JNEST EISSN: 2961-8738 ● PISSN: 2961-8916 ● DOI: 10.56741/jnest.v4i02.806
Article Received 4 January 2025. Revised 16 April 2025.

Design and Implementation of an IoT-Based Solar Power Measurement System for Charging Stations of Electric Vehicles

Myo Ko Ko, Ei Mon, Thank Than Htike, Hla Myo Tun*

***Abstract*— Because of its potential to improve monitoring and management skills, integrating Internet of Things (IoT) technology with renewable energy systems has attracted much interest recently. This study describes an experiment that uses an IoT-based solar power monitoring system to measure the output power of a solar panel in real-time. A 50-watt solar panel is used in this paper to demonstrate the design and execution of an Internet of Things-based solar power monitoring system. The use of the IoT can significantly improve solar energy surveillance by better monitoring solar panel performance. The system comprises a 50-watt solar panel, a microcontroller unit, various sensors for measuring power, voltage, current, and temperature, and a wireless communication module for transmitting data. The collected data is sent to a cloud-based platform, where it is processed and analyzed. The results indicate that the Internet of Things (IoT)- based solar power measuring system provides a scalable solution for broader applications in renewable energy management and improves the reliability and precision of power-producing data. Real-time solar power generation monitoring is the goal of the proposed system, which would allow for effective energy management and optimization.**

***Index Terms*— 50-Watt Solar Panel, Energy Management, Internet of Things, Real-Time Measurement, Solar Power Monitoring.**

I. Introduction

THE technology for solar power has advanced significantly due to the growing need for sustainable energy sources. One of the most plentiful and sustainable forms of renewable energy, solar energy has found broad use in various settings, from commercial to household. The increasing number of solar panels installed means that reliable and accurate monitoring systems are essential for maintaining peak performance and energy conservation. Conventional solar power monitoring systems rely on labor-intensive, error-prone manual data collection and analysis. The introduction of the Internet of Things (IoT) has completely changed how we communicate with and operate energy infrastructure. With the help of Internet of Things (IoT) technology, solar power systems may be managed more effectively and reliably by using real-time data collection, remote monitoring, and intelligent analysis.

This work uses a 50-watt solar panel to demonstrate the design and execution of an Internet of Things-based solar power monitoring system. The suggested system uses Internet of Things capabilities to track vital indicators like power, voltage, current, and temperature in real-time, providing a thorough understanding of the solar panel's functioning. The system gathers data via a microcontroller and multiple sensors, which are then wirelessly transferred to a cloud-based platform for processing and analysis. Users are empowered to make knowledgeable decisions about energy management and system maintenance thanks to the availability of real-time data. The IoT-based measurement system may be integrated into larger solar power systems by offering a scalable and adaptable solution, promoting the broader adoption of renewable energy technology.

Additionally, by addressing the difficulties in designing and implementing such systems, this study hopes to provide valuable data for future developments in the field. In the following sections, describe the IoT-based solar power measuring system's methodology, architecture, and implementation specifics. Additionally, give the experiment outcomes and discuss how the results might affect the management of renewable energy.

Much research and development have been done to integrate Internet of Things (IoT) technologies with solar power systems in recent years. This literature review looks at significant research and developments in the area, emphasizing the techniques and tools used to improve solar power system monitoring and management. The potential of Internet of Things (IoT) technology to transform the renewable energy industry through real-time data processing and tracking has been acknowledged. Numerous investigations have examined the application of IoT in solar power systems. Ruaan Schoeman, Christo Pienaar, Augustine Ozemoya, and James Swart studied the analysis and control of how ambient air temperature influences a solar PV module's surface temperature, which in turn influences the amount of power generated. This work attempts to maximize the output power of a solar PV module through an investigation and eventual control over variables that affect the surface temperature of the module.

The results show that the surface temperature of the solar PV module is significantly affected by the tilt angle and the surrounding air temperature [1]. Uglješa Jovanović, Dragan Mančić, Igor Jovanović, and Zoran Petrušić examined a specially designed system for monitoring the temperature of solar photovoltaic modules using an infrared temperature sensor and a microcontroller. On a PC, the measurement results are processed, shown, and stored using the virtual instrument that was developed. The suggested approach resolves several touch sensor application-related problems while providing more flexibility and accurate readings. The proposed method

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works incredibly effectively when the type of measurement device that can be employed is limited by cost [2].

The application of a novel, financially advantageous IoT-based methodology for remotely monitoring solar plants for performance assessment was looked into by Manish Katyarmal, Suyash Walkunde, Arvind Sakhare, and Mrs. US Rawandale. This will facilitate preventative maintenance and the identification of plant defects, in addition to real-time monitoring [3]. Prakhar Srivastava, Mohit Bajaj, and Ankur Singh Rana studied the article, which provides a case study of how the Internet of Things can be effectively applied to traditional agriculture. It demonstrates using ESP8266 and an Arduino-based intelligent irrigation system control and monitoring [4].

II. Materials And Method

This section describes in detail the materials and methodology utilized in the design and implementation of the Internet of Things-based solar power measurement system. The system, which integrates several hardware and software tools, allows for the real-time monitoring of a 50-watt monocrystalline solar panel.

A. Arduino Uno

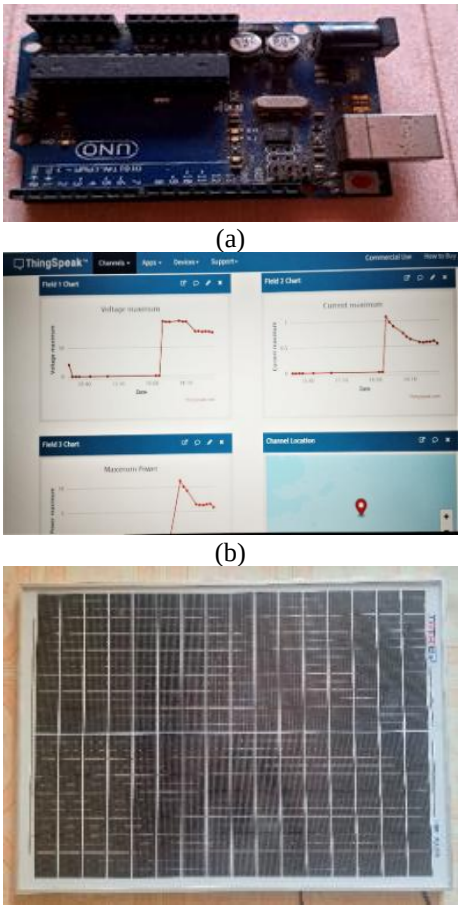
The Arduino Uno microcontroller board was developed by Arduino.cc and is based on the Microchip ATmega328P microcontroller (MCU). It features fourteen digital and six analog input/output (I/O) pins, with six digital pins capable of producing PWM signals. These I/O pins enable communication with various expansion boards (shields) and other electronic circuits. The board can be programmed using the Arduino IDE (Integrated Development Environment) [5]. Fig. 1 shows the Equipment for Real-time Measurement.

B. ThingSpeak Cloud platform

MathWorks, the company that operates the ThingSpeak service, requires users to create or log into a MathWorks account to register for ThingSpeak. ThingSpeak is an Internet of Things cloud platform that allows users to develop applications and transfer measurement results to the cloud for analysis and visualization using MATLAB or other software.

C. Monocrystalline Solar Panel

Single-crystal solar cells are used to create monocrystalline solar panels. Higher efficiency and cleaner looks are the main benefits of monocrystalline solar panels, even if these panels are usually considered premium solar products. The electrons that produce an electrical flow have more space to travel in a monocrystalline cell comprising just one crystal. Monocrystalline solar cells are, therefore, more efficient than polycrystalline solar cells.



(a)

(b)

(c)

Fig. 1. Equipment for Real-time Measurement (a) Arduino Uno microcontroller board, (b) ThingSpeak IoT Platform, (c) Monocrystalline Solar Panels.

D. Thermocouple K-Type

Solar panel temperature is measured using a K-type thermocouple sensor. The K-type thermocouple possesses the most comprehensive operational temperature range. Its structure consists of a nonmagnetic positive leg and a magnetic negative leg. Compared to other thermocouples, K-type thermocouples have several advantages, such as the capacity to function in various atmospheric and challenging environmental circumstances. They are dependable, inexpensive, and capable of responding quickly. Fig. 2 illustrates the Sensor Components in this study.

E. MAX6675 module

The MAX6675 module is used for the analog-to-digital conversion process. The MAX6675 thermocouple-to-digital converter has a robust 12-bit analog-to-digital converter (ADC), a digital controller, an SPI-compatible interface, cold-junction compensation sensing and correction, and associated control logic. The MAX6675 is designed to work with an external microcontroller or other intelligence in thermostatic, process control, or monitoring applications.

F. ESP8266 (ESP-01) module

Microcontrollers can access wireless networks through a Wi-Fi module called the ESP8266 ESP-01. The ESP8266 ESP-01 module processes all calculation results from the Arduino Uno. It saves them on the Internet of

Things (IoT), where they can be evaluated at any time using the Thingspeak IoT platform.

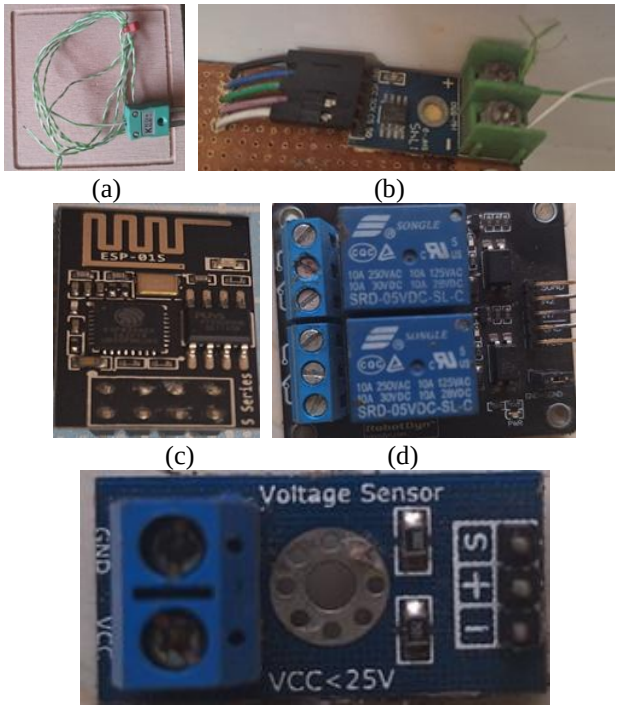


Fig. 2. Sensor Components (a) Thermocouple K-Type (b) MAX6675 module (c) ESP8266 (ESP-01) module (d) Relay Module (e) Voltage Sensor Module

G. Relay Module

A two-channel relay divides the solar panel's output voltage and current. Microcontrollers like Arduino and PIC can operate the 2-channel relay module directly. The switch configuration of the 2-channel relay module consists of two ordinarily open (NO), two normally closed (NC), and two standard pins. It is commonly employed in an automatic control circuit. The contacts ordinarily closed or opened are controlled by starting the relay.

H. Voltage Sensor

A voltage sensor is used for solar panel output voltage sensing. A voltage divider comprises two resistors with resistances of 30KΩ, and 7.5KΩ, making up the voltage sensor. As a result, the following equation yields the solar panel's observed voltage:

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

V_{in} is the input voltage, V_{out} is the output voltage, and R_1 and R_2 are the series resistance. The data were analyzed and post-processed using Microsoft Excel software. Experiment data was loaded into Excel for output data calculation, visualization, and graphical representation creation.

III. Analysis Of Parallel Load Resistors For Current Sensing

A load resistor is an output testing device or component used in any electrical circuit that can dissipate considerable power from the source to give the required output. The law is that for any circuit, the electric current is directly proportional to the voltage and is inversely proportional to the resistance. Ohm's law is a formula used to calculate the relationship between voltage, current, and resistance in an electrical circuit. Mathematically, this current-voltage relationship is written as,

$$V = IR \quad (2)$$

Where V = voltage, I = current, and R = resistance. Ohm's Law: The Law rearranges to define the current I as

$$I = V / R \quad (3)$$

A parallel connection of 10-ohm 10-Watt resistors uses load resistance. The number of resistors is five because the solar panel output is 50 watts. The total current flowing in the circuit is the sum of the separate currents flowing through the resistors: $I_T = I_1 + I_2 + I_3 + ... + I_n$. The total resistance of the parallel resistor equation is $1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + ... + 1/R_n$. Therefore, the calculation of the total resistance value of the circuit is $1/R_T = 1/10 + 1/10 + 1/10 + 1/10 + 1/10$. Fig. 3 mentions the Parallel Connection of 10 Ohm 10-watt resistors.



Fig. 3. Parallel Connection of 10-Ohm 10-Watt resistors

IV. System Design and Implementation

The system is designed to monitor and measure key output parameters of a solar power generation setup, including power, voltage, current, and temperature. These parameters are essential for evaluating the performance, efficiency, and safety of solar energy systems. To ensure continuous and accessible monitoring, the system provides real-time data transmission to the ThingSpeak cloud platform, where users can visualize, analyze, and store data remotely through the internet.

At the heart of the system is the Arduino Uno microcontroller, a versatile and widely used development board based on the Microchip ATmega328P microcontroller (MCU). The Arduino Uno acts as the central control unit, coordinating the operation of various connected modules and sensors. It reads data from sensors that measure electrical and environmental conditions, processes the information, and transmits it to the cloud. The communication between the Arduino and peripheral components is achieved through its digital and analog input/output (I/O) pins, some of which support Pulse Width Modulation (PWM) for advanced control applications. Programming and uploading code to the board are done using the Arduino IDE (Integrated Development Environment), which supports easy integration of libraries and customization of functions. This combination of hardware and software enables efficient, low-cost, and flexible implementation of solar power monitoring solutions.

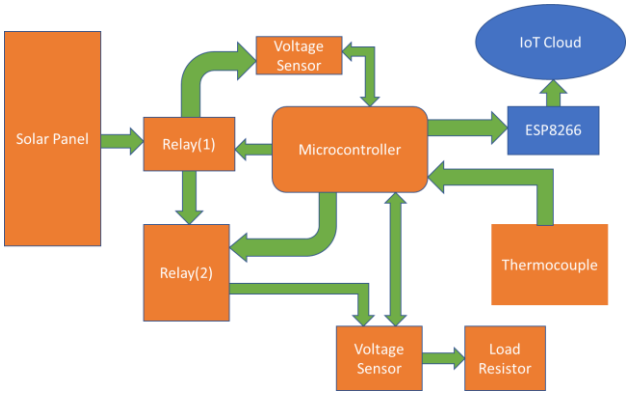
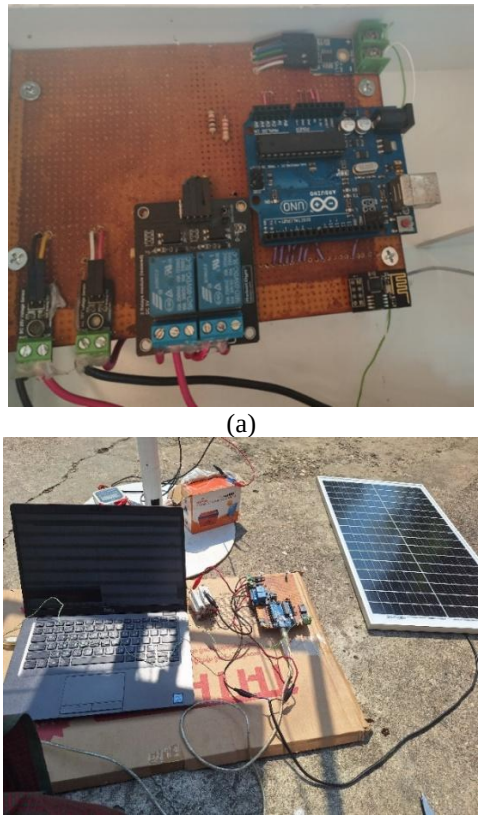


Fig. 4. Block Diagram of Circuit



(a)

(b)

Fig. 5. IoT-based Solar Power Monitoring System

Fig. 4 shows the Block Diagram of the Circuit, and Fig. 5 demonstrates the IoT-based Solar Power Monitoring System.

V. Results and Discussion

An examination of the solar panel's performance indicates a strong relationship between its temperature and its output power. Initially, power output increases in parallel with temperature increases from morning to early afternoon, suggesting that moderate temperatures can improve solar panel efficiency. The results highlight the need for efficient thermal management techniques to maximize solar panel performance and maintain steady power production under temperature fluctuations.

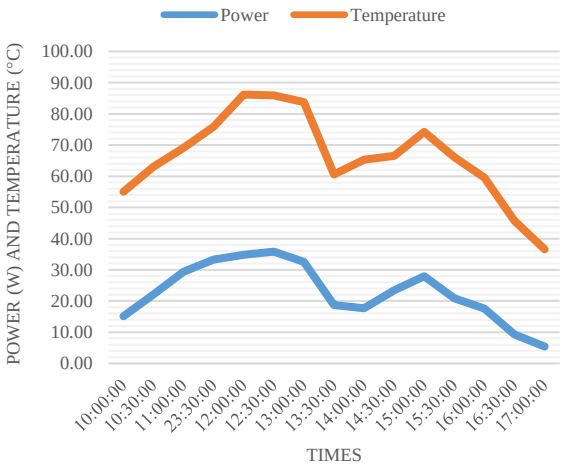


Fig.6. Output Power and Temperature

The 50-watt monocrystalline solar panel's output power and temperature relationship over time are shown in Fig. 6. It demonstrates that while power production peaked at about 30 watts at 1:00 p.m. before experiencing a decrease, the temperature generally increased from 10:00 a.m. to 1:00 p.m., reaching about 80 °C. After 1:00 p.m., a subsequent drop in power and temperature indicates the influence of outside elements like cloud cover or shade. Up to a certain point, higher temperatures are correlated with higher power output, according to the research; after that, overheating may cause efficiency to decrease. This highlights how vital heat control is to maximizing the efficiency of solar panels.

In Fig. 7, throughout the day, the 50-watt monocrystalline solar panel's temperature and output power are displayed on the graph. It shows that starting at 10:00 a.m., the temperature increased gradually and peaked at about 1:30 p.m. when the power output reached a maximum of roughly 30 watts. The temperature began to drop at 1:30 p.m., and the power production decreased. The temperature dropped more dramatically in the later hours. While greater temperatures are generally associated with higher power output, this pattern suggests that temperatures that are too high may decrease efficiency. These results emphasize how crucial it is to keep an eye on and adjust the temperature of solar panels to maintain peak performance.

Fig. 8 shows a graph that shows the relationship over a day between the 50-watt monocrystalline solar panel's output power and temperature. The power output also increases, reaching a maximum of roughly 34 watts at midday. The temperature rises quickly, starting at 10:00 a.m., and peaks at about 85 °C at about 1:30 p.m. Following 1:30 p.m., the temperature and power output gradually drop; however, the power output drops more gradually than the temperature. According to this research, heat can cause a loss in efficiency even if higher temperatures are often linked to higher power production up to a certain degree. The results highlight how important it is to manage heat well to maximize solar panel performance.

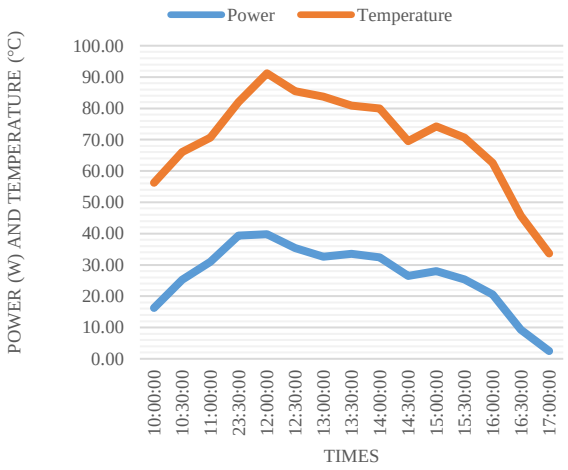


Fig.7. Output Power and Temperature (Day 2)

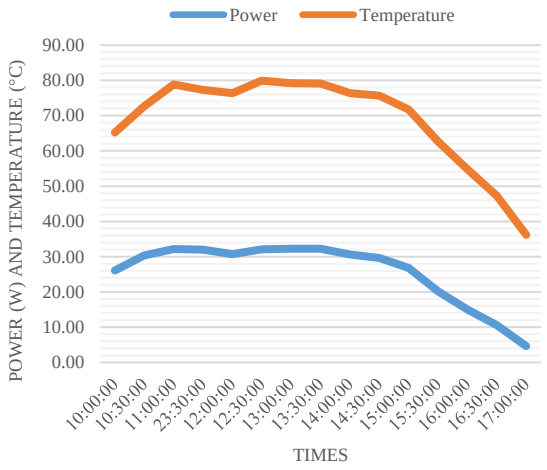


Fig. 9. Output Power and Temperature (Day 4)

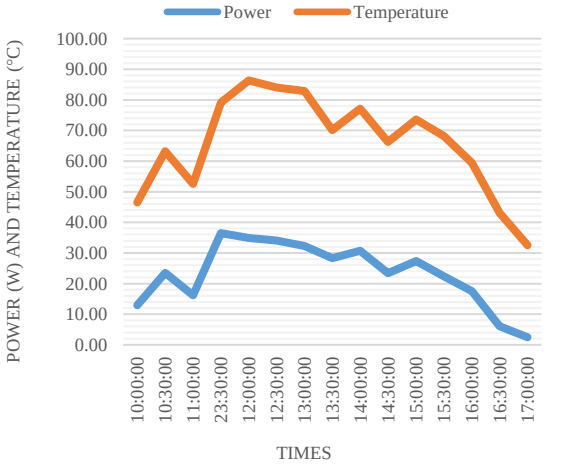


Fig. 8. Output Power and Temperature (Day 3)

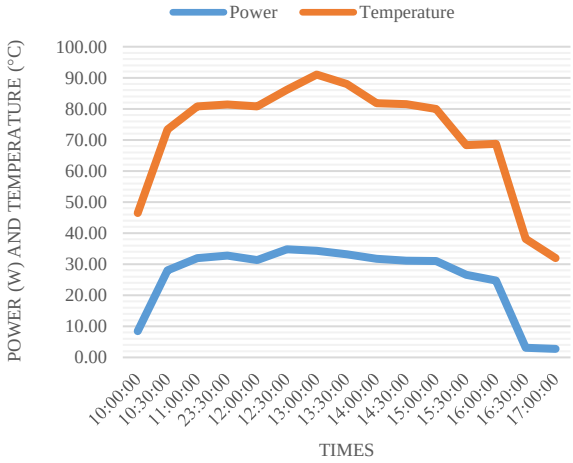


Fig. 10. Output Power and Temperature (Day 5)

In Fig. 9, from 10:00 a.m. to 5:00 p.m., the graph displays the relationship between a system's output power (W) and temperature (°C). From 10:00 a.m. to 2:00 p.m., the temperature increases to around 70 °C, peaks at about 80 °C, and falls to about 50 °C by 5:00 p.m. On the other hand, the output power begins at approximately 30 W, stays relatively constant until 2:00 p.m., and then gradually drops to approximately 10 W by 5:00 p.m. The system's power output appears to be adversely affected by higher temperatures, as seen by this inverse Connection. Maintaining the system's optimal performance and efficiency requires effective heat control.

In Fig. 10, from 10:00 a.m. to 5:00 p.m., the graph shows the relationship between output power (W) and temperature (°C). From 50°C at 10:00 a.m. to about 80°C by 11:30 a.m., the temperature climbs quickly, stays steady until 3:00 p.m., and then falls to 50°C by 5:00 p.m. On the other hand, at 10:00 a.m., the output power is 10W; by 11:00 a.m., it is 30W; it remains reasonably consistent until 3:00 p.m.; and by 5:00 p.m., it drops to 10W. The system's power output appears to be adversely affected by higher temperatures, as seen by this inverse Connection. Effective heat management is essential to keep the system operating at peak efficiency and performance.

The development of an IoT-based solar power measurement system represents a promising advancement in renewable energy monitoring and management. By employing a monocrystalline 50-watt solar panel and integrating real-time data acquisition for voltage, current, and temperature via the ThingSpeak cloud platform, this system offers not only transparency in energy performance but also crucial insights into environmental impacts on solar efficiency.

The findings underscore the significant influence of temperature on solar panel output. As observed, while moderate temperature increases can momentarily boost performance due to enhanced electron mobility, efficiency begins to decline when panel temperatures exceed 85 °C. This phenomenon aligns with previous studies, which emphasize the inverse relationship between high operating temperatures and photovoltaic efficiency [9],[10]. Excessive heat increases the internal resistance and reduces the open-circuit voltage of the solar cells, thereby impairing overall power conversion.

The adoption of IoT technologies has revolutionized solar energy systems by enabling continuous remote monitoring, predictive maintenance, and energy forecasting [11]. In particular, platforms such as ThingSpeak have demonstrated their utility in providing user-friendly dashboards and analytics for both researchers

and practitioners [12]. These tools not only help in identifying performance bottlenecks but also allow for data-driven decision-making regarding system optimization and energy management.

Scalability remains a vital concern in the current implementation. While the system performs effectively for a single panel, extending the architecture to a larger solar farm demands enhanced network protocols, robust data handling capabilities, and efficient energy consumption by the IoT devices themselves [13]. Future work should address these aspects, alongside the integration of machine learning algorithms for anomaly detection and output prediction [14].

Furthermore, to mitigate the adverse effects of overheating, innovative cooling strategies must be considered. Passive and active cooling mechanisms, including phase-change materials, heat sinks, and water spraying systems, have shown promising results in recent experiments [15]. The inclusion of such techniques could lead to improved long-term efficiency and component lifespan.

VI. Conclusion

An Internet of Things (IoT)-based solar power measuring system intended to track a 50-watt monocrystalline solar panel's performance is presented in the study. The system successfully tracks essential metrics like voltage, current, and temperature, which then sends the data for real-time analysis and visualization to the ThingSpeak cloud platform. The findings show a direct correlation between the temperature of the solar panel and its power output. Temperature rises that are not excessive (over 85 °C) cause efficiency to decrease, even though they initially improve power production. This emphasizes the significance of heat control in preserving the best possible performance from solar panels. To increase efficiency even more, future work should concentrate on making the system more scalable and incorporating cutting-edge cooling techniques. Optimizing solar energy harvesting and providing sustainable energy solutions can be significantly simplified by deploying Internet of Things-based monitoring systems.

Acknowledgment

The authors acknowledge the Ministry of Science and Technology for partial financial support in completing this study.

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