Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

IoT based photovoltaic monitoring system application

To cite this article: W Priharti *et al* 2019 *J. Phys.: Conf. Ser.* **1367** 012069

IoT based photovoltaic monitoring system application

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Abstract. Solar photovoltaic (PV) system has become the greatest attraction in the clean, renewable electricity generation. However, the performance is varying due to various parameters and environmental conditions. Hence, a remote and real-time monitoring system is needed to assess its performance. Implementation of the Internet of Things (IoT) in the monitoring of the solar PV system was proposed and its performance was studied. The system consists of data acquisition, data gateway, and smartphone application display. The data acquisition was successfully collect the data with 98.49% accuracy and was uploaded to the data gateway. The data gateway was able to send the graphical representation of the data to the smartphone application with a mean transmission time of 52.34 seconds. The results demonstrate that the proposed monitoring system can be a promising solution for intelligent remote and real-time monitoring of a solar PV system.

1. Introduction

Solar energy has become one of major clean energy sources around the world in the recent years. Especially in Indonesia, solar energy has a potential of 4,8 kWh/m^2 or equals to 112,000 GW. Unfortunately, only 10 MW was already utilized up until now [1]. Based on the roadmap arranged by the Ministry of Energy and Mineral Resources of the Republic of Indonesia in 2017, solar energy is expected to be utilized until 6,5 GW in 2025 [2].

The main application of solar energy is electrical generation through a photovoltaic (PV) system. This system consists of solar panels that can directly convert sunlight or solar energy into electricity [3]. PV is one of the renewable energy sources with the greatest future projection due to its unique features such as simple installation, high reliability, low maintenance cost and zero fuel cost [4]. However, the amount of energy produced from this system is sometimes unpredictable due to the unpredictable nature of the solar energy [5]. Several factors can contribute to the total energy produced by PV, namely the intensity, angle and duration of the sunlight, the temperature of the panel and and also some environmental conditions such as weather, wind and dust [6].

To increase the total energy produced by a PV system, sufficient measures need to be taken on its installation. However, since a PV system is usually located in a remote or high location, there still be chances of failures or maintenance problem during its operation. Hence, a suitable frequent monitoring system is essential to ensure the efficiency of power delivery.

The conventional method of monitoring systems mainly include manual investigation and remote wired monitoring. These methods have some disadvantages such as time-consuming and wiring complexity [7]. The emerging technique of communication technology called Internet of Things (IoT) offers a new solution to overcome these problems. The IoT is the network of physical objects embedded with electronics, software, sensors, and network connectivity. It allows objects to be sensed and controlled remotely across the existing network infrastructure resulting in improved efficiency, accuracy and economic welfare [8].

The IoT is reported can enables quick and easy interactions with everyday objects like personal computer, smart-phones, sensors and actuators to the Internet with the help of devices like microcontrollers, transceivers, and information and network protocols [9,10]. Hence, the communication network with IoT can provide a better monitoring and controlling of a PV system in a remote and large field compared to human inspection. Table 1 shows the various aplications of IoT use in PV systems.

Table 1. IoT applications in solar PV system.

Application in PV system	Microcontroller	Transceiver	IoT Platform	Reference
Monitoring of dust accumulation in PV system	Arduino Uno	ESP8266	Thinkspeak	[11]
Monitoring of PV power and sunlight intensity	Arduino Uno	ESP8266	Thinkspeak	[12]
	Arduino Uno	ESP8266	Thinkspeak	[13]
	Arduino Uno	Wemos D1 Mini	Thinkspeak	[5]
PV array inspection	N/A	Raspberry Pi	Zigbee	[14]
PV tracking system	N/A	Raspberry Pi	Thinkspeak	[15]
PV cleaning system	Particle Photon	N/A	Ubidots	[16]
	N/A	Raspberry Pi	Zigbee	[17]
PV fault and control	Arduino Uno	Xbee	Zigbee	[18]

All these works demonstrated that the implementation of IoT in monitoring and controlling of PV system is practical and flexible. Therefore, this work is also try to design and implement the use of IoT in the monitoring of PV system using Arduino ATMega2560 as the microcontroller, ESP8266 as the wireless transceiver and Thingspeak as the IoT platform. A smartphone application is also produced using MIT App Inventor to better display the data to the user.

2. Methods

The system described in this paper is capable of measuring the values of voltage, current and temperature of the solar PV panel and also the intensity of the sunlight received by the panel. All the data was recorded by a microcontroller Arduino ATMega2560 and uploaded to the internet by a wireless transceiver NodeMCU ESP8266. An open source of IoT cloud platform namely

Thinkspeak is used to store all the data from the sensor and visualize it in the graphical representation so the user can monitor the data remotely as long as the internet connection is available. The monitoring can be done via Thinkspeak website and also via smartphone application that were designed using MIT App Inventor. The block diagram of the system is shown in figure 1.

2.1. Data acquisition

A PV system consists of a monocyrtalline solar photovoltaic panel connected to a Maximum Power Point Tracking (MPPT) solar charge controller is used to produce the energy that need to be monitored. This panel have a maximum power output, P_{max} of 100 W, maximum power voltage, V_{mp} of 18 V and maximum power current, I_{mp} of 5.56 A. A Valve Regulated Lead Acid (VRLA) battery with a capacity of 12 V and 7 Ah was used as a storage. The solar PV voltage was sensed using a voltage divider circuit as shown in figure 2, where V_{in} = 18.30 V, R_1 = 1 kΩ and R_2 = 10 kΩ.

The sensor output voltage is calculated using equation (1) below:

$$V_{out} = V_{in} \times \frac{R_2}{R_1+R_2} \quad (1)$$

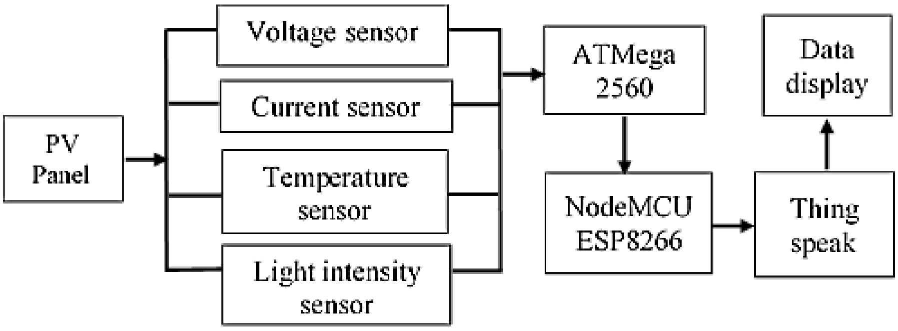

Figure 1. Block diagram of PV monitoring system using IoT.

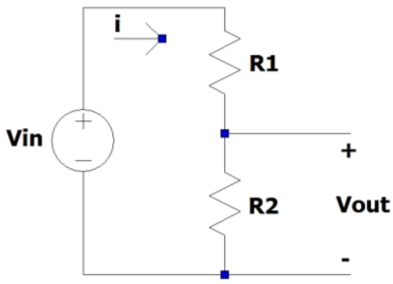

Figure 2. Voltage divider circuit.

ACS712 Hall effect based current sensor was used to sensed the current in the circuit. Hall effect is the generation of potential difference across a current carrying conductor in a perpendicular magnetic field. It has total output error of ±1.5% with a optimized accuracy range of ±30 A. The temperature of the panel was measured using LM35 temperature sensor. It gives very accurate reading over a range of 0 – 100°C while drawing very low current of about 60 µA. Light intensity sensor GY-49 MAX44009 was used to measure the intensity of the sunlight exposed to the panel. The ensure the accuracy of the data acquisition, all the sensors were first calibrated to the respective standard. The calibrated value was then analysed by calculating the mean, µ and the standard deviation, σ of the percentage difference.

The performance of PV system was measured in three consecutive days with a duration of eight hours a day (8 am to – 16 pm). The PV system was placed on top of a building which is exposed to a direct sunlight without much interference from the enviromental shadow. The system is mounted on a fixed 30^0 angle facing the northern sunlight. The tracker of the solar movement was not used.

The Arduino Mega based on ATMega2560 acted as the microcontroller that collect and process all the data from the sensors. The data was then sent to the wifi module NodeMCU ESP8266 via serial communication protocol. Figure 4 shows the hardware design of solar PV system consists of all the components stated above.

2.2. Data gateway

An open source of IoT cloud platform application namely Thinkspeak is used in this study. This application can retrieves and stores the data from the sensor through internet that uses hypertext transfer protocol (HTTP). The data from the sensor was uploaded from the Arduino board connected to a wifi module to the cloud. It updates all the data logs received from the sensors and giving the status application to the users.

To use this features, the user need to create an account or specific IP address which contains different channels for monitoring the different parameters in the system. The flowchart diagram of the data gateway system is shown in figure 3.

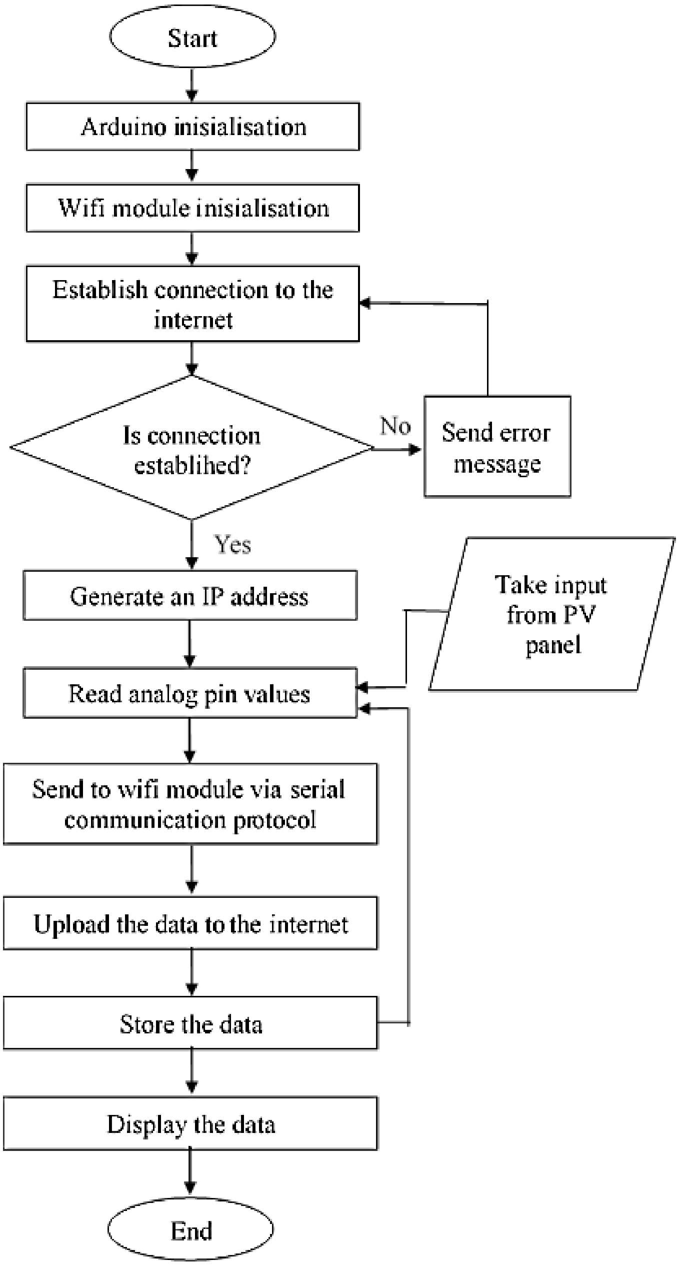

Figure 3. Flowchart diagram of PV monitoring system using IoT.

This platform enables the user to visualize the data in graphical representation. With internet-based monitoring, the data would be easily accessible through an online interface (via computer or smartphone). The major advantage of this systems is that the solar PV panel output information can be easily monitored anywhere with an available internet connection.

2.3. PV monitoring system application

The data collected by Thingspeak IoT platform can be accessed directly via Thinkspeak website (https://thingspeak.com/) using a computer or a smartphone. However, to give the user the convenience and simplicity in accessing the data, a smartphone application was designed. This application aims to give a better display of graphical representation of the data while displaying up to 6 sensors data at the same time. The application was made using MIT App Inventor with a display shown in Figure 5.

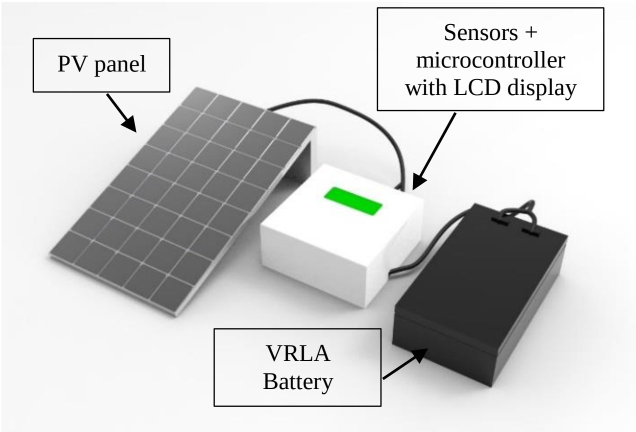

Figure 4. Hardware design of PV monitoring system.

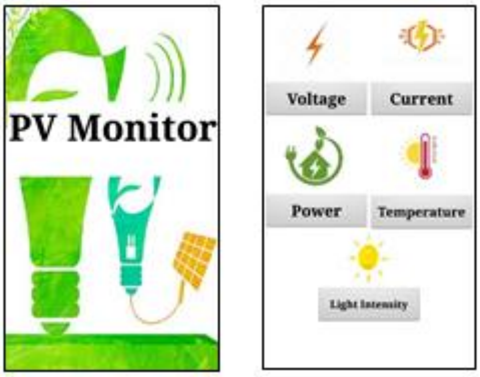

Figure 5. PV monitoring system application designed using MIT App Inventor.

3. Results and Discussions

The results of this paper are categorized into three parts, namely the calibration of sensors results, the performance of PV system results and the performance of PV monitoring application results.

3.1. The calibration of sensors

Figure 5 (a), (b), (c) and (d) respectively show the sensor calibration data of voltage, current, temperature and light intensity. From these figures, it can be seen that all the measured sensors data were finely matched the standard measuring instrument, i.e. multimeter for voltage and current, thermometer for temperature and lux meter for light intensity. Especially for voltage and current sensors, two types of calibration were carried out, i.e recurring and non-recurring calibration. In the recurring calibration, 30 set of data were taken for a single value of voltage or current. Whereas in the non-recurring calibration, one set of data was taken for various value of voltage or current, i.e 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 V for voltage and 0.5, 1, 1.5, 2, 2.5 and 3 A for current. Figure 6 shows the recuring calibration data and the non-recurring calibration data for voltage and current respectively. The detail value of the percentage difference for each sensor and standard are given in Table 2

Table 2. Data calibration of each sensor utilized in data acquisition

Sensor Type	Number of data	Percentage of difference from standard measuring instrument (μ ± 1σ %)
Voltage	30 × 10[a]	3.05 ± 3.25
Current	30 × 6[b]	1.85 ± 1.57
Temperature	30	0.22 ± 1.38
Light intensity	30	0.92 ± 3.03

[a]The value of voltage used in calibration were 1 – 10 V (given by power supply)
[a]The value of current used in calibration were 0.5, 1, 1.5, 2, 2.5 and 3 A (given by power supply)

. The percentage difference value are displayed in term of mean and standard deviation (μ ± 1σ %). The standard deviation value shows the amount of dispersion or data spreadness from the actual data. The percentage difference mean and standard deviation value for voltage, current, temperature and light intensity sensors are 3.05 ± 3.25, 1.85 ± 1.57, 0.22 ± 1.38 and 0.92 ± 3.03 % respectively. The mean accuracy from all sensors was 98.49%. These value indicate that all the sensors are in a good condition and the results obtained from data acquistion were valid and reliable.

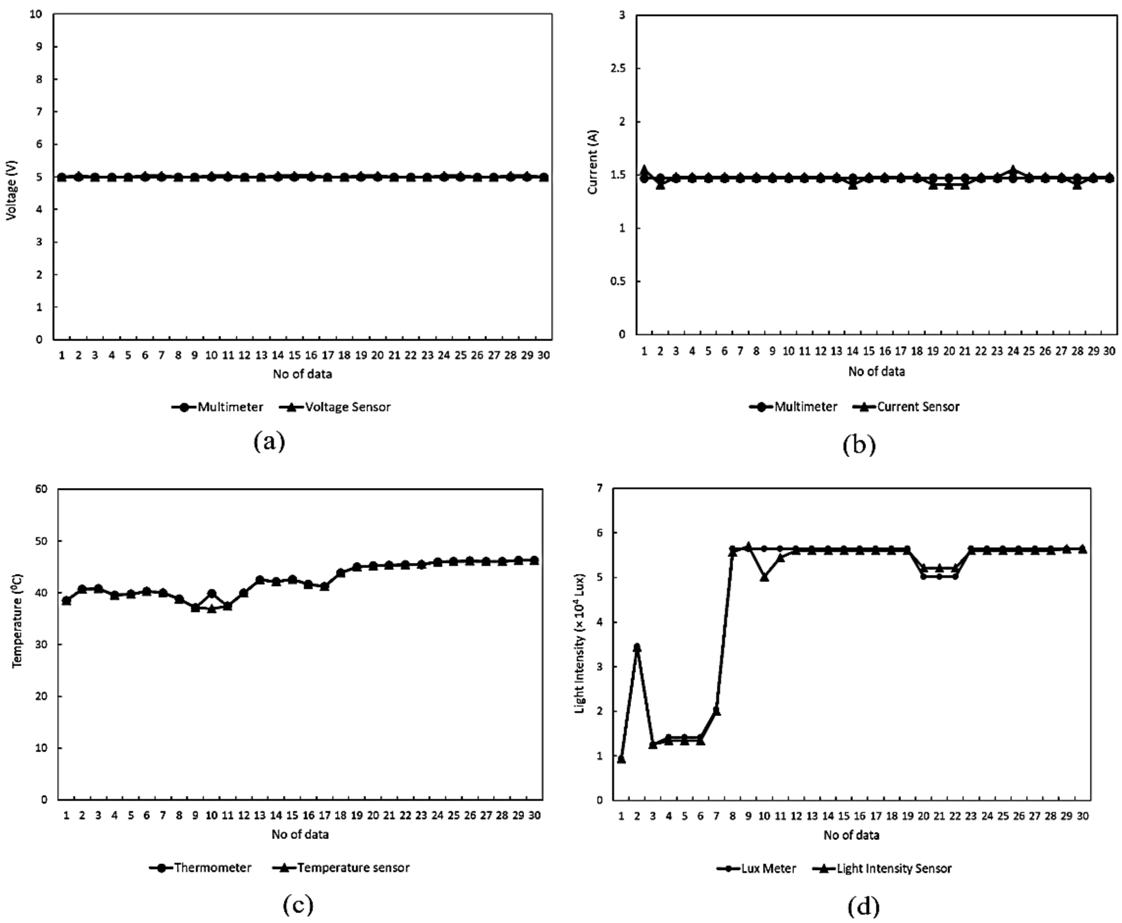

Figure 6. Sensors recurring calibration data.

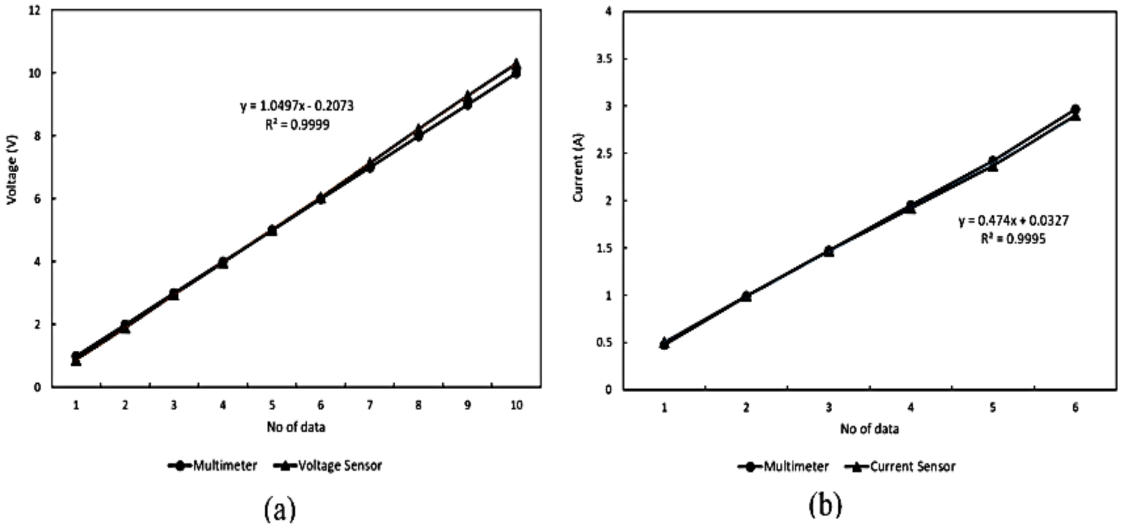

Figure 7. Voltage and current sensors non-recurring calibration data.

3.2. The performance of PV system

The performance of PV system was examined in three consecutive days from 8.00 to 16.00 (8 hours). The data obtained from the sensors were in term of voltage, current, temperature and light intensity. Based on the value of voltage and current, power can be calculated using formula $P = V I$ with the unit of Watt. Panel temperature and the amount of intensity of light exposed to the panel were also measured to estimate the environmental contribution to the total power produced. The result of power versus temperature and power versus light intensity are respectively shown in figure 8 and figure 9.

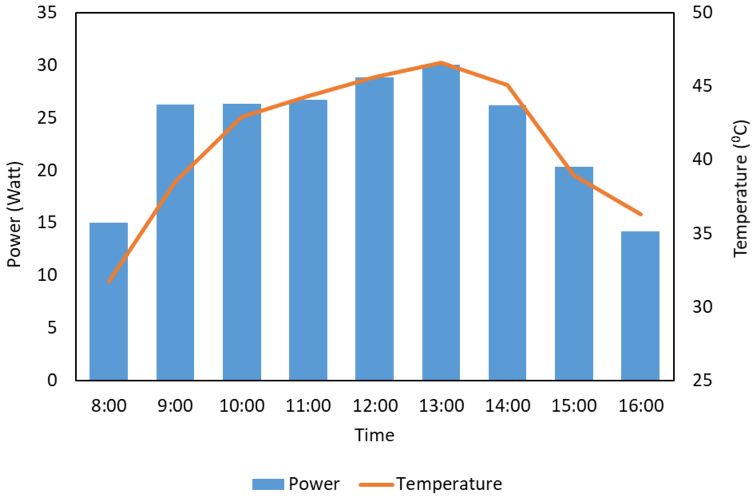

Figure 8. PV performance system result of power versus temperature.

The highest mean power obtained from three days was at 13.00 with a value of 30.02 Watt. The graphic shows that the total power produced was directly proportional to the temperature of the panel with the highest temperature obtained at the same time with a value of 46.59^{0}C. The increase in the temperature could be the result of the increase in the solar irradiation or the amount of sunlight power density received at a certain location (measured in W/m^2).

Study conducted by Arjyadhara et al. in 2013 [19] showed that the amount of solar irradiation is perpendicular to the amount of sunlight intensity or solar flux (measured in lux). The increase in solar flux has a little effect on output voltage of a PV but it is directly proportional to the output current. As the result, it could increase the output power of the PV [20].

3.3. The performance of PV monitoring application

The monitoring system of the PV panel can be accessed through Thinkspeak website and also from the PV Monitor application proposed in this study. The displayed data of both methods is exactly similar. The only difference is that the data were displayed simultaneously in the website as shown in figure 9. Whereas in the PV Monitor application, user can choose which data is needed to be displayed and hide the others. The PV Monitor display is shown in figure 10 dan figure 11.

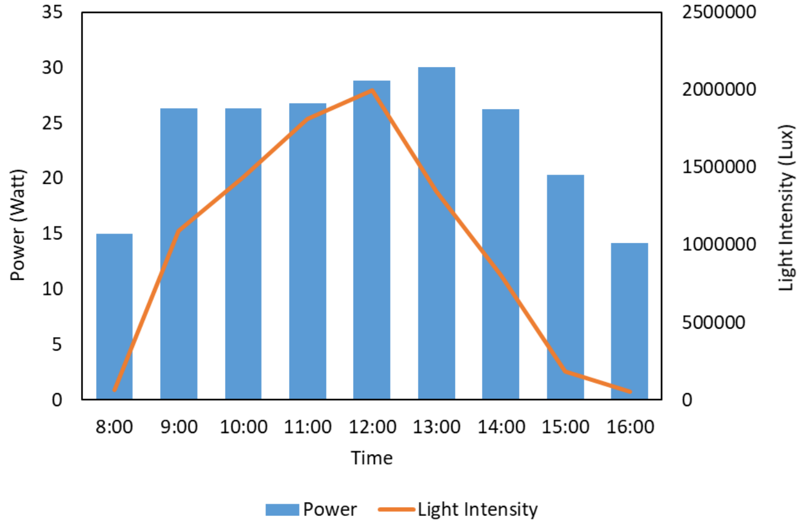

Figure 9. PV performance system result of power versus light intensity.

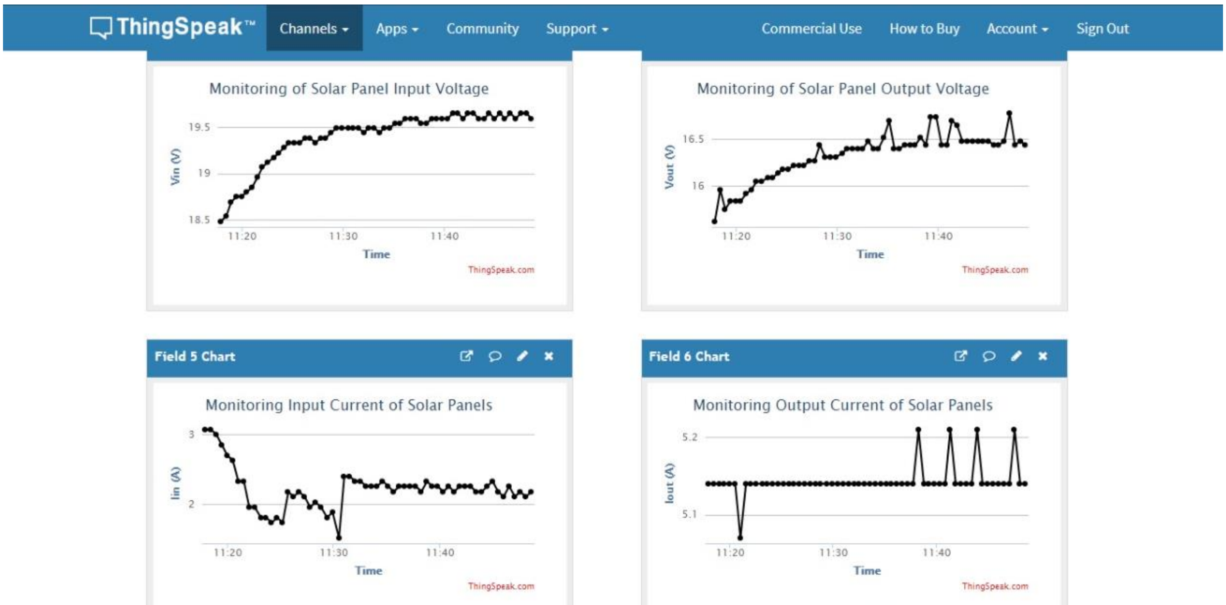

Figure 10. The display of PV monitoring system in Thinkspeak website.

The performance of the PV monitoring application was examined from the time required to transmit the data from the hardware (data acquisition) through the data gateway and finally being displayed in the application. It was obtained that the mean transmission time was 52.34 seconds with a minimum and maximum transmission time of 30 and 102 seconds respectively.

4. Conclusions

An implementation of Internet of Things (IoT) in the monitoring of solar PV system consists of data acquisition, data gateway and smartphone application display was proposed. The data acquisition was succesfully collect the data with 98.49% accuracy. The data gateway was able to send the graphical representation of the data to the smartphone application with a mean transmission time of 52.34 second. The results demonstrate that the proposed monitoring system can be a promising solution for intelligent remote and real-time monitoring of a solar PV system.

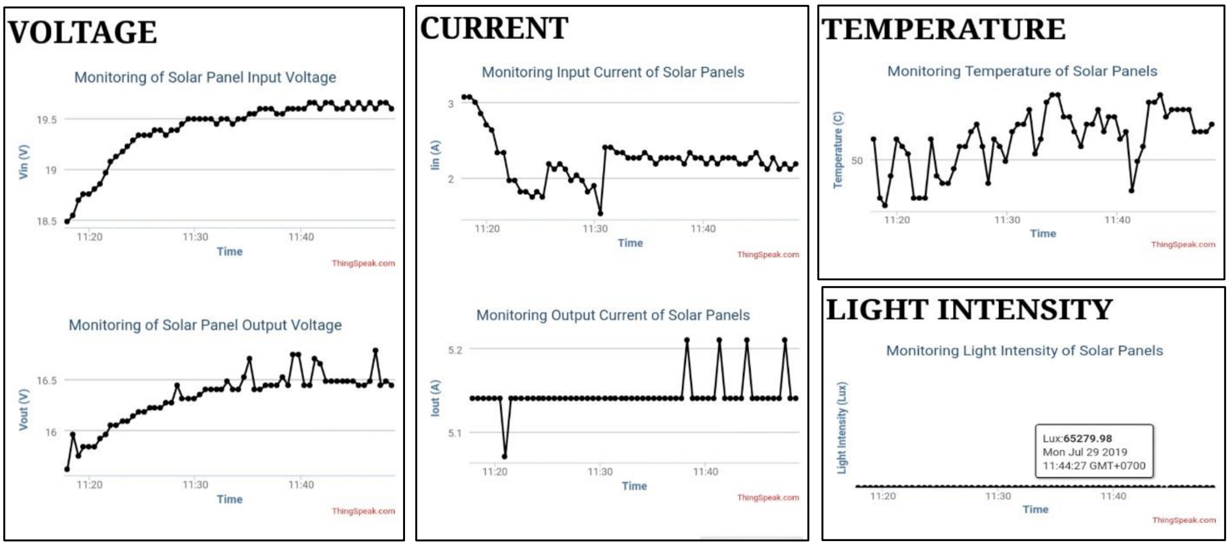

Figure 11. The display of PV monitoring system in PV Monitor application. Each parameter can be displayed separately for the convenience of the user.

Acknowledgments

Authors wishing to acknowledge the financial support from Direktorat Penelitian dan Pengabdian Masyarakat (PPM) Telkom University to attend this conference.

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