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A laboratory scale IoT-based measuring of the solar photovoltaic parameters

Arsyad Cahya Subrata[1,2], Tole Sutikno[1,2], Sunardi[1], Anggit Pamungkas[2], Watra Arsadiando[2], Ahmad Raditya Cahya Baswara[1]
[1]Department of Electrical Engineering, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
[2]Embedded Systems and Power Electronics Research Group, Yogyakarta, Indonesia

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ABSTRACT

Harvesting solar energy as a renewable energy source has received significant attention through serious studies that could be applied massively. However, the nonlinear nature of photovoltaic (PV) concerning the surrounding environment, especially irradiation and temperature, affects the resulting output. Therefore, the correlation between environmental parameters and PV's energy needs to be studied. This paper presents a design for measuring solar PV parameters monitored on a laboratory scale. The monitoring is based on internet of things (IoT) technology analyzed in real-time. The system was tested in various weather conditions for 18 hours. The results obtained indicate that the output voltage was influenced by the lighting factor of the PV and the surrounding temperature.

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Corresponding Author:

Tole Sutikno
Department of Electrical Engineering, Universitas Ahmad Dahlan
Jl. Ringroad Selatan, Kragilan, Tamanan, Banguntapan, Bantul, D. I. Yogyakarta 55191, Indonesia
Email: tole@ee.uad.ac.id

1. INTRODUCTION

The generation of electricity from renewable energy sources is a promising solution to the problems associated with the impact of carbon generated by fossil fuels. Renewable energy sources have been widely developed because they offer clean and sustainably available energy solutions for conventional non-hydro technologies [1], [2]. As a renewable energy source technology, photovoltaic (PV) systems are increasingly being recognized as cost-effective and clean energy technologies [3]–[6]. This allowed PV systems to have advantages in terms of availability, cost-effectiveness, accessibility, capacity, and efficiency compared to other renewable energy sources [7].

A study released by the International Energy Agency (IEA) on world energy consumption shows that solar panel installations in 2050 will supply 45% of the world's demand [8]. Based on the General National Energy Plan (RUEN) in Presidential Decree No. 22 of 2017 [9], in 2025, Indonesia targets the development of new and renewable energy by up to 23%. Research and development of solar panel technology as a renewable energy source needs to be done to increase [10]. Various learning laboratories install solar panels and windmills as learning tools in the US [11]. Besides being open to the public to know the performance of solar panels and windmills, the data taken from the laboratory is also used by its members for further research.

The solar panel system installed far from the monitoring lab is one of the obstacles. The best method to solve the problem is to adopt a remote monitoring system using a frequently used technique called the internet of things (IoT) [12], [13]. IoT technology has rapidly expanded into a variety of fields, enabling quick and easy interaction with most everyday objects and assisting in the gathering of much more detailed information about objects to provide a wide range of new developments [14]–[18].

Measurement of solar panel parameters wirelessly can be done with various communication protocols. The Bluetooth protocol, as done by Le *et al*. [19], has the advantage of being a low-cost device. Bikrat *et al*. [20], [21] in their studies also used Bluetooth and WiFi protocols in their research. Parameter data from each solar panel is sent via Bluetooth to the minicomputer, and then the minicomputer sends the data to the web server via WiFi protocol. However, the minicomputer cannot receive data sent via Bluetooth if the distance between them is greater than 10 meters. Nkoloma *et al*. [22] used text messages (short message service (SMS)) to send data. By using this, data can be sent over long distances, but it is constrained by data transmission speed and cannot be done quickly. Data transmission utilizing radio frequency protocols provides advantages in terms of speed of delivery and distances that can be achieved up to 100 meters or more, depending on the device used. In their studies, Papageorgas *et al*. [23], Ranhotigamage *et al*. [24], Parikh *et al*. [25], and Shariff *et al*. [26] used Zigbee, which utilizes radio frequency for data transmission. The distance that this device can cover is 50 to 60 meters. In their studies, Guerriero *et al*. [27], [28] used MiWi, a wireless protocol that uses 2.4 radio frequency as its communication protocol. Spanias *et al*. [29] used a smart monitoring device (SMD), that uses radio frequency to detect system failures from solar panels. Despite being widely used for data transmission, radio frequency incurs higher costs depending on the desired coverage distance.

By utilizing IoT technology with an internet network, this alternative for sending data can offer speed and a vast distance. This paper develops IoT technology for sending parameter data from solar panels and ships it directly to a web server. The data stored on the webserver can then be processed for further identification for 24 hours. Then, this data can be used as a lesson for researchers to determine the characteristics of the PV employed in a PV system during the daily cycle and influenced by weather factors. Also, the proposed system can figure out how much electricity the solar system could produce.

2. PV ENERGY CONVERSION SYSTEM

A PV system generally consists of a PV module, a power conversion device, and a load, as shown in Figure 1. The configuration of the PV system varies depending on the requirements of the application. For applications with high voltage requirements, a multilevel power conversion (DC-AC-DC) is usually required or used in conjunction with a power converter with a high voltage ratio [30]. But when there is a DC load or a need to charge a battery, the configuration is usually simpler.

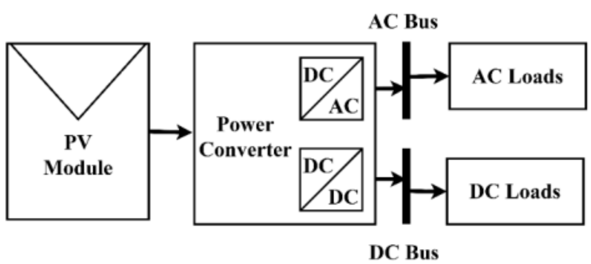


Figure 1. PV system configuration

The PV module consists of a combination of PV cells made of pn junction semiconductor material. Accurate modeling is needed to anticipate the nonlinear structure of the PV module output due to the input variable temperature and solar irradiation. Figure 2 shows the equivalent circuit of the widely used single-diode PV model. The cell output current (I_{cell}) can be calculated by (2) via Kirchhoff's law.

$$-I_{cell} - I_{SH} + I_{PH} - I_D = 0 \tag{1}$$

and

$$I_{cell} = I_{PH} - I_0\left(e^{\frac{V_{cell}+I_{cell}R_S}{nV_t}} - 1\right) - \frac{V_{cell}+I_{cell}R_S}{R_{SH}} \tag{2}$$

where STC-I_{PH} is the photocurrent generated under standard test conditions, STC-I_0 is the saturation current of the diode, R_S is the series resistance, R_{SH} is the shunt resistance, and ideally diode factor-n which can be estimated by the Bisection and Lambert-W methods [31].

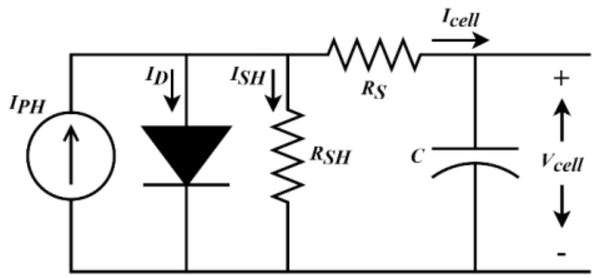


Figure 2. Single diode model PV module equivalent circuit

In this system, the PV panel has a voltage of 18 V with an output power of 50 W. The PV panel is connected to the input of a buck-boost DC-DC converter-type power conversion device. The converter is embedded in a solar charge control (SCC) device, which is then connected to the load. If the PV panel generates sufficient power, the SCC will regulate the power supplied to the load and supply power to charge the battery while it is not fully charged. However, if the PV panel does not have enough power, then the SCC will arrange for the battery to provide power to the load.

SCC regulates four stages of battery charging, and the charging process diagram is shown in Figure 3. When the battery is not fully charged, in this case, the battery is in the bulk charge stage, and the power will be fully sent to the battery. The charging process operates at the absorption stage until the battery is almost at the absorption voltage setpoint. At this stage, a constant voltage is applied for 150–180 minutes (depending on the type of battery) so that the battery voltage is at the setpoint [32]. Finally, once the battery is fully charged, the voltage is reduced to a float voltage setpoint so that it can be used to supply the load. If the load exceeds the SCC current, the battery cannot be maintained at the float setpoint. Also, if the battery voltage is lower than the setpoint of the float stage for a certain period, then charge back to the bulk stage.

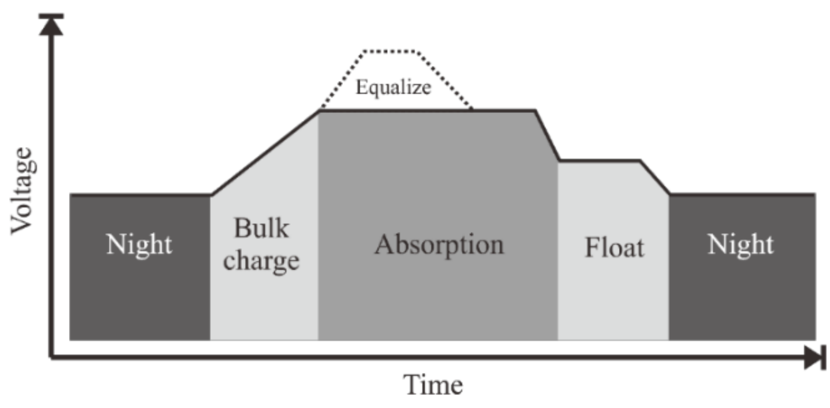


Figure 3. Battery charging stage

3. METHOD

In this process, a system is designed for measuring solar panel parameters, and the purpose is to measure voltage, current, power, temperature, and light intensity. The LCD is used to display the output of these parameter values off, while to store the solar panel parameter values, the microSD and Web Server are used. The components used in this paper are summarized in Table 1.

Table 1. List of components and their functions

Components	Function
Solar Panel 50Wp	Power generator
12V battery	Load and energy backup system
PWM SCC	Charging controller
NodeMCU ESP8266	Main controller + WiFi module
Inverter	AC load converter
ACS712 5A	Current sensor
INA219	Voltage sensor
ADS1115	ADC 16bit reader
Photodiode	Solar irradiance level sensor
DHT11	Ambient temperature sensor

The IoT system in this system is used as a monitoring output of parameter values generated from sensors to identify data in real-time. Then, the collected data is displayed on the LCD output and stored on the web server. After that, the parameter value data can be processed for further processing. Figure 4 shows a system diagram, while Figure 5 shows the process of the system.

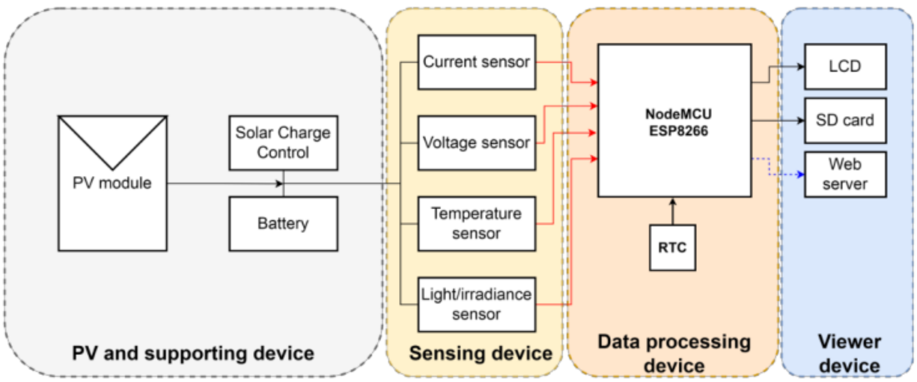


Figure 4. PV system parameter measurement configuration

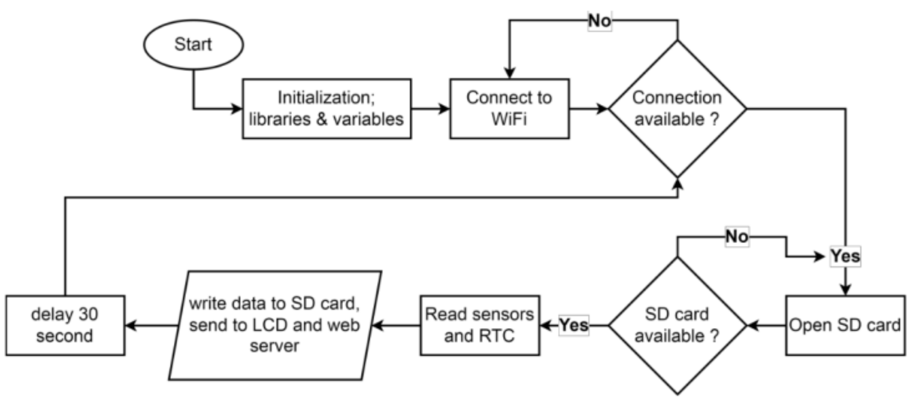


Figure 5. The process of the PV parameter monitoring system

3.1. PV and supporting device

The PV block and the supporting device are PV systems applied for battery charging. The instruments used in this block are 50 W monocrystalline PV, SCC with a capacity of 10 A PWM type, 12 V 7.2 Ah battery, and 30 W load.

3.2. Sensing device

The sensor device serves to measure essential parameters in the PV system. The current sensor is a sensor that works based on field effects. This sensor can be used to measure AC or DC. It has been equipped with an operational amplifier circuit to increase the current measurement sensitivity and measure small current changes. A voltage sensor is a sensor used to measure AC or DC voltage. The working principle of the voltage sensor module is based on the principle of suppression of resistance and can reduce its original input voltage up to 5 times.

The voltage sensor is based on a voltage divider circuit converted to a reference voltage (V_{ref}) of the microcontroller. The value of this sensor's voltage divider resistor (R_1 and R_2) depends on the magnitude of the input voltage as a voltage. In this case, the PV voltage (V_{PV}), will be measured. The voltage divider circuit equation is obtained as (3) [33].

$$V_{ref} = V_{PV} \frac{R_2}{R_1+R_2} \tag{3}$$

On the side of the current sensor, the output current generated is identical to the oscillation generated by the sensor. Therefore, a signal conditioning circuit consisting of a subtractor and an inverter is needed. The subtractor circuit uses an Op-Amp with an output voltage of (4).

$$V_{o,U_1} = \left(\frac{R_3}{R_2+R_3} V_{RV1}\right) - \left(\frac{R_4}{R_1} V_i\right) = \left(V_{R_{V2}} - V_i\right) \tag{4}$$

While inverting uses Op-Amp U_2 with an output voltage of (5).

$$V_{o,U_2} = -\left(\frac{R_{V2}}{R_5}\right) V_{o,U_1} \tag{5}$$

The DHT11 sensor used in this paper is a sensor module that functions to sense temperature and humidity in objects with an analog voltage output which can be further processed using a microcontroller. The light sensor uses a light dependent resistor (LDR) sensor. This module allows for detecting ambient light brightness and intensity using the LM393 comparator chip. The operating voltage of this LDR module is 3.3V–5V. This module generates both analog and digital signals.

3.3. Data processing device

In this paper, the microcontroller is the NodeMCU. The NodeMCU. It is integrated with the ESP8266 module, which is a very effective platform for communication or control over the internet, either used as a stand-alone or by using an additional microcontroller, in this case, Arduino as the controller. The use of this module is to control devices via the internet to support the IoT system. Furthermore, the RTC module, which is one type of module that functions as a real-time clock (RTC) or digital timer, is used. In this paper, the RTC module is used to calculate time starting from seconds, minutes, hours, days, dates, months, and years accurately and maintain or store time data.

3.4. Viewer device

The main viewer in this paper is via a web server. A web server is software that functions as a recipient of requests sent through a browser and then responds to requests in the form of website pages. In this paper, the webserver is ThingSpeak, an IoT platform and API to store sensor data monitored in real-time. The next display device is a 16x2 LCD, which is placed close to the PV system. This is intended to make it easier to monitor the system directly. An additional device in the form of a microSD card is used to store data offline. This is meant to be a backup for your data in case something goes wrong with your internet connection.

4. RESULTS AND DISCUSSION

The PV parameter monitoring system has been developed, as shown in Figure 6. The system starts by initializing the sensor library and ThingSpeak as well as the variables used in the algorithm. The ACS172 sensor carries out the data collection of voltage and current from the PV module. Pseudocode for taking voltage and current parameters using the following pseudocode.

```
void temp_current(){
 adc_value = analogRead(pinADC);
 voltage = (adc_value / 1024.0) * 5.0;
 current = ((voltage - offset_voltage) / s);
}
```

NodeMCU has a 10-bit ADC, so it can represent $2^{10} = 1024$. This program snippet is a voltage conversion, so `5.0` is the value of the I/O pin voltage used. While `s` is a constant of sensor sensitivity. Furthermore, the ambient temperature data is obtained with the following pseudocode.

```
DHT dht(DHTPIN, DHTTYPE);
dht.begin();
float celcius_1 = dht.readTemperature();
```

In this pseudocode, we apply the DHT11 library included with the sensor. This library facilitates the development of code listings because it shortens the program. Furthermore, the light intensity data using pseudocode is based on a similar principle to the pseudocode to access the ACS712 sensor.

```
void irradiance(){
 int value = analogRead (pin_ldr);
 float voltage_out = 5.0 * value / 1024;
}
```

Furthermore, WiFi connectivity is checked. If it is available, the microcontroller will access the SD card. If there is an SD card, the algorithm will read the sensors and time reference from the RTC module. The collected data is then stored in the SD card and displayed on the LCD. Further, the information is sent to the cloud server via a WiFi gateway, which is accessed via ESP8266.

Figure 6 shows the process of taking parameter data in a PV system. The PV system consists of a PV module controlled by the SCC as the primary source of power generation used for battery charging. The ThingSpeak platform as a graphics viewer is accessed via a laptop. The sensors, microcontrollers, and other parts are put in a box, which is then attached to the PV module holder.

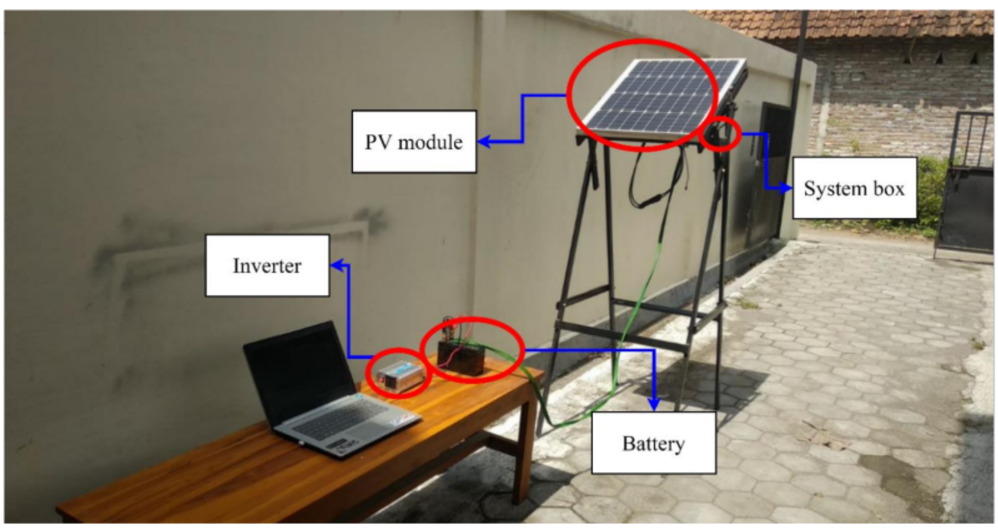
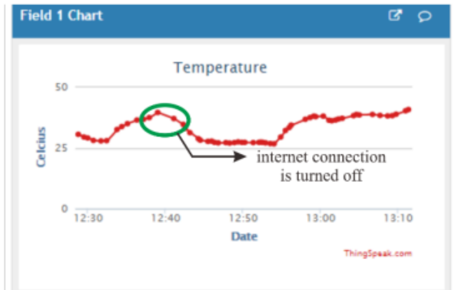
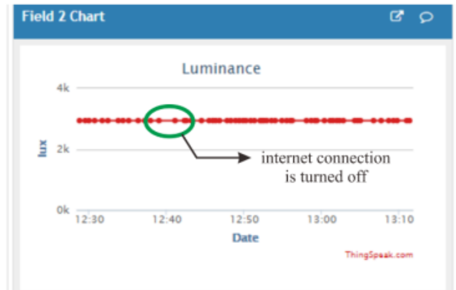


Figure 6. PV system parameter data collection

The measurement results of PV system parameters displayed graphically with the ThingSpeak platform are shown in Figures 7 and 8. The most commonly used parameters as variables in the PV performance optimization algorithm are temperature and irradiance. Figures 7(a) and 7(b) show the varying temperature and irradiance values from 12.30 to 13.10 (GMT+7). This is caused by environmental influences such as being blocked by clouds, trees, or buildings.



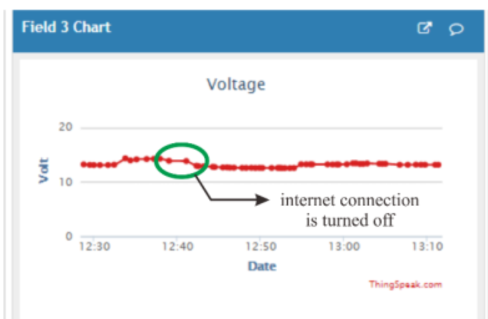
(a)



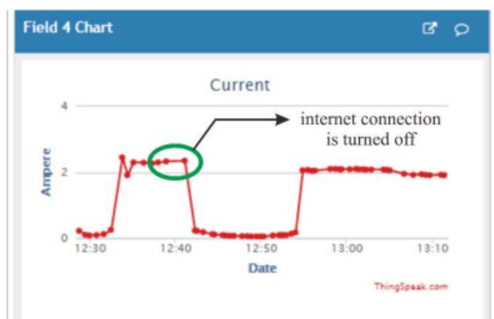
(b)

Figure 7. Measurement results of (a) temperature and (b) irradiance displayed graphically on ThingSpeak

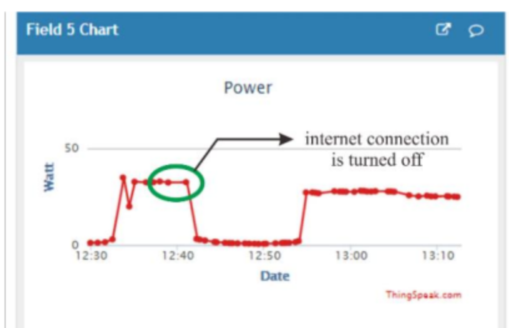
Changes in temperature and irradiance variables will cause the PV output power value to change. As shown in Figures 8(a) and 8(b), the PV output is in the form of fluctuating voltage and current. This is because temperature and irradiance affect the PV output voltage and current. As a result, the PV output power depicted in Figure 8(c) varies.



(a)



(b)



(c)

Figure 8. Measurement results (a) voltage, (b) current, and (c) power due to variations in temperature and irradiance

Overall, the PV system parameter monitoring must be running well. Sending data from the microcontroller to ThingSpeak runs according to a predetermined time interval. Since this parameter monitoring system works based on IoT techniques, an internet connection must send and display data to ThingSpeak. In Figures 7 and 8, the internet connection is temporarily turned off. As a result, there was a failure while sending data by the microcontroller to ThingSpeak for a moment.

Furthermore, the test was carried out for 18 hours with a full internet connection. It aimed to determine the correlation between essential parameters in the PV system and the surrounding environment. The parameter values are stored on the microSD and recorded in real-time via the RTC module. Figures 9 and 10 show the effect of daily time on the irradiation and stress parameters, respectively. The irradiation value shown in Figure 9 was recorded and started to increase after 04.00 to 06.00, then began to decrease after 16.00 to 18.00. In daylight, irradiation was recorded to be relatively stable due to bright lighting. But between 14:00 and 16:00, there was shading, which made the irradiation value temporarily drop.

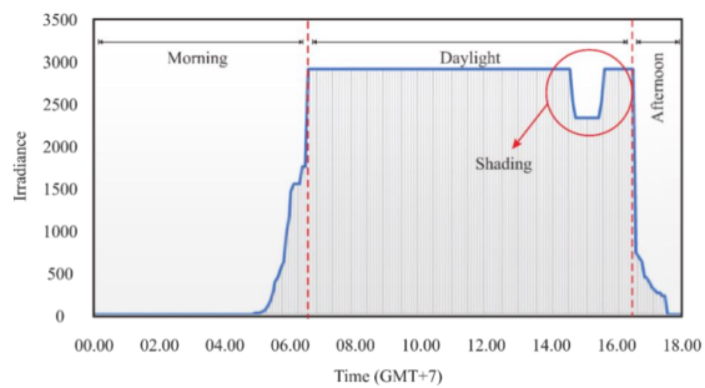


Figure 9. Irradiation value measured from morning to evening

On the side of the voltage parameters shown in Figure 10, the characteristics are not much different from the irradiation parameters when tested from morning to evening. The shading phenomenon that causes the irradiation value to decrease also affects the measured voltage value. It can be seen that the voltage value decreases similarly to irradiation. On the other hand, the voltage values measured during daylight show uneven fluctuations. This is influenced by the ambient temperature value, which also varies. This clearly shows that the parameters of irradiation and the temperature of the environment affect the PV output voltage.

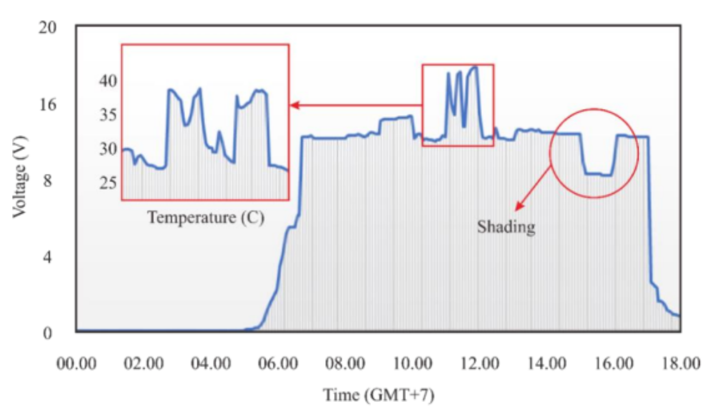


Figure 10. Voltage values measured from morning to evening

5. CONCLUSION

This research carried out parameter measurements of IoT-based PV systems on a laboratory scale. The IoT system utilizes the ThingSpeak platform, easily accessible for general purposes and real-time analysis. The system developed includes NodeMCU ESP8266 as a microcontroller, ACS712 5A for measuring current, INA219 for PV output voltage, a photodiode for measuring irradiance hitting PV panels, and DHT11 for measuring ambient temperature. This system is equipped with an ADS1115 as an ADC 16-bit reader. Other supporting components are a 50 Wp solar panel, a 12 V battery, a PWM SCC as a charging controller, and an inverter. Overall, the developed system successfully measures the parameters of the PV system in various weather conditions for 18 hours and sends them to the data viewer both online and offline correctly. This research can be used as a learning model for lab-scale PV systems in the future. Another application that will be developed is the management of energy loads from solar PV systems and grid power to optimize consumption and save energy for consumers. This management system monitors the energy generated by PV due to changing weather.

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REFERENCES

[1] V. Devabhaktuni, M. Alam, S. S. S. R. Depuru, R. C. Green, D. Nims, and C. Near, "Solar energy: Trends and enabling technologies," *Renewable and Sustainable Energy Reviews*, vol. 19. pp. 555–564, 2013, doi: 10.1016/j.rser.2012.11.024.
[2] E. Kabir, P. Kumar, S. Kumar, A. A. Adelodun, and K. H. Kim, "Solar energy: Potential and future prospects," *Renewable and Sustainable Energy Reviews*, vol. 82. pp. 894–900, 2018, doi: 10.1016/j.rser.2017.09.094.
[3] M. Datta, T. Senjyu, A. Yona, and T. Funabashi, "Photovoltaic output power fluctuations smoothing by selecting optimal capacity of battery for a photovoltaic-diesel hybrid system," *Electric Power Components and Systems*, vol. 39, no. 7, pp. 621–644, 2011, doi: 10.1080/15325008.2010.536809.
[4] T. Rout, A. Chowdhury, M. K. Maharana, and S. Samal, "Analysis of energy management system for photovoltaic system with battery and supercapacitor using fuzzy logic controller," in *2018 Technologies for Smart-City Energy Security and Power (ICSESP)*, Mar. 2018, no. 2, pp. 1–4, doi: 10.1109/ICSESP.2018.8376737.
[5] Z. Cabrane, M. Ouassaid, and M. Maaroufi, "Analysis and evaluation of battery-supercapacitor hybrid energy storage system for photovoltaic installation," *International Journal of Hydrogen Energy*, vol. 41, no. 45, pp. 20897–20907, 2016, doi: 10.1016/j.ijhydene.2016.06.141.
[6] M. R. Maghami, H. Hizam, C. Gomes, M. A. Radzi, M. I. Rezadad, and S. Hajighorbani, "Power loss due to soiling on solar panel: A review," *Renewable and Sustainable Energy Reviews*, vol. 59, pp. 1307–1316, 2016, doi: 10.1016/j.rser.2016.01.044.
[7] N. Kannan and D. Vakeesan, "Solar energy for future world: - A review," *Renewable and Sustainable Energy Reviews*, vol. 62. pp. 1092–1105, 2016, doi: 10.1016/j.rser.2016.05.022.
[8] S. Mekhilef, R. Saidur, and A. Safari, "A review on solar energy use in industries," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 4. pp. 1777–1790, 2011, doi: 10.1016/j.rser.2010.12.018.
[9] R. Indonesia, "Presidential Regulation Number 22 of 2017 on National Energy Master Plan (RUEN)(in Bahasa)," *Lembaran Negara RI Tahun*. 2017.
[10] P. G. V. Sampaio and M. O. A. González, "Photovoltaic solar energy: Conceptual framework," *Renewable and Sustainable Energy Reviews*, vol. 74, pp. 590–601, 2017, doi: 10.1016/j.rser.2017.02.081.
[11] J. Wennermark, C. Smallwood, and J. Parker, "Creating a learning laboratory: Lessons for United's members and the public about distributed generation," *IEEE Industry Applications Magazine*, vol. 20, no. 4, pp. 21–30, 2014, doi: 10.1109/MIAS.2013.2288407.
[12] A. Čolaković and M. Hadžialić, "Internet of Things (IoT): A review of enabling technologies, challenges, and open research issues," *Computer Networks*, vol. 144. Elsevier B.V., pp. 17–39, 2018, doi: 10.1016/j.comnet.2018.07.017.
[13] K. K. Patel and S. M. Patel, "Internet of things-IoT: Definition, characteristics, architecture, enabling technologies, application & future challenges," *International Journal of Engineering Science and Computing*, vol. 6, no. 5, pp. 1–10, 2016, doi: 10.4010/2016.1482.
[14] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of things: A survey on enabling technologies, protocols, and applications," *IEEE Communications Surveys and Tutorials*, vol. 17, no. 4, pp. 2347–2376, 2015, doi: 10.1109/COMST.2015.2444095.
[15] C. Sarkar, A. U. Akshay, R. V. Prasad, A. Rahim, R. Neisse, and G. Baldini, "DIAT: A scalable distributed architecture for IoT," in *IEEE Internet of Things Journal*, 2015, vol. 2, no. 3, pp. 230–239, doi: 10.1109/JIOT.2014.2387155.
[16] M. Kim, H. Ahn, and K. P. Kim, "Process-aware internet of things: A conceptual extension of the internet of things framework and architecture," *KSII Transactions on Internet and Information Systems (TIIS)*, vol. 10, no. 8, pp. 4008–4022, 2016, doi: 10.3837/tiis.2016.08.032.
[17] G. Hwang, J. Lee, J. Park, and T. W. Chang, "Developing performance measurement system for internet of things and smart factory environment," *International Journal of Production Research*, vol. 55, no. 9, pp. 2590–2602, May 2017, doi: 10.1080/00207543.2016.1245883.
[18] P. Daponte, F. Lamonaca, F. Picariello, L. De Vito, G. Mazzilli, and I. Tudosa, "A survey of measurement aApplications based on IoT," in *2018 Workshop on Metrology for Industry 4.0 and IoT*, 2018, pp. 157–162, doi: 10.1109/METROI4.2018.8428335.
[19] P. T. Le, H. L. Tsai, and T. H. Lam, "A wireless visualization monitoring, evaluation system for commercial photovoltaic modules solely in MATLAB/Simulink environment," *Solar Energy*, vol. 140, pp. 1–11, 2016, doi: 10.1016/j.solener.2016.10.043.
[20] Y. Bikrat, D. Moussaid, A. Benali, and A. Benlghazi, "Electronic and computer system for monitoring a photovoltaic station," in *2018 International Conference on Intelligent Systems and Computer Vision (ISCV)*, 2018, vol. 2018-May, pp. 1–6, doi: 10.1109/ISACV.2018.8354018.
[21] Y. Bikrat, K. Salmi, A. Benlghazi, A. Benali, and D. Moussaid, "A photovoltaic wireless monitoring system," in *2018 International Symposium on Advanced Electrical and Communication Technologies (ISAECT)*, Nov. 2018, pp. 1–5, doi: 10.1109/ISAECT.2018.8618825.

[22] M. Nkoloma, M. Zennaro, and A. Bagula, "SM2: Solar monitoring system in Malawi," in *Proceedings of ITU Kaleidoscope 2011: The Fully Networked Human? - Innovations for Future Networks and Services (K-2011)*, 2011, pp. 1–6.

[23] P. Papageorgas, D. Piromalis, K. Antonakoglou, G. Vokas, D. Tseles, and K. G. Arvanitis, "Smart solar panels: In-situ monitoring of photovoltaic panels based on wired and wireless sensor networks," in *Energy Procedia*, 2013, vol. 36, pp. 535–545, doi: 10.1016/j.egypro.2013.07.062.

[24] C. Ranhotigamage and S. C. Mukhopadhyay, "Field trials and performance monitoring of distributed solar panels using a low-cost wireless sensors network for domestic applications," *IEEE Sensors Journal*, vol. 11, no. 10, pp. 2583–2590, 2011, doi: 10.1109/JSEN.2011.2150214.

[25] A. Parikh, F. Pathan, B. Rathod, and S. Shah, "Solar panel condition monitoring system based on wireless sensor network," *International Journal of Science, Engineering and Technology Research (IJSETR)*, vol. 4, no. 12, pp. 4320–4324, 2015, doi: 10.13140/RG.2.2.18029.69605.

[26] F. Shariff, N. A. Rahim, and W. P. Hew, "Zigbee-based data acquisition system for online monitoring of grid-connected photovoltaic system," *Expert Systems with Applications*, vol. 42, no. 3, pp. 1730–1742, 2015, doi: 10.1016/j.eswa.2014.10.007.

[27] P. Guerriero *et al*., "A wireless sensor network for the monitoring of large PV plants," in *2014 International Symposium on Power Electronics, Electrical Drives, Automation and Motion*, 2014, pp. 960–965, doi: 10.1109/SPEEDAM.2014.6872084.

[28] P. Guerriero, F. Di Napoli, G. Vallone, V. Dalessandro, and S. Daliento, "Monitoring and diagnostics of PV plants by a wireless self-powered sensor for individual panels," *IEEE Journal of Photovoltaics*, vol. 6, no. 1, pp. 286–294, 2016, doi: 10.1109/JPHOTOV.2015.2484961.

[29] A. S. Spanias, "Solar energy management as an Internet of Things (IoT) application," in *2017 8th International Conference on Information, Intelligence, Systems and Applications, IISA 2017*, 2018, vol. 2018-Janua, pp. 1–4, doi: 10.1109/IISA.2017.8316460.

[30] A. C. Subrata, T. Sutikno, S. Padmanaban, and H. S. Purnama, "Maximum power point tracking in PV arrays with high gain DC-DC boost converter," in *International Conference on Electrical Engineering, Computer Science and Informatics (EECSI)*, 2019, pp. 358–362, doi: 10.23919/EECSI48112.2019.8977072.

[31] H. S. Sahu, S. Kumar, and S. K. Nayak, "Maximum power point estimation of a PV array by using improve bisection method," in *2018 IEEE Transportation Electrification Conference and Expo, Asia-Pacific (ITEC Asia-Pacific)*, 2018, pp. 1–5, doi: 10.1109/ITEC-AP.2018.8432595.

[32] L. Guo and J. Kors, "Design of a laboratory scale solar microgrid cyber-physical system for education," *Electronics (Switzerland)*, vol. 10, no. 13, p. 1562, 2021, doi: 10.3390/electronics10131562.

[33] B. L. Hart, "Precision voltage-divider circuit," *Electronics Letters*, vol. 7, no. 23, pp. 679 –680, 1971, doi: 10.1049/el:19710464.

BIOGRAPHIES OF AUTHORS

Arsyad Cahya Subrata received B.E. and M.E. in electrical engineering from Universitas Ahmad Dahlan, Indonesia and Universitas Diponegoro, Indonesia in 2016 and 2020, respectively. Currently, he is a member of the Embedded Systems and Power Electronics Research Group (ESPERG) research team since 2018, and has been a Lecturer with the Electrical Engineering Department, Universitas Ahmad Dahlan (UAD), Yogyakarta, Indonesia since 2021. His research interests include renewable energy, robotics, artificial intelligence, control instrumentation, intelligent control, and internet of things. He can be contacted at email: arsyad.subrata@te.uad.ac.id.

Tole Sutikno is a lecturer in Electrical Engineering Department at the Universitas Ahmad Dahlan (UAD), Yogyakarta, Indonesia. He received his B.Eng., M.Eng. and Ph.D. degrees in Electrical Engineering from Universitas Diponegoro, Universitas Gadjah Mada and Universiti Teknologi Malaysia, in 1999, 2004 and 2016, respectively. He has been an Associate Professor at UAD, Yogyakarta, Indonesia since 2008. He is currently the Editor-in-Chief of TELKOMNIKA and the Head of the Embedded Systems and Power Electronics Research Group (ESPERG). His research interests include the fields of digital design, industrial applications, industrial electronics, industrial informatics, power electronics, motor drives, renewable energy, FPGA applications, embedded systems, artificial intelligence, intelligent control, information technology and digital library. He can be contacted at email: tole@ee.uad.ac.id, or tole@te.uad.ac.id.

Sunardi received the B.E. and M.E. in electrical engineering from Universitas Gadjah Mada and Institut Teknologi Bandung in 1999 and 2003, respectively. He also received his Ph.D. in electrical engineering from Universiti Teknologi Malaysia in 2011. He is currently as Associate Professor with the Electrical Engineering Department, Universitas Ahmad Dahlan (UAD), Yogyakarta, Indonesia. His current research interests include signal processing, image processing, and artificial intelligence. He can be contacted at email: sunardi@ee.uad.ac.id.

Anggit Pamungkas received his B.E. in electrical engineering from Universitas Ahmad Dahlan, Indonesia, in 2018. Currently, he is a member of the Embedded Systems and Power Electronics Research Group (ESPERG) research team since 2019. His current research interests include power electronics, renewable energy development and robotics. He can be contacted at email: Anggitpamungkas17@gmail.com.

Watra Arsadiando received his B.E. in electrical engineering from Universitas Ahmad Dahlan, Indonesia, in 2017. Currently, he is a member of the Embedded Systems and Power Electronics Research Group (ESPERG) research team since 2019. His current research interests include power electronics, renewable energy development and robotics. He can be contacted at email: watra24arsadiando@gmail.com.

Ahmad Raditya Cahya Baswara received the B.E. and M.E. in electrical engineering from Universitas Gadjah Mada in 2014 and 2018, respectively. He is currently a Lecturer with the Electrical Engineering Department, Universitas Ahmad Dahlan (UAD), Yogyakarta, Indonesia. His current research interests include renewable energy, power electronics, wireless power, energy conversion. He can be contacted at email: ahmadradityac@ee.uad.ac.id.

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