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Design of Industrial Internet of Things (IIoT) for Monitoring and Remote Control of Photovoltaic Pumped Hydroelectric Storage system

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***Abstract*— In this study design of Industrial Internet of Things (IIoT) for monitoring and remote control of Photovoltaic Pumped Hydroelectric Storage (PHES) system is presented. The IIoT helps in monitoring key parameters such as water levels, voltage, current, flow rate, valve angle, and turbine speed. It also helps in controlling components including the pump and valve, and is configured to operate a single turbine at a time, with the flexibility to upgrade to larger or smaller alternatives. Various sensor were installed at carefully selected height along the water tank and the IIOT network was used to acquire the data collected by those sensors. The analysis conducted on the IIOT acquired dataset shows that the tank discharge time, tank recharge time and water wheel rotational speed have similar relationship with the water height in the tank. Similarly, the flow rate and the power output have similar relationship with the water height in the tank. The correlation result shows that the power output has perfect correlation of 1 with the water height followed by the flow rate with correlation of 0.9992. Equally, the other three parameters, namely the tank discharge time, tank recharge time and water wheel rotational speed have correlation of o,9972, 0.987 and 0.9897. In all, the results showed that with the knowledge of the water height, it is possible to estimate the power output of the solar hydro power plant being studied. This results therefore justifies the use of the IIoT in the monitoring and control of the solar hydro power plant.**

Keywords*— Monitoring System, Remote Control Mechanism, Industrial Internet of Things (IIoT) , Photovoltaic, Pumped Hydroelectric Storage system

1. Introduction

Today, internet of things (IoT) has greatly transforms the monitoring and control facilities across the globe p1,2,3]. Their application in the industrial sector is termed industrial internet of things (IIoT) [4]. With IIoT robotic machines, heavy duty plants among many components and systems in various industries are monitored and controlled using the IIoT network [4,5].

In practice, IIoT enables sensors that are located at strategic points or attached to selected system components are used to collect relevant data items in real-time and transmit same to a designated server or storage facility where the data can be accessed and utilized [6,7,8]. In the present study, the focus is on the IIoT applied to monitoring and remote control of photovoltaic pumped hydroelectric storage system [9,10,11]. The essence of the IIoT is to enable the automatic collection of the operating parameters of the solar hydro power plant with possible application of the data to the enhancement of the system performance and also to carry out data driven control of the system [12,13,15]. Such approach particularly important in this era of smart technologies and stems which can automatic adjust itself to optimize its performance and adapt affectively to changing operating conditions.

2. *Methods*

This study examined a solar-powered pumped hydroelectric system that utilizes water wheels to generate electricity, with focus on design and integration of Industrial Internet of Things (IIoT) capabilities for real-time monitoring and control. A numbed of sensors and actuators (shown in Figure 1 to Figure 10) are used to accomplish the project. The Arduino Uno processes sensor data and controls the actuator [16]. On the other hand, the ESP8266 module handles the communication with the Firebase Realtime Database [17]. The system monitors key parameters such as water levels, voltage, current, flow rate, valve angle, and turbine speed. It also controls components including the pump and valve, and is configured to operate a single turbine at a time, with the flexibility to upgrade to larger or smaller alternatives. The control code includes modular features that support customizable parameters such as blade size and gear ratio. This enables easy monitoring of the key parameters of the power system at various height of the tank. The data captured through the IoT can be used to conduct further research. In this work, the sample dataset acquired by the IoT is used to study the variation of the key parameters with the tank stand.

2.2 Sensors

The following sensors and actuators are used to measure parameters for monitoring, data capturing and control of Photovoltaic Pumped Hydroelectric Storage (PHES) system;

2.2.1 The Sensors

i. **Water Level Sensors (Overhead Tank and Underground Reservoir)**
Model: HC-SR04 Ultrasonic Sensor (2 units) [18].
Purpose: Measuring of the water levels in the tanks

Figure 1: HC-SR04 Ultrasonic Sensor.

ii. **Voltage Sensor**
Model: Voltage Divider Module (25V max)
Purpose: Measurement of the generator voltage output

Figure 2: Voltage Divider Module (25V max).

iii. **Current Sensor**
Model: ACS712 (5A version) [19]
Purpose: Measures the current output of the generator.

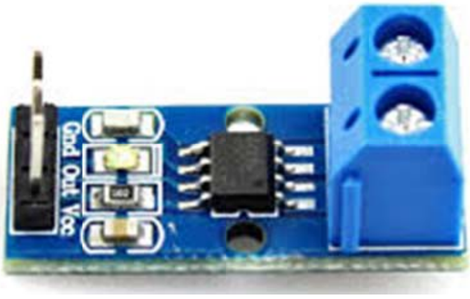

Figure 3: ACS712 (5A version).

iv. **Flow Sensor**
Model: YF-S201 [20]
Purpose: Measures the flow rate of water through the turbine (ANN input parameter).

Figure 4: YF-S201.

v. **Valve Angle Sensor**
Model: 10kΩ Potentiometer
Purpose: Measures the angle of the valve controlling water flow (ANN input parameter).

Figure 5: Valve Angle Sensor.

vi. **Turbine Speed Sensor**
Model: A3144 Hall Effect Sensor [21]
Purpose: Measures turbine rotational speed (RPM, ANN input parameter).

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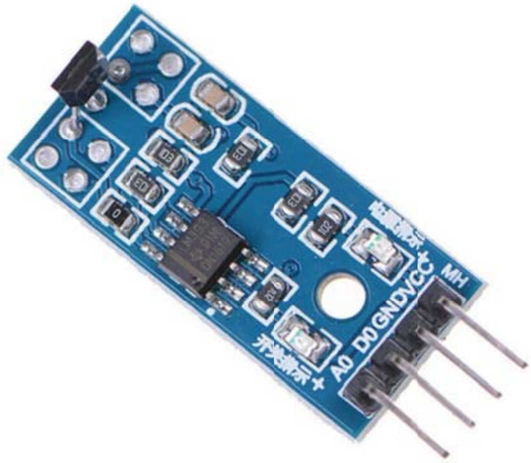


Figure.6: A3144 Hall Effect Sensor.

2.2.2 The Actuators

The following actuators are controlled based on sensor data and Firebase commands.

1. **Pump Relay**

vii. **Model:** 5V Single-Channel Relay Module

Purpose: Controls the electric pump to transfer water from the underground reservoir to the overhead tank.

Figure 7: 5V Single-Channel Relay Module (Pump Relay).

viii. **Valve Servo**

Model: SG90 Micro Servo [22]

Purpose: Adjusts the valve angle to control water flow to the turbine (ANN input parameter).

Figure 8: SG90 Micro Servo.

ix. **Turbine Relays**

Model: 5V Single-Channel Relay Module (6 units)

Purpose: Controls and stabilizes power fluctuations .

Figure 9: 5V Single-Channel Relay Module (Turbine Relay).

x. **ESP8266 (WiFi Module):**

Model: ESP-01

Purpose: Handles WiFi communication to send sensor data to Firebase and receive control commands.

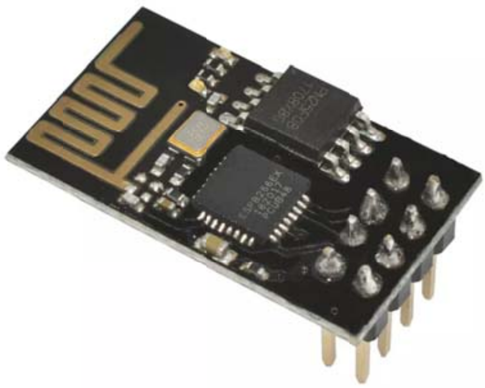


Figure 10: ESP8266 WiFi Module.

2.3 The design of the IIOT

The system employs an Arduino Uno for sensor data processing and actuator control, and an ESP8266 for communication with Firebase Real-time Database. The system monitors water levels, voltage, current, flow rate, valve angle, and turbine speed, and controls a pump, valve, and turbine upgrade. The IIOT circuit diagram is presented in Figure 11. The IIOT Circuit Diagram Components are summarized in Table 1.

In the circuit diagram of Figure 11, all red wires represent the positive DC power lines and are connected to all sensors and actuators from the power rail to the Arduino Uno board. All black wires represent the ground (GND) or neutral DC power lines and are similarly connected to all sensors and actuators, completing the power loop to the Arduino Uno. All data signal wires are color-coded to differentiate the type of signal they carry (e.g., cyan, brown, yellow, green, purple, lavender, blue, orange, white, gray, pink, dark green, etc.) for easy identification and maintenance.

The some aspects of the algorithms for the IIoT control, monitoring, and communication are present as Algorithm I for the Arduino Uno Module and Algorithm II for the ESP8266 Module. Also, the flowchart visualization of Arduino Uno pseudo code is presented in Figure 12 while the flowchart visualization of ESP8266 pseudo code is presented in Figure 13.

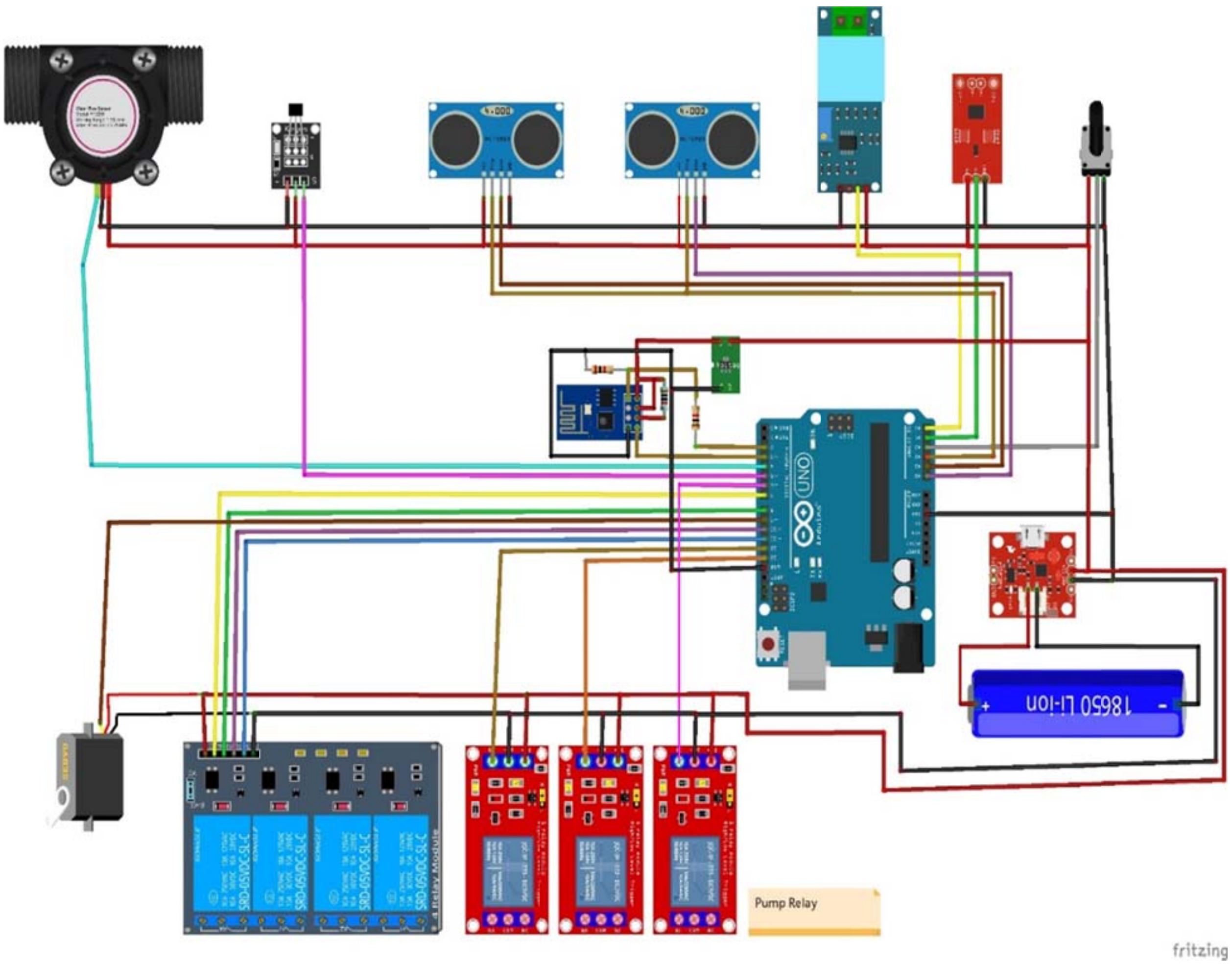


Figure 11: The IIOT circuit diagram.

Table1: The IIOT Circuit Diagram Components

S/N	Component	Function
1	YF-S201 Water Flow Sensor	Measures the flow rate within the pipe.
2	A3144 Hall Effect Sensor	Detects turbine speed (RPM) through magnetic pulses.
3	HC-SR04 Ultrasonic Sensors (×2)	Monitor water levels in both the overhead tank and the underground reservoir.
4	DHT11/DHT22 Sensor	Reads ambient humidity and supports environmental monitoring.
5	ACS712 Current Sensor	Measures the electrical current output from the generator.
6	10kΩ Potentiometer	Measures the angular position of a control valve.
7	Voltage Divider (two resistors)	Steps down voltage to a level suitable for Arduino input.
8	ESP8266 Wi-Fi Module	Transmits sensor data to the cloud for remote monitoring and control.
9	AMS1117 Voltage Regulator (3.3V)	Converts 5V to 3.3V to safely power the ESP8266.
10	Arduino Uno	Serves as the central microcontroller, processing sensor inputs and outputs.
11	16×2 LCD Display (with I2C)	Displays system data such as voltage, flow rate, and status updates.
12	Relay Modules (4-channel + 3-channel = 7 relays total)	Control up to six turbines (alternative operation) and one water pump.

ALGORITHM I: Algorithm for the Arduino Uno Module

1) **Reads sensors:** water level (overhead tank, underground reservoir), voltage, current (ACS712 30A), flow rate, valve angle, turbine speed.
2) **Controls actuators**: pump relay, valve servo, turbine relays.
3) Sends sensor data to ESP8266 via SoftwareSerial.
4) Receives (from ESP8266) the control commands (which may include pump state, turbine selection, and valve angle).
5) Displays data on an optional LCD.

ALGORITHM II: Algorithm for the ESP8266 Module

1) Receives sensor data from Arduino Uno.
2) Sends data to Firebase Realtime Database.
3) Retrieves control commands from Firebase and sends them to Arduino Uno.

Parameters:

4) **Inputs:** Flow rate, valve angle, turbine speed (measured); blade size, effective head, power input/gear ratio (fixed, not in code).
5) **Output:** Power output (calculated from voltage and current)..

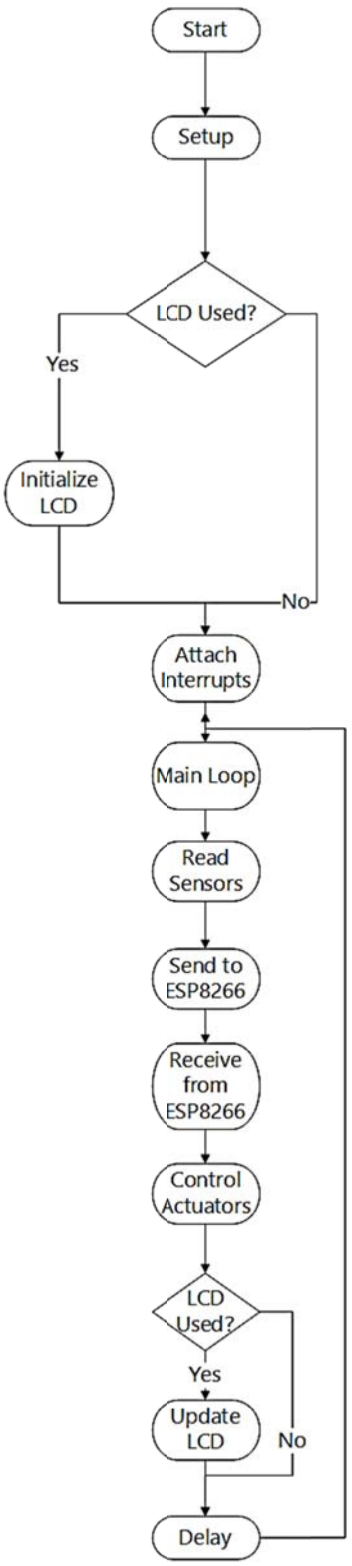


Figure 12: Flowchart Visualization of Arduino Uno Pseudo Code

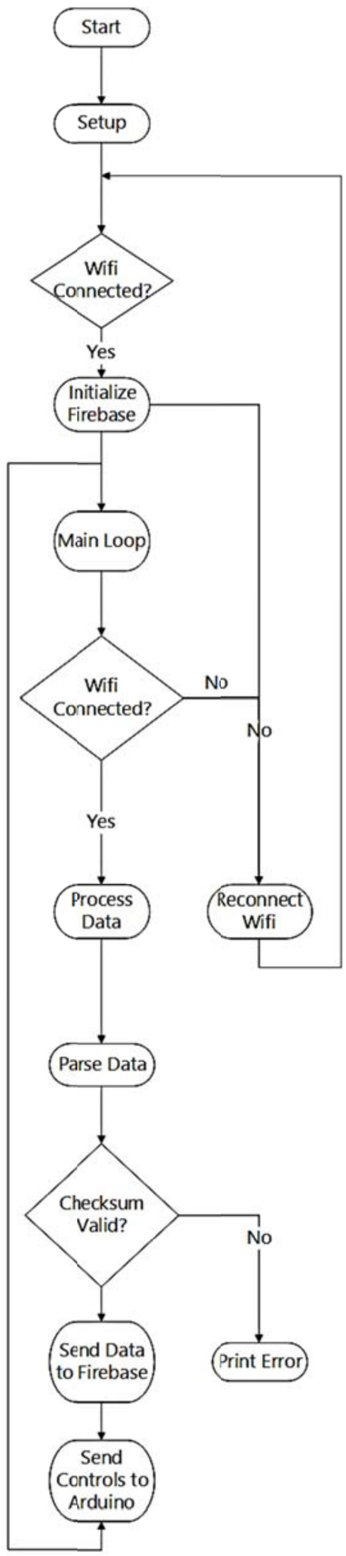


Figure 13: Flowchart Visualization of ESP8266 Pseudo Code.

3. Results and Discussion

Various sensor were installed at carefully selected height along the water tank and the IIOT network was used to acquire the data collected by those sensors. The results of the sample dataset acquired through the IIOT network is presented in Table 1. The graph showing the relationship between the water heights in the tank and the various parameters captured in the dataset of Table 1 are presented in Figure 14 to Figure 18.

The graphs show that the tank discharge time, tank recharge time and water wheel rotational speed have similar relationship with the water height in the tank. Similarly, the flow rate and the power output have similar relationship with the water height in the tank. Accordingly, the correlation result shows that the power output has perfect correlation with the water height followed by the flow rate with correlation of 0.9992. Equally, the other three parameters, namely the tank discharge time, tank recharge time and water wheel rotational speed have correlation of o,9972, 0.987 and 0.9897. In all, the results showed that with the knowledge of the water height, it is possible to estimate the power output of the solar hydro power plant being studied. This results therefore justifies the use of the IIoT in the monitoring and control of the solar hydro power plant.

Table 1 Sample dataset acquired through the IIOT network

Height (m)	Flow rate (m^3/s)	Rotational Speed (rad/s)	Tank Discharge Time (seconds)	Tank Recharge Time (seconds)	Power Output (W)
17.438	0.00088	20.94	4420.8	1176	1800
17.1942	0.00088	17.94	4400.8	1146	1770
16.9504	0.00088	16.94	4390.8	1136	1740
16.7066	0.00088	15.94	4380.8	1126	1710
16.4628	0.00088	14.94	4370.8	1116	1680
16.219	0.00088	13.94	4360.8	1106	1650
15.9752	0.00087	12.94	4350.8	1096	1620
15.7314	0.00087	11.94	4340.8	1086	1590
15.4876	0.00087	10.94	4330.8	1076	1560
15.2438	0.00087	9.94	4320.8	1066	1530
15	0.00087	8.94	4310.8	1056	1500

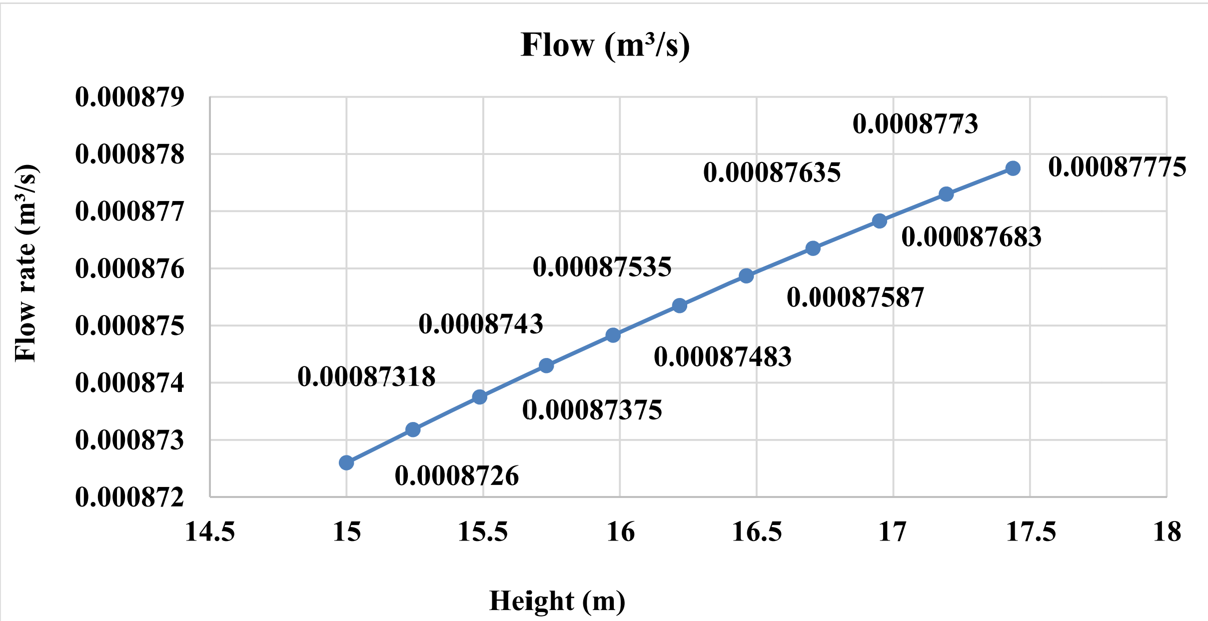


Figure 14 The flow rate versus height of water in the tank

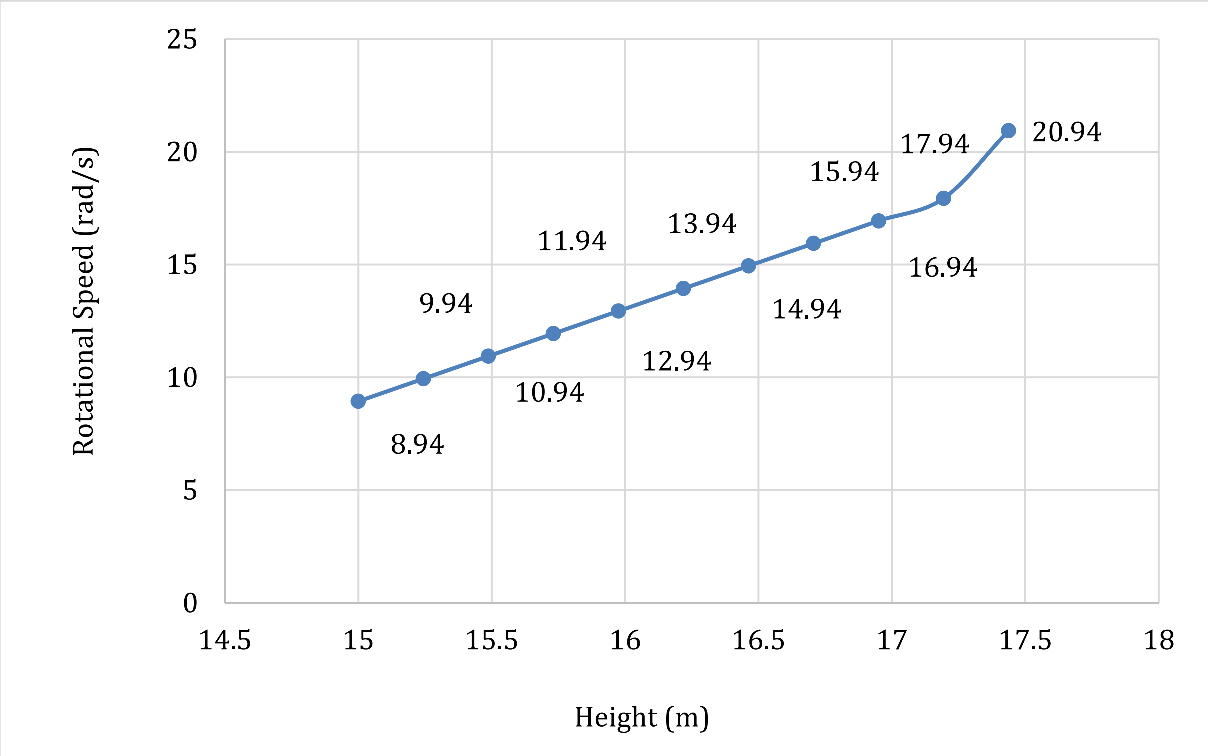


Figure 15 The rotational speed versus height of water in the tank

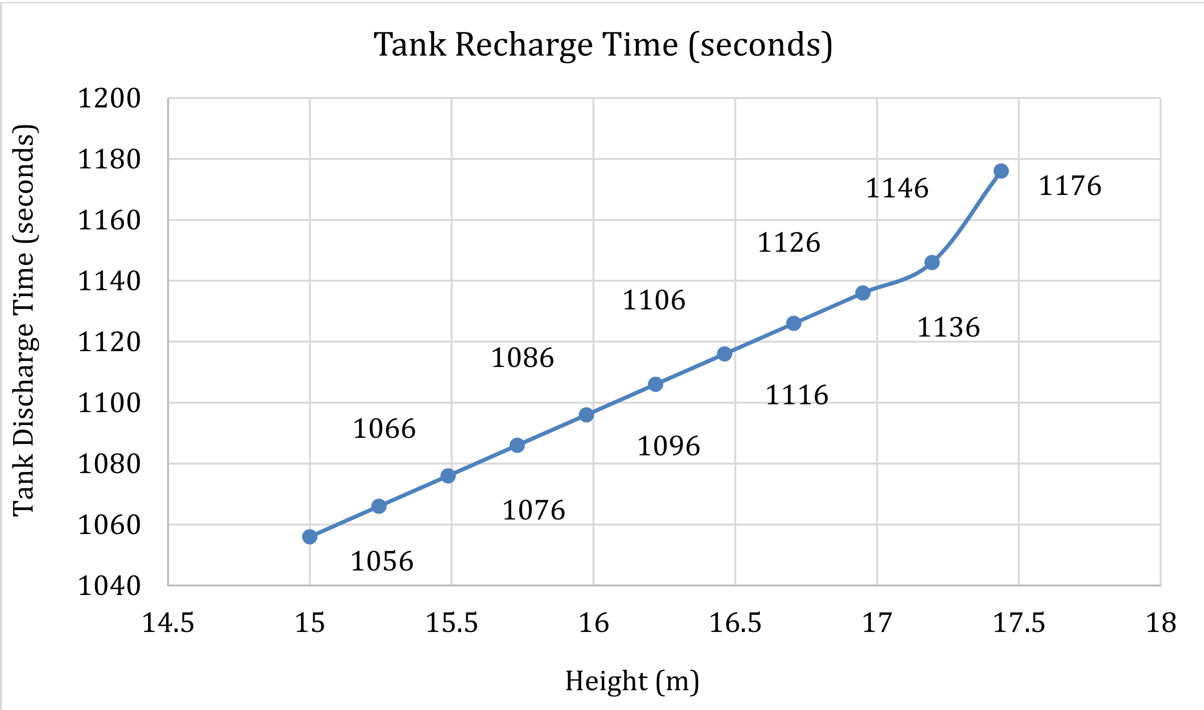


Figure 16 The tank discharge time versus height of water in the tank

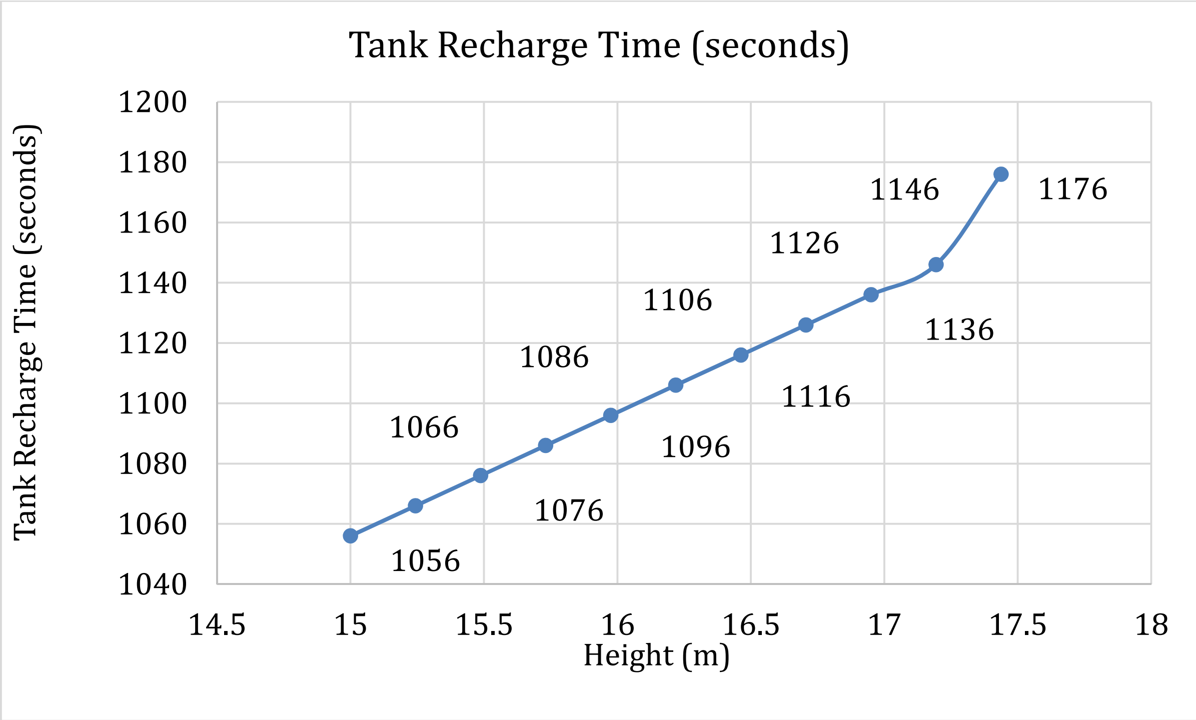


Figure 17 The tank recharge time versus height of water in the tank

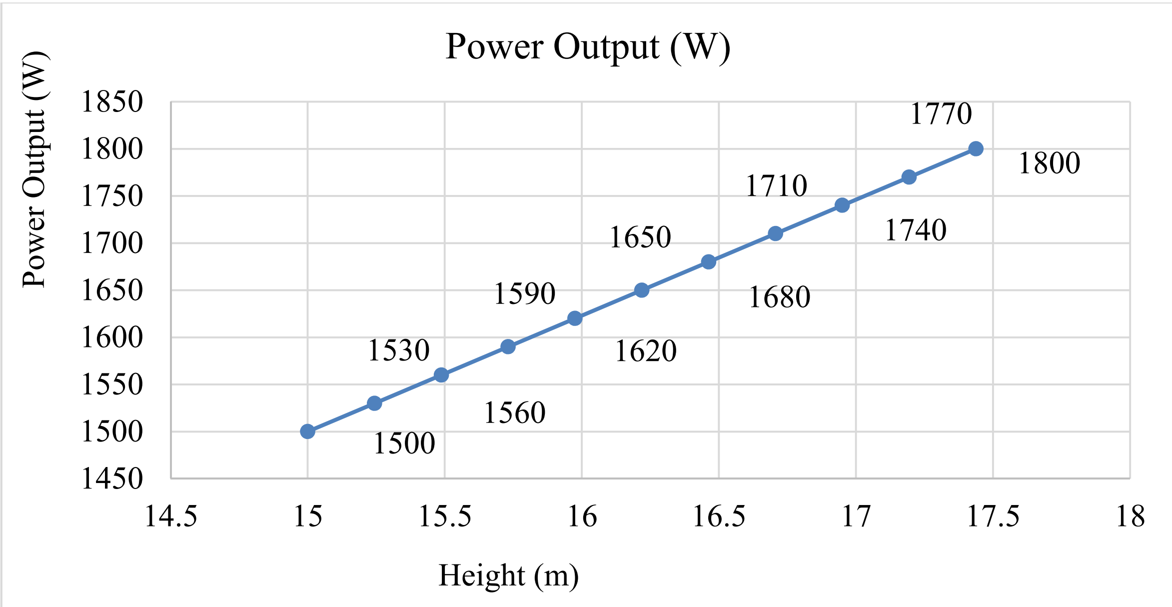
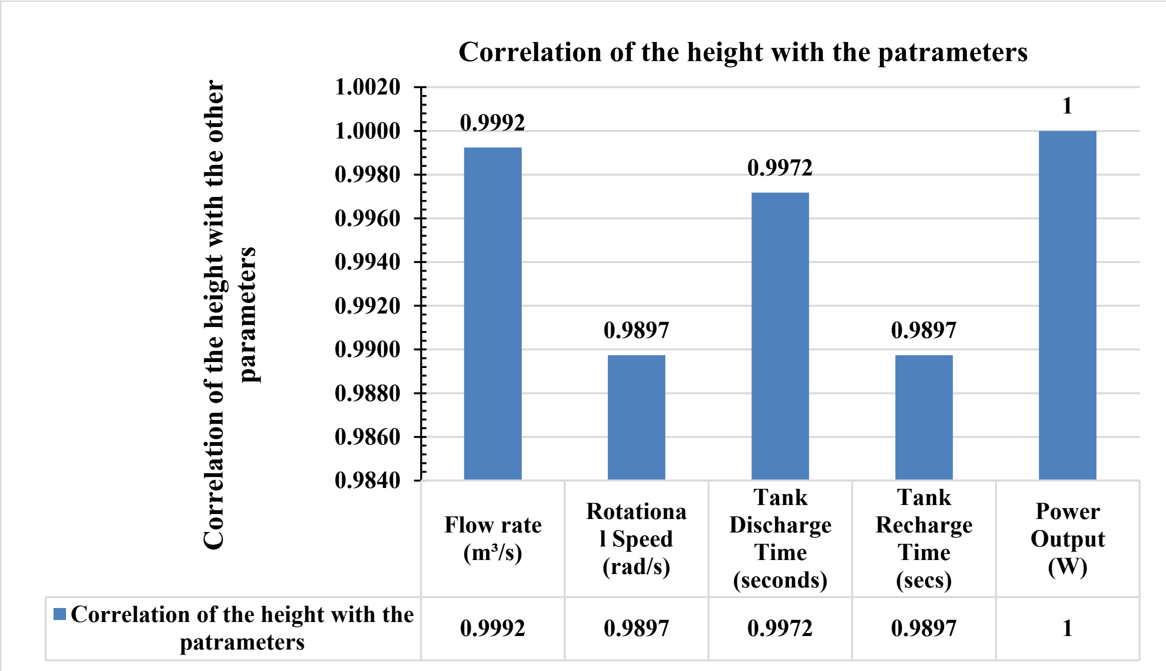


Figure 18 The power output versus height of water in the tank



4. Conclusion

The application of Industrial Internet of Thing (IIoT) to monitoring and control of Photovoltaic Pumped Hydroelectric Storage (PHES) system is presented. The circuit diagram and system components are presented along with algorithms and flow charts that show how the various modules in the system operate are presented. Also, the data captured by the sensors installed at various heights on the water tank are presented as a dataset consisting of six parameters. The relationship of the parameters to the water height in the tank are presented. The results showed high correlation between the water height and the output power. These result makes the IIOT relevant for development of smart renewable energy system that can be controlled using artificial intelligent technologies.

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