Signal and Image Processing Letters
Vol. 3., No. 3, 2021, pp. 9-19
ISSN 2714-6677
https://simple.ascee.org/

Monitoring and Power Control on Solar Panels Based on the Internet of Things (IoT)

Binnerianto [a,1], Alfian Ma'arif [a,2,*], Iswanto [b,3]

[a] Electrical Engineering, Universitas Ahmad Dahlan, Yogyakarta, Indonesia.
[b] Electrical Engineering, Universitas Muhammadiyah Yogyakarta, Yogyakarta, Indonesia.
[1] binnerianto1800022071@webmail.uad.ac.id; [2] alfianmaarif@ee.uad.ac.id; [3] iswanto_te@umy.ac.id

ARTICLE INFO

Keywords
Voltage Sensor
Solar Panel
Node Mcu Esp8266
Arduino Uno
Blnyk

ABSTRACT

Indonesia is a tropical country. Therefore, to utilize abundant solar energy, solar power plants or solar power are made. This research aims to make it easier to monitor the voltage of solar panels and batteries through the Blynk application and Google spreadsheets, as well as automatic power controllers. The tools used in this study are Arduino Uno, MCU ESP8266 node, voltage sensors, relays, solar charge controllers, inverters, batteries, and solar panels. The monitoring and power control tool in this study works at voltages of 12VDC, 5VDC, and 220VAC. Solar panel and battery voltage measurement results are automatically updated in the Blynk app and Google sheets. In the Blynk app the data is updated every 6 seconds, but in Google sheets the data is updated every 1 minute. The average voltage sensor readings per day of solar panels and batteries are 13.011V and 12.969V, with the average error percentage of solar panel voltage is 0.13875% and on batteries is 0.0059%.

This is an open access article under the CC–BY-SA license.

1. Introduction

In today's era with the rapid development of technology and knowledge, it greatly impacts the improvement of the quality and welfare of human life. Developed countries are characterized by technological developments, one of which is solar panel monitoring technology. Solar panels function to convert solar light energy into electrical energy directly [1]. The problem with solar panel systems is how to find out the voltage conditions of solar panels and batteries in Realtime. The problem can be solved using a monitoring system.

The solar panel monitoring system has the function of monitoring and recording the output of solar panels automatically. This tool can make it easier to find out performance and record output data from solar panels. Technology that continues to improve certainly facilitates human activities [2]. Technology such as IoT makes it very easy for us to manage the distribution of load usage freely through smartphone devices. The Internet of Things (IoT) is a network that connects various objects that have identifying labels and IP addresses, in order to communicate and exchange information about themselves and the environment they detect [3].

Solar panel installation (Photovoltaic) certainly requires protection to protect solar charge controllers, batteries, and inverters. Problems commonly faced in solar home systems, MCB (Miniature Circuit Breaker) often trip or fall due to the condition of the battery in full condition but the input of energy from solar panels in watt peak conditions and the use of small loads, to overcome that usually users turn on all loads manually. With such circumstances, the author made a monitoring and power control tool on IoT-based solar panels, making it easier for users to monitor and share the load used as optimally as possible.

There are several studies related to monitoring and power control on Internet of Things (IoT)-based solar panels, including as described below.

1. The solar panel performance monitoring system using Arduino Uno aims as material for research consideration. The solar panel performance monitoring system is designed to be equipped with calibrated current, voltage and air quality measuring sensors, the data captured will be integrated with the web application as well as a database as a data store. The Arduino Uno microcontroller-based system design is connected to a computer via the ESP8266 Wi-Fi module with UART (Universal Asynchronous Receiver-Transmitter) communication and UDP (User Datagram Protocol) delivery method [4].

2. Output monitoring system and data recording on solar panels based on Arduino microcontroller, this system uses current sensors and voltage sensors to obtain current values, voltage as well as output power values from solar panels, measurement results are automatically stored on SD Card every 15 minutes. Data is stored in the form of Microsoft Excel in CSV format (comma separated values), where the data stored on the SD Card is date and time data, current values, voltage values, and power values [2].

3. Solar rotation control system on solar panels based on Arduino Uno, this system uses two LDR (Light Dependent Resistor) sensors, I2C LCD, Arduino Uno microcontroller, and servo motor to control the rotation of solar panels [5].

4. Research on the design of a solar panel performance monitoring system based on the ATMEGA 328 microcontroller. In this study using a voltage sensor, and an ACS712 current sensor. How the tool works if the voltage from the solar panel is less than 8V, then the red LED (Light Emitting Diode) will light up but the LED will light up green if the voltage is 8V or more than 8V. Sensor readings will be sent to GCS (Ground Control Software) created in Microsoft Visual Studio 2010 software [6].

5. Wireless sensor system research for solar panel efficiency monitoring using NodeMCU ESP8266, voltage sensor, ACS712, and BH1750 light intensity module. The data obtained will be sent to the database and web [7].

6. Research on Arduino-based battery voltage monitoring and SMS gateway using voltage sensors, GSM SIM900A modules, solar panels, and VRLA (Valve Regulated Lead Acid) type batteries. The data obtained is in the form of VRLA battery voltage values then the data is sent via SMS [8].

7. Research designs and makes a monitoring tool for the current and voltage of solar panels, as well as the intensity of sunlight that affects the output of IoT-based and real time solar panels. The monitoring data is stored and displayed on thing speak. This research uses the Research and Development method of the Borg and Gall model [9].

8. Research monitoring and clustering systems in real time and automatically that can monitor the performance of solar panels, batteries, and electricity consumption by users, and can regulate the battery by disconnecting charging when the battery voltage reaches the maximum threshold limit and disconnecting usage when the battery voltage reaches the minimum threshold limit. The transmission of monitoring data to the server is carried out by the Arduino microcontroller through an ESP8266 Wi-Fi module using the 802.11b communication protocol. The monitoring data will be displayed on the Web monitoring and will be processed using the K-Means algorithm to classify the power generated by solar panels to assist in analyzing solar panel performance [10].

9. Research on monitoring systems on IoT-based dual axis solar tracking systems to improve the efficiency of light reception by solar panels, as well as monitoring the power generated by IoT-based solar panels. The tracking system is a method that is able to make solar panels move following the movement of the direction of the light source so that the solar panel gets maximum light, so that the power produced will also be maximized. To find out the amount of power generated by solar panels, it can be done using a monitoring system. As technology develops, monitoring systems can be done remotely using IoT methods [11].

10. Research Solar panel monitoring system solar tracker based on the Internet of things with GOIOT is a tool to monitor numbers and graphs from INA 219 sensor reading data used to read current and voltage values on and MAX 44009 sensors used to read light intensity values [12].

11. The development research of two-axis solar-tracking developers uses Arduino Uno as the main controller of the system. To develop this project, four light-dependent resistors (LDRs) have been used to detect sunlight and maximum light intensity [13].

12. Using Internet of Things Technology to supervise solar power plants can greatly improve the performance, monitoring, and maintenance of power plants. With advances in technology, the cost of renewable energy equipment is falling globally, driving the installation of large-scale solar power plants [14].

13. Research simulated acquisition of solar panel data in real time in LabVIEW. A prototype model has been created in which two Arduinos are used. One is used to interface solar panels with PCs for data acquisition and the other is used with servomotors. The servo motor is connected with the solar panel with the help of shaft and rotated according to the LDR output. Two LDRs are installed on either side of the solar panel to track sunlight [15].

2. Methods

2.1. Materials

2.1.1. Microcontroller

A microcontroller is a complete microprocessor system contained in a chip. Consists of minimal microprocessor system support components, namely memory, I/O INTERFACE, ADC, PLL, and EEPROM in one package [16]. Arduino Uno is an open source-based microcontroller, which is a microcontroller that can be developed by third parties that makes it easier for users to develop automation projects and other microcontrollers easily [17] (Fig. 1).

Fig. 1. Arduino Uno

2.1.2. Node MCU ESP8266

MCU ESP8266 node is a versatile wifi module because it has been equipped with GPIO, ADC, UART and PWM (Fig. 2). NodeMCU besides being programmable using the LUA language can also be programmed using the C language using the Arduino IDE [18].

Fig. 2. Node MCU ESP8266

2.1.3. Voltage Sensor

Voltage sensors are used to obtain voltage data in an electronic component. The principle of this sensor is based on the resistance pressure and makes the terminal input voltage reduced by 5 times of the original voltage [2].

2.1.4. Relay

Relay is an electromechanical component that has two main parts, namely electromagnet (coil) and mechanical (switch switch contact) and is a switch (switch) that is operated through electricity [19].

2.1.5. Mini Circuit Breaker (MCB)

MCB (Mini Circuit Brea ker) adalah material instalasi listrik yang cara bekerjanya berdasarkan thermo/suhu panas. MCB berfungsi sebagai proteksi arus lebih yang disebabkan oleh beban lebih (over load) dan arus lebih karena adanya hubung singkat (short circuit) [20].

2.1.6. Solar Panel

Solar panel is a device composed of semiconductor material that can convert sunlight into electric power directly. Often also used the term photovoltaic or photovoltaic [4].

2.1.7. Inverter

Electronic systems consisting of dc-link buses, switching devices and controllers, data protection, logging and monitoring, and communication modules are called inverters [21].

2.1.8. Lead Acid Battery

Dry-element lead acid batteries are typically used as energy backup storage for remote communities, telecommunications systems, or electric vehicles. Problems that often occur in this battery are overcharge and overdischarge. The problem causes temperature changes and physical deformation in the battery, thus affecting its performance [22].

2.1.9. Solar Charger Controller (SCC)

SCC is an electronic device used to regulate the current regulator entering from the solar cell to the battery and the output load and serves to keep the battery from overcharging so that the battery lasts longer [23].

2.1.10. Arduino IDE

The Arduino IDE (Integrated Development Environment) application is useful for opening, creating, and editing programs that will be included in the Arduino board [24].

2.1.11. Blynk

Blynk is an application available on IOS and ANDROID operating systems that is used to control Arduino, Rasbery Pi, Wemos and similar devices using the internet network [25].

2.2. Methods

The block diagram of the system is shown in Fig. 3 using voltage sensors, Arduino Uno, Nodemcu8266, Solar Charge Controller, inverter and relay. The voltage sensor functions to get the voltage value on the solar panel and battery. The values obtained by sensors are processed through Arduino Uno and then sent via Nodemcu8266 to Blynk and Google spreadsheets. Data from sensors will be displayed on Blynk and Google sheets so that data can be accessed via smartphones and laptops. Data from solar panel and battery voltage sensors will be used as a reference to enable or disable the dummyload relay. The relay will turn on the dummyload (9W lamp) when the solar panel and battery voltage reaches 13.5V.

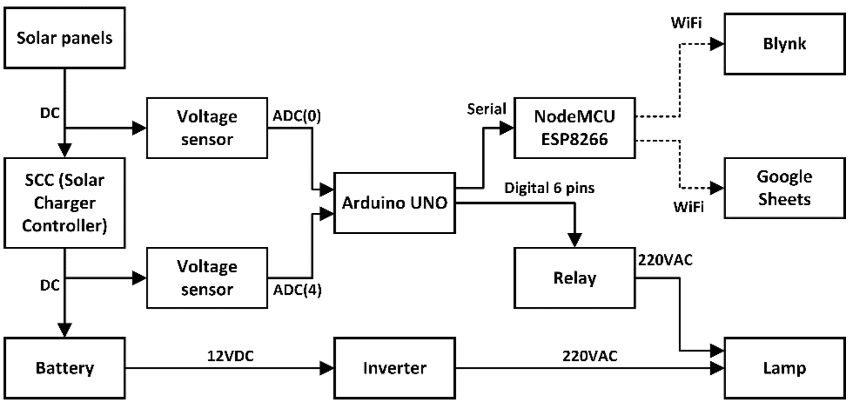


Fig. 3. System block diagram

Based on the wiring diagram of the system shown in Fig. 4, the placement of the Arduino Uno pin used is obtained. A description of the tools used can be seen in Table 1 and the pins of the Arduino Uno used in Table 2.

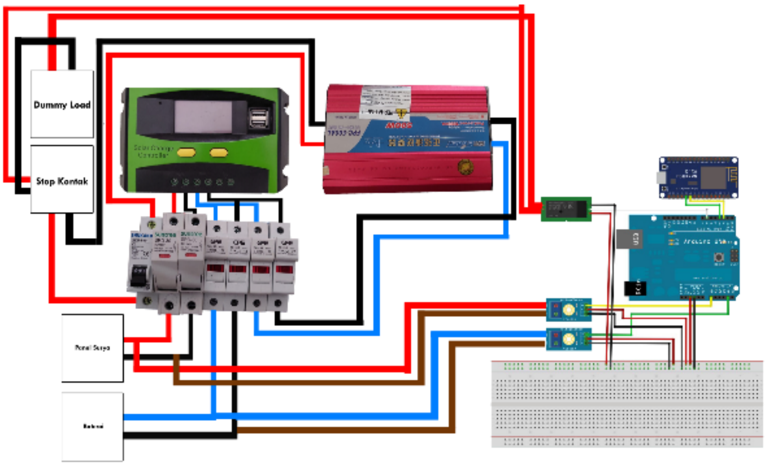


Fig. 4. Wiring digram

Table 1. Tools used

No.	Information
1	Arduino Uno
2	Node MCU ESP8266
3	Relay 1 Channel
4	Voltage sensor
5	Inverter 500Watt
6	SCC
7	Fuse box DC
8	MCB AC

Table 2. Pins used

No.	Arduino Uno Pin	Information
1	5V	Pin + (solar panel voltage sensor and battery voltage sensor) and Vcc pin on relay.
2	Gnd	Pin – (solar panel voltage sensor and battery voltage sensor) and Gnd pin on relay.
3	A0	Pin S on solar panel voltage sensor.
4	A4	Pin S on the battery voltage sensor.
5	6	Pin In1 on the relay.
6	2	Pin 7 on ESP8266 MCU Node as RX.
7	3	Pin 8 on MCU Node ESP8266 as TX.

3. Results and Discussion

Trials in this study were carried out by comparing the voltage values of solar panels and batteries read by voltage sensors with multimeters. The solar panel used in this study has a specification of 30Wp and monocrystalline type, and the battery used has a specification of 12VDC 3AH. This trial was carried out for 3 days.

Voltage log data stored in Google spreadsheets is transferred to Microsoft Excel for analysis of voltage sensor reading errors with a multimeter. The sample data taken per day amounted to 30 data. The difference in data read by the voltage sensor with the multimeter is then analyzed by the variant. Analysis of variance is carried out to obtain standard deviation, after standard deviation it can analyze the standard error value. Here are the variant, standard deviation, and standard error formulas,

$$\boldsymbol{S^2} = \frac{\sum(\boldsymbol{X}-\boldsymbol{\bar{X}})^2}{(\mathbf{n}-\mathbf{1})} \qquad SD = \sqrt{S^2} \qquad Error\ Standards = SE = \sqrt{\frac{SD^2}{n}} \tag{1}$$

S^2 is Varian, SD is Standard deviation, SE is Error Standards, X is Value difference, $\bar{X}$ is Average difference value, and N is Number of samples.

Voltage sensor calibration tests are taken as much as 30 data or for 30 minutes, this is to get the error value from the voltage sensor. In Table 3 the comparison of voltage measured by a multimeter with a voltage sensor starting at 08.30.43 WIB to 08.59.52 WIB, the average difference in solar panel voltage is 0.04 and the average difference in battery voltage is 0.09733. The result of the difference will be used to find the standard error of the voltage sensor.

Table 2. First day voltage sensor calibration

Solar panel voltage sensor (V)	Multimeter (V)	Difference	Battery voltage sensor (V)	Multimeter (V)	Difference
12.88	12.8	0.08	12.73	12.6	0.13
12.88	12.8	0.08	12.73	12.6	0.13
12.88	12.8	0.08	12.76	12.6	0.16
12.9	12.8	0.1	12.73	12.6	0.13
12.9	12.8	0.1	12.73	12.6	0.13
12.88	12.8	0.08	12.76	12.6	0.16
12.85	12.8	0.05	12.73	12.6	0.13
12.88	12.8	0.08	12.71	12.6	0.11
12.85	12.8	0.05	12.71	12.6	0.11
12.85	12.8	0.05	12.71	12.6	0.11
12.85	12.8	0.05	12.68	12.6	0.08
12.83	12.8	0.03	12.71	12.6	0.11
12.88	12.8	0.08	12.73	12.6	0.13
12.85	12.8	0.05	12.73	12.6	0.13
12.88	12.8	0.08	12.73	12.6	0.13
12.88	12.8	0.08	12.73	12.6	0.13
12.9	12.9	0	12.76	12.7	0.06
12.9	12.9	0	12.76	12.7	0.06
12.88	12.9	-0.02	12.76	12.7	0.06
12.88	12.9	-0.02	12.73	12.7	0.03
12.88	12.9	-0.02	12.73	12.7	0.03
12.9	12.9	0	12.73	12.7	0.03
12.9	12.9	0	12.76	12.7	0.06
12.88	12.9	-0.02	12.76	12.7	0.06
12.85	12.9	-0.05	12.73	12.7	0.03
12.9	12.9	0	12.76	12.7	0.06
12.88	12.9	-0.02	12.73	12.7	0.03
12.9	12.8	0.1	12.76	12.6	0.16
12.85	12.8	0.05	12.73	12.6	0.13
12.88	12.8	0.08	12.71	12.6	0.11

In Table 4 the voltage comparison measured by a multimeter with a voltage sensor starting at 08.10.29 WIB to 08.39.34 WIB, the average difference in solar panel voltage is 0.40667 and the average difference in battery voltage is 0.09733. In Table 5 the voltage comparison measured by a multimeter with a voltage sensor starting at 09.15.35 WIB to 09.44.40 WIB, the average difference in solar panel voltage is 0.027666667 and the average difference in battery voltage is 0.09.

The graph of monitoring the voltage of solar panels on the first day can be seen in Fig. 5. Based on Fig. 5, the average solar panel voltage read by the sensor is 12.97V, the highest voltage is 13.56V at 13:49:32 WIB and 14:00:34 WIB, and the lowest voltage is 0.49V at 08:25:43 WIB. The solar panel voltage sensor failed to read the voltage 4 times with a long distance of time, while for the solar panel voltage sensor error reading of 0.0083%, the error results were obtained from the difference in solar panel and battery voltage measurements which can be seen in Table 3, while the battery voltage sensor on the first day experienced a reading error twice, namely at 08.25.43 WIB and 11.19.55 WIB and the error value read by the sensor was 0.0079%. The highest value of battery voltage read by the sensor on the third day was 13.49V at 13.48.32 WIB, and the lowest voltage read by the sensor was 0V, and the average voltage stored by the battery on the first day was 12.92V.

Data collection on the second day with very sunny weather conditions so that the voltage results captured by solar panels are very maximal. The highest voltage obtained on the second day was 14.22V at 11.00.03 WIB, the smallest voltage was 0.49V at 08.17.21 WIB, and the average voltage produced by solar panels on the second day was 13.06V. Based on Fig. 6 the solar panel voltage sensor reading error has a voltage read error of 6 times, this is due to the voltage surge caused by the burning of the dummy load (9W lamp) and the Arduino Uno failed to send data to the ESP8266 MCU Node.

The sensor has a read error every time the dummy load is on, therefore the percentage of solar panel voltage sensor error on the second day is greater than the first day which is 0.443%, the error results are obtained from the difference in solar panel and battery voltage measurements which can be seen in Table 4. The battery voltage sensor also experiences an error when the dummy load is on for 1 minute, after which the sensor reads the voltage normally. The error value read by the battery voltage sensor on the second day was 0.0058%, the highest voltage was 15.1V at 13.56.41 WIB, the lowest voltage value read was 0V, and the average battery voltage on the second day was 13.07V.

Table 3. Second day voltage sensor calibration

Solar panel voltage sensor (V)	Multimeter (V)	Difference	Battery voltage sensor (V)	Multimeter (V)	Difference
13	13	0	12.85	12.8	0.05
13.03	13	0.03	12.9	12.8	0.1
13.07	13	0.07	12.93	12.8	0.13
13.03	13	0.03	12.9	12.8	0.1
13.03	13	0.03	12.88	12.8	0.08
13.05	13	0.05	12.88	12.8	0.08
13.03	13	0.03	12.9	12.8	0.1
0.49	13	-12.51	12.9	12.8	0.1
13.03	13	0.03	12.9	12.8	0.1
13.05	13	0.05	12.9	12.8	0.1
13.03	13	0.03	12.9	12.8	0.1
13.03	13	0.03	12.88	12.8	0.08
13.07	13	0.07	12.93	12.8	0.13
13.05	13	0.05	12.9	12.8	0.1
13.05	13	0.05	12.93	12.8	0.13
13.07	13.1	-0.03	12.93	12.9	0.03
13.07	13.1	-0.03	12.93	12.9	0.03
13.1	13.1	0	12.93	12.9	0.03
13.05	13.1	-0.05	12.93	12.9	0.03
13.07	13.1	-0.03	12.95	12.9	0.05
13.07	13.1	-0.03	12.95	12.9	0.05
13.1	13.1	0	12.95	12.9	0.05
13.07	13.1	-0.03	12.93	12.9	0.03
13.1	13.1	0	12.95	12.9	0.05
13.1	13.1	0	12.95	12.9	0.05
13.1	13.1	0	12.98	12.9	0.08
13.07	13.1	-0.03	12.95	12.9	0.05
13.07	13.1	-0.03	12.95	12.9	0.05
13.1	13.1	0	12.95	12.9	0.05
13.12	13.1	0.02	12.98	12.9	0.08

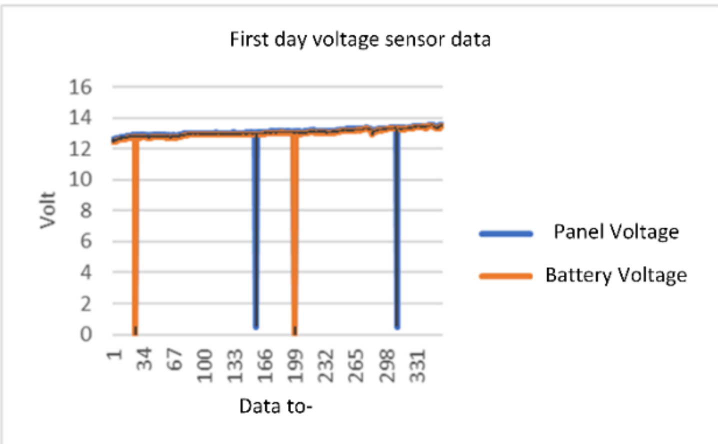


Fig. 5. First day voltage sensor data

Table 4. Third day voltage sensor calibration

Solar panel voltage sensor (V)	Multimeter (V)	Difference	Battery voltage sensor (V)	Multimeter (V)	Difference
12.9	12.9	0	12.76	12.7	0.06
12.9	12.9	0	12.78	12.7	0.08
12.9	12.9	0	12.76	12.7	0.06
12.93	12.9	0.03	12.76	12.7	0.06
12.9	12.9	0	12.78	12.7	0.08
12.88	12.9	-0.02	12.76	12.7	0.06
12.9	12.9	0	12.76	12.7	0.06
12.93	12.9	0.03	12.78	12.7	0.08
12.9	12.9	0	12.76	12.7	0.06
12.9	12.9	0	12.78	12.7	0.08
12.9	12.9	0	12.76	12.7	0.06
12.95	12.9	0.05	12.78	12.7	0.08
12.93	12.9	0.03	12.81	12.7	0.11
12.95	12.9	0.05	12.83	12.7	0.13
12.93	12.9	0.03	12.81	12.7	0.11
12.95	12.9	0.05	12.83	12.7	0.13
12.95	12.9	0.05	12.83	12.7	0.13
12.95	12.9	0.05	12.81	12.7	0.11
12.95	12.9	0.05	12.81	12.7	0.11
12.98	12.9	0.08	12.81	12.7	0.11
12.93	12.9	0.03	12.81	12.7	0.11
12.95	12.9	0.05	12.78	12.7	0.08
12.93	12.9	0.03	12.81	12.7	0.11
12.93	12.9	0.03	12.81	12.7	0.11
12.93	12.9	0.03	12.81	12.7	0.11
12.95	12.9	0.05	12.78	12.7	0.08
12.93	12.9	0.03	12.81	12.7	0.11
12.9	12.9	0	12.76	12.7	0.06
12.95	12.9	0.05	12.81	12.7	0.11
12.95	12.9	0.05	12.76	12.7	0.06

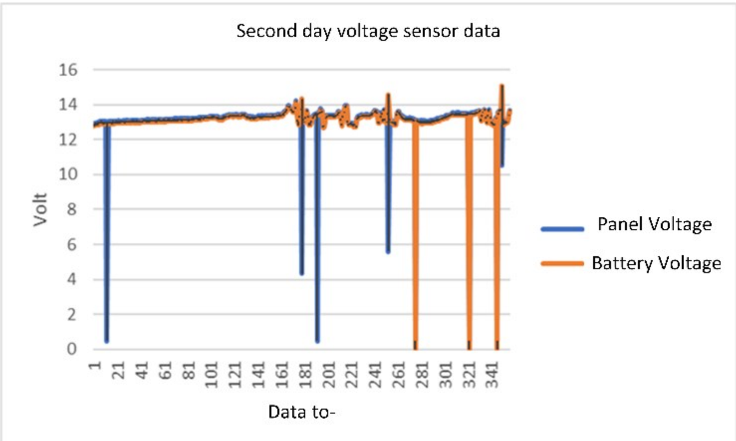


Fig. 6. Second day voltage sensor data

The reading of the solar panel voltage sensor on the third day experienced a read error once, namely at 08.05.15 WIB can be seen in Fig. 7, this is because it failed to send the ESP8266 MCU Node to Google spreadsheet. Weather conditions on the third day of data collection were cloudy. The highest voltage produced by solar panels on the third day was 13.37V at 13.16.38 WIB, the average voltage read by the third day solar panel voltage sensor was 13V, and the smallest voltage read by the sensor was 0.49V. The error value obtained by the solar panel voltage sensor on the third day is 0.004%, the error results are obtained from the difference in solar panel and battery voltage measurements which can be seen in Table 5. While the battery voltage sensor does not experience read failure, this is due to the absence of sudden voltage changes. The error value obtained by the battery voltage sensor is 0.0045%, the highest battery voltage on the third day read by the sensor is 13.29V at 13.18.38 WIB, and the lowest voltage value is 12.51V at 08.00.13 WIB, and the average voltage read by the sensor is 12.9V.

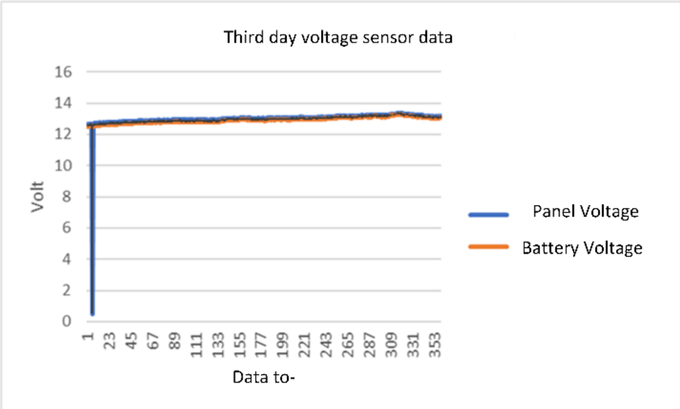
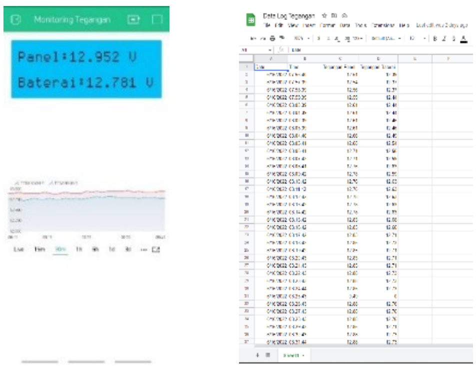


Fig. 7. Third day voltage sensor data

The Blynk app is used to display data on LCD screens and graphs, while the Google spreadsheet app is used to store data retrieved from sensors. The graph on Blynk is updated every 6 seconds, while on Google sheets the data is updated every 1 minute. Fig. 8 shows the Blynk view page and Google spreadsheets.



(a) (b)

Fig. 8. (a) Blynk's page (b) Google sheets page

4. Conclusion

Research has succeeded in determining the amount of voltage produced by solar panels and batteries in real time through the Blynk application and Google spreadsheets. The average error value of solar panel voltage sensors is 0.13875% and in batteries 0.0059%. Research has successfully tested active relays under conditions of solar panel and battery voltage of more than 13.5V on the second day. When the dummyload relay is on, the voltage sensor will experience an error in reading the voltage value. Based on the results and discussion on testing the voltage of solar panels and batteries, sudden load changes cause sensor errors in reading voltage for 1 minute, then normal again. Data sent to MCU ESP8266 Node sometimes has send errors, resulting in zero data received.

References

[1] G. Sasikala, "Arduino Based Smart Solar Photovoltaic Remote Monitoring System," *Malaysian Journal of Science*, pp. 58-62, 2022, https://doi.org/10.22452/mjs.vol41no3.8.

[2] A. B. Pulungan, L Son, S. Syafii, S. Huda, and U. Ubaidillah, "Design and Implementation Data Logger with *Integrated* Circuit Multiplexer for Solar Panel Park," *TEM Journal*, vol. 11, no. 1, p. 427, 2022, https://www.ceeol.com/search/article-detail?id=1027573.

[3] A. Rejeb, J. G. Keogh, and H. Treiblmaier, "Leveraging the Internet of Things and Blockchain Technology in Supply Chain Management," *Future Internet,* vol. 11, no. 7, p. 161, 2019, https://doi.org/10.3390/fi11070161.

[4] M. Gopal, T. C. Prakash, N. V. Ramakrishna, and B. P. Yadav, "IoT based solar power monitoring system," *In IOP Conference Series: Materials Science and Engineering*, vol. 981, no. 3, p. 032037, 2020, https://doi.org/10.1088/1757-899X/981/3/032037.

[5] F. Z. Siti *et al*., "Autonomous Solar Rotary Composter Equipped with a Remote Management System," *2021 9th International Renewable and Sustainable Energy Conference (IRSEC)*, pp. 1-5, 2021, https://doi.org/10.1109/IRSEC53969.2021.9741218.

[6] H. Hamdani, A. B. Pulungan, D. E. Myori, F. Elmubdi, and T. Hasannuddin, "Real Time Monitoring System on Solar Panel Orientation Control Using Visual Basic," *Journal of Applied Engineering and Technological Science (JAETS)*, vol. 2, no. 2, pp. 112-124, 2021, https://doi.org/10.37385/jaets.v2i2.249.

[7] A. T. Demetillo, M. V. Japitana, and E. B. Taboada, "A system for monitoring water quality in a large aquatic area using wireless sensor network technology," *Sustainable Environment Research*, vol. 29, pp. 1-9, 2019, https://doi.org/10.1186/s42834-019-0009-4.

[8] M. Setiawan and R. D. Puriyanto, "Arduino-Based Battery Voltage Monitoring and SMS Gateway Monitoring Tegangan Baterai Berbasis Arduino dan SMS Gateway," *Buletin Ilmiah Sarjana Teknik Elektro,* vol. 2, no. 3, pp. 111–118, 2020, https://doi.org/10.12928/biste.v2i3.1478.

[9] D. A. Feriando, R. Feriza, and Y. Don, "Realtime And Centralized Solar Panel Online Monitoring System Design Using Thingspeak," *Journal of Railway Transportation and Technology*, vol. 2, no. 1, pp. 1-9, https://doi.org/10.37367/jrtt.v2i1.18.

[10] L. Liang, *et al*., "Status evaluation method for arrays in large-scale photovoltaic power stations based on extreme learning machine and k-means," *Energy Reports*, vol. 7, pp. 2484-2492, 2021, https://doi.org/10.1016/j.egyr.2021.04.039.

[11] M. Saifuzzaman, S. F. Shetu, N. N. Moon, F. N. Nur and M. H. Ali, "IoT Based Street Lighting Using Dual Axis Solar Tracker and Effective Traffic Management System Using Deep Learning: Bangladesh Context," *2020 11th International Conference on Computing, Communication and Networking Technologies (ICCCNT)*, pp. 1-5, 2020, https://doi.org/10.1109/ICCCNT49239.2020.9225590.

[12] A. B. Pulungan, R. Risfendra, W. Purwanto, H. Maksum, and O. Setiawan, "Design and development of real time monitoring single axis solar tracker by using internet of things," *International Journal of GEOMATE*, vol. 18, no. 69, pp. 81-87, 2020, http://repository.unp.ac.id/id/eprint/26346.

[13] M. N. A. Mohd Said, S. A. Jumaat, and C. R. A. Jawa, "Dual axis solar tracker with iot monitoring system using arduino,"*Int. J. Power Electron. Drive Syst*., vol. 11, no. 1, pp. 451–458, 2020, http://download.garuda.kemdikbud.go.id/article.php?article=1492788&val=147&title=Dual%20axis%20solar%20tracker%20with%20IoT%20monitoring%20system%20using%20arduino .

[14] M. Katyarmal, S. Walkunde, A. Sakhare, and M. U. S. Rawandale, "Solar power monitoring system using IoT," *Int Res J Eng Technol (IRJET),* vol. 5, no. 3, pp. 3431–3432, 2018, [Online]. Available: www.irjet.net.

[15] S. Mandal and D. Singh, "Real Time Data Acquisation of Solar Panel Using Arduino and Further Recording Voltage of the Solar Panel," *Int. J. Instrum. Control Syst.,* vol. 7, no. 3, pp. 15–25, 2017, https://doi.org/10.5121/ijics.2017.7303.

[16] S. J. Sokop, D. J. Mamahit, M. Eng, and S. R. U. A. Sompie, "Trainer Periferal Antarmuka Berbasis Mikrokontroler Arduino Uno," *Jurnal Teknik Elektro Dan Komputer,* vol. 5, no. 3, 2016.

[17] G. Parise, L. Martirano, U. Grasselli and L. Benetti, "The arc-fault circuit protection," *Conference Record of the 2001 IEEE Industry Applications Conference. 36th IAS Annual Meeting (Cat. No.01CH37248),* vol. 3, pp. 1817-1822, 2001, https://doi.org/10.1109/IAS.2001.955778.

[18] S. I. Azid, B. N. Sharma, K. Raghuwaiya, A. Chand, S. Prasad, and A. Jacquier, "SMS based flood monitoring and early warning system," *ARPN Journal of Engineering and Applied Sciences*, vol. 10, no. 15, pp. 6387-6391, 2016, http://repository.usp.ac.fj/id/eprint/8920.

[19] D. Wicaksono and T. Kamal, “Micro climate monitoring system in closed broiler cages based on the internet of things,” *J. Teknol. dan Sist. Komput.*, vol. 8, no. 2, pp. 100–105, 2020, https://doi.org/10.14710/jtsiskom.8.2.2020.100-105.

[20] M. Darji, N. Parmar, Y. Darji, and S. Mehta, “A Smart Home Automation System Based on Internet of Things (IoT) Using Arduino,” *In Futuristic Trends in Networks and Computing Technologies: Select Proceedings of Fourth International Conference on FTNCT*, pp. 279-293, 2022, https://doi.org/10.1007/978-981-19-5037-7_19.

[21] I. N. Satya Kumara, I. W. Gede Santika, I. G. Eka Wiantara Putra, D. Sitompul, and C. Gede Indra Partha, “Design of DC Wirings for Urban House in Indonesia including Analysis on Appliances, Power Losses, and Costs: An alternative to Support Rooftop PV Uptake,” *E3S Web Conf.*, vol. 188, pp. 1–12, 2020, https://doi.org/10.1051/e3sconf/202018800012.

[22] A. Qurthobi, A. B. K. Pambudi, D. Darmawan, and R. F. Iskandar, “Correlation between battery voltage under loaded condition and estimated state of charge at valve-regulated lead acid battery on discharge condition using open circuit voltage method*,” Int. J. Power Electron. Drive Syst*., vol. 9, no. 1, pp. 357–364, 2018, https://www.proquest.com/openview/51c46fb8d1d395896a2bb222e578cfd2/1?cbl=1686343&pq-origsite=gscholar.

[23] F. Fianti, A. Perdana, B. Astuti, and I. Akhlis, “Analysis of PWM- and MPPT-solar charge controller efficiency by simulation,” *J. Phys. Conf. Ser.,* vol. 1918, no. 2, p. 022004, 2021, https://doi.org/10.1088/1742-6596/1918/2/022004.

[24] J. M. Hernández-Mangas and J. A. Álvarez, "Project-Based Learning in “Practical Development of Electronic Systems” Course, Weaknesses and Strengths in the Context Imposed by the COVID-19 Disease," in IEEE Revista Iberoamericana de Tecnologias del Aprendizaje, vol. 16, no. 2, pp. 194-203, 2021, https://doi.org/10.1109/RITA.2021.3089920.

[25] K. L. Raju, V. Chandrani, S. S. Begum and M. P. Devi, "Home Automation and Security System with Node MCU using Internet of Things," *International Conference on Vision Towards Emerging Trends in Communication and Networking (ViTECoN),* pp. 1-5, 2019, https://doi.org/10.1109/ViTECoN.2019.8899540.