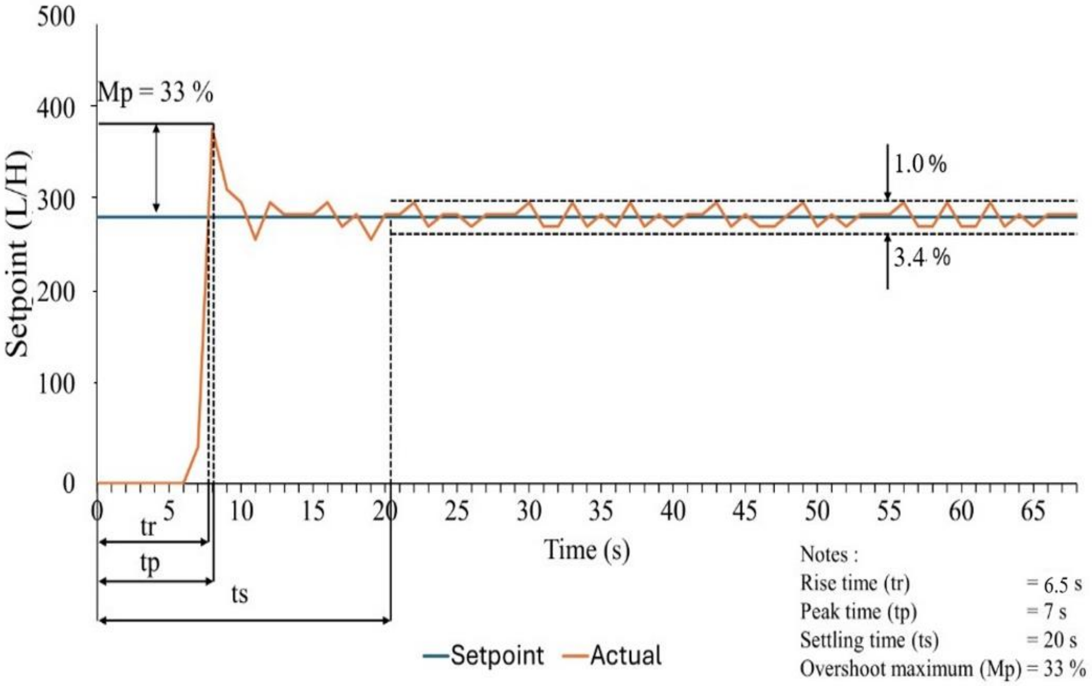


Figure 7. Response curve of the system at a set point of 290 *L/H*

In Figure 7 is a response curve of the system at a set point of 290 *L/H*, it can be concluded that the Rise Time (tr) = 6.5 seconds, Peak Time (tp) = 7 seconds, then Settling Time (ts) = 20 seconds with a tolerance according to the set point of 1.0% ~ 3.4% and Maximum Overshoot (Mp) = 33% then in Figure 8. is the average power consumption using the pulse width modulation method at a set point of 290 *L/H* only 0.26 Watts.

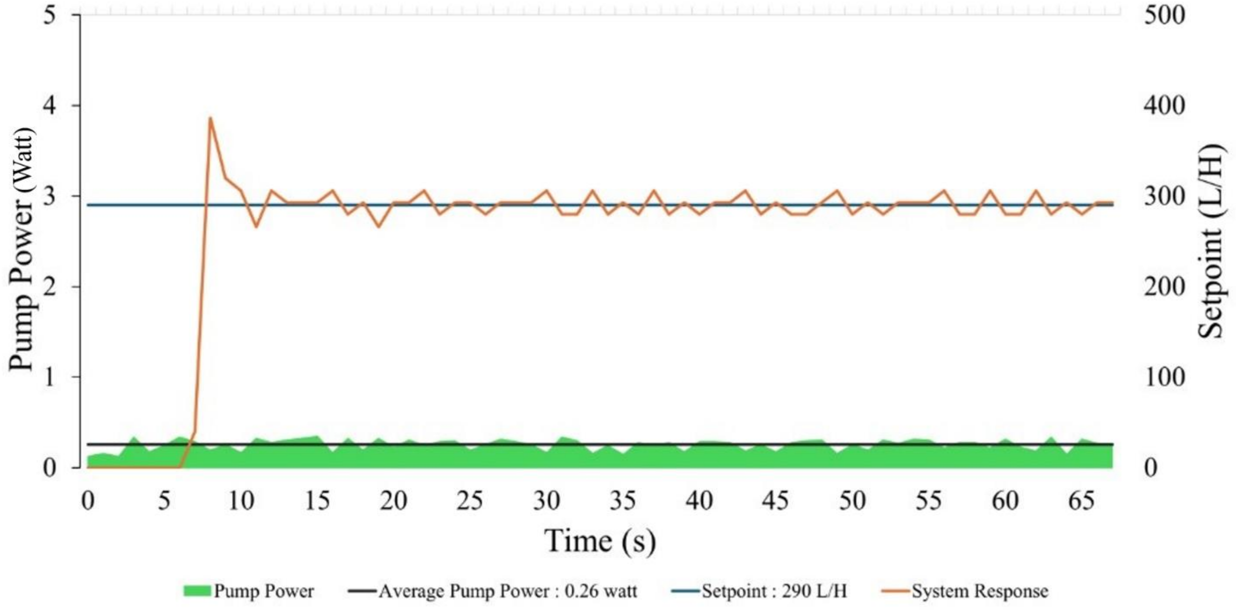
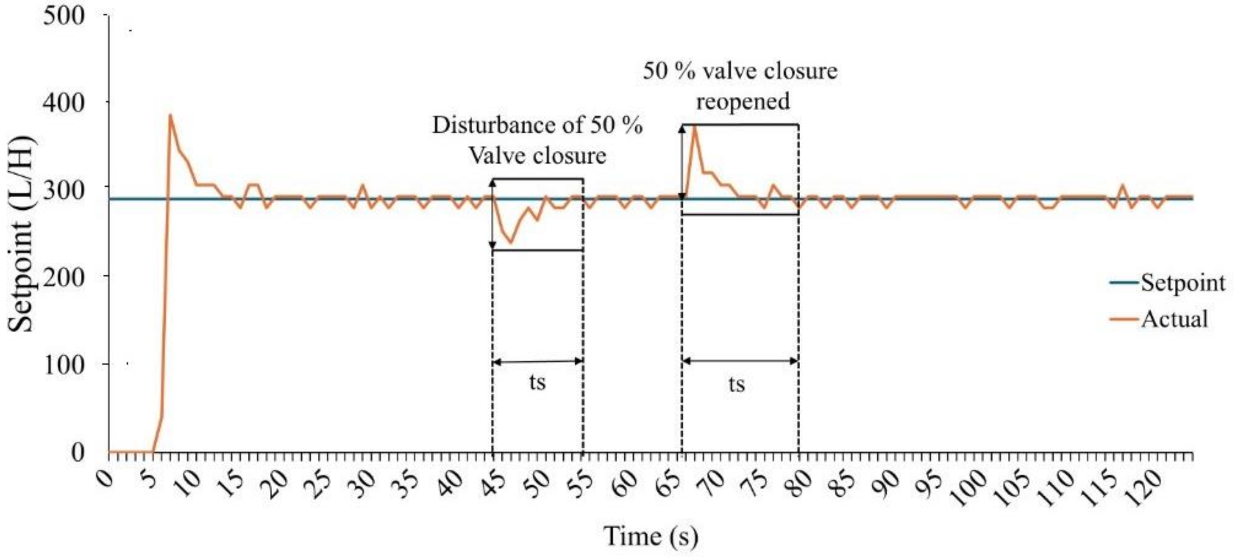


Figure 8. Pump power consumption at set point 290 *L/H*

Then, at a set point of 290 *L/H*, it is also tested with a disturbance in the form of a valve closing by 50%, the following system response to disturbance is shown in Figures 9 and 10 this is the use of pump power at a set point of 290 *L/H* when there is a disturbance in the form of 50% valve closing. This test is carried out to determine the impact and the response of the control system when users reduce or increase the consumption of water they are using.



Notes
*Settling time (ts) with 50 % valve closure disturbance = 10 s
*Settling time (ts) when 50 % valve closure reopened = 15 s

Figure 9. System response at set point 290 *L/H* with disturbance of 50% valve closed

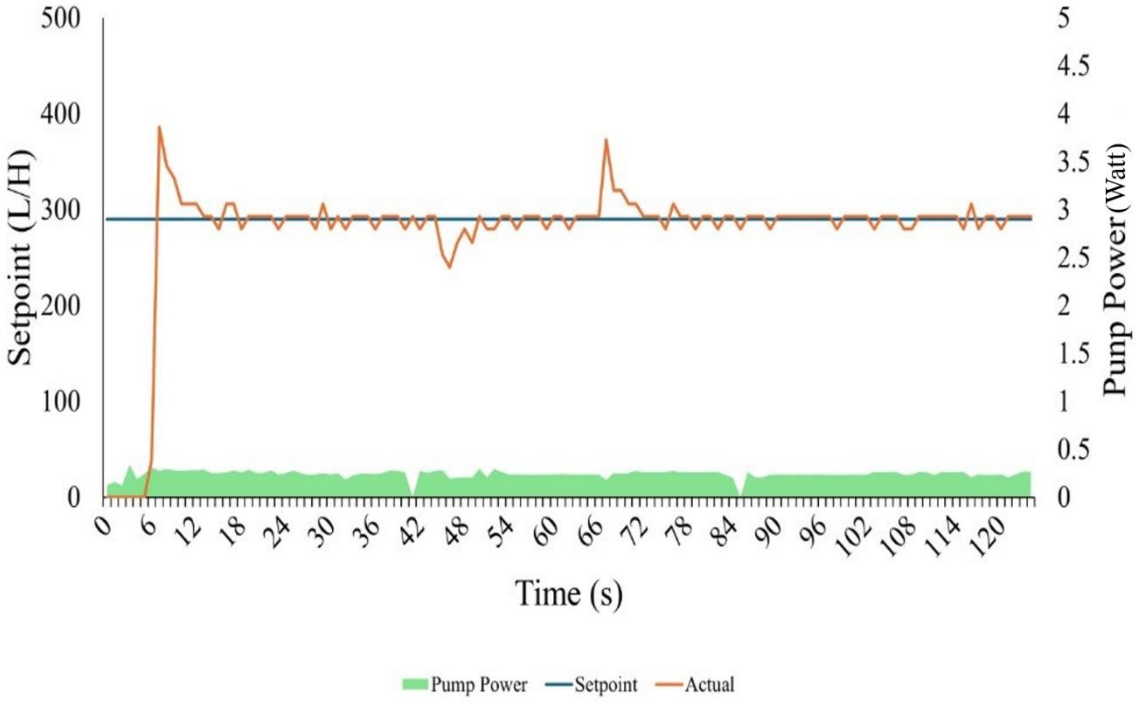


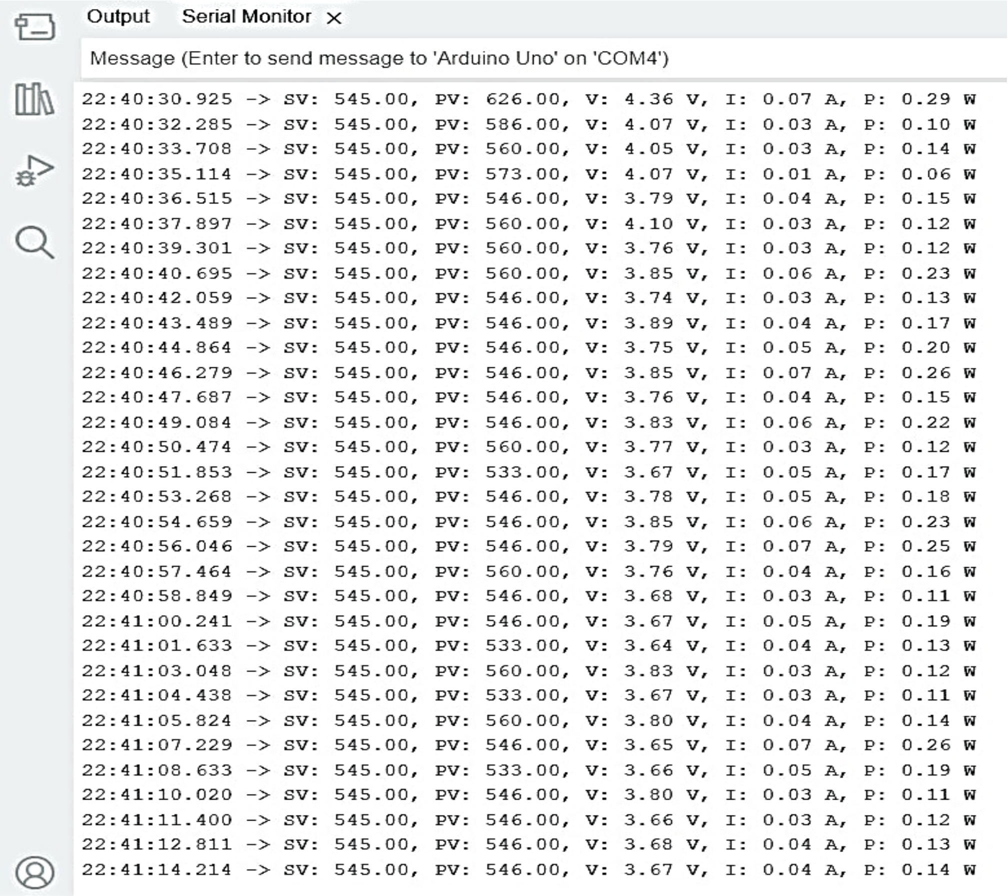
Figure 10. Pump power utilization at 290 *L/H* set point system response with disturbance in the form of 50% valve closure

In Figures 9 and 10 when the valve is closed by 50%, there is a decrease in the actual discharge reading. This indicates that the system is experiencing a disturbance that affects the water discharge. In response to this disturbance, the system sends an error signal to the controller. After receiving the error signal, the controller is then tasked with adjusting the pump operation, which includes adjusting the voltage, current, and power, so that the actual discharge returns to the predetermined set point of 290 *L/H*. The time required for the system to return to stability, or Settling Time (ts) when given a disturbance in the form of valve closure by 50% at a set point of 290 *L/H*, only takes 10 seconds. This is characterized by an increase in the power used by the pump so that the discharge returns to the set point Although there is an increase in power during this adjustment process, the power increase is not significant. This is because the discharge of 290 *L/H* can still be operated with relatively low power.

Furthermore, after the system reaches stability in accordance with the set point, the valve that was previously closed by 50% is then fully opened again. As a result, there is a spike in the actual discharge reading. The system then detects this spike as an error signal. In response, the system sends another error signal to the controller to adjust the pump operation. The time taken for the system to stabilize at the set point of 290 *L/H* after the valve is fully opened is about 15 seconds, characterized by a decrease in the power used by the pump to return to the predetermined set point. This test process demonstrates the efficiency and responsiveness of the system in maintaining the stability of the discharge in accordance with the desired set point, in spite of the disturbance of the valve settings. The average power required during the test with 50% valve closure interruption was only 0.30 Watts. This shows that the system is not only responsive but also efficient in regulating power during the pump operational adjustment process to maintain the discharge at the desired level.

3.2.2 545 *L/H* set point testing

At set point 545 L / H the reading results will also be displayed on the serial monitor following Figure 11 which is the result of the system reading at set point 545 *L/H* displayed on the serial monitor. As shown in Figure 12, the results of the system response readings that have been processed from the readings displayed on the serial monitor so that it becomes a system response graph for set point 545 *L/H*.



Message (Enter to send message to 'Arduino Uno' on 'COM4')

```
22:40:30.925 -> SV: 545.00, PV: 626.00, V: 4.36 V, I: 0.07 A, P: 0.29 W
22:40:32.285 -> SV: 545.00, PV: 586.00, V: 4.07 V, I: 0.03 A, P: 0.10 W
22:40:33.708 -> SV: 545.00, PV: 560.00, V: 4.05 V, I: 0.03 A, P: 0.14 W
22:40:35.114 -> SV: 545.00, PV: 573.00, V: 4.07 V, I: 0.01 A, P: 0.06 W
22:40:36.515 -> SV: 545.00, PV: 546.00, V: 3.79 V, I: 0.04 A, P: 0.15 W
22:40:37.897 -> SV: 545.00, PV: 560.00, V: 4.10 V, I: 0.03 A, P: 0.12 W
22:40:39.301 -> SV: 545.00, PV: 560.00, V: 3.76 V, I: 0.03 A, P: 0.12 W
22:40:40.695 -> SV: 545.00, PV: 560.00, V: 3.85 V, I: 0.06 A, P: 0.23 W
22:40:42.059 -> SV: 545.00, PV: 546.00, V: 3.74 V, I: 0.03 A, P: 0.13 W
22:40:43.489 -> SV: 545.00, PV: 546.00, V: 3.89 V, I: 0.04 A, P: 0.17 W
22:40:44.864 -> SV: 545.00, PV: 546.00, V: 3.75 V, I: 0.05 A, P: 0.20 W
22:40:46.279 -> SV: 545.00, PV: 546.00, V: 3.85 V, I: 0.07 A, P: 0.26 W
22:40:47.687 -> SV: 545.00, PV: 546.00, V: 3.76 V, I: 0.04 A, P: 0.15 W
22:40:49.084 -> SV: 545.00, PV: 546.00, V: 3.83 V, I: 0.06 A, P: 0.22 W
22:40:50.474 -> SV: 545.00, PV: 560.00, V: 3.77 V, I: 0.03 A, P: 0.12 W
22:40:51.853 -> SV: 545.00, PV: 533.00, V: 3.67 V, I: 0.05 A, P: 0.17 W
22:40:53.268 -> SV: 545.00, PV: 546.00, V: 3.78 V, I: 0.05 A, P: 0.18 W
22:40:54.659 -> SV: 545.00, PV: 546.00, V: 3.85 V, I: 0.06 A, P: 0.23 W
22:40:56.046 -> SV: 545.00, PV: 546.00, V: 3.79 V, I: 0.07 A, P: 0.25 W
22:40:57.464 -> SV: 545.00, PV: 560.00, V: 3.76 V, I: 0.04 A, P: 0.16 W
22:40:58.849 -> SV: 545.00, PV: 546.00, V: 3.68 V, I: 0.03 A, P: 0.11 W
22:41:00.241 -> SV: 545.00, PV: 546.00, V: 3.67 V, I: 0.05 A, P: 0.19 W
22:41:01.633 -> SV: 545.00, PV: 533.00, V: 3.64 V, I: 0.04 A, P: 0.13 W
22:41:03.048 -> SV: 545.00, PV: 560.00, V: 3.83 V, I: 0.03 A, P: 0.12 W
22:41:04.438 -> SV: 545.00, PV: 533.00, V: 3.67 V, I: 0.03 A, P: 0.11 W
22:41:05.824 -> SV: 545.00, PV: 560.00, V: 3.80 V, I: 0.04 A, P: 0.14 W
22:41:07.229 -> SV: 545.00, PV: 546.00, V: 3.65 V, I: 0.07 A, P: 0.26 W
22:41:08.633 -> SV: 545.00, PV: 533.00, V: 3.66 V, I: 0.05 A, P: 0.19 W
22:41:10.020 -> SV: 545.00, PV: 546.00, V: 3.80 V, I: 0.03 A, P: 0.11 W
22:41:11.400 -> SV: 545.00, PV: 546.00, V: 3.66 V, I: 0.03 A, P: 0.12 W
22:41:12.811 -> SV: 545.00, PV: 546.00, V: 3.68 V, I: 0.04 A, P: 0.13 W
22:41:14.214 -> SV: 545.00, PV: 546.00, V: 3.67 V, I: 0.04 A, P: 0.14 W
```

Figure 11. System readings at set point 545 *L/H* on serial monitor

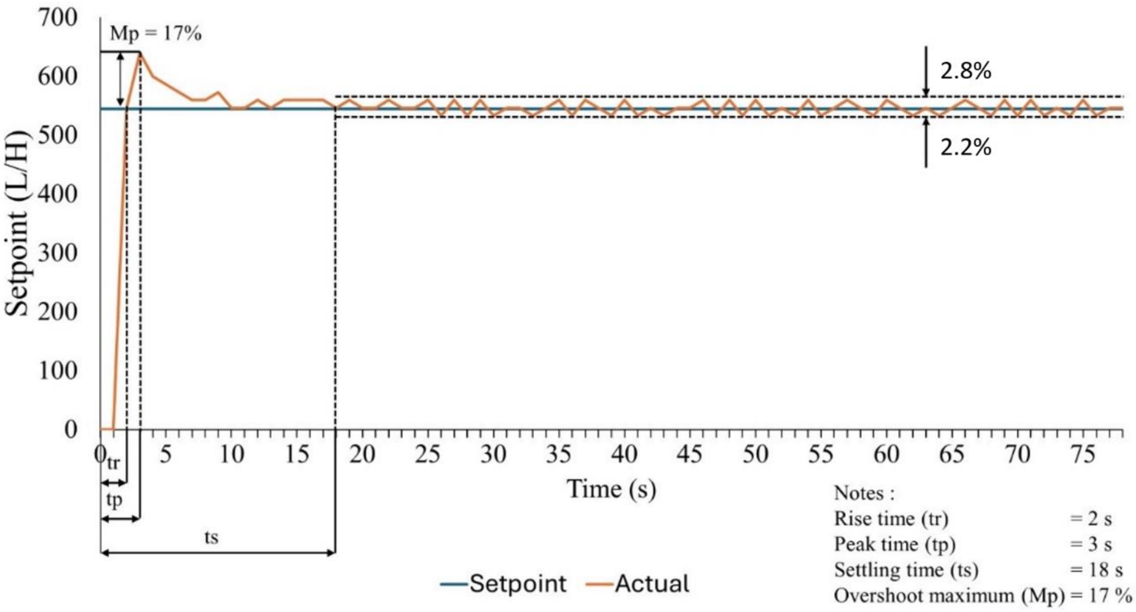


Figure 12. System response at set point 545 *L/H*

In Figure 12 is the system response with a set point of 545 (*L/H*), which can be concluded Rise Time (tr) = 2 seconds, Peak Time (tp) = 3 seconds, then Settling Time (ts) = 18 seconds with a tolerance in accordance with the set point of 2.8% ~ 2.2% and Maximum Overshoot (Mp) = 17% then in Figure 13 is the average power usage using the pulse width modulation method at a set point of 545 *L/H* of only 0.16 Watts.

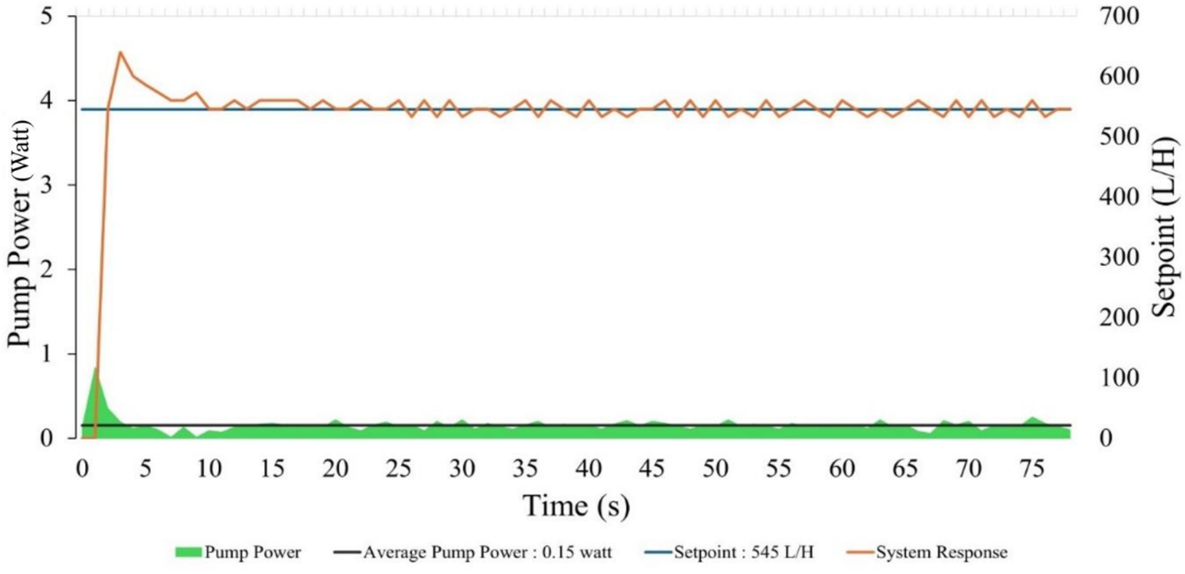
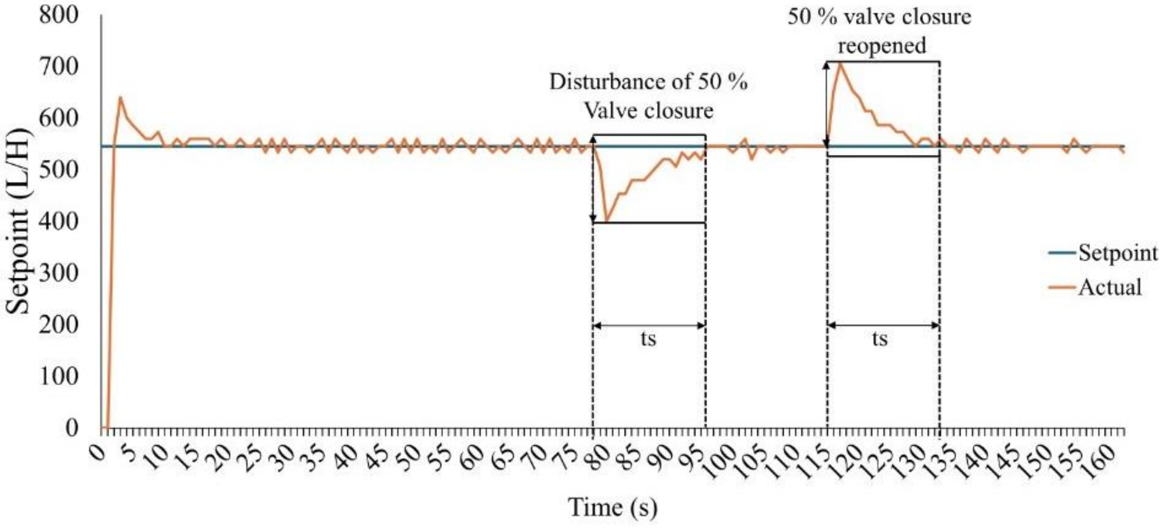


Figure 13. Pump power consumption at set point 545 *L/H*

At a set point of 545 *L/H*, testing is also carried out with a disturbance in the form of a valve closure of 50%, the following system response when there is a disturbance in Figures 14 and 15. In Figures 14 and 15 when the valve is closed by 50%, there is a decrease in the actual discharge reading. This makes the system experience a disturbance that affects the water discharge. In response to this disturbance, the system will send an error signal to the controller. After receiving the error signal, the controller is then tasked with adjusting the pump operation, which includes adjusting the voltage, current, and power, so that the actual discharge returns to the predetermined set point of 545 *L/H*. The time required for the system to return to stability, or Settling Time (ts) when given a disturbance in the form of valve closure by 50% at a set point of 545 *L/H*, only takes 15 seconds. This is characterized by an increase in the power used by the pump so that the discharge returns to the set point. Although there is an increase in power during the adjustment process, the power increase is quite significant.



Notes
*Settling time (ts) with 50 % valve closure disturbance = 15 s
*Settling time (ts) when 50 % valve closure reopened = 20 s

Figure 14. System response at set point 545 *L/H* with disturbance in the form of 50% valve closure

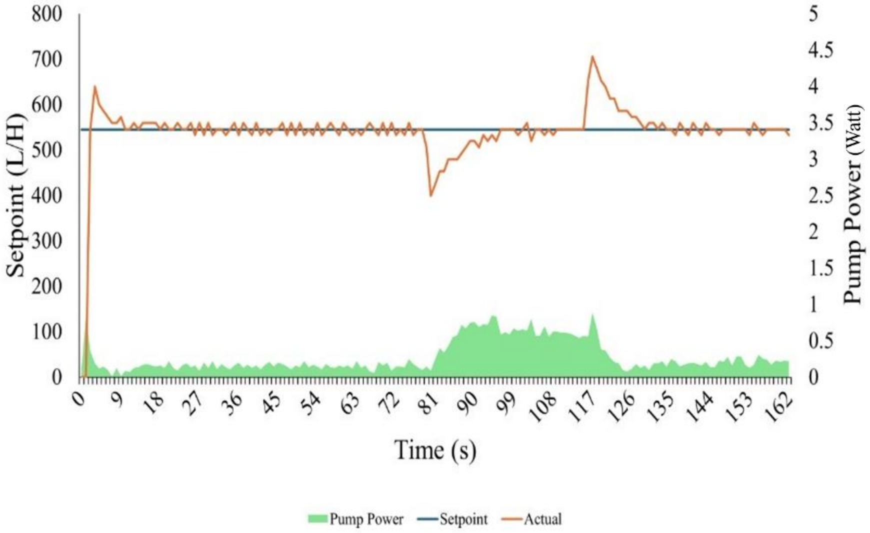
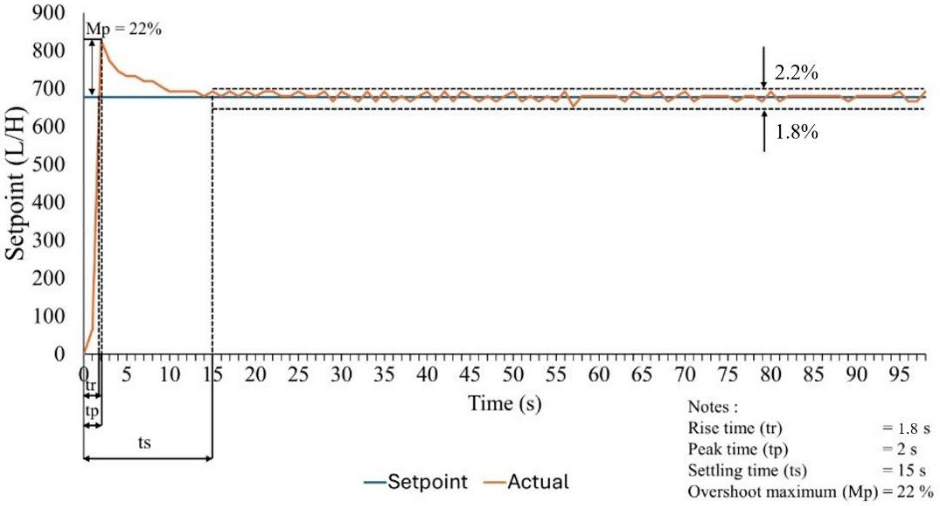


Figure 15. Pump power utilization at 545 *L/H* set point system response with disturbance in the form of 50% valve closure

Then, after the system reaches stability in accordance with the set point, the valve that was previously closed by 50% is then fully opened again. As a result, there is a spike in the actual discharge reading. The system then detects this spike as an error signal. In response, the system sends another error signal to the controller to adjust the pump operation. The time taken for the system to stabilize at the set point of 545 *L/H* after the valve is fully opened is approximately 20 seconds, characterized by a decrease in the power used by the pump to return to the predetermined set point. This test shows the efficiency and responsiveness of the system in maintaining the stability of the discharge according to the desired set point, despite the disturbance in the valve setting. Then, the average power required during the test with a 50% valve closure disturbance was only 0.28 Watts. This shows that the system is not only responsive but also efficient in regulating power during the pump operational adjustment process to maintain the discharge at the desired level.

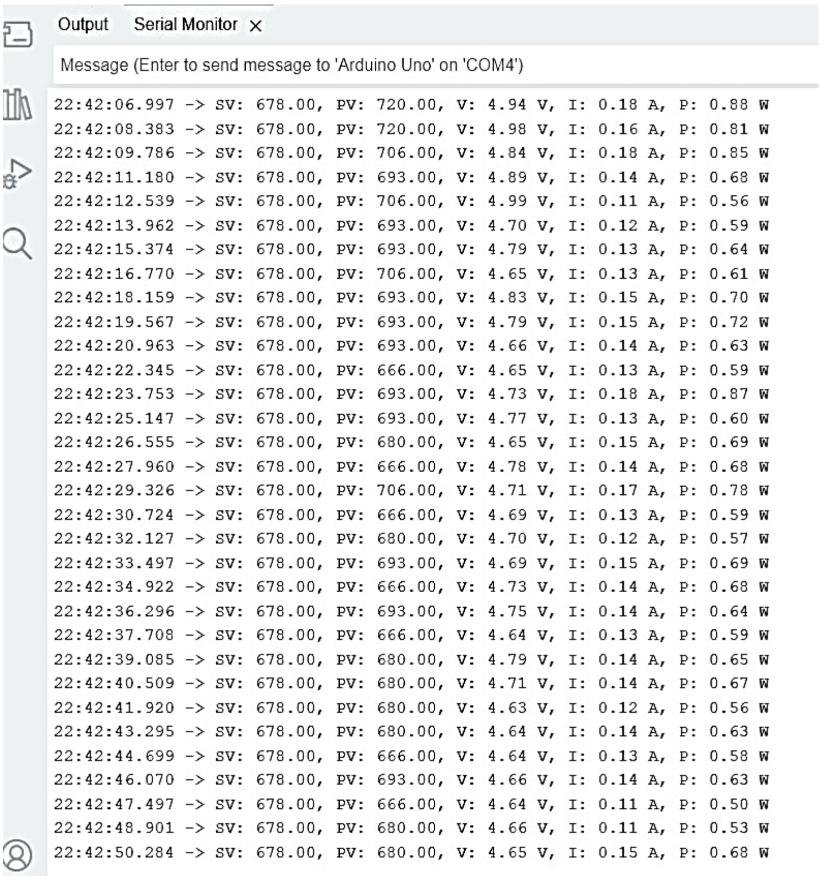
3.2.3 678 *L/H* set point testing

The following Figure 16 is the result of the system response readings that have been processed from the readings displayed on the serial monitor so that it becomes a system response graph for the 678 *L/H* set point. The readings from the system will also be displayed on the serial monitor as shown in Figure 17 which is the result of the system reading at set point 678 *L/H* displayed on the serial monitor.



Notes :
Rise time (tr) = 1.8 s
Peak time (tp) = 2 s
Settling time (ts) = 15 s
Overshoot maximum (Mp) = 22 %

Figure 16. Discussion of system response at set point 678 *L/H*



Message (Enter to send message to 'Arduino Uno' on 'COM4')

```
22:42:06.997 -> SV: 678.00, PV: 720.00, V: 4.94 V, I: 0.18 A, P: 0.88 W
22:42:08.383 -> SV: 678.00, PV: 720.00, V: 4.98 V, I: 0.16 A, P: 0.81 W
22:42:09.786 -> SV: 678.00, PV: 706.00, V: 4.84 V, I: 0.18 A, P: 0.85 W
22:42:11.180 -> SV: 678.00, PV: 693.00, V: 4.89 V, I: 0.14 A, P: 0.68 W
22:42:12.539 -> SV: 678.00, PV: 706.00, V: 4.99 V, I: 0.11 A, P: 0.56 W
22:42:13.962 -> SV: 678.00, PV: 693.00, V: 4.70 V, I: 0.12 A, P: 0.59 W
22:42:15.374 -> SV: 678.00, PV: 693.00, V: 4.79 V, I: 0.13 A, P: 0.64 W
22:42:16.770 -> SV: 678.00, PV: 706.00, V: 4.65 V, I: 0.13 A, P: 0.61 W
22:42:18.159 -> SV: 678.00, PV: 693.00, V: 4.83 V, I: 0.15 A, P: 0.70 W
22:42:19.567 -> SV: 678.00, PV: 693.00, V: 4.79 V, I: 0.15 A, P: 0.72 W
22:42:20.963 -> SV: 678.00, PV: 693.00, V: 4.66 V, I: 0.14 A, P: 0.63 W
22:42:22.345 -> SV: 678.00, PV: 666.00, V: 4.65 V, I: 0.13 A, P: 0.59 W
22:42:23.753 -> SV: 678.00, PV: 693.00, V: 4.73 V, I: 0.18 A, P: 0.87 W
22:42:25.147 -> SV: 678.00, PV: 693.00, V: 4.77 V, I: 0.13 A, P: 0.60 W
22:42:26.555 -> SV: 678.00, PV: 680.00, V: 4.65 V, I: 0.15 A, P: 0.69 W
22:42:27.960 -> SV: 678.00, PV: 666.00, V: 4.78 V, I: 0.14 A, P: 0.68 W
22:42:29.326 -> SV: 678.00, PV: 706.00, V: 4.71 V, I: 0.17 A, P: 0.78 W
22:42:30.724 -> SV: 678.00, PV: 666.00, V: 4.69 V, I: 0.13 A, P: 0.59 W
22:42:32.127 -> SV: 678.00, PV: 680.00, V: 4.70 V, I: 0.12 A, P: 0.57 W
22:42:33.497 -> SV: 678.00, PV: 693.00, V: 4.69 V, I: 0.15 A, P: 0.69 W
22:42:34.922 -> SV: 678.00, PV: 666.00, V: 4.73 V, I: 0.14 A, P: 0.68 W
22:42:36.296 -> SV: 678.00, PV: 693.00, V: 4.75 V, I: 0.14 A, P: 0.64 W
22:42:37.708 -> SV: 678.00, PV: 666.00, V: 4.64 V, I: 0.13 A, P: 0.59 W
22:42:39.085 -> SV: 678.00, PV: 680.00, V: 4.79 V, I: 0.14 A, P: 0.65 W
22:42:40.509 -> SV: 678.00, PV: 680.00, V: 4.71 V, I: 0.14 A, P: 0.67 W
22:42:41.920 -> SV: 678.00, PV: 680.00, V: 4.63 V, I: 0.12 A, P: 0.56 W
22:42:43.295 -> SV: 678.00, PV: 680.00, V: 4.64 V, I: 0.14 A, P: 0.63 W
22:42:44.699 -> SV: 678.00, PV: 666.00, V: 4.64 V, I: 0.13 A, P: 0.58 W
22:42:46.070 -> SV: 678.00, PV: 693.00, V: 4.66 V, I: 0.14 A, P: 0.63 W
22:42:47.497 -> SV: 678.00, PV: 666.00, V: 4.64 V, I: 0.11 A, P: 0.50 W
22:42:48.901 -> SV: 678.00, PV: 680.00, V: 4.66 V, I: 0.11 A, P: 0.53 W
22:42:50.284 -> SV: 678.00, PV: 680.00, V: 4.65 V, I: 0.15 A, P: 0.68 W
```

Figure 17. System readings at set point 678 *L/H* on serial monitor

In Figure 16, the system response with a set point of 678 (*L/H*), it can be concluded that the Rise Time (tr) = 1.8 seconds, Peak Time (tp) = 2 seconds, then Settling Time (ts) = 15 seconds with a tolerance in accordance with the set point of 2.2% ~ 1.8% and Maximum Overshoot (Mp) = 22% while in Figure 18 is the average power usage using the pulse width modulation method at a set point of 678 *L/H* of only 0.72 Watts.

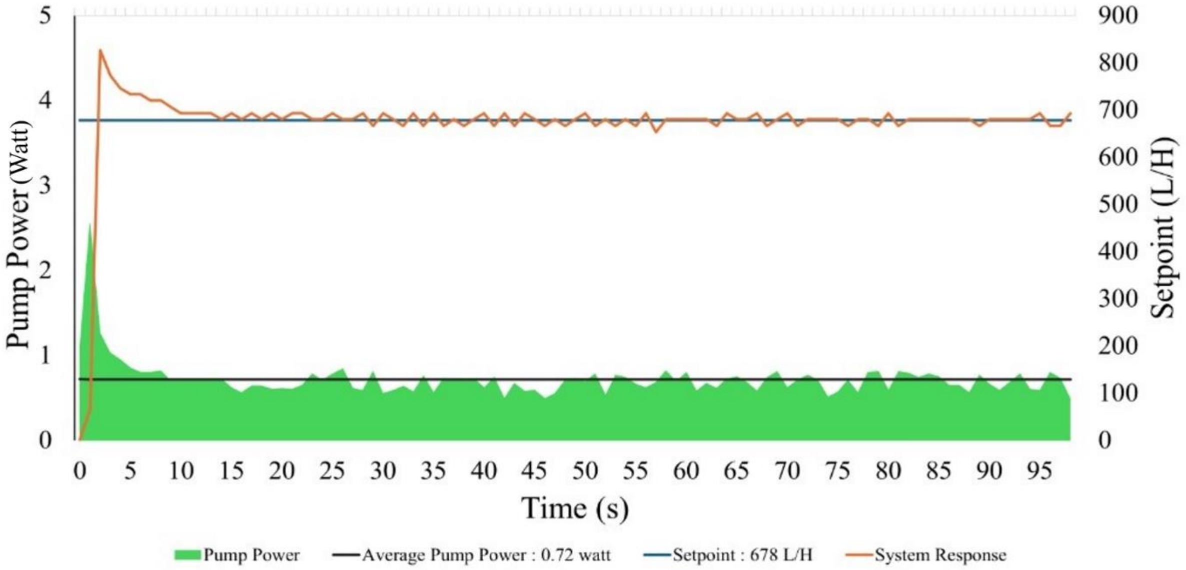
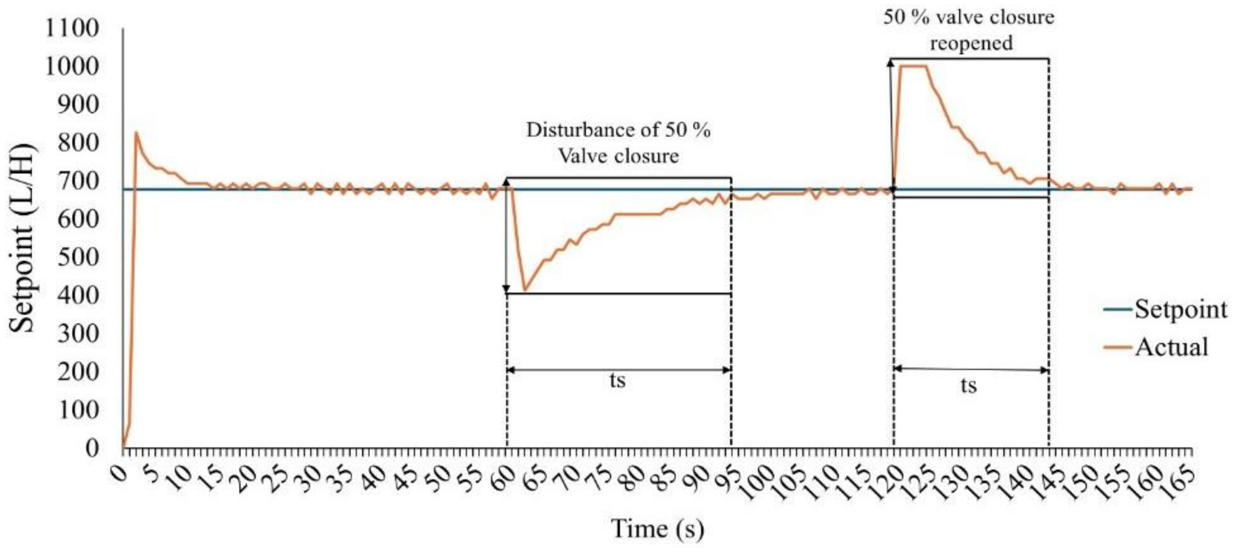


Figure 18. Pump power utilization at set point 678 *L/H*

At a set point of 678 *L/H*, testing is also carried out with disturbance in the form of a 50% valve closure, the following system response when there is a disturbance in Figures 19 and 20.



Notes
*Settling time (ts) with 50 % valve closure disturbance = 35 s
*Settling time (ts) when 50 % valve closure reopened = 25 s

Figure 19. System response at set point 678 *L/H* with disturbance in the form of 50% valve closure

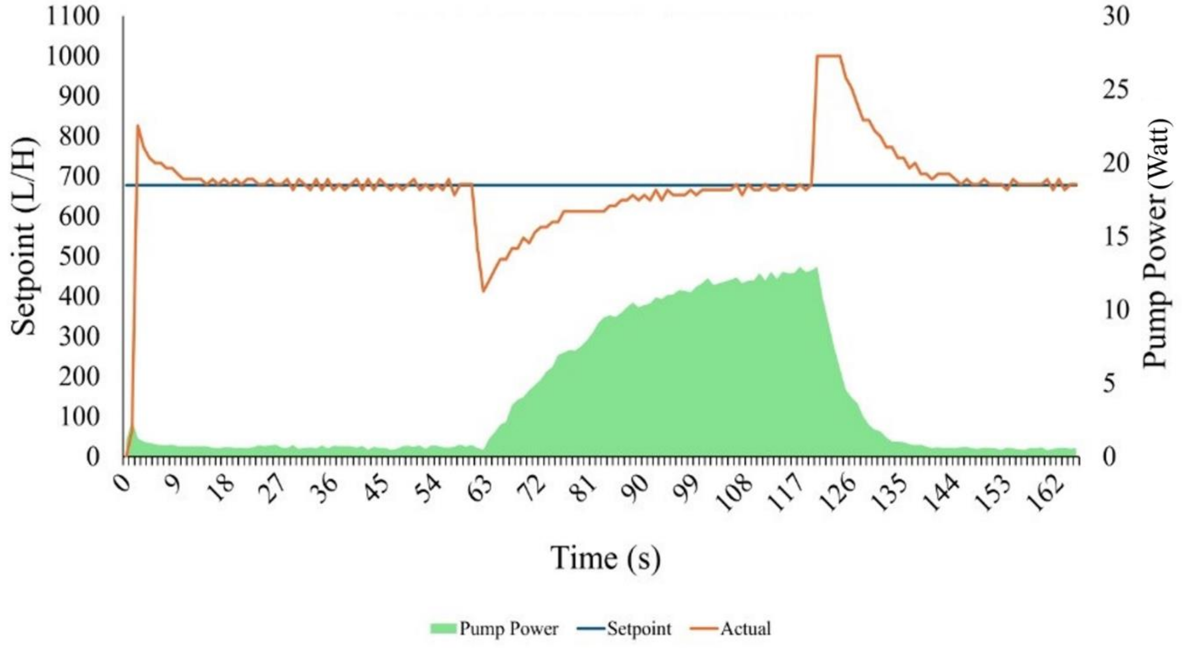


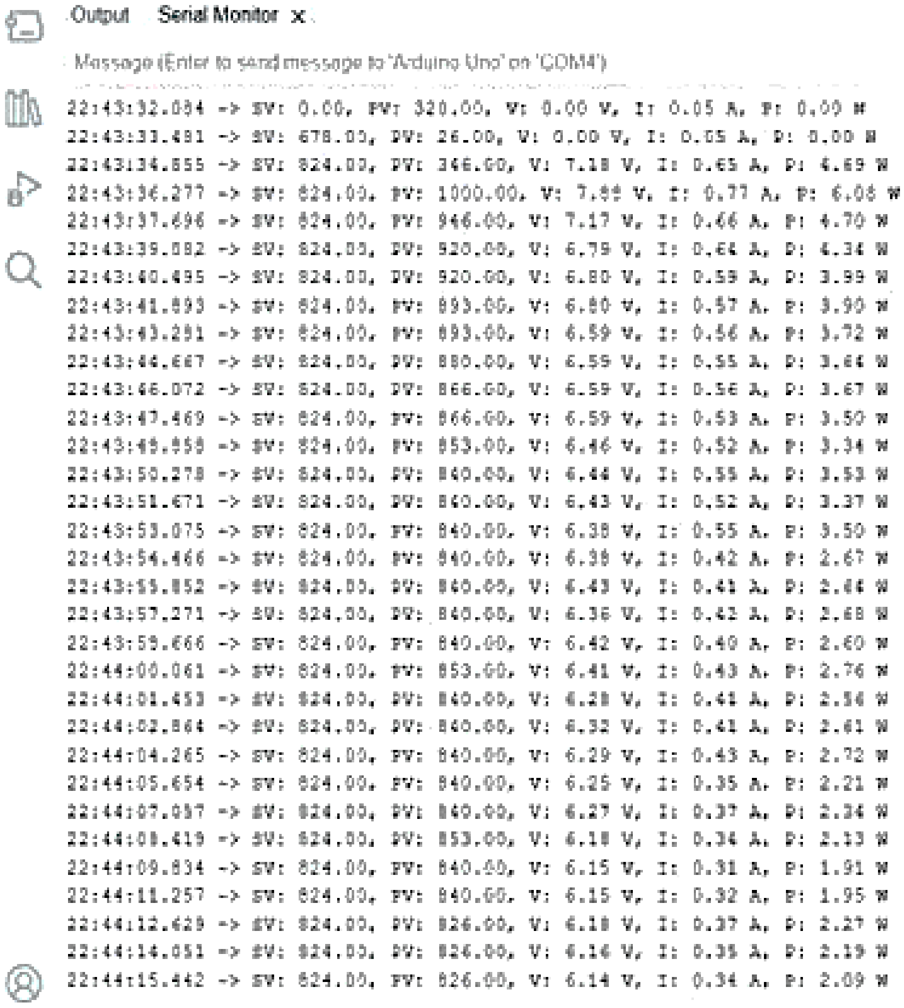
Figure 20. Pump power utilization at 678 *L/H* set point system response with disturbance in the form of 50% valve closure

In Figures 19 and 20, when the valve is closed by 50%, there is a decrease in the actual discharge reading. This makes the system experience a disturbance that affects the water discharge. In response to this disturbance, the system will send an error signal to the controller. After receiving the error signal, the controller is then tasked with adjusting the pump operation, which includes adjusting the voltage, current, and power, so that the actual discharge returns to the predetermined set point of 678 *L/H*. The time required for the system to return to stability, or Settling Time (ts) when given a disturbance in the form of valve closure by 50% at a set point of 678 *L/H* is 35 seconds. This is characterized by a significant increase in the power used by the pump, this happens so that the discharge returns to the set point.

Then, after the system reaches stability in accordance with the set point, the valve which was previously closed by 50% is then fully opened again which results in a spike in the actual discharge reading. The system then detects this spike as an error signal. In response to the error signal, the system sends another error signal to the controller to adjust the pump operation. The time required for the system to return to stable at the set point of 678 *L/H* after the valve is fully opened is about 25 seconds marked by a significant decrease in the power used by the pump, this significant decrease in power occurs so that the system returns to the predetermined set point. This test shows the efficiency and responsiveness of the system in maintaining the stability of the discharge according to the desired set point, despite the disturbance in the valve setting. Then the average power required during the test with a 50% valve closure disturbance was only 4.01 Watts. This shows that the system is not only responsive but also efficient in regulating power during the pump operational adjustment process to maintain the discharge at the desired level.

3.2.4 824 *L/H* set point testing

The readings from the system will also be displayed on the serial monitor as shown in Figure 21 which is the result of the system reading at set point 824 *L/H* displayed on the serial monitor. Furthermore, Figure 22 is the result of the system response readings that have been processed from the readings displayed on the serial monitor so that it becomes a system response graph for the 824 *L/H* set point.



```
22:43:32.034 -> SV: 0.00, PV: 320.00, V: 0.00 V, I: 0.05 A, P: 0.00 W
22:43:33.481 -> SV: 678.00, PV: 26.00, V: 0.00 V, I: 0.05 A, P: 0.00 W
22:43:34.855 -> SV: 824.00, PV: 346.00, V: 7.18 V, I: 0.65 A, P: 4.69 W
22:43:36.277 -> SV: 824.00, PV: 1000.00, V: 7.88 V, I: 0.77 A, P: 6.06 W
22:43:37.696 -> SV: 824.00, PV: 946.00, V: 7.17 V, I: 0.66 A, P: 4.70 W
22:43:39.082 -> SV: 824.00, PV: 920.00, V: 6.79 V, I: 0.64 A, P: 4.34 W
22:43:40.495 -> SV: 824.00, PV: 920.00, V: 6.80 V, I: 0.59 A, P: 3.99 W
22:43:41.893 -> SV: 824.00, PV: 893.00, V: 6.80 V, I: 0.57 A, P: 3.90 W
22:43:43.291 -> SV: 824.00, PV: 893.00, V: 6.59 V, I: 0.56 A, P: 3.72 W
22:43:44.667 -> SV: 824.00, PV: 880.00, V: 6.59 V, I: 0.55 A, P: 3.64 W
22:43:46.072 -> SV: 824.00, PV: 866.00, V: 6.59 V, I: 0.56 A, P: 3.67 W
22:43:47.469 -> SV: 824.00, PV: 866.00, V: 6.59 V, I: 0.53 A, P: 3.50 W
22:43:48.858 -> SV: 824.00, PV: 853.00, V: 6.46 V, I: 0.52 A, P: 3.34 W
22:43:50.278 -> SV: 824.00, PV: 840.00, V: 6.44 V, I: 0.55 A, P: 3.53 W
22:43:51.671 -> SV: 824.00, PV: 840.00, V: 6.43 V, I: 0.52 A, P: 3.37 W
22:43:53.075 -> SV: 824.00, PV: 840.00, V: 6.38 V, I: 0.55 A, P: 3.50 W
22:43:54.466 -> SV: 824.00, PV: 840.00, V: 6.38 V, I: 0.42 A, P: 2.67 W
22:43:55.852 -> SV: 824.00, PV: 840.00, V: 6.43 V, I: 0.41 A, P: 2.64 W
22:43:57.271 -> SV: 824.00, PV: 840.00, V: 6.36 V, I: 0.42 A, P: 2.68 W
22:43:58.666 -> SV: 824.00, PV: 840.00, V: 6.42 V, I: 0.40 A, P: 2.60 W
22:44:00.061 -> SV: 824.00, PV: 853.00, V: 6.41 V, I: 0.43 A, P: 2.76 W
22:44:01.453 -> SV: 824.00, PV: 840.00, V: 6.28 V, I: 0.41 A, P: 2.56 W
22:44:02.864 -> SV: 824.00, PV: 840.00, V: 6.32 V, I: 0.41 A, P: 2.61 W
22:44:04.265 -> SV: 824.00, PV: 840.00, V: 6.29 V, I: 0.43 A, P: 2.72 W
22:44:05.654 -> SV: 824.00, PV: 840.00, V: 6.25 V, I: 0.35 A, P: 2.21 W
22:44:07.057 -> SV: 824.00, PV: 840.00, V: 6.27 V, I: 0.37 A, P: 2.34 W
22:44:08.419 -> SV: 824.00, PV: 853.00, V: 6.18 V, I: 0.34 A, P: 2.13 W
22:44:09.834 -> SV: 824.00, PV: 840.00, V: 6.15 V, I: 0.31 A, P: 1.91 W
22:44:11.257 -> SV: 824.00, PV: 840.00, V: 6.15 V, I: 0.32 A, P: 1.95 W
22:44:12.629 -> SV: 824.00, PV: 826.00, V: 6.18 V, I: 0.37 A, P: 2.27 W
22:44:14.051 -> SV: 824.00, PV: 826.00, V: 6.16 V, I: 0.35 A, P: 2.19 W
22:44:15.442 -> SV: 824.00, PV: 826.00, V: 6.14 V, I: 0.34 A, P: 2.09 W
```

Figure 21. System readings at setpoint 824 *L/H* on serial monitor

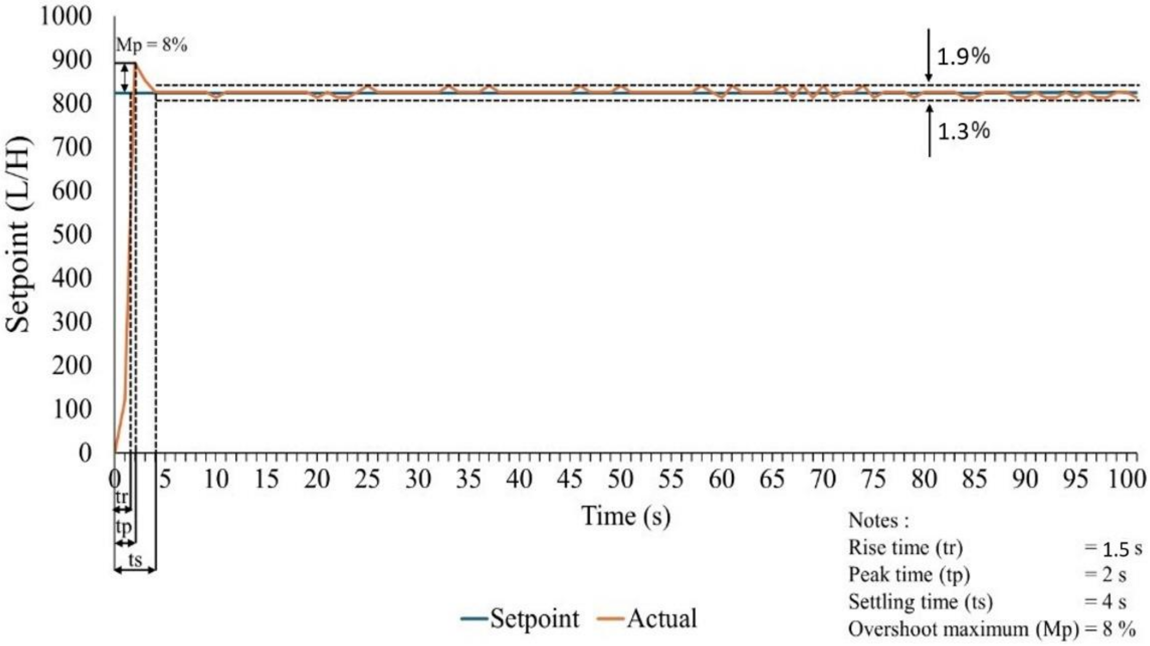


Figure 22. System response at set point 824 *L/H*

In Figure 22 the system response with a set point of 824 (*L/H*), which can be concluded that Rise Time (tr) = 1.5 seconds, Peak Time (tp) = 2 seconds, then Settling Time (ts) = 4 seconds with a tolerance in accordance with the set point of 1.9% ~ 1.3% and Maximum Overshoot (Mp) is only 8%. In Figure 23 is the average power usage using the pulse width modulation method at a set point of 824 *L/H* of only 2.01 Watts.

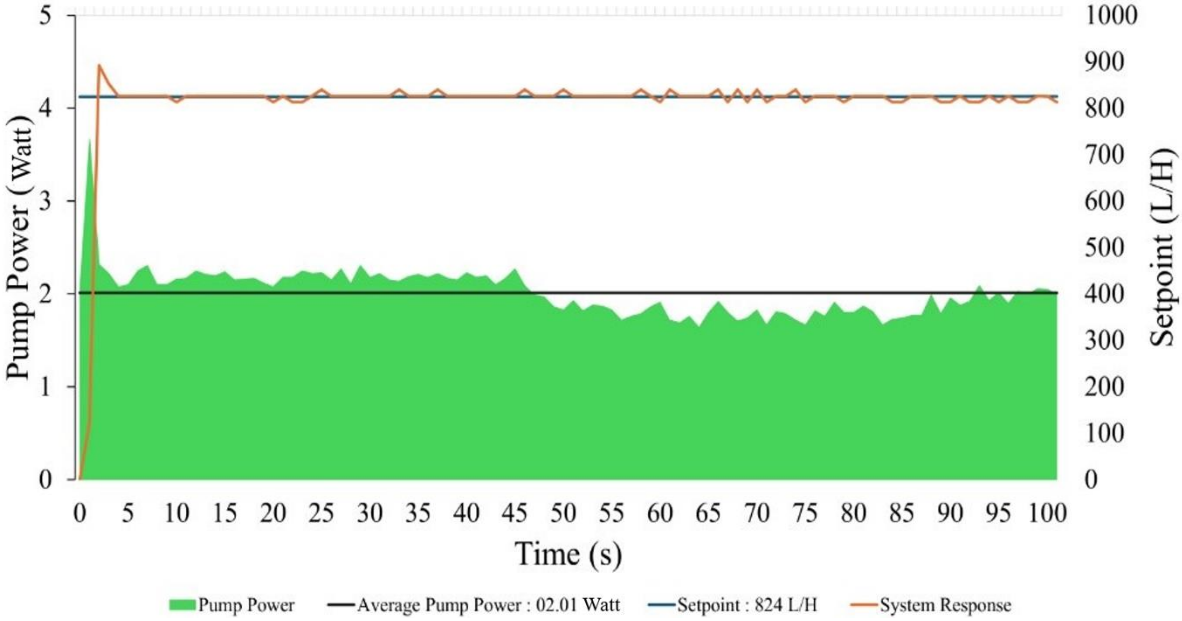
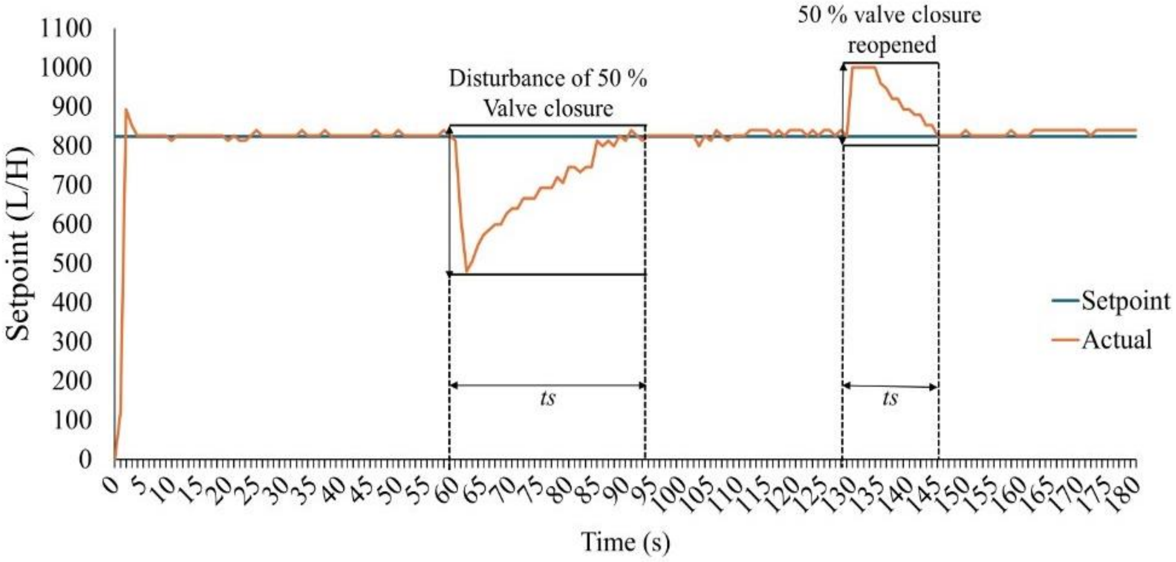


Figure 23. Pump power utilization at set point 824 *L/H*

Then, at a set point of 824 *L/H*, testing is also carried out with a disturbance in the form of a 50% valve closure, the following system response when there is a disturbance in Figures 24 and 25.



Notes
*Settling time (ts) with 50 % valve closure disturbance = 35 s
*Settling time (ts) when 50 % valve closure reopened = 17 s

Figure 24. System response at set point 824 *L/H* with disturbance in the form of 50% valve closure

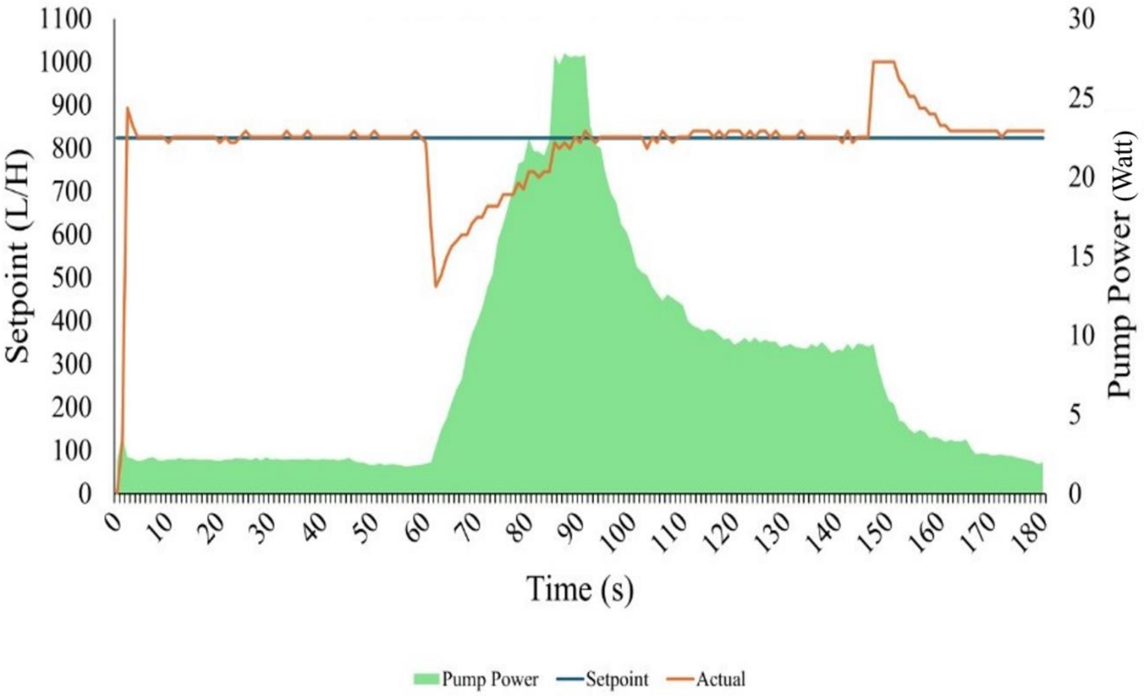


Figure 25. Pump power utilization at 824 *L/H* set point system response with disturbance in the form of 50% valve closure

In Figures 24 and 25, when the valve is closed by 50%, there is a decrease in the actual debit reading. This indicates that the system is experiencing a disturbance that affects the water discharge. In response to this disturbance, the system will send an error signal to the controller. After receiving the error signal, the controller is then tasked with adjusting the pump operation, which includes adjusting the voltage, current, and power, so that the actual discharge returns to the predetermined set point of 824 *L/H*. The time required for the system to stabilize at the set point of 824 *L/H*, or Settling Time (ts) when given a disturbance in the form of valve closure by 50% only takes 35 seconds. This is characterized by an increase in the power used by the pump to bring the discharge back in line with the set point. The increase in power during the adjustment process is very significant. This is because the discharge of 824 *L/H* requires relatively high power.

Furthermore, after the system reaches stability in accordance with the set point, the valve that was previously closed by 50% is then fully opened again. As a result, there is a spike in the actual discharge reading. The system then detects this spike as an error signal. In response, the system sends another error signal to the controller to adjust the pump operation. The time taken for the system to stabilize at the set point of 824 *L/H* after the valve was fully opened was approximately 17 seconds, characterized by a gradual decrease in the power used by the pump to return to the predetermined set point. This test process shows the efficiency and responsiveness of the system in maintaining the stability of the discharge according to the desired set point, despite the disturbance of the valve settings. The average power required during the test with a 50% valve closure interruption at a set point of 824 *L/H* was only 7.85 Watts. This shows that the system is not only responsive but also efficient in regulating power during the pump operational adjustment process to maintain the discharge at the desired level. So that from the tests carried out on 4 set points, namely 290, 545, 678, and 824 *L/H*, it produces conclusions that include the system response and the average operational use of the pump (voltage, current, and power) as presented in Table 2 which is a table of conclusions from system testing using pulse width modulation.

Table 2. Conclusion of system testing using pulse width modulation

Parameter	**Setpoint**			
	290 *L/H*	**545 *L/H***	**678 *L/H***	**824 *L/H***
Rise time or tr (s)	6.5	2	1.8	1.5
Peak time or tp (s)	7	3	2	2
Settling time or ts (s)	20	18	15	4
Maximum overshoot or Mp (%)	33	17	22	8
Average voltage (v)	2.70	3.82	4.73	6.16
Average flow (a)	0.10	0.04	0.15	0.33
Average power (Watts)	0.26	0.16	0.72	2.01

3.3 Comparison results of systems that do not use pulse width modulation with systems that use pulse width modulation

Furthermore, this sub chapter will present the results and analysis of the comparison between the system that does not use pulse width modulation and the system that uses pulse width modulation. The focus of this discussion is on the efficiency of the power used for 12 V_{DC} pump operations. More fully and clearly will be shown in Table 3 regarding the comparison between systems that do not use pulse width modulation with systems that use pulse width modulation. from starting the average use of voltage, average use of current, average power to the comparison of power efficiency at 4 types of set points namely 290 *L/H*, 545 *L/H*, 676 *L/H*, and 824 *L/H*.

Table 3. Comparison of system without PWM with system using PWM

Set point	**Without PWM**			**With PWM**			**Power Efficiency (%)**
	Average			Average			
	(V)	(A)	(W)	(V)	(A)	(W)	
290	12.00	2.00	24.00	2.70	0.10	0.26	98.93
545	12.00	2.14	25.68	3.82	0.04	0.15	99.39
676	12.00	2.24	26.88	4.73	0.15	0.72	97.34
824	12.00	2.36	28.32	6.16	0.33	2.01	92.89
Average Power Efficiency							97.13

***V: Voltage, A: Ampere, W: Watt**

Therefore, it can be concluded that to be stable at a set point of 290 *L/H* only requires an average power of 0.26 Watts, set point 545 *L/H* requires an average power of 0.16 Watts, set point 676 *L/H* requires an average power of 0.72 Watts and at set point 824 *L/H* only 2.01 Watts. Figure 26 presents a comparison image of the average power required between the system without PWM and the system using PWM.

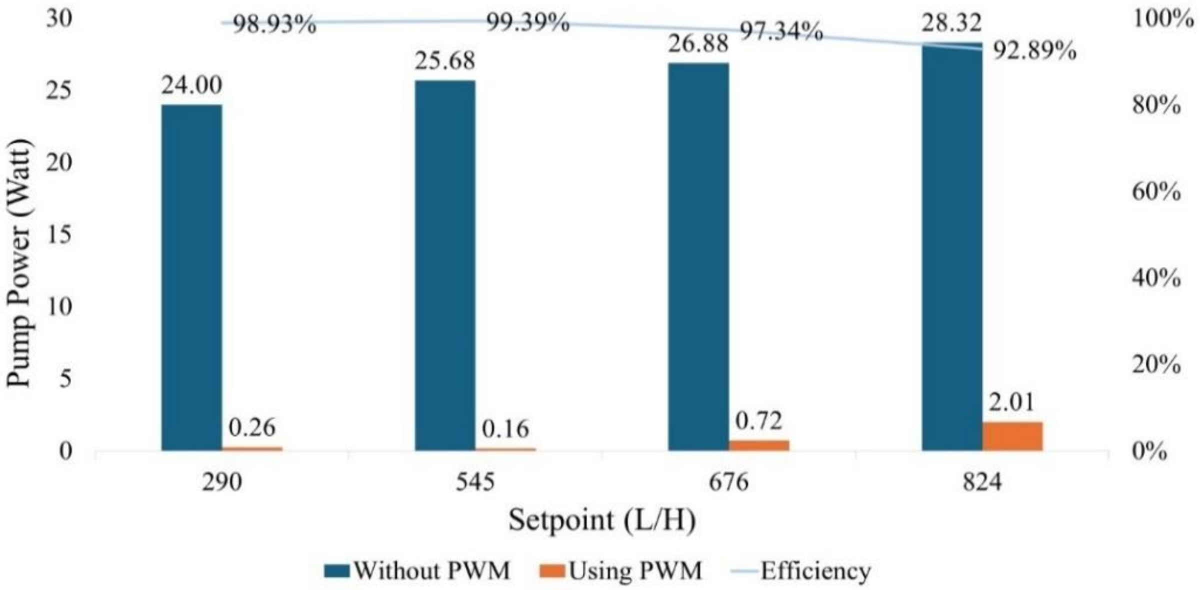


Figure 26. Power average comparison efficiency

Based on the test results and analyses presented in the form of graphical images in Figure 26, it is noted that:

a. At a set point of 290 *L/H*, the use of the pulse width modulation method resulted in an average power consumption of 0.26 Watts, a very significant decrease when compared to the power consumption without the use of PWM of 24 Watts. This shows the achievement of system power efficiency of 98.93%.

b. For a set point of 545 *L/H*, the average power required is only 0.16 Watts with the pulse width modulation method, compared to 25.68 Watts without the use of the pulse width modulation method. At this set point, the system power efficiency is 99.39%.

c. When the system is operated at a set point of 676 *L/H*, the average power consumption required is only 0.72 Watts with the use of the pulse width modulation method, while without the use of pulse width modulation the power consumption is 26.88 Watts. This indicates that the system achieves a very significant efficiency of 97.34%.

d. At a set point of 824 *L/H*, the system only requires an average power of 2.01 Watts using the pulse width modulation method, compared to the system without the pulse width modulation method which is 28.32 Watts. At a set point of 824 *L/H*, the efficiency increase was recorded at 92.89%.

Therefore, from four different set points, the average efficiency is 97.13% compared to systems that do not use the pulse width modulation method.

4 Conclusions

In designing a water pump control system using the pulse width modulation method using Arduino UNO R3 as a controller, potentiometer as set point input, BTS7960 driver as a pump driver, water flow sensor YF-S201 as feedback, equipped with a 0-25 V_{DC} voltage sensor and ACS712 5A current sensor then I2C 20x4 LCD is used as a display that displays several parameters such as set point discharge, actual discharge, voltage, current, and pump operational power. The application of the Pulse width modulation method in controlling water discharge produces an effective effect in achieving the right discharge set point, in this study 4 set points were tested, namely 290 *L/H*, 545 *L/H*, 676 *L/H*, and 824 *L/H*, using the pulse width modulation method allows adaptive adjustment of the pump motor speed, and makes more efficient use of power compared to systems that do not use pulse width modulation. The application of the Pulse width modulation method greatly affects the power efficiency as in the 290 *L/H* set point which only requires an average power of 0.26 Watts or 98.93% more efficiency than a system that does not use pulse width modulation, at a set point of 545 *L/H* the average operational power is only 0.16 Watts or 99.39% more efficiency than a system that does not use pulse width modulation, then at a set point of 676 *L/H* requires an average power of 0.72 Watts or 97.34% more efficient than a system that does not use pulse width modulation, while at set point 824 *L/H* the average power is 2.01 Watts or 92.89% more efficient than a system that does not use pulse width modulation. Therefore, from the 4 set points, if they are averaged, then the efficiency is 97.13% compared to the system without using PWM.

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