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# Integrated IoT Monitoring, Tracking, and Cleaning System for PV Floating Structures

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**Abstract**: Floating solar photovoltaic (FSPV) systems, also known as floatovoltaics, have emerged as promising clean energy solutions with numerous environmental benefits. This paper presents a comprehensive study of FSPV systems, focusing on their advantages, implementation methods, and efficiency analysis. The project involved the development and testing of three key systems: a tracking sun position system, a cleaning robot PV panel system, and an Internet of Things (IoT) monitoring power system. The materials and methods employed in this project are also described, involving the use of various hardware components such as Arduino microcontrollers, sensors, motors, and software tools like Arduino IDE and Blynk. The results and discussion section presents the testing and calibration of voltage and current sensors, the functionality of the tracking sun position system, and the challenges faced in the implementation of the cleaning robot PV panel system. While the cleaning robot system encountered certain motor-related issues, the overall implementation of FSPV systems demonstrated the IoT monitoring power system can help users or engineers monitor floating PV panels successfully.

**Keywords**: Floating Solar Photovoltaic (FSPV), Tracking Sun Position System, Cleaning Robot PV Panel System, Iot Monitoring Power System

## 1. Introduction

Tenaga Nasional Bhd's (TNB) wholly-owned subsidiary TNB Power Generation Sdn Bhd launched its first floating solar farm project on 4 March 2022 [1]. The pilot project would be using floating photovoltaic (PV) solar panels which would be installed at an ash pool at a power station to generate solar energy. The 175-hectare pond which is a dumping ground for ash from the power plant, can now be potentially used as a floating solar farm to generate energy of at least 100 MW. Other places also installed solar farms which as Solarvest Holdings Bhd in Dengkil, Selangor with about 38,790 pieces of solar panels installed on a panel of floaters that extends approximately 53 hectares of a lake surface, equivalent to 30 football fields [2]. The generation from floating solar photovoltaic (FSPV) plants is

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found to be 1.5-3.5% more than ground-mounted PV plants [3]. The single-axis tracking system increases generation efficiency by 18–21% as compared to the fixed-mount plant [3].

Solar energy is classified as a clean and renewable alternative to fossil fuels. With the strong commitments of the national governments around the world toward greenhouse gas (GHG) reduction, solar PV has chosen to play its leading role as a clean technology solution to reduce GHG emissions in the power sector. In this context, floating solar PV systems are acceptable ecological alternative solutions. By covering a significant surface area on a body of water, the FSPV system conserves water by reducing evaporation. FSPV plants, being positioned on the water's surface, provide shade that reduces the amount of solar energy reaching the water and diminishes the interaction between wind and water. These combined benefits may potentially mitigate water evaporation losses [4,5]. More importantly, the natural cooling effect provided by the water allows the PV panels to operate more efficiently and produce more power than traditional ground-mounted systems. As the panels prevent excessive heat from reaching the water bodies, they are cooled, enhancing their energy productivity [6]. Some studies have reported up to a 10% improvement in efficiency compared to land-based PV systems [7,8]. The efficiency of the solar panel and the conversion of light to energy are both impacted by how clean the solar panel surface becomes. Based on literature study also mentions that dirt and bird droppings [9] on the surface of PV panels significantly affect the overall output yield. Some researchers think that it was possible to quantify how much dirt reduced the effectiveness and output of solar PV modules. Additionally, adding tracking of the Sun's position will increase the PV panel's efficiency and allow it to convert more solar radiation into electricity.

## 2. Materials and Method

Figure 1 shows the block diagram for monitoring the power system and tracking system while Figure 2 illustrates the block diagram for the cleaning system.

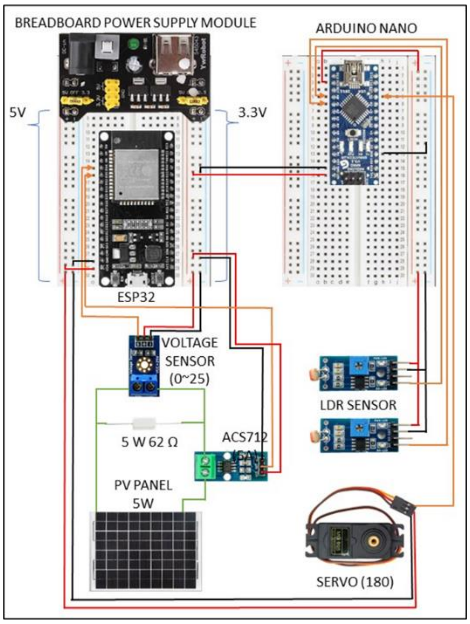


**Figure 1: Block Diagram for Monitoring Power System and Tracking System**

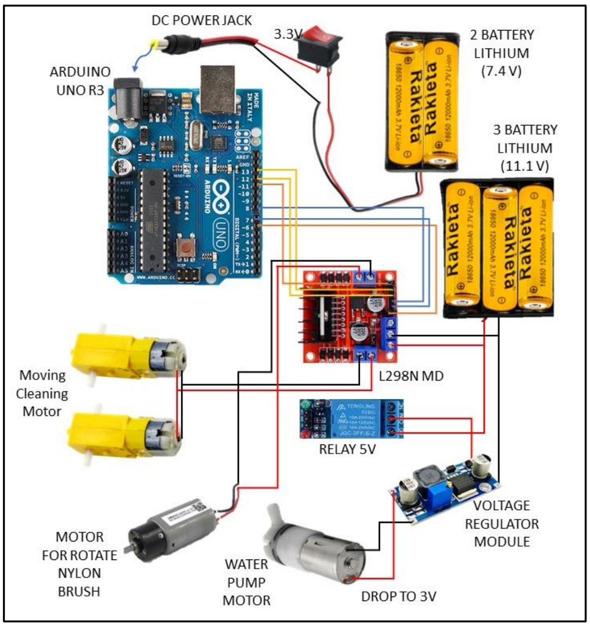


**Figure 2: Block Diagram for Cleaning System**

Based on Figure 1, the circuit connection for the tracking system in block diagram form. Light-dependent resistors (LDR) are used as the sensor to detect the intensity of sunlight while the main heart of this project is Arduino Nano, where all the processing is done to know the position of the sun. A servo motor is used to move the solar panel based on a signal received from Arduino. The process of the system is Arduino processes according to the coding in the Arduino IDE software and calculates the position of the sun by using the LDR. Then, it gives commands to a servo motor to rotate to a certain angle. Another circuit connection in Figure 1 is for monitoring the power system in block diagram form. This project uses using IoT system to get data voltage output, current and power from PV panels by using an Arduino Wi-Fi module such as ESP32. The reason this is a more accurate result in graph form or data is because each data is taken in every minute. A voltage sensor is used to monitor, calculate and determine the voltage from the PV panel. A current sensor is a device that detects and converts current to an easily measurable output voltage, which is proportional to the current through the measured path. The value of the output power from the PV panel will be determined by coding in the Arduino IDE programmed collected data from the voltage and current output from the PV panel. In this paper, IoT systems are created using Blynk apps. The ESP32 component has been programmed to require a mobile hotspot or nearby Wi-Fi. The user of the Blynk apps can see the output from a mobile phone or laptop no matter where the user is if the ESP32 is turned on and has a hotspot or Wi-Fi connection.

Based on Figure 2, the circuit connection for the tracking system is in block diagram form. This project uses a timer and switch ON/OFF to activate the cleaning system by using a microcontroller the Arduino Uno R3 module with L298N Motor Driver and one Relay. The reason chose this L298N MD is it can control 2 motors more easily than using other motor drivers. Two motors will operate as moving cleaning robots on PV panels, and one motor will operate as a rotating cylindrical nylon brush. Another motor which is a water pump that is connected to a relay will operate as a water pump motor for the nylon brush to get wet.

The hardware and software used to complete the project are shown in Table 1. As mentioned before, this project uses three systems: a tracking sun position system, a cleaning robot PV panel system, and an IoT monitoring power system, as shown in Table 1.

**Table 1: List of Hardware and Software Based on System**

| System | Hardware | Software |
|---|---|---|
| Tracking Sun Position | Arduino Atmega328P Nano, Light Dependent Resistor (LDR), MG996 Metal Servo Motor (180 Degree) | Arduino IDE |
| Cleaning Robot PV Panel System | Arduino Compatible UNO R3, 6V DC Motor (200 rpm), 17 mm DC Motor Micro 180 Planetary Gearbox Gear Motor, 12V Water Pump Motor, LM2596 Adjustable Step-Down Voltage Regulator Module 3A, Li-ion Rechargeable Battery 3.7V, Cylindrical Nylon Brush | Arduino IDE |
| IoT Monitoring Power System | NODEMCU ESP32, B25 Voltage Sensor Module, ACS712 5A Current Sensor Module, Breadboard Power Supply Module MD-102 | Arduino IDE, Blynk |

## 3. Results and Discussion

### 3.1. Testing Calibration for Voltage Sensor and Current Sensor

Table 2 shows the comparison of multimeter readings with Blynk app readings. Based on Table 2, the data was collected to obtain accurate voltage and current outputs for the IoT system by comparing the readings from a multimeter. On June 5, 2023, both the voltage and current readings were significantly different from the actual readings as per the recorded data. Consequently, changes need to be made to the algorithm due to mistakes and insufficient information. On June 7, 2023, the voltage reading on the Blynk app closely matched the multimeter reading, but the current reading still differed significantly. To ensure stable readings from the ACS712 current sensor, the input voltage range needs to be adjusted to 4.5 V ~ 5 V. Finally, the tests were successful as both the multimeter readings and the readings on the Blynk app were very close to each other on June 8, 2023.

**Table 2: Comparison of Multimeter Readings with Blynk Apps Readings**

| Date | Test | Multimeter | | Blynk Apps | |
|---|---|---|---|---|---|
| | | Voltage Reading (V) | Current Reading (A) | Voltage Reading (V) | Current Reading (A) |
| 5/6/2023 | 1 | 4.77 | 0.065 | 2.544 | 0.095 |
| | 2 | 4.68 | 0.074 | 2.314 | 0.099 |
| | 3 | 4.96 | 0.079 | 2.765 | 0.097 |
| | 4 | 4.88 | 0.077 | 2.674 | 0.095 |
| | 5 | 5.24 | 0.084 | 2.786 | 0.095 |
| 7/6/2023 | 6 | 15.945 | 0.257 | 15.662 | 0.703 |
| | 7 | 11.566 | 0.186 | 11.218 | 0.734 |
| | 8 | 13.436 | 0.216 | 13.256 | 0.756 |
| | 9 | 13. 892 | 0.226 | 13.567 | 0.654 |
| | 10 | 12.423 | 0.200 | 12.142 | 0.766 |
| 8/6/2023 | 11 | 13.93 | 0.321 | 13.607 | 0.259 |
| | 12 | 14.78 | 0.238 | 15.021 | 0.242 |
| | 13 | 14.89 | 0.240 | 15.070 | 0.243 |
| | 14 | 15.07 | 0.243 | 15.517 | 0.250 |
| | 15 | 14.91 | 0.240 | 15.146 | 0.244 |

The first and second readings of the multimeter and Blynk Apps are shown in Figures 3 and 4, respectively. Based on Figures 3 and 4, the readings based on the multimeter and Blynk apps (an IoT system) are close and acceptable because the output energy based on the input photon is different each time because sunlight and the sun's position cannot remain the same. Other than that, the reading of the multimeter is faster than the IoT system because the coding for the ESP32 had a delay when taking each voltage and current of the PV panel input.

**Figure 3: First Reading of Multimeter and Blynk Apps**

**Figure 4: Second Reading of Multimeter and Blynk Apps**

3.2. Testing Tracking Sun Position System

To test whether the LDR sensor sends a signal to the Arduino Nano, the solar panel handle is initially turned in the opposite direction from the Sun's direction based on Figure 5. The system's coding is successful if the servo rotates in the desired direction after receiving the proper signal from the Arduino Nano.

**Figure 5: The PV Panel Moved According to the Sunlight.**

In accordance with Figure 5, once the solar panel has been initially adjusted against the sunlight, the servo continues to rotate the solar panel holder at a moderate speed while maintaining its orientation towards the direction of the sun. This successful implementation confirms the system's efficacy. After testing the sun position tracking, this project will involve measuring the angle of the servo based on the irradiance of the sun that the PV panel is facing. The following Table 3 provides the servo angles and corresponding times for the PV panel angle based on the sun position system, which operates from 0800 hours to 1700 hours in the 24-hour system. Initially, the servo angle is set to 90° when the Arduino Nano connection is switched ON.

**Table 3: Servo Angles and Corresponding Times for the PV Panel Angle Based on Sun Position**

| Times (hours) | Servo Angle (Degree ° ) |
|---|---|
| 0800 | 170 |
| 0900 | 160 |
| 1000 | 130 |
| 1100 | 105 |
| 1200 | 98 |
| 1300 | 90 |
| 1400 | 85 |
| 1500 | 68 |
| 1600 | 46 |
| 1700 | 34 |

Using the Global Monitoring Laboratory website, the time zone for the specified location, Simpang Renggam (1.776965, 103.308172), and date, June 17, 2023, were determined. Figure 6 depicts the movement of the sun from left to right. The green line represents the sunrise, while the red line indicates the sunset on the map, demonstrating the direction of the sunrise and sunset based on the local time and date input. The solar noon for this location is at 13:07 p.m., and the ideal servo angle during solar noon should be 90°. Comparing this with the servo angle at 13:00 p.m. from Table 3, it is observed that the angle is indeed 90°. The data provided in Table 3 is deemed acceptable, as the sun's movement is depicted from right to left, while the servo angle ranges from 170° to 34°. It is worth noting that the servo cannot reach 180° or 0° due to the limited time frame of data collection, which starts at 8:00 a.m. and ends at 5:00 p.m. The apparent sunrise is observed at 7:01 a.m., and the apparent sunset occurs at 7:14 p.m., as illustrated in Figure 6.

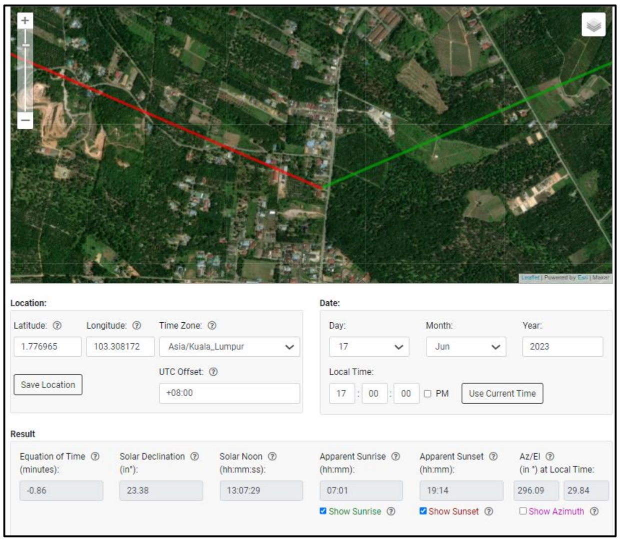


**Figure 6: Sunrise and Sunset Times Based on the Project Location**

### 3.3. Testing Robot Cleaning PV Panel System

In a successful scenario, the Arduino Uno R3 is able to give input with the relay that is turned on at the right moment and then it turns on the water pump at the right moment. Water can be successfully sucked in by the water pump and sprayed onto the solar panel. However, there is a problem with the other three motors that connect with the L298N motor driver. Based on Figure 7, there are four different situations occur such as:

- Sometimes all three motors don't turn on.
- Sometimes the brush motor is on, but the two motors cannot move the robot.
- Sometimes the two motors can move the robot, but the brush motor is not moving.
- Sometimes all the three motors are successfully moving, but only for a while.

Figure 7: Cleaning Robot PV Panel

The reason of other three motors do not move is because not enough current flow or current flow is interrupted by the other motor. So, the solution to this problem is by adding the MOSFET. A MOSFET is a device used to control a motor. It acts like a switch that turns the motor on and off by allowing or interrupting the flow of current by other motors. By adjusting the voltage applied to the MOSFET, it can regulate the amount of current flowing through the motor, which controls its speed.

### 3.4. Result of Monitoring IoT System on Floating PV Panel Type Structure

This section presents findings on PV panel performance, displayed through three graphs showing voltage, current, and power. The floating PV panel-type structure is shown in Figure 8. Data was collected using Blynk Apps as an IoT system, coded on Arduino IDE and uploaded to the ESP32. It is believed that the data was collected correctly because already tested based on Table 2. Voltage was measured using a DC voltage sensor module, current using an ACS712 current sensor, and power was calculated as the product of voltage and current.

**Figure 8: Floating PV Panel Type Structure**

Based on the information provided, three graphs representing the voltage, current, and power of a floating PV panel structure over time are shown in Figures 9, 10 and 11. The x-axis indicates time and the y-axis is voltage, current or power. Based on Figure 9, the highest reading occurred at 11:52 a.m., measuring 18.2606 V, which is approximately 4.34% higher than the nominal voltage of 17.5 V. The red line in the graph represents the 17.5 V reference. When the reading exceeds 17.5 V, the voltage suddenly decreases, possibly due to overload or excessively high temperatures, which can affect the accuracy of the measurements and power loss. Upon observing the graph after 2:00 p.m., the voltage reading appears balanced and stable until it gradually decreases towards 6:00 p.m. This decline is attributed to insufficient sunlight or insufficient brightness, resulting in reduced energy generation from the PV panel.

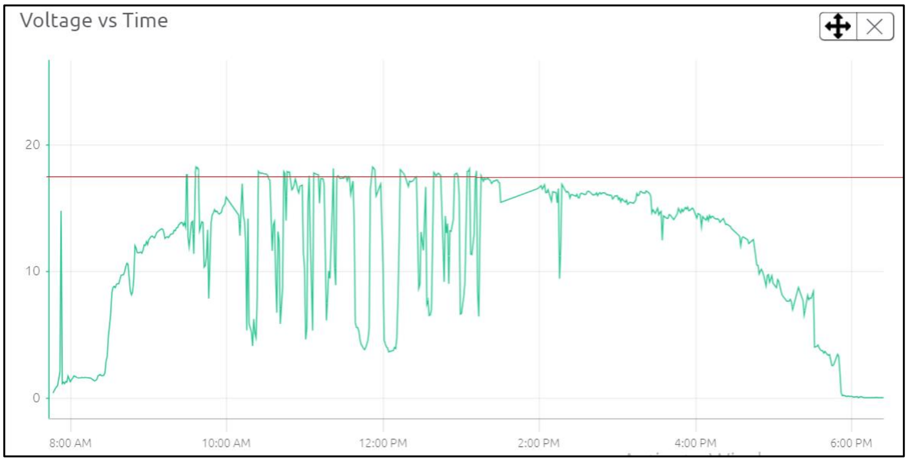


**Figure 9: Graph of Voltage against Time for Floating PV Panel Structure**

Based on Figure 10, the highest reading occurred at 11:52 a.m., measuring $0.2946\ A$, which is approximately 4.34% higher than the nominal current of 0.29 A. The red line in the graph represents the $0.29\ A$ reference. When the reading exceeds $0.29\ A$, the current suddenly decreases, possibly due to overload or excessively high temperatures, which can affect the accuracy of the measurements and power loss. Upon observing the graph after 2:00 p.m., the current reading appears balanced and stable until it gradually decreases towards 6:00 p.m. This decline is attributed to insufficient sunlight or insufficient brightness, resulting in reduced energy generation from the PV panel.

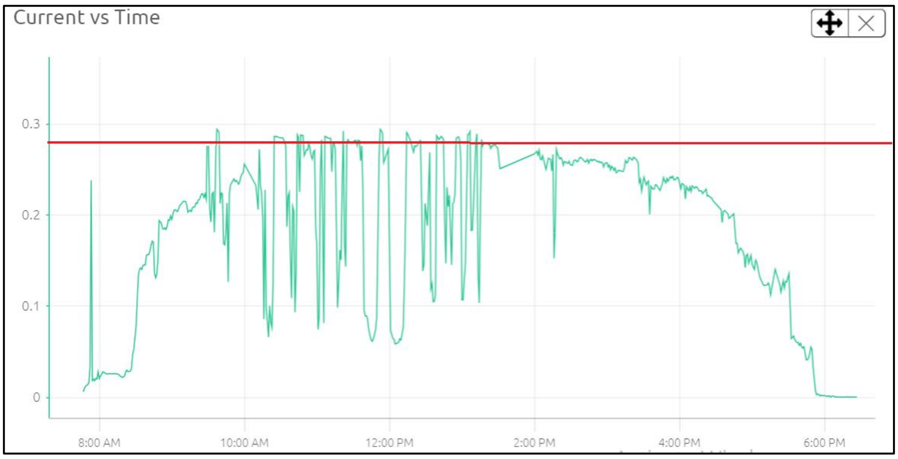


**Figure 10: Graph of Current against Time for Floating PV Panel Structure**

For highest reading power is 5.379 W at 11:52 a.m. based on Figure 11. The reading power is 7.58 % of the maximum power (5 $W$). The situations are also similar with voltage and current possibly due to overvoltage or exceeding high temperatures. For explanation, exceeding the nominal voltage and current rating of a solar panel can lead to overloading. This means that the panel is forced to deliver more current than it is designed for. Overloading can cause the solar panel to heat up, potentially leading to reduced efficiency, accelerated aging, and even damage to the panel. While exceeding the nominal voltage or current may result in an initial increase in power output, it can lead to inefficiencies and power losses in the system. This can result in reduced conversion efficiency and overall system performance. It proved that when analyzing the graph in Figure 12, 2:00 PM has the highest average power of 4.142 $W$. Figure 11 shows the power reading at 11:52 a.m., which is the highest, but after averaging power throughout the day, it becomes lower (below 4 $W$) due to power loss after exceeding the PV panel's nominal voltage and current.

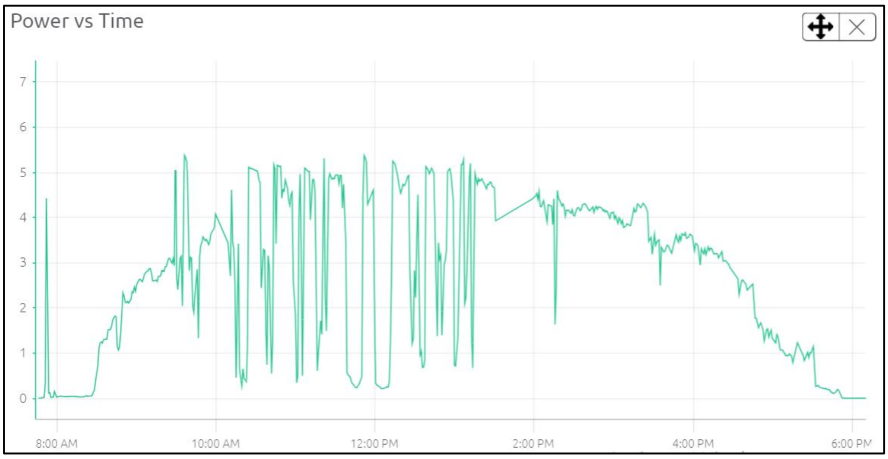


**Figure 11: Graph of Power against Time for Floating PV Panel Structure**

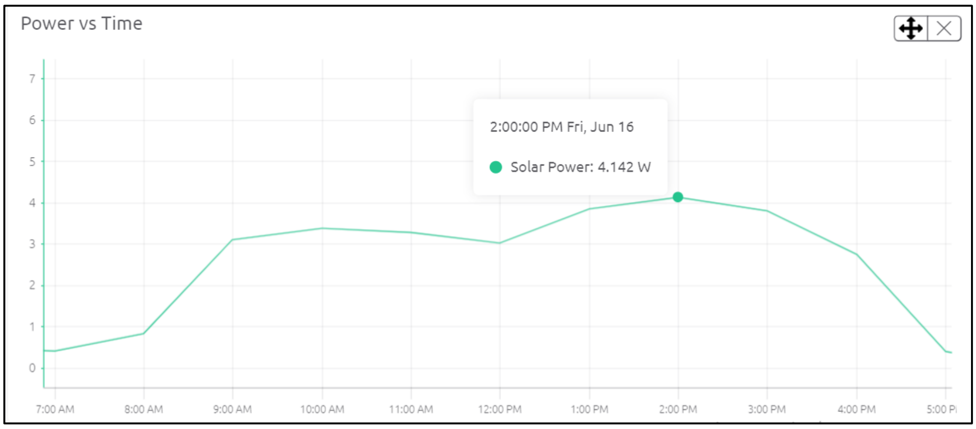


**Figure 12: Graph of Average Power against Time for Floating PV Panel Structure**

Based on that situation, the engineer needs to take action to reduce power loss on floating PV panel such as:

- Examine the wiring connections between the PV panel
- Improve panel cooling
- Consult the professional to evaluate its performance and determine if any maintenance or replacement is required

In the scenario based on Figure 13, the Blynk app is online, but there are no readings despite the sun still being bright. So, to overcome that situation, the technician or engineer responsible for handling the PV panel needs to check and maintenance such as:

i. Examine the panel's surface carefully for any dirt, dust, or anything else that might be impeding sunlight absorption. Use the non-abrasive cleaning techniques advised by the panel's manufacturer to clean the panel. Make sure there are no potential impurities on the panel surface that can interfere with power output.

ii. Look for any damage to the wiring. Examine the wire connections between the inverter, charge controller, and PV panel (if applicable). Keep an eye out for any indications of harm, such as loosened connections or frayed wires. To guarantee a trustworthy electrical connection, repair or replace any broken wire components.

iii. Check the Wi-Fi or internet connection to the IoT system for reliability and functionality: Make sure the IoT system's Wi-Fi or internet connection, which receives and displays readings from the PV panels, is reliable and functional. Verify the device's connectivity and signal strength when it is attached to the PV panel. If required, troubleshoot the connection or reset it.

iv. Verify any system indicators and the inverter: Check for any problem codes or warning signs on the inverter and any other system indicators. Diagnostic capabilities on inverters frequently offer information about the system's performance. For help deciphering error codes and performing troubleshooting procedures, consult the inverter handbook or get in touch with the manufacturer. In accordance with the manufacturer's instructions, take care of any problems that are found.

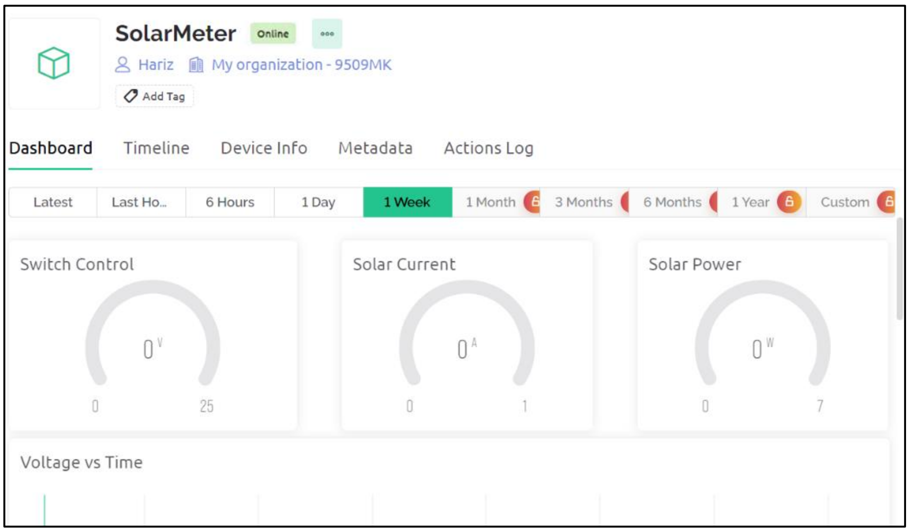


**Figure 13: Reading Zero Output Values on Blynk Apps Online.**

## 4. Conclusion

In conclusion, the implementation of floating photovoltaic panels (PV) in this final year project has shown several activities that have been implemented. First, the tracking of a sun position was also successfully implemented and tested by turning the PV panel holder against the sunlight beam many times and it turned itself towards the sunlight. Besides that, the PV panel cleaning robot did not work. The probability is it didn't work because the motor couldn't get enough current interrupted by another motor that also needed current and caused not enough power energy to move. To solve that problem by controlling a motor with a MOSFET and an L298N motor driver, the MOSFET serves as a switch or a gate control device. A MOSFET is a device used to control a motor. It acts like a switch that turns the motor on and off by allowing or interrupting the flow of current by other motors. By adjusting the voltage applied to the MOSFET, it can regulate the amount of current flowing through the motor, which controls its speed. In summary, the MOSFET is a crucial component in controlling a motor, allowing it to turn it on/off, regulate current, adjust speed, and ensure safe operation. Surely, that's how it can regulate the current of the motor and make it move on the PV panel holder. Another reason may be that it needs more improvement to mechanical work so easily the motor can move the cleaning robot. Finally, the monitoring of floating PV panel performance has been successfully achieved.

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