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# Development of Photovoltaic Data Observing With IoT Interface

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**Abstract*:*** *Photovoltaic (PV) system is extensively used recently due to its benefits and to support green technology. The photovoltaic recording system is considered a crucial aspect to observe the efficiency of the PV solar panels. However, there has been no recording or monitoring device to ensure the continuous functionality of the PV system. Hence, this project focuses on developing a parameter for the recording system to overcome this problem. By using the recording system, users are allowed to monitor their photovoltaic solar panels output (voltage and current) in real-time through the Internet of Things (IoT) method. The recorded values from the developed sensors can be continuously stored and updated in the cloud service. The system consisted of sensors, each for measuring two voltage values, current and temperature. NodeMCU microcontroller was chosen as the open-source IoT platform. The data were sent to the Adafruit IO webpage through a WIFI connection. Overall, the result revealed that the developed sensors for recording PV data worked correctly. Data processed by the microcontroller NodeMCU were displayed on the dashboard of the Adafruit IO cloud service webpage. The dashboard showed the output of voltage and current obtained from the solar panel, the voltage output from the rechargeable battery and the environment temperature surrounding the PV solar panels. From the photovoltaic recording system, the efficiency of the developed system and other factors that contributed to the malfunction in the solar system can be recorded.*

**Keywords:** Photovoltaic, Recording System, Cloud Services, Internet of Thing, NodeMCU

## 1. INTRODUCTION

Electricity has a unique characteristic; once it is generated it has to be consumed. Future electricity needs to have high levels of flexibility embedded to accommodate the variability and uncertainty in electricity demand. In Malaysia, wind power resources are less suitable. Thus, solar PV is a better choice in line with the rise of awareness of green technology. People are getting aware of the advantages of solar energy as solar technology has improved. A solar energy system can be utilized in smart homes, cars, appliances, and cities. Photovoltaic solar panels are the most common form of solar energy system to generate electricity. A photovoltaic solar panel can generate electricity by absorbing the sun's radiation. As for PV cell and module production, China currently is the leading country.[1] PV receives tremendous attention due to the ease of installation, operation and maintenance. PV can be installed on available rooftops of warehouses, factories, houses and others. The performance of a PV panel depends on the sunlight irradiance blocking obstacles, dirt accumulated in the solar panel protection glass and the field-aged degradation.[2]

Lillo-Bravo[3] revealed that the energy losses due to failures reach 0.96% of the net energy yield and the inefficiencies of up to 27.5%. An appropriate monitoring system is essential for providing information about the performance of any photovoltaic installation. The monitoring procedure helps to evaluate the quality of any product, identify and localize faults, reduce maintenance costs, and avoid system breakdowns.[4] Internet of Things (IoT) refers to the use of sensors, actuators, and data communications technology built into physical objects. The integration will enable the function of tracking, coordinating or controlling across a data network or the internet. IoT is also capable to support on monitoring and controlling the environment by using the devices to sense, process and wirelessly transmit data to remote storage. The data then will be used for other useful applications.[5] A remote monitoring system through the IoT is a proven solution in applications like photovoltaic monitoring (temperature, voltage, and current). Web technology is essential and attractive when it comes to monitoring and control of a system, allowing remote access over the internet.

However, there are a few obstacles that need to be overcome. One of the obstacles is the time delay which can lead to uneven data transmission and data loss. Another problem is related to the security is the ability of malicious hackers to grant access to the system.[6] An efficient monitoring technology of the solar PV system improves the performance efficiency as it provides updated information and executes the preventive measures if any flaws are detected. The monitoring of the solar PV power plant is performed either at the module, string, or system level. The monitoring of the solar PV at the system level provides information about the system exclusively. The monitoring technology related to panels and strings helps in identifying the root cause of the problem precisely. Every panel and string need to be monitored for the overall efficiency improvement of a solar PV power plant, as even a change in the output from a single panel can affect the efficiency of the entire system. There has been a change in trend from wired to wireless monitoring systems in the past decade. In the past, the wired monitoring system was commonly used for transferring data through an RS232 cable or an RS485 cable.[7] However, as the solar PV system has expanded, real-time monitoring using conventional wired cables has resulted in additional significant costs. Moreover, the cables carrying the data are exposed to environmental conditions such as rain, humidity, temperature, and more. In contrast, the wireless monitoring system is less prone to environmental conditions compared to the wired monitoring system and can deliver faster decision-making in real-time. This is due to the exposure of sensors and nodes to the open environment installed for data acquisition and transmission.

## 2. RELATED WORKS

Wireless monitoring technologies not only increase mobility and network security by implementing associated security protocols, but they also have a longer range, a high response time, and low maintenance costs. Nevertheless, various factors can cause a change in the output of the system, including a change from a sunny sky to a cloudy sky, the temperature of the panel, humidity, irradiance, the mounting angle, and the mismatch between the specification from the manufacturers and the actual PV output.[6,7] Therefore, further exploration is required to design an effective solar PV monitoring technology before the system can be implemented, considering the number of anticipated challenges. Wireless sensor network as part of a web-based building environment monitoring system (BEMS). This part of the research shows how advanced wireless sensor technology can be used by engineers to monitor conditions in and around buildings.[8] The system was developed to allow a user to mine the database using parameters such as type of data, location of the sensor, and time of data acquisition. The project is divided into three different steps. In the first step, wireless sensor hardware was programmed to process signals obtained from the sensors and transmitted the data in a designated format. Next, the signals were sent using the wireless sensor nodes. A Java program was written to decipher messages transmitted from a wireless receiver over a computer's serial port and then placed the data in the database. Finally, a web-based system was developed to allow a user to access the database. Figure 1 shows the project application diagram for a building monitoring system. The benefit of this project is to monitor the building environment and assist engineers when contemplating the use of wireless sensor networks for the monitoring system.

An IoT-based smart solar PV remote monitoring and control unit presents the implementation of a new cost-effective methodology based on IoT to remotely monitor a solar photovoltaic plant for performance evaluation. It facilitates preventive maintenance, fault detection, and historical analysis of the plant in addition to real-time monitoring.[9] There are three steps in IoT applications; capturing data/ information from the object, accumulating the information and acting on the information over a period of time. The proposed conceptual system in this work is to monitor the state of a photovoltaic system through an IoT based network in order to control it remotely. The information from the sensors was transmitted via the mobile radio network. A GPRS module was employed to send data to the remote server. Figure 2 shows the IoT application schematic for solar power plants. The schematic diagram contained a three-layered system starting with the sensing layer at the bottom. It comprised current sensors, voltage sensors, pyranometer for irradiance measurement and other sensors. This bottom layer also included microcontroller-based data processing acquiring data from the sensors. The microcontroller communicated with the wireless module to initiate and transmit data to the server.

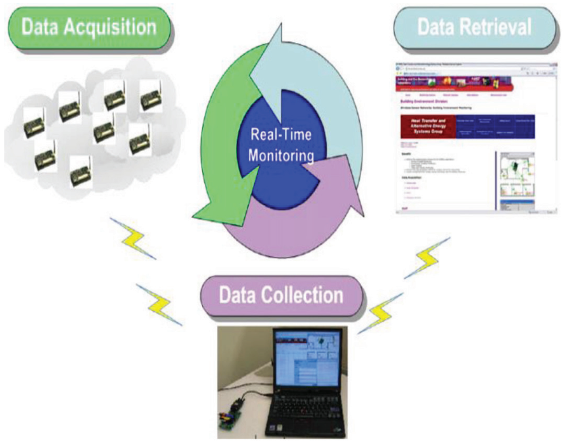


Figure 1: Diagram flow for a building monitoring system[8].

Communication protocols utilizing various wireless communication modules such as ZigBee, Wi-Fi (ESP8266 module), Bluetooth, GSM, and the LoRa module have been reviewed for monitoring solar PV systems. The advancements in solar PV monitoring systems concerning BeagleBone, Arduino Raspberry Pi, PLC, and microcontroller chips such as ATMEGA8 and ATMEGA16 have been studied along with their limitations.[7] On the other hand, the microcontroller is an embedded computer system that has transformed the IoT. Today, microcontrollers are extensively used in various fields both in scientific research and industrial use.[8] The microcontroller module along with different interfaces is designed to monitor different parameters of solar PV power plants. The load and battery were connected to the solar panel through a relay. The microcontroller sensed the power requirement of the load and accordingly managed two PV cells to connect to the load. The relay system was employed to manage the direction of the power from the solar panel either to the load or to the battery. The microcontroller is prone to unlimited physical access from attackers investigating its design and functionality.

A smart power monitoring and control system IoT using cloud data storage was designed to implement smart power monitoring and control system through IoT using cloud data storage. The power consumed by various appliances in monitoring through an ARM-based controller interfaced to Hall Effect current sensors and stored in a cloud database known as Xively. Xively is a software which enables cloud data storage. The project using power control of home appliances is achieved through actuators such as relays which can be controlled by the client with the help of a web server.[10] The system starts with checking the Ethernet connection and if the ethernet connection is proper, then the IP address is displayed in the serial terminal. If there is some problem with Ethernet, an error is shown. After checking the ethernet connection, the server port configuration is verified. If there is some problem, an error message appears in the serial terminal. If the server port configuration is proper then the server runs, the TCP socket gets connected and RPC is established. Users can give options on the web server to control appliances. PPC commands internally invoke the microcontroller actions. When the TCP connection gets established, the HTTP server starts running. Then, the HTML5 code also gets initiated. When the IP is given in the URL, the background HTML5 code runs and the webpage is displayed. Once a user gives signals, the corresponding RPC gets initiated and the action is performed by the microcontroller as per the signal given by the user.

## 3. METHODOLOGY

The system is comprised of software and hardware devolution. The details of the development can be explained and separated into a few parts; 1. System requirement, 2. Hardware, 3. Software.

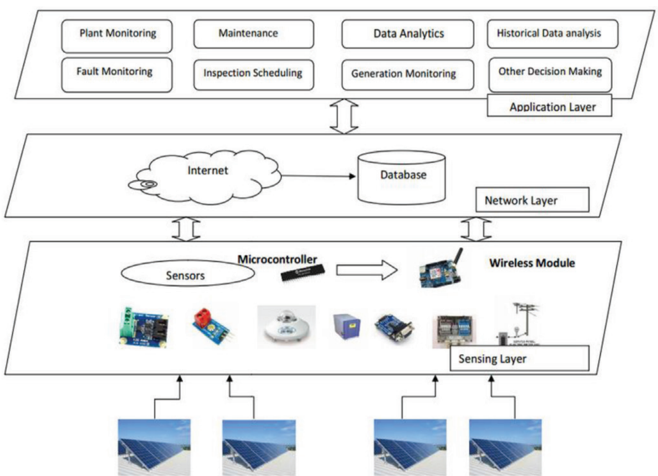


Figure 2: Proposed IoT Application for Solar Power Plant.[9]

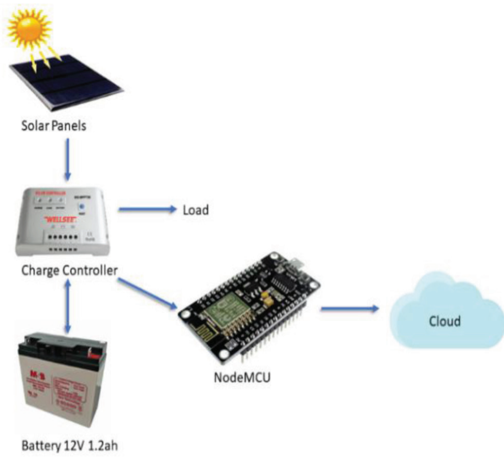


Figure 3: System Block Diagram for the Monitoring System.

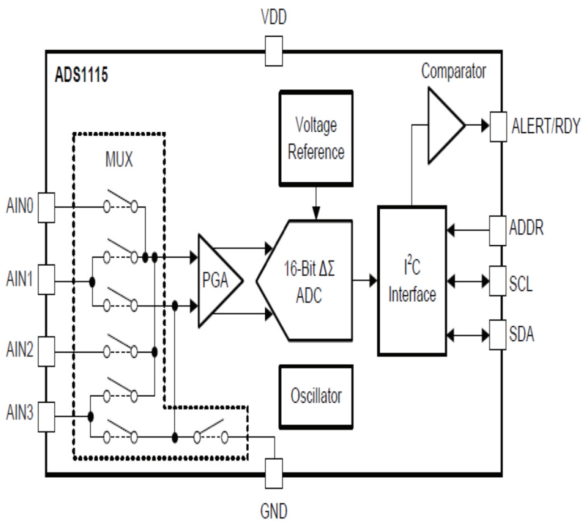


Figure 4: Simplified Block Diagrams of ADS1115.[10]

## 3.1 System Requirement

### 3.1.1 NodeMCU microcontroller

The central unit was a microcontroller (Arduino IoTLoL in NodeMCU V3 Lua Based ESP8266 WIFI Development Board) and acted as the main processing unit for the entire system developed. It interfaced with the sensors for receiving the voltage, current and temperature readings and was able to send the received data to the cloud services over the IoT. The microcontroller collected data from the sensors and send them over to the IoT to Adafruit IO cloud services for storing. The NodeMCU microcontroller received the measured analogue input data from the sensors and uploaded the data to the Adafruit IO cloud service. The development board acted as the main processing unit for the entire system development. Figure 3 illustrates the components in the system. Figure 4 shows the multiplexer configuration which made extending the analogue input ADC of NodeMCU successful.

#### 3.1.2 Cloud Services

The monitored values from sensors can be continuously stored and updated in a cloud service. The monitoring system will provide the display of the real-time data on the cloud services, Adafruit IO where the consumer can have access everywhere and anytime using the IoT. Adafruit IO is free to use but limited to only 30 data points per minute, 30 days of data storage, 10 feeds, and 5 dashboards. Only one feed on Adafruit IO can be created for each unique source of data that is sent from the microcontroller and only one feed is designated for one sensor. For this project, the microcontroller has four sensors; two voltage sensors, one current sensor, and one temperature sensor. Thus, four feeds were created using Adafruit IO.

#### 3.1.3 Dashboards

The function of the dashboards is to allow data visualizations and control of Adafruit IO connected projects from any modern web browser. Widgets such as charts, sliders, and buttons are available to help quickly get our IoT project up and running without the need for any custom code.[11] In this project, only one designed dashboard was able to display feeds to the consumer so that they could access and monitor it remotely using the IoT. The dashboard showed the sliders which represented the voltage output level of the solar panel and rechargeable battery and the current level output of the solar panel of the project.

#### 3.1.4 Feeds

Feeds are the core of Adafruit IO that hold the uploaded data and meta-data. These are the data that are received from the microcontroller sensors and pushed to Adafruit IO. For example, the date and time when it was uploaded or the GPS coordinates where the data came from. This includes the setting of whether the data is public or private, the type of license that the stored sensor data is categorized, and the general description of the data.[12] For this project, the microcontroller has four sensors; two voltage sensors, one current sensor, and one temperature sensor. Thus, four feeds were created using Adafruit IO.

### 3.1.5 Data Transmission

Data transmission between the sensors measurement data and Adafruit IO cloud service was performed using the microcontroller NodeMCU. Figure 5 shows the flowchart of the data transmission for the process. The execution flows in the figure started with checking the WIFI connection. If the WIFI is properly connected, then the sensors will measure the data and the NodeMCU microcontroller can send the measured data to the cloud service without any disturbance or loss of the data. The NodeMCU will reconnect if there is a problem with the WIFI connection. The transferred data were received by the feeds in the cloud service and the users were able to monitor their solar PV panels output with the aid of a friendly graphical user interface and easy-to-understand system architecture.

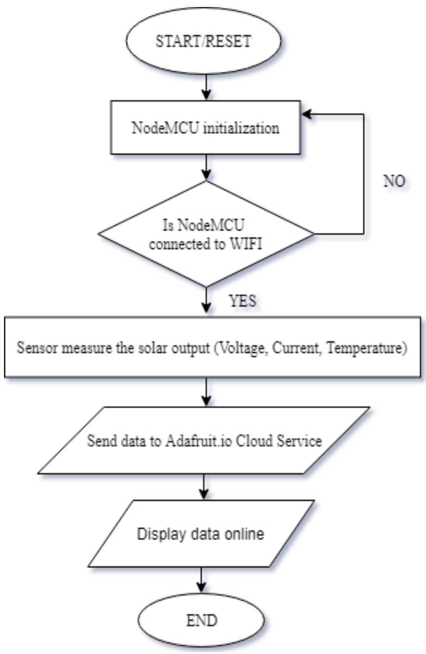


Figure 5: Flowchart for Data Transmission.

### 3.2 Hardware Description

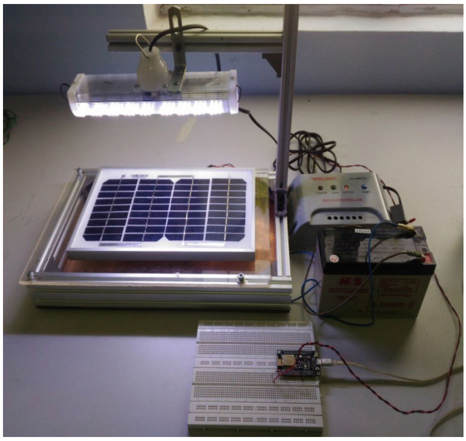

Figure 6: Experimental Set-up in the laboratory

In this work, the solar panels are made of polycrystalline silicon solar cells. The solar panel specifications and electrical characteristics are shown in Table 1 and Table 2 respectively.

Table 1: Solar Panel Specifications

| | |
|---|---|
| Cells | Polycrystalline silicon solar cells 156x156mm |
| Number of cells | 36(4×9) |
| Dimensions (mm) | 760 x668 x 35 |
| Weight (kg) | 6.5 |

Table 2: Solar Panel Electrical Characteristics

| Model | SPM050-P |
|---|---|
| Max Power Pm(W) | 50 |
| Max Power Voltage Vm (V) | 18.8 |
| Max Power Current Im (A) | 2.65 |
| Open-Circuit Voltage Voc(V) | 21.3 |
| Short-Circuit Current Isc (A) | 2.84 |
| Cell Efficiency (%) | 13.2 |
| Module Efficiency (%) | 10.0 |
| Maximum System Voltage(V) | DC715V |
| Power Tolerance (%) | ±3 |
| Series Fuse Rating (A) | 10 |

We used MPPTWS-MPPT30 solar charge controller to regulate the voltage and current from the solar panel to the rechargeable battery to prevent overcharging and discharging. An MPPT, or maximum power point tracker is an electronic DC to DC converter that optimizes the match between the solar panel, and the battery bank. The power point tracker is a high-frequency DC to DC converter. The output voltage from the solar panel will be changed to high-frequency AC and will be converted back to a different DC voltage and current level to exactly match the panel to the rechargeable battery.[13] The NodeMCU (Node Microcontroller Unit) is an open-source ultra-simple IoT development platform, fast hardware prototyping platform that includes firmware and a development board to develop applications with a few simple Lua scripts.[14] The system operates hardware IO like Arduino and provides a high-level interface to hardware that frees application developers from complex hardware configurations and register operations. It includes firmware on the ESP8266 WI-FI microcontroller designed by Espressif System. The ESP8266 is a self-contained WI-FI networking solution offering a bridge from the existing microcontroller to WI-FI and is also capable of running self-contained applications. This module comes with a built-in USB connector and a rich assortment of pinouts. With a micro USB cable, we can connect NodeMCU to our computer and flash it without any trouble, just like any other Arduino.[15]

The ADS1115 devices are precision, low-power, 16-bit, I2C compatible, analog-to-digital converters (ADCs) offered in an ultra-small, leadless, X2QFN-10 package, and a VSSOP-10 package. The ADS1115 devices incorporate a low-drift voltage reference and an oscillator. The ADS1115 also incorporate a programmable gain amplifier (PGA) and a digital comparator. These features, along with a wide operating supply range, make the ADS1115 well suited for power- and space-constrained, sensor measurement applications. The ADS1115 contains an input multiplexer (MUX). Either four single-ended or two differential signals can be measured. Additionally, AIN0 and AIN1 may be measured differentially from AIN3. A rheostat is a type of variable resistance that can be changed to vary the amount of current. In this research, a rheostat rated (16.5Ω, 6.2A) was used as a load for the solar panel. This voltage detection/sensor module is based on the resistance points pressure principle, and it can make the input voltage of the red terminal reduce 5 times its original voltage.

The microcontroller Arduino analog input is 5V, so the input voltage detection of the voltage sensor should not be more than 5V x 5 = 25V (for a 3.3V system, the input voltage should not be more than 3.3V x 5 = 16.5V). The ACS712 current detection/sensor module is designed to be easily used with a microcontroller like the Arduino and NodeMCU. These sensors are based on the Allegro ACS712ELC chip. The loads used are connected in series to the connections between the current sensor and solar panel, having a resistance value of 16.5ohm with a maximum current of 6.2A. The rheostat was set to 100% or 16.5ohm. The MAX6675 Type K Thermocouple Module and Temperature Sensor Module were used to measure the environment temperature around the solar panels. The MAX6675 performs cold-junction compensation and digitizes the signal from a type-K thermocouple. The data is output in a 12-bit resolution, SPI™-compatible, and read-only format.

### 3.3 Software Description

Arduino IDE was used to upload the C++ coding to program the microcontroller for the data retrieval from the sensors and data transmission to the cloud services. The following coding is part of C++ coding that was built for the function of current sensor;

```
//Current sensor
RawValue = analogRead(analogIn);
Voltage = ((RawValue -308) / 1024.0) * 5000; // Gets you mV
Amps = ((Voltage - ACSoffset) / mVperAmp);
Serial.print("Raw Value = " ); // shows pre-scaled value
Serial.print(RawValue);
Serial.print("\t mV = "); // shows the voltage measured
Serial.print(Voltage,3); // the '3' after voltage allows you to display 3 digits after decimal point
Serial.print("\t Amps = "); // shows the voltage measured
Serial.println(Amps,3); // the '3' after voltage to display 3 digits after decimal point
```

## 4. RESULTS AND DISCUSSION

The results can be separated into two major observations. The first observation is from the dashboards and the second observation is from the feeds. Figures 7 and 8 show the dashboard of measured data with and without shading effect on the solar panel, respectively. The voltage output level for the rechargeable battery showed an unchanged value of 12.9 V for both unshaded and shaded dashboards. It can be concluded that the rechargeable battery was working perfectly fine. The environment temperature changed from 31.75°C to 33.50°C when the dashboard has a shading effect. In this work, the solar panels were tested under two different conditions to observe the effect of shading on the performance of the solar panel. The shading effect for this experiment passed the clouds. The dashboard data was acquired based on two weather conditions; sunny and cloudy. When the weather was cloudy, the dashboard showed that the output voltage and current level from the solar panel were only 10.72V and 0.66A, respectively. But when the weather was sunny, the outputs were 17.66V and 0.9A. This is because solar photovoltaic panels consisted of solar photovoltaic cells wired together into a series of a circuit. When the power output of a single cell was significantly reduced, the power output for the whole system arranged in series was reduced to the level of current passing through the weakest cell. This condition reduced the effectiveness of the photovoltaic solar panel system.

The voltage output level for the rechargeable battery showed an unchanged value of 12.9 V for both with and without shading effect. It can be concluded that the rechargeable battery was working perfectly fine. Figure 10 shows the recorded data of voltage output for PV solar panels and rechargeable batteries. For environment temperature, the value changed from 31.75°C to 33.50°C. The obtained results might be varied depends on the surrounding temperature. The stored data from Adafruit IO feeds were downloaded from the feeds list and in a string format which contained the time created and value of the data. The tabulated table data was taken randomly from some of the string formats of the downloaded data feeds. The user was given two file formats to download the feed data either as a JavaScript Object (JSON) or comma-separated values (CSV) file. Both files contained all the data points from the feed. This research used only CSV files to monitor the measured data through an external program to manipulate, analyse, and graph the feed data.[12]

Table 3 tabulates the compilation of feed data for PV solar panel voltage output, current output, rechargeable battery voltage output and environment temperature for 20 readings. Feed data were downloaded from voltage feed in the Adafruit IO cloud storage. The table is tabulated with 8 to 9 seconds intervals which were set in the source code for data transmission. Peak voltage output for PV solar panel recorded at the minute of 7:17 was 17.792812 V. The average voltage output of PV solar panel for every 30 points data was around 17.63019 V. For current output, the value of load was fixed to 16.5 Ω using rheostats to measure the current output for PV solar panel. The average current output of PV solar panels for every 30 points of data was around 0.771572 A. The feed data for rechargeable battery voltage output remained steady at around 12.90 V at any time taken. The purposes of these recordings are to prove that the data is accurate by comparing the voltage output level of voltage sensors and multimeter. The operation temperature will give a high impact on the efficiency of the PV module. Commonly, the relation will be in contrast. If the temperature increases, the efficiency will be decreased. At different temperatures, the output power of the PV panels depends on the difference in the panel temperature. In this work, the consumer will be allowed to monitor their photovoltaic solar panel output (voltage, current) in real-time data, through the web-based system using the Internet of Things (IoT). The monitored values from the developed sensors can be continuously stored and updated in the cloud services. The open-source cloud platform, the Adafruit IO is used for storing and displaying the data online. NodeMCU microcontroller is chosen as the open-source IoT platform which includes firmware which runs on the ESP8266 WIFI Development Board. The data will be sent to the Adafruit IO webpage through a WIFI connection.

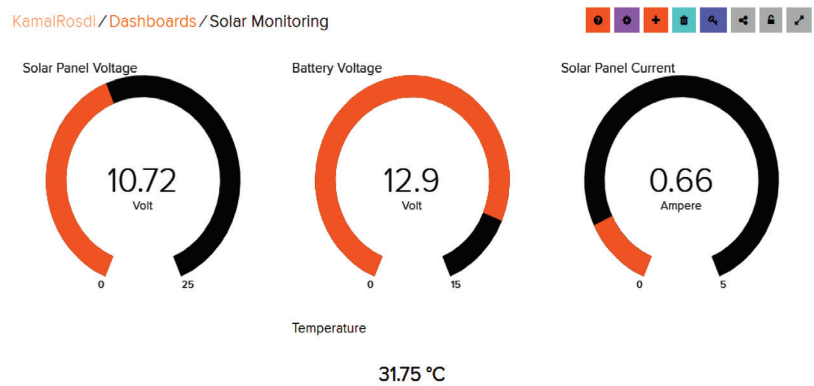


Figure 7: Dashboard with Shading Effect.

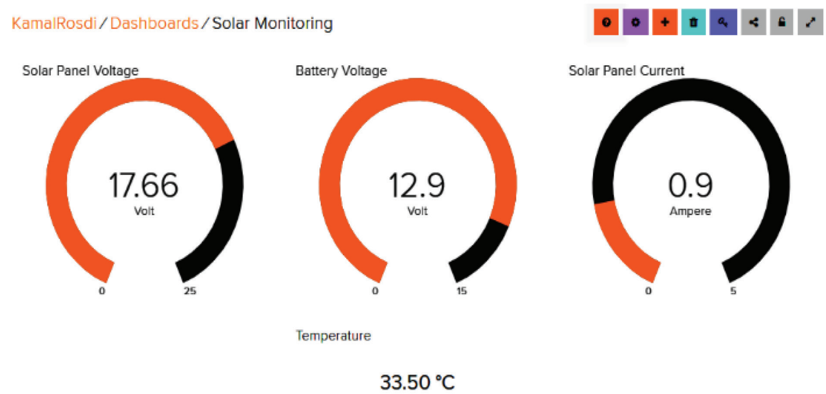


Figure 8: Dashboard without Shading Effect.

Table 3: Compilation of Feed Data for PV Solar Panel Voltage Output (V), Current Output (A), Rechargeable Battery Voltage Output (v) and Environment Temperature

| Date & Time | Voltage (V) | Current (A) | Voltage (v) | Temperature (°C) |
|---|---|---|---|---|
| 2019-05-03 07:16:39 | 17.354063 | 0.870988 | 12.900000 | 29.00 |
| 2019-05-03 07:16:48 | 17.355938 | 0.923775 | 12.900000 | 28.75 |
| 2019-05-03 07:16:56 | 17.364374 | 0.897382 | 12.899062 | 29.25 |
| 2019-05-03 07:17:05 | 17.361563 | 0.897382 | 12.900000 | 29.50 |
| 2019-05-03 07:17:14 | 17.358749 | 0.844595 | 12.900000 | 30.00 |
| 2019-05-03 07:17:23 | 17.359688 | 0.923775 | 12.899062 | 29.75 |
| 2019-05-03 07:17:32 | 17.833124 | 0.976562 | 12.900000 | 29.75 |
| 2019-05-03 07:17:40 | 17.807812 | 0.844595 | 12.899062 | 30.25 |
| 2019-05-03 07:17:49 | 17.792812 | 1.082137 | 12.900000 | 30.50 |
| 2019-05-03 07:17:57 | 17.786249 | 0.686233 | 12.899062 | 30.50 |
| 2019-05-03 07:18:06 | 17.782499 | 0.844595 | 12.900000 | 30.75 |
| 2019-05-03 07:18:14 | 17.775938 | 0.791807 | 12.900000 | 30.50 |
| 2019-05-03 07:18:24 | 17.767500 | 0.765414 | 12.899062 | 30.25 |
| 2019-05-03 07:18:32 | 17.762812 | 0.870988 | 12.899062 | 30.75 |
| 2019-05-03 07:18:41 | 17.752501 | 0.765414 | 12.900000 | 31.00 |
| 2019-05-03 07:18:49 | 17.740313 | 0.739020 | 12.899062 | 30.75 |
| 2019-05-03 07:18:58 | 17.718750 | 0.897382 | 12.899062 | 31.25 |
| 2019-05-03 07:19:06 | 17.698126 | 0.659840 | 12.899062 | 31.25 |
| 2019-05-03 07:19:15 | 17.658751 | 0.712627 | 12.898125 | 31.25 |
| 2019-05-03 07:19:23 | 17.670000 | 0.739020 | 12.899062 | 30.75 |

## 5. CONCLUSION

A complete system for recording PV solar panels using microcontroller NodeMCU was successfully developed. Microcontroller NodeMCU is a good solution for recording the PV solar panel wirelessly besides ZigBee and other microcontrollers. The design for this monitoring system is simple, without any complex configurations. The related measurement output of PV solar panel was stored correctly by connecting voltage, current and temperature sensors to microcontroller NodeMCU. Sensors for measuring data parameters from photovoltaic solar panels were successfully developed. Data processed by the microcontroller NodeMCU were displayed on the Adafruit IO cloud service webpage. Adafruit IO webpage displayed the data such as voltage and current level output from the solar panel and voltage output from the rechargeable battery and the environment temperature. When the weather was cloudy, the dashboard showed that the output voltage and output current level from the solar panel was only 10.72 V and 0.66 A, respectively. However, when the weather was sunny, the output voltage and output current from the solar panel increased to 17.66 V and 0.9 A. The controller-based system to collect data parameters and send them to the cloud service was successfully achieved.

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