Research Article

Prototype of a Solar Panel Voltage Monitoring Tool Using IoT

[1,*] Dino Dwi Aryanto, [2]Firdaus Ashari, [3]Rani Nur Yulianti, [4]Eliza Bahora, [5]Agung Tri Novianto

[1,2,3,4,5] Subang State Polytechnic, Subang Regency, West Java 41211, Indonesia

* Corresponding Author: dino.aryanto@polsub.ac.id

Abstract: The use of solar energy as a renewable energy source continues to grow, but many solar panel systems are still not equipped with real-time performance monitoring tools. This research aims to design and implement an Internet of Things (IoT)-based solar panel monitoring system using a NodeMCU microcontroller and the ThingSpeak platform. This system is capable of monitoring electrical parameters such as the voltage generated by solar panels, then periodically sending the data to the ThingSpeak server via a WiFi connection to be displayed in the form of graphs that can be accessed online. The INA219 sensor is used to measure voltage and current values directly, while the NodeMCU functions as a data processor and sends information to the cloud. Test results show that the system can work well and stably in displaying monitoring data in real-time, and allows users to monitor the condition of solar panels remotely easily. This system is considered effective, simple, and economical as a solar energy monitoring solution, especially for small to medium-scale needs. The results of the experiments conducted on the first day showed an average voltage of 15.52 V. On the second day, the average voltage was 15.05 V, and on the third day, it was 14.99 V, with productive hours from morning to evening.

Keywords: solar panels, monitoring, IoT, NodeMCU, ThingSpeak, INA219

Citation: Aryanto, D. D., Ashari, F., Yulianti, R. N., Bahora, E., & Novianto, A. T. (2025). Prototype of a solar panel voltage monitoring tool using IoT. *Iota*, 5(3). https://doi.org/10.31763/iota.v5i3.991

Academic Editor: Adi, P.D.P

Received: June 15, 2025

Accepted: July 06, 2025

Published: August 01, 2025

1. Introduction

The rapid advancement of renewable energy technologies has placed solar power at the forefront of sustainable energy solutions. Given its clean, abundant, and renewable nature, solar energy is increasingly adopted across various sectors [1]. However, optimizing the performance of photovoltaic (PV) systems remains a key concern, particularly when environmental conditions such as light intensity, ambient temperature, or dust significantly influence energy output [2].

Residential, commercial, industrial, and utility customers now have a range of choices for meeting their solar energy production needs, thanks to polycrystalline silicon solar PV modules and new generations of thin-film solar PV technology. Depending on the needs of your project, the many solar power systems available range in efficiency, affordability, durability, and adaptability. The photovoltaic effect causes materials like silicon to produce an electrical current when they absorb sunlight, which is how PV solar technology generates electricity [3]. Accurate, consistent, and real-time observation of PV parameters is therefore essential to ensure system efficiency. Traditional approaches that rely on periodic manual measurements are no longer considered practical, especially for remote or unattended installations [4]. As a result, Internet of Things (IoT)-based monitoring systems are becoming increasingly relevant, offering the ability to remotely access data, track performance, and detect anomalies in real time [5].

IoT represents a transformative advancement within today's digital landscape that facilitates the real-time monitoring of the global environment, encompassing parameters such as temperature, humidity, thunderstorms, earthquakes, and floods, which can subsequently trigger alerts pertinent to human safety [6].

Undoubtedly, the current technological advancements achieved by IoT systems have exposed businesses and individuals to security threats, prompting researchers to brainstorm various ways to improve data privacy [7], [8]. Interaction, monitoring, and control of environmental conditions have been made easy using microcontrollers, with a focus on Arduino boards [9], [10], [11].

In recent years, low-cost sensors and microcontroller technologies have enabled the integration of compact and affordable monitoring modules into solar applications [12]. One such sensor, the INA219, has shown considerable potential for use in PV systems due to its ability to monitor voltage and current over an I^2C interface with high accuracy [13]. Its compatibility with popular microcontrollers such as ESP8266 NodeMCU has enabled researchers and practitioners to design scalable monitoring systems that are both efficient and easy to deploy [14]. Microcontrollers are embedded systems that control a device's actions and features. They are specialized microcomputers, often referred to as single-board computers, that focus on controlling specific tasks within a device [15].

In addition, platforms like ThingSpeak provide a simple interface for uploading, storing, and visualizing real-time data from field-deployed sensors. Combining these technologies allows for effective implementation of solar monitoring systems that are not only low in cost but also adaptable to a wide range of use cases, from residential solar rooftops to off-grid systems in rural environments [16], [17]. Energy harvesting from rooftop solar panels reduces or eliminates the need for changing batteries, allowing wireless devices to recharge their energy reserves and contributing to a long-term, free-of-maintenance Internet of Things (IoT) [18]. The sustainability and financial aspects of these use cases rely on little to no maintenance to operate sustainably [19]. IoT devices may operate more strategically and thus effectively, depending on the forecasting: They can plan heavy energy actions for times when there is an excess of energy, as well as change their recognition intervals [20].

Building on insights from previous work, this research proposes an IoT-based monitoring system that utilizes the INA219 sensor and ThingSpeak platform to capture and present voltage, current, and power output data from solar panels in real time. The system is designed to be efficient, user-friendly, and suitable for real-world implementation where ongoing monitoring is essential for maintaining energy performance (Abidin et al., 2024; Sutikno, 2024) [5], [15].

On the other hand, the effective monitoring, control, and automation for hybrid green energy systems using simulation models are essential as the groundwork for managing real dynamic situations and ensuring operational efficiency[15]. Researchers have recently explored the integration of Industrial Internet of Things (IoT) technology for real-time monitoring, control, and automation. IoT applications have expanded extensively across various domains, notably in developing smart cities where intelligent devices are harnessed to create interconnected ecosystems to enhance the quality of residents [5].

Furthermore, IoT finds diverse applications in agriculture, where it facilitates crop monitoring. IoT in healthcare enables early disease diagnosis through smart devices. IoT aids in tracking pollution levels in environmental monitoring [21]. Even in the realm of space exploration, IoT plays a pivotal role. Within hybrid green energy systems, IIoT primarily connects intelligent components such as smart sensors, actuators, and gateways [22]. These components collect and process data, subsequently transmitted to cloud servers for analysis. Supervisory Control and Data Acquisition (SCADA) system emerges as a pivotal player in real-time monitoring, control, and automation strategies [23].

This study aims to develop an IoT-based monitoring system for solar panels by utilizing the INA219 sensor and the ThingSpeak platform. The proposed system is designed to enable real-time remote monitoring of solar panel parameters to improve performance evaluation and support proactive maintenance strategies.

The novelty of this journal lies in the ability to perform real-time monitoring of the solar panel, where the data received by the microcontroller can be recorded and stored on a web platform. This feature facilitates easier performance analysis and system monitoring. Table 1 explains that many papers can relate to this paper.

Table 1. State of The Art

No	Research Title	Result and Analysis
1	Thingspeak-Based Sensing and Monitoring System for IoT with Matlab Analysis	The Thingspeak IoT web service represents a promising and innovative web-based technology that has the potential to shape and align with the evolving expectations of engineers.
2	ThingSpeak sebagai Sistem Monitoring Tangki SPBU Berbasis Internet of Things	ThingSpeak in this IoT-based fuel tank monitoring system is designed to enable remote monitoring of the fuel volume in underground storage tanks via the internet. The system utilizes the ESP8266 WiFi module to transmit data over a WiFi network to the internet. ThingSpeak is used as the cloud platform for storing the monitoring data, while the Virtuino application serves as the user interface on Android devices.
3	Smart Community Monitoring System using Thingspeak IoT Platform	The community was able to receive data from smart homes to the ThingSpeak platform via the MQTT protocol, save the data in the database, and visually display it in the ThingSpeak webpage. The system functioned well as designed.
4	Real-time and Centralized Solar Panel Online Monitoring System Design Using Thingspeak	An online monitoring system records data on current, voltage, and light intensity in real time and is centralized. The system will store and record measurement data every 15 seconds in the form of JSON, XML, and CSV file extensions.
5	Smart microgrid with the Internet of Things for adequate energy management and analysis	The developed technology also identifies the demand pattern and allows the microgrid to supply power, and it's applicable for low demand as well as high demand. During low demand, the IoT device charges the battery, and when fully charged, cuts down the PV supply. During high demand, IoT device prioritizes the loads and satisfy the demands.
6	Building an Intrusion Detection System for an IoT Environment using Machine Learning Techniques	In generating a realistic and high-quality training dataset, there should be a good quality of data flow in the network during the process of attack, because interception is possible only during the continuous flow of data.

2. Theory

2.1 Parameters, Hardware, Software, and Application Server used

Some of the essential parameters in this research are shown in detail at the following points: [1] ThingSpeak is an open-source platform designed to support the Internet of Things (IoT). It allows users to collect, analyze, and visualize data obtained from sensors connected to a network. ThingSpeak can be integrated with a wide range of sensors and devices to enable automated system monitoring and control. Several studies have been conducted on IoT-based monitoring systems using ThingSpeak, each focusing on specific objects and parameters [24]. [2] NodeMCU is an open-source IoT platform that includes hardware based on the ESP8266-12 System on Chip (SoC) developed by Espressif Systems, along with firmware that supports the Lua scripting language. Although the term "NodeMCU" is often used to refer to the hardware, it technically refers to the firmware. NodeMCU can be considered a version of the Arduino board specifically designed for the ESP8266 chip[25]. [3] The INA219 sensor module is capable of monitoring both voltage and current within an electrical circuit. This sensor utilizes an I2C or SMBus-compatible interface, allowing it to simultaneously monitor shunt voltage and bus voltage, while also supporting programmable timing and signal filtering processes. The INA219 features a maximum input amplifier range of ±320 mV, enabling it to measure currents up to ±3.2 A. With its internal 12-bit ADC, the current measurement resolution within the 3.2 A range is approximately 0.8 mA. When the internal gain is set to its minimum level (div8), the maximum measurable current is ±400 mA, with a resolution of up to 0.1 mA. Additionally, the INA219 is capable of detecting shunt voltages on the bus within a range of 0 to 26 V [26].

Moreover, [4] A solar panel is a device that functions to convert sunlight into electrical energy. It is made of semiconductor materials, such as silicon, which are coated with specific substances to enhance efficiency. When sunlight strikes the surface of the panel, electrons in the silicon atoms are released and begin to move, generating an electric current within a circuit. The primary role of a solar panel, or photovoltaic (PV) system, is to convert solar irradiance into electrical energy. The greater the intensity of sunlight received, the more energy is generated. To ensure that the power demands of the water pump motor can be met by the battery, the system capacity must be properly adjusted. In this implementation, a solar panel with a capacity of 50 Wp is used, with an estimated effective sunlight exposure of approximately 5 hours per day [27].

3. Method

3.1 ADDIE Research Methodology

This research is a development research that aims to design and build a solar panel monitoring system based on the Internet of Things (IoT) using the ThingSpeak platform as an online data monitoring medium. This system is designed to monitor important parameters of solar panels in real-time, such as voltage, making it easier for users to analyze the performance of solar power systems without being on-site directly. To support the tool development process, a research method development model was used, which was included in the research and combined with the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) method [28]. This consists of five systematic stages to produce structured and efficient technology products. Can be shown in Figure 1.

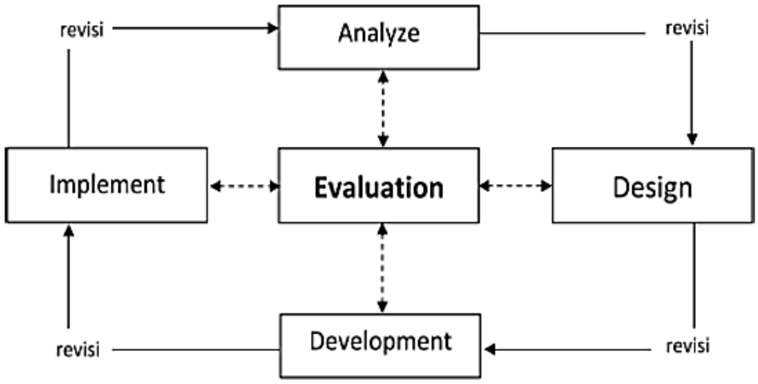

Figure 1. ADDIE Research Methodology

The description of the ADDIE methodology in Figure 1 will be explained as follows:

3.1.1 Analysis

This research begins with an analysis phase that includes problem identification, namely determining user needs for a tool that is easy to use and can be accessed remotely, determining the parameters to be monitored, selecting components such as sensors, microcontrollers, and IoT platforms, and establishing evaluations based on sensor measurement accuracy, data transmission stability to the IoT platform, system reliability in a real-world operational environment, and ease of use by end users. From the results of field observations, researchers analyzed data collected in the vehicle parking lot of the Mechanical Engineering Department at Subang State Polytechnic, spanning 12 hours from 08:00 to 19:00 over three consecutive days.

3.1.2 Design

After the analysis stage is completed, the next stage involves designing the monitoring tool system, which includes selecting sensors, microcontrollers, and connections to the IoT platform, as well as designing the interface and schematic of the tool circuit. After this stage is completed, an evaluation is conducted using the results of the monitored parameters, which include only voltage. The platform used is ThingSpeak, the controller used is NodeMCU, and the sensor used is INA219. In Figure 2, an illustration of the tool installation, and in Figure 3, a view of the IoT platform.

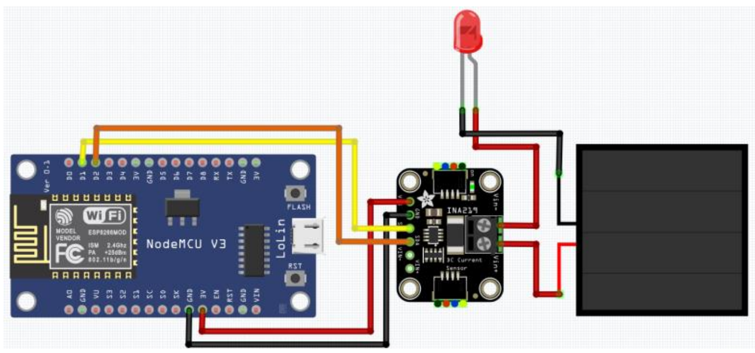

Figure 2. Installation Wiring

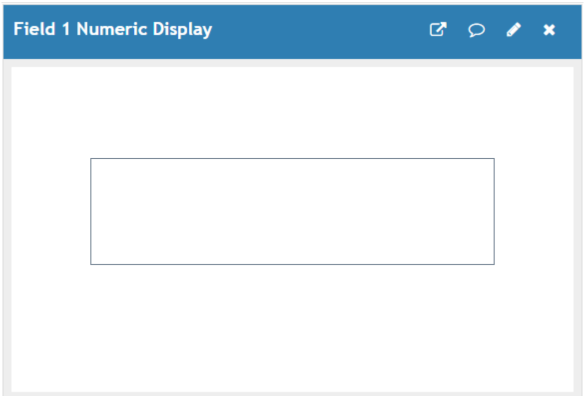

Figure 3. Tool Dashboard View

The monitoring system can be illustrated by the block diagram shown in Figure 4, which explains the following components:

- The solar panel functions to capture voltage energy from light sources.
- The voltage sensor, which is based on the I2C protocol, is used to measure voltage in real time within electronic or microcontroller systems.
- The LED serves as an indicator for the system.
- The microcontroller is responsible for storing the voltage data and transmitting it via Wi-Fi to the IoT platform.
- The IoT platform stores and displays the data in real time in graphical form.

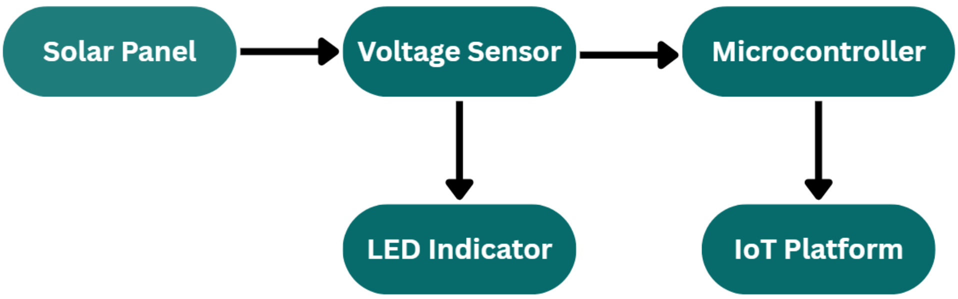

Figure 4. Diagram Block System Development

During the development stage, hardware assembly was performed by connecting the INA219 sensor to the NodeMCU microcontroller to measure voltage. This was followed by creating a program using the Arduino IDE to read the data and send it periodically to the ThingSpeak platform via a Wi-Fi connection. An evaluation was conducted to assess the system's functionality, the accuracy of sensor readings compared to standard measuring instruments, the stability of the data connection, and the system's reliability in displaying data in real-time during the trial period. After that, the evaluation stage is carried out by modifying the tool installation to include actuators and converting the display to a graphical form. Figure 2 is the latest installation developed, and Figure 5 is the latest dashboard display.

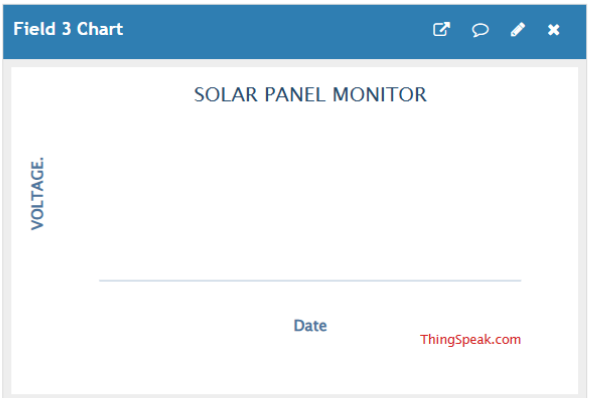

Figure 5. Tool Dashboard View

3.1.3 Implementation

The developed monitoring system was tested on solar panels operating in a real environment. Testing includes sensor performance, data accuracy, internet connectivity, and data display on the ThingSpeak platform. The INA219 sensor can read the voltage value from the solar panel in various lighting conditions. Then the NodeMCU processes the data to calculate the amount of voltage produced by the solar panel. The developed monitoring system was tested on solar panels operating in a real environment. Testing includes sensor performance, data accuracy, internet connectivity, and data display on the ThingSpeak platform. The INA219 sensor can read the voltage value from the solar panel in various lighting conditions. Then the NodeMCU processes the data to calculate the amount of voltage produced by the panel.

3.1.4 Evaluation

Evaluation is conducted to assess the effectiveness and reliability of the monitoring system. User feedback and test data are used to make system improvements and enhance tool performance. This research employs a development method, specifically Research and Development (R&D), using the ADDIE model. According to several journals, the ADDIE development model has both strengths and weaknesses. One of the main advantages of the ADDIE model is that it provides a clear, simple, and systematic sequence of steps. However, its primary weakness lies in the considerable amount of time required to complete each stage of the research process [29].

Based on these references, it can be concluded that the strength of the ADDIE model is its straightforward and structured phases, which facilitate the development of tools or systems. On the other hand, its weakness is the extended time needed to proceed to the next phase, as each step requires evaluation to ensure optimal implementation. Considering both the strengths and weaknesses of the ADDIE model, this model is regarded as more effective and efficient compared to other development methods. Each step must be carried out systematically and accompanied by an evaluation to ensure that the system functions optimally.

4. Result and Analysis

After the design, assembly, and programming process of the solar panel monitoring tool, a series of tests were carried out to determine the system's performance under actual conditions. The system consists of an INA219 sensor as a voltage measuring device, a NodeMCU microcontroller as a data processing and sending center, and ThingSpeak as an online monitoring platform. Figure 7 is a prototype of a solar panel voltage monitoring tool.

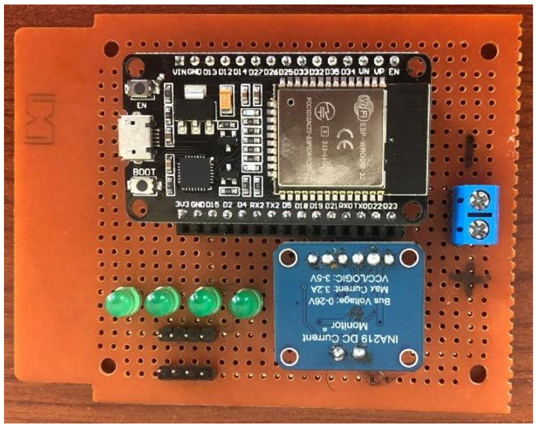

Figure 5. Prototype of a Solar Panel Voltage Monitoring Tool

The test results show that the INA219 sensor successfully reads the voltage value from the solar panel stably in various lighting conditions, whether in strong, medium, or dim sunlight. The NodeMCU receives data from sensors via I2C communication, then processes it into voltage information, and sends the measurement results to the ThingSpeak platform via a WiFi connection. The data sending process is carried out periodically every 15 seconds, following the minimum sending limit on the free ThingSpeak account.

During the testing period, the system demonstrated consistent and reliable performance. No significant disruptions were found in the data reading process or sending it to the cloud. The graph on the ThingSpeak dashboard displays changes in voltage values in real-time, adjusting to changing weather conditions and sunlight intensity throughout the day. The visualization is well accessible through the device, indicating that the system supports remote monitoring functions well.

Additionally, testing involves observing the system's stability during operation over a specified period. The system can operate continuously for more than 12 hours without interruption, provided that the electrical voltage from the panel and backup sources is sufficient. The interface display in ThingSpeak can provide daily data history information, which is useful for analyzing panel performance over time.

In general, this monitoring tool can effectively record and display important information regarding the condition of solar panels, making it easier for users to monitor solar power systems remotely. This feature also opens up the potential for integration into larger energy monitoring systems in the future. Figure 8 shows the results of the experiments that have been carried out.

Based on the results of the experiments carried out, the solar panel monitoring system, based on NodeMCU and the ThingSpeak platform, demonstrates quite good performance in executing real-time monitoring functions. The INA219 sensor can read the voltage value from the solar panel with a fast response to changes in sunlight intensity. The NodeMCU processes these values and automatically sends them to ThingSpeak using a WiFi connection, which is then visualized in the form of a voltage graph.

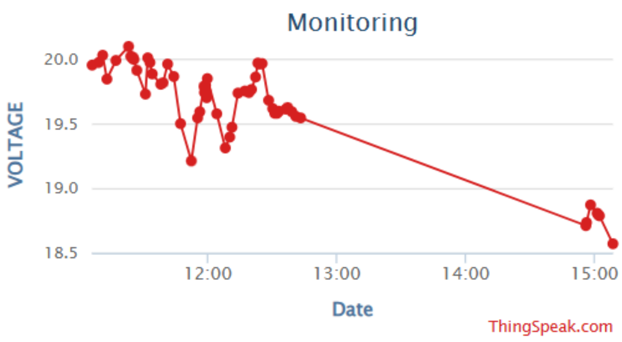

Figure 6. Experimental Graphic Data

The system is capable of sending data periodically, every 15 seconds, according to the minimum sending time limit on the free ThingSpeak account. During testing, the data appeared consistently, without any significant loss of information or connection interruptions. This demonstrates the successful integration between the sensor, microcontroller, and IoT platform. Additionally, the system enables users to remotely monitor solar panel performance using a mobile device or computer, eliminating the need to be physically present at the panel location. This is particularly helpful in maintaining and monitoring the performance of solar power systems, especially in remote or hard-to-reach areas.

Table 2. Experimental Result Data Day 1

	Day 1	
No.	**Trial hours**	**Average Voltage**
1	8:00	19.45 V
2	9:00	20.03 V
3	10:00	20.07 V
4	11:00	19.85 V
5	12:00	19.31 V
6	13:00	19.06 V
7	14:00	19.33 V
8	15:00	18.96 V
9	16:00	17.42 V
10	17:00	12.37 V
11	18:00	0.18 V
12	19:00	0.18 V

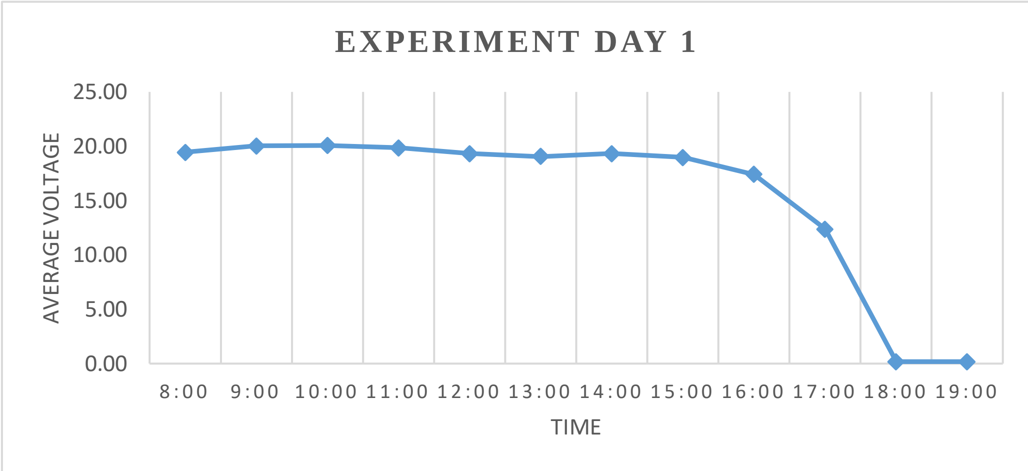

Figure 7. Experimental Result Data Day 1

However, there are some important points to consider for further development. First, the system relies on a stable WiFi connection; If a network disruption occurs, data cannot be sent to the server. Second, ThingSpeak's interface, while informative, is still limited in graphic customization compared to other paid IoT platforms. Third, the power supply for the NodeMCU needs to be designed in a way that allows it to continue operating when the sun's intensity is low, such as during cloudy conditions or at night. The average hourly electrical voltage data generated from the solar panels on day 1 is shown in Table 2 and visualized in Figure 9.

Table 3. Experimental Result Data Day 2

Day 2		
No.	**Trial hours**	**Average Voltage**
1	8:00	19.41 V
2	9:00	19.57 V
3	10:00	20.04 V
4	11:00	19.84 V
5	12:00	19.62 V
6	13:00	19.24 V
7	14:00	18.87 V
8	15:00	17.76 V
9	16:00	17.38 V
10	17:00	8.42 V
11	18:00	0.22 V
12	19:00	0.19 V

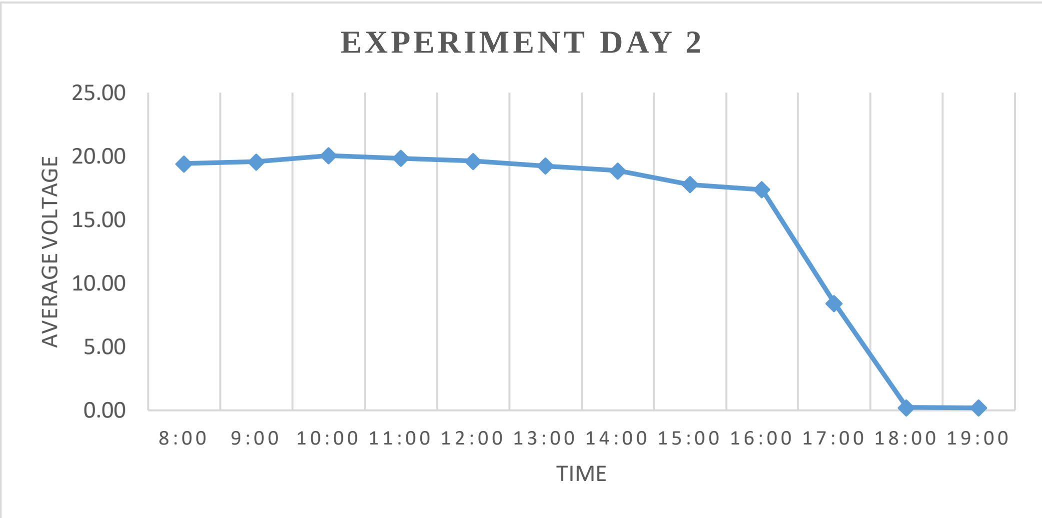

Figure 8. Experimental Result Data Day 2

The table and graph in Figure 9 show that 8:00 AM to 3:00 PM is a productive period for generating electrical voltage with an average of 19.51 V. After 3:00 PM, there is a continuous decrease with an average electrical voltage of 7.54 V. The average hourly electrical voltage data generated from solar panels on the second day is shown in Table 3 and visualized in Figure 10.

Based on the table and graph in Figure 10, it is evident that the period from 8:00 AM to 3:00 PM is a productive time for generating electrical voltage, with an average voltage of 19.29 V. After 3:00 PM, there is a significant decrease in the average electrical voltage to 6.55 V. The average hourly electrical voltage data generated by solar panels on the third day is shown in the table and visualized in the graph.

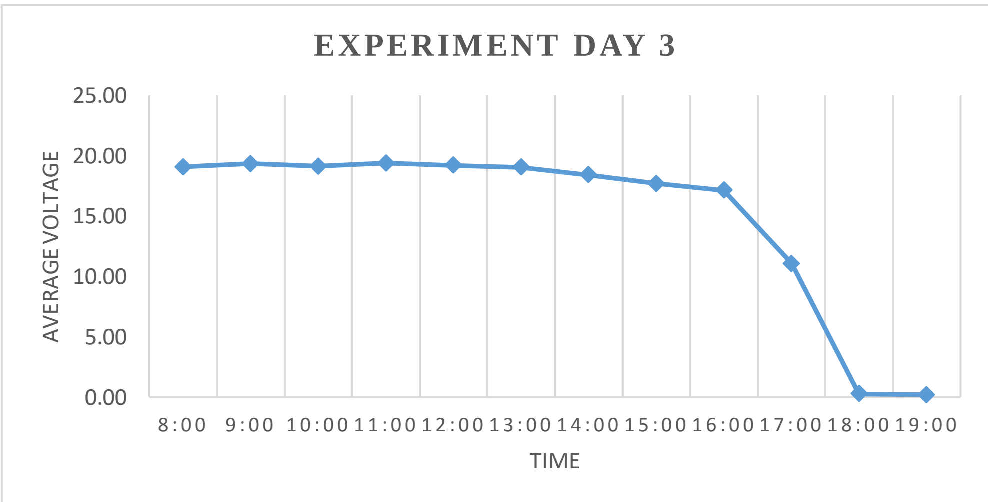

Figure 9. Experimental Result Data Day 3

Table 4. Experimental Result Data Day 3

Day 3		
No.	**Trial hours**	**Average Voltage**
1	8:00	19.07 V
2	9:00	19.33 V
3	10:00	19.13 V
4	11:00	19.39 V
5	12:00	19.19 V
6	13:00	19.05 V
7	14:00	18.39 V
8	15:00	17.69 V
9	16:00	17.14 V
10	17:00	11.05 V
11	18:00	0.27 V
12	19:00	0.19 V

Table 4 and Figure 11 show that the period from 8:00 AM to 3:00 PM is the most productive for generating electricity, with an average voltage of 18.91 V. After 3:00 PM, there is a significant decrease, with an average voltage of 7.16 V. The three graphs display changes in voltage values according to changing sunlight conditions, and can be accessed via laptop or smartphone from different locations. This proves that the system is capable of providing remote monitoring information practically, enabling users to determine the operational condition of solar panels without requiring direct inspections at the location.

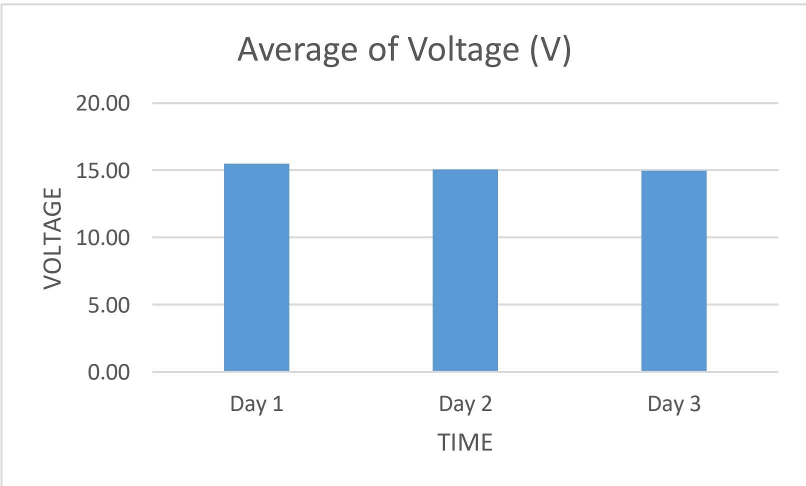

Figure 10. Average Trial Data Per Day

From Figure 12, slightly productive results were obtained. Thus, the results of the 3-day experiment produced slightly better results, so further development is needed to produce more optimal electricity. Voltage measurements are obtained using the INA219 sensor, which communicates via the I2C protocol—a digital communication interface between the sensor and the microcontroller. The INA219 sensor has a voltage measurement error margin of ±1% within the temperature range of –25°C to 85°C, as stated in the INA219 datasheet [30].

5. Conclusions

Overall, this system has successfully fulfilled its function as a simple, affordable, and user-friendly IoT-based solar panel monitoring tool, providing users with accurate measurement and monitoring results to track solar power system performance remotely in real-time. The experimental results demonstrated that the developed solar panel monitoring system performed effectively and fulfilled its intended function. Data was sent automatically and periodically, every 15 seconds, to the ThingSpeak platform via a Wi-Fi connection, meeting the minimum transmission interval allowed in the free version. During testing, the system demonstrated stable data transmission, no significant connectivity disruptions were encountered, and data was successfully displayed in real-time graphs on the ThingSpeak dashboard. After three days of testing, the device successfully monitored the electrical voltage via the internet, with a voltage reading of 15.19 V. These results warrant further development to optimize electricity absorption. In this study, it is recommended that the solar panel monitoring device still requires further development, particularly in implementing a more comprehensive monitoring system. Future improvements may include not only voltage measurement but also current and power measurements. On the solar panel side, the system could be enhanced by integrating a controller and a battery to store the generated power.

Acknowledgments: We would like to thank the Department of Mechanical Engineering, Subang State Polytechnic, for providing the laboratory space and solar panels for this research.

Author contributions: The authors are responsible for building Conceptualization, Methodology, analysis, investigation: **Aryanto, D. D., Ashari, F., Yulianti, R. N., Bahora, E., & Novianto, A. T.** data curation, writing—original draft preparation, writing—review and editing, visualization: **Aryanto, D. D., Ashari, F., Yulianti, R. N., Bahora, E., & Novianto, A. T.** supervision of project administration, funding acquisition: **Aryanto, D. D., Ashari, F., Yulianti, R. N., Bahora, E., & Novianto, A. T.** and have read and agreed to the published version of the manuscript.

Funding: The study was conducted without any financial support from external sources.

Availability of data and Materials: All data are available from the authors.

Conflicts of Interest: The authors declare no conflict of interest.

Additional Information: No Additional Information from the authors.

References

[1] M. D. Phung, M. De La Villefromoy, and Q. Ha, "Management of solar energy in microgrids using IoT-based dependable control," Oct. 2017, doi: 10.1109/ICEMS.2017.8056441.

[2] B. Politi, A. Foucaran, and N. Camara, "Low-Cost Sensors for Indoor PV Energy Harvesting Estimation Based on Machine Learning," Energies (Basel), vol. 15, no. 3, Feb. 2022, doi: 10.3390/en15031144.

[3] S. Hasib Cheragee, N. Hassan, S. Ahammed, and A. Z. Md. Touhidul Islam, "A Study of IoT based Real-Time Solar Power Remote Monitoring System," The International Journal of Ambient Systems and Applications, vol. 9, no. 2, pp. 27–36, Jun. 2021, doi: 10.5121/ijasa.2021.9204.

[4] M. Junaidi, M. Fadillah, and I. Rahmat, "Smart photovoltaic performance tracking using cloud-based data logging system," Journal of Green Energy Applications, vol. 5, no. 2, pp. 78–86, 2025.
[5] T. Sutikno, H. S. Purnama, A. Pamungkas, A. Fadlil, I. M. Alsofyani, and M. H. Jopri, "Internet of things-based photovoltaics parameter monitoring system using NodeMCU ESP8266," International Journal of Electrical and Computer Engineering, vol. 11, no. 6, pp. 5578–5587, Dec. 2021, doi: 10.11591/ijece.v11i6.pp5578-5587.
[6] O. F. Awad, L. R. Hazim, A. A. Jasim, and O. Ata, "Enhancing IIoT security with machine learning and deep learning for intrusion detection," Malaysian Journal of Computer Science, vol. 37, no. 2, pp. 139–153, 2024.
[7] R. Sindhuja and A. S. Kapse, "iAAP: INTERDEPENDENCY ATTRIBUTE AUTHENTICATION PROTOCOL FOR IoMT SYSTEMS SECURITY ENHANCEMENT AND ANALYSIS," Malaysian Journal of Computer Science, pp. 107–114, 2023.
[8] M. A. Khan, S. M. Khan, and S. K. Subramaniam, "Security issues in cloud computing using edge computing and blockchain: threat, mitigation, and future trends-a systematic literature review," Malaysian Journal of Computer Science, vol. 36, no. 4, p. 20, 2023.
[9] H. K. Kondaveeti, N. K. Kumaravelu, S. D. Vanambathina, S. E. Mathe, and S. Vappangi, "A systematic literature review on prototyping with Arduino: Applications, challenges, advantages, and limitations," Comput Sci Rev, vol. 40, p. 100364, 2021.
[10] A. Eltaweel, Y. Su, M. Hafez, and W. Eltaweel, "An automated louver with innovative parametrically-angled reflective slats: Prototyping and validation via using parametric control in Grasshopper along with Arduino board," Energy Build, vol. 231, p. 110614, 2021.
[11] Q. Lin et al., "Design and experiment of a sun-powered smart building envelope with automatic control," Energy Build, vol. 223, p. 110173, 2020.
[12] A. Khudhair, H. Al Rubaie, and M. Nouri, "Accuracy evaluation of INA219 sensor in energy monitoring systems," Journal of Electrical Engineering and Technology, vol. 18, no. 2, pp. 123–130, 2023.
[13] A. Dewadi, E. Hartanto, and M. Yusuf, "Utilization of INA219 current sensor on solar power monitoring system," Indonesian Journal of Electrical Engineering, vol. 21, no. 3, pp. 145–152, 2023.
[14] B. Setyo-Supratno, L. Sari, and T. Wahyuni, "Integration of ESP8266 with INA219 sensor for solar power monitoring," Journal of Embedded Systems and Applications, vol. 10, no. 1, pp. 22–29, 2024.
[15] Z. Abidin, A. Nurhayati, and H. Mahendra, "Design and implementation of solar panel monitoring system using ESP8266 and INA219 sensor on IoT platform," Journal of Renewable Energy Systems, vol. 12, no. 1, pp. 35–43, 2024.
[16] M. Asrori and D. Yudiyanto, "Monitoring sistem panel surya berbasis Internet of Things menggunakan ThingSpeak," Jurnal Teknologi Terapan, vol. 7, no. 2, pp. 89–95, 2019.
[17] A. Tradacete-Ágreda, M. Gómez, and J. Rodríguez, "Real-time solar data logging with ThingSpeak: A practical implementation," International Journal of IoT Applications, vol. 9, no. 1, pp. 34–41, 2024.
[18] D. D. Prasanna Rani, D. Suresh, P. Rao Kapula, C. H. Mohammad Akram, N. Hemalatha, and P. Kumar Soni, "IoT based smart solar energy monitoring systems," Mater Today Proc, vol. 80, pp. 3540–3545, 2023, doi: https://doi.org/10.1016/j.matpr.2021.07.293.
[19] K. Kaliaperumal et al., "Antibacterial wound dressing with hydrogel from chitosan and polyvinyl alcohol from the red cabbage extract loaded with silver nanoparticles," Green Processing and Synthesis, vol. 12, no. 1, p. 20230035, 2023.
[20] A. B. Kathole, D. Jadhav, K. N. Vhatkar, S. Amol, and N. Gandhewar, "Solar energy prediction in IoT system based optimized complex-valued spatio-temporal graph convolutional neural network," Knowl Based Syst, vol. 304, p. 112400, 2024, doi: https://doi.org/10.1016/j.knosys.2024.112400.
[21] G. J. Rani, G. S. Rama, R. K. Marrikukkala, Y. Srikanth, and C. V. K. Reddy, "An IOT based environmental monitoring system," in IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2020, p. 032025.
[22] T. Ahmad and D. Zhang, "Using the internet of things in smart energy systems and networks," Sustain Cities Soc, vol. 68, p. 102783, 2021.
[23] E.-T. Bouali, M. R. Abid, E.-M. Boufounas, T. A. Hamed, and D. Benhaddou, "Renewable energy integration into cloud & IoT-based smart agriculture," IEEE access, vol. 10, pp. 1175–1191, 2021.
[24] B. F. Hutabarat, M. Peslinof, M. F. Afrianto, and Y. Fendriani, "Sistem basis data pemantauan parameter air berbasis Internet of Things (IoT) dengan platform ThingSpeak," Journal Online of Physics, vol. 8, no. 2, pp. 42–50, 2023.
[25] A. Satriadi, W. Wahyudi, and Y. Christyono, "Perancangan home automation berbasis NodeMCU," Transient: Jurnal Ilmiah Teknik Elektro, vol. 8, no. 1, pp. 64–71, 2019.
[26] M. H. Susanta, "LAMPU TIDUR OTOMATIS MENGGUNAKAN SENSOR LDR BERBASIS ARDUINO UNO," Jurnal Teknologi Komputer dan Informatika, vol. 3, no. 1, 2024.
[27] M. Mardianto, A. Akmal, A. Hafid, and A. Adriani, "Perancangan solar cell untuk sumber energi listrik mesin pompa air," VERTEX ELEKTRO, vol. 15, no. 1, pp. 48–56, 2023.
[28] D. D. Aryanto and Sukir, "Development of Automatic Sorting Station Basen on PLC, HMI and SCADA System," in AIP

Conference Proceedings, American Institute of Physics, Feb. 2025. doi: 10.1063/5.0262476.
[29] M. P. B. Silalahi and F. Faizal, "Implementasi Lembar Kerja Peserta Didik Interaktif Berbasis Hots Tema 7 Subtema 1 Di Kelas 1 SD," Jurnal Tonggak Pendidikan Dasar: Jurnal Kajian Teori dan Hasil Pendidikan Dasar, vol. 1, no. 1, pp. 58–69, 2022.
[30] T. Instruments, "Ina219 zero-drift, bidirectional current/power monitor with i2c interface," Reference Manual, 2015.