

Original Article

IoT-based Photovoltaic Solar Panel Performance Analysis using Arduino Uno and Wifi Module

J. Saranya¹, V. Divya²

¹Department of Computer Applications, C.T.T.E College for Women, Chennai, India.

²Department of Computer Applications (UG), School of Computing Sciences, VISTAS, Chennai, India.

¹Corresponding Author: saran.vel1987@gmail.com

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Abstract - The Solar Monitoring System is a forward-thinking initiative designed to enhance the reliability and efficacy of solar energy systems. This system offers users a thorough insight into solar panel performance by combining ongoing observation of solar radiation levels with accurate assessments of voltage, current, temperature and power output. The Solar Monitoring System employs cutting-edge sensors and smart algorithms to provide real-time data analysis via an intuitive interface, enabling easy access to and response to essential performance metrics. The interface acts as a central point for data visualization, facilitating real-time monitoring as well as historical analysis. The system includes a notification feature to improve user experience, which alerts users to any variations from anticipated performance metrics. The Solar Monitoring System project seeks to make monitoring solar energy systems easier. And more effective, supporting the larger objectives of sustainable energy solutions and ongoing development of solar technology by using monitoring techniques, users can assess and enhance their use of renewable energy, thereby alleviating worries related to electricity consumption. This paper introduces a solar photovoltaic monitoring system utilizing the Internet of Things, incorporating an Arduino Uno and an ESP8266 for real-time assessment of voltage, current, power, and temperature. The MPPT Algorithm also implemented to increase the efficiency of PV panel power.

Keywords - Internet of Things (IoT), Liquid Crystal Display (LCD), Photovoltaic solar panel (PV), Maximum Power Point Tracking (MPPT).

1. Introduction

As the worldwide need for clean, sustainable energy escalates, Photovoltaic (PV) systems have surfaced as a vital alternative for renewable energy generation. However, fluctuations in solar irradiation, temperature, and shading have a substantial impact on PV panel efficiency, preventing them from operating at maximum power production. Most electricity Point Tracking (MPPT), which continually modifies the PV system's operating point to gather the most amount of electricity feasible under changing environmental circumstances, addresses this issue. By enabling remote access, real-time monitoring, and performance evaluation, Internet of Things (IoT) integration enhances photovoltaic systems.

An IoT-based photovoltaic solar panel monitoring system, powered by an Arduino Uno, provides a low-cost and efficient platform for collecting electrical parameters, optimizing power generation, and communicating operational data to cloud-based applications. This combination enhances energy harvesting, allows for predictive maintenance, and promotes intelligent energy management. This study offers a low-cost, Arduino Uno-based IoT system that uses IoT

technologies to increase solar efficiency while offering real-time monitoring and remote supervision. The Proposed method seeks to provide a cost-effective, dependable, and scalable approach to smart solar Energy management in residential, educational, and small-scale renewable energy applications. The IoT application can be utilized to monitor power generation from renewable sources. India's atmosphere, which emits solar radiation, is a blessing as it attracts the installation of massive solar power plants. Everyone has a fundamental requirement for electricity in their lives. With the rise in energy consumption, energy resources are diminishing correspondingly.

This is caused by the rise in demand stemming from the growing population. To address the electricity shortfall, utilize different resources to produce electricity and meet the demand. Electricity can be produced through two methods: the conventional method and the non-conventional method [1]. The electricity is produced from energy carriers, including fossil fuels and nuclear fuels. However, these energy carriers have the drawback of being non-renewable resources, meaning they cannot be reused. Solar energy, which is sustainable, is used to overcome that. It is widely available globally. Throughout the year, the sun produces this energy,



which can be harnessed to generate electricity that is further converted into electric power. This application, referred to as solar thermal power energy, is conventional [2].

2. Literature Review

The literature survey shows that, when compared to manual inspection alone, traditional photovoltaic monitoring systems greatly increase the dependability and upkeep of solar installations. The fundamental structure for gathering electrical and environmental data, keeping historical records, and assessing system performance was developed by these systems. However, they also showed a number of Drawbacks, such as high installation costs, reliance on wired communication infrastructure, limited scalability, delayed failure detection, restricted remote accessibility, and challenges with monitoring individual solar modules. A few papers are discussed in the section below.

Bollipo et al. In this work, indicate that while intelligent algorithms augment the precision of solar panel oversight, they also need heightened computational intricacy in the domain. The issue is resolved by the utilization of IoT technology [3].

Abidi et al. conducted a systematic review and comparative analysis using various approaches for monitoring PV systems. The study examined the system accuracy, tracking speed, processing needs, and implementation complexity [4].

Ahmad et al. examined photovoltaic energy harvesting solutions intended for IoT devices. The paper examined lightweight low-power devices and compared several converter topologies. It also emphasized the significance of energy-efficient hardware and communication technologies for IoT-powered solar applications [5].

Dewri et al. the study describes the uses of Internet of Things technology to watch energy generation and consumption in time and it uses energy management plans to keep supply and demand in balance. The suggested system helps energy use become more efficient it helps manage demand. It helps renewable energy be used more. The study shows the promise of IoT-based monitoring, for current renewable energy systems yet there is still more room to mix solar power forecasting, predictive analysis and automatic decision making to make the whole system run better [6].

Kangkana Hazarika et al. described an automated monitoring system for Solar Photovoltaic (SPV) modules that constantly monitors the operational state and performance of PV panels. The research concentrates on the automated collection and monitoring of electrical characteristics which helps identify changes in PV module performance under different operating conditions. This approach removes the

need for inspection and supports more effective maintenance of solar PV installations. The study stresses the importance of monitoring to improve system reliability and performance, yet it suggests that adding IoT-based remote monitoring and advanced power forecasting algorithms could lead to smarter solar energy management [7].

Enuru Holland Simera describes the research demonstrates how IoT-based monitoring can enhance energy usage, system visibility and operational efficiency. Nevertheless, the effectiveness of these systems relies on sensing, stable connectivity and timely data processing [8].

Salah Necaibia et al. Proposed Incremental Conductance. This study examined to establish methodologies for the correct computation of the maximum power point under changing operational circumstances and solar exposure. More accurate tracking is made possible by the new INC technique [9].

Preethi Sekar et al. the study focuses on using sensors to gather data on voltage, current, and power and then using the Internet of Things to send that data. The technology allows for remote monitoring of electricity generation, making it easy to observe how effectively the system is performing and identify any issues. The authors demonstrated how IoT-based monitoring can make solar PV setups more usable, more efficient and easier to manage. However, the study is mostly about verification. There is room for better power prediction, better performance checking and smarter fault findings [10].

Venkatesan and Malathi the study describes a system collects PV data like voltage, current and power by using sensors and then sends that information through an IoT platform for checking from a distance. The findings reveal that the Internet of Things facilitates the user-friendliness and control of solar PV systems through the provision of instantaneous information on their functioning. However, the study is about watching and collecting data, leaving room for future improvements in power forecasts, smart analysis and better fault detection [11].

Basem et al. suggested an Internet of Things-powered deep learning system for airport security with an emphasis on automatically detecting threats and offering smart suggestions. The project utilizes Internet of Things technology to collect data in time and algorithms based on deep learning to check security information and find potential dangers. The smart suggestion Part helps security folks make better decisions.

The study demonstrates how integrating IoT, intelligence, and deep Learning might enhance security, risk identification, and real-time monitoring. But these kinds of systems need sensor data, sufficient computing power and strong safety rules to work properly [12].

The research found good solar monitoring systems can improve energy use, improve system reliability and help with maintenance planning. Monitoring systems are made with sensor tech, wireless connections, and cloud computing and smart data analysis. With more people in the world using energy, good monitoring systems will be more important to get more energy and keep the costs low and help the energy grow.

Therefore, a meticulous assessment of the prevailing research on panel monitoring systems delivers crucial perspectives on the advancement of monitoring technology.

This includes what hardware and software are most used, what communication methods are common, how performance is checked and what research trends are coming up. Understanding these changes helps build more reliable and smarter solar monitoring systems that can meet the growing needs of renewable energy uses.

3. Problem Statement

The demand for renewable energy is growing, and Photovoltaic (PV) systems are being adopted widely. However, fluctuating environmental circumstances such as difficult to monitoring solar panel, temperature, and shading frequently degrade solar panel efficiency.

This results in significant energy losses. In addition, most small photovoltaic systems are not equipped with real-time monitoring and remote administration features, hindering the identification of performance issues and the enhancement of system functionality.

Absence of ongoing real-time monitoring. Parameters cannot be continuously monitored in real time.

- Users cannot easily monitor or control the system remotely. Difficulty in remote monitoring and controlling.
- There is no past data to analyse performance or optimize. Limited analysis of historical data for performance optimization.
- No historical data available to analyse performance and optimize.
- The system's performance and dependability are diminished by a lack of intelligent monitoring.
- System data is not kept in a database or cloud for later access and analysis.

To overcome these issues, an Internet of Things (IoT) based Arduino Uno system is proposed. The IoT sensors continuously monitor the energy generated from solar panel and collect voltage, current, power and environmental conditions like temperature, this approach is developed to improve the energy efficiency.

It's used to minimize the operational losses and provide a cost-effective solution for smart solar energy management in residential, educational and small-scale industrial applications.

4. Research Gap

The primary research emphasis is on creating a cost-effective photovoltaic solar panel monitoring system utilizing Arduino Uno and IoT, incorporating effective maximum power tracking alongside real-time monitoring and remote data access functionalities. Existing solutions typically focus on either power optimization or monitoring, and affordable systems that effectively combine both capabilities and have been validated under real-world operating conditions are limited.

- Limited integration of 24 * 7 IoT monitoring system and IoT in low-cost systems
- High implementation cost.
- Lack of real-time remote monitoring
- Limited validation under varying environmental conditions.
- Computational limitations of Arduino Uno.
- Insufficient performance comparison.
- Energy-efficient IoT communication.

5. Existing Technology

In the existing technology, a sensor is often attached to a microcontroller or data logger, which takes information from the solar panels and displays it locally or sends it to a monitoring platform. Various existing traditional methods are generating power from solar panel using a dual-axis solar panel system, and SCADA applications, the real-time monitoring data are displayed in LCD panel. But it generates less power, or parameter issues are identified. There was monitoring of the solar panels. The combination of a microcontroller, sensors, and software produced these outcomes. It is considerably simpler to use the program that uses the current sensor.

In many emerging nations, power generation plays a significant role. The industrial and commercial sectors' advancements have led to a peak in energy demand. In order to fulfil the energy demand, everyone is excited about renewable energy sources that generate green energy. By doing this, society is able to lessen ozone depletion and greenhouse gas emissions for coming generations. Temperature, voltage, and current are all important parameters that influence solar module efficiency.

A real-time PV monitoring system is thus required to improve PV module performance in contrast to test results. Take preventative action. Numerous investigations on solar energy have been attempted in recent years.

6. Proposed Technology

A variety of elements are meant to be included in the proposed system section, including user data, device specifications, device status, power levels, voltage, current, Temperature, and time.

Every piece of information is kept in both the database and the cloud.

The proposed system aims to:

1. Design a low 24 * 7 IoT PV Panel real-time monitoring system using Arduino Uno.
2. Add IoT connectivity for real-time monitoring, cloud data logging and remote access.
3. Analyze the system's performance in various temperature scenarios.

The early PV pioneers made the contemporary PV industry possible. Apart from space programs, the initial generation of solar cells was not very popular and was inefficient. Research has been done to clarify how the PV panel's features, including temperature, time, voltage, and current measurement using the MPPT algorithm, actually work. As dust builds up on the solar panel, the primary goal is to increase its power output.

It indicates whether the load was linked to the solar panel or the battery, as well as when the solar panel last failed. The system will identify an administrator or user, notify them, and show their predefined data. Among the metrics presented on the LCD display. The following Figure 1 shows the PV Panel workflow architecture.

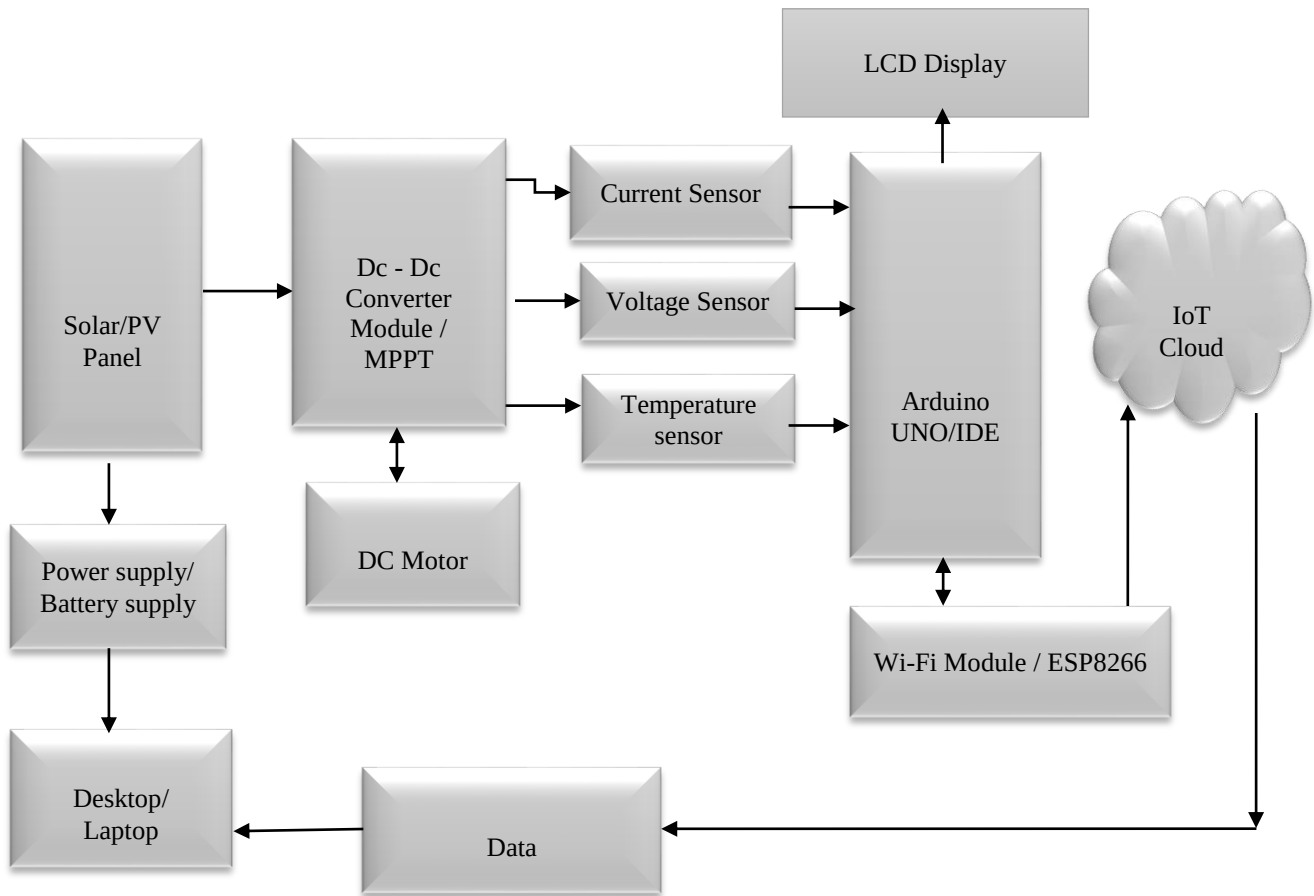


Fig. 1 Photovoltaic solar panel system workflow architecture

6.1. Hardware Requirements

- PV panel
- Arduino UNO
- Voltage, Current & Temp. sensor
- Wi-F ESP 8266
- Battery (12V 7Ah)
- DC Motor

- Converter Module
- LCD Panel

6.2. Requirements

- Arduino IDE
- Arduino IoT Cloud
- IoT Cloud Remote Dashboard

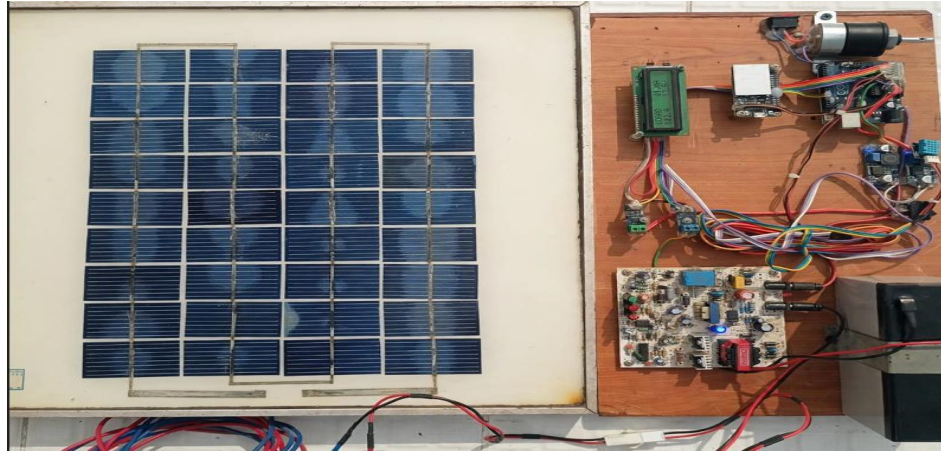


Fig. 2 Solar Photovoltaic panel working module

7. System Design

This system has been modelled with programs such as Proteus. The components together and connected them according to the circuit connections specified below. The motor runs on simulated solar electricity, and the values are shown on the LCD. The simulation uses Arduino code, with the parameters delineated as follows: The LCD display of the operational module of the photovoltaic solar panel system, as shown in the earlier Figure 2, presents the voltage rating and current metrics.

Real-time data from the PV panel monitoring system is shown on both an LCD screen and the Arduino IDE software. A USB cable connects the hardware Arduino UNO kit to the computer device, and the serial monitor displays the values.

The Serial Plotter, an integrated feature of the Arduino IDE, uses data delivered over the serial connection to visualize sensor readings or other numerical output.

8. Maximum Power Tracking Implementation

A crucial technique for enhancing energy production in Photovoltaic (PV) systems is Maximum Power Point Tracking, also referred to as MPPT. The PV module's operating point varies during the day since a solar panel's output power is constantly affected by temperature and sunshine intensity. In the absence of MPPT, the solar panel might not function as efficiently as it should, leading to a large loss of power. In order to extract the greatest amount of energy under changing environmental circumstances, an

The MPPT controller regularly assesses the electrical parameters of the photovoltaic module and alters the operating voltage inside a solar system that includes a converter module, frequently using the MPPT algorithm. By adjusting the converters, the controller modifies the panel voltage. The performance sequence persists until the maximum power point is attained. This process occurs automatically and regularly, enabling the system to react swiftly to changes in temperature.

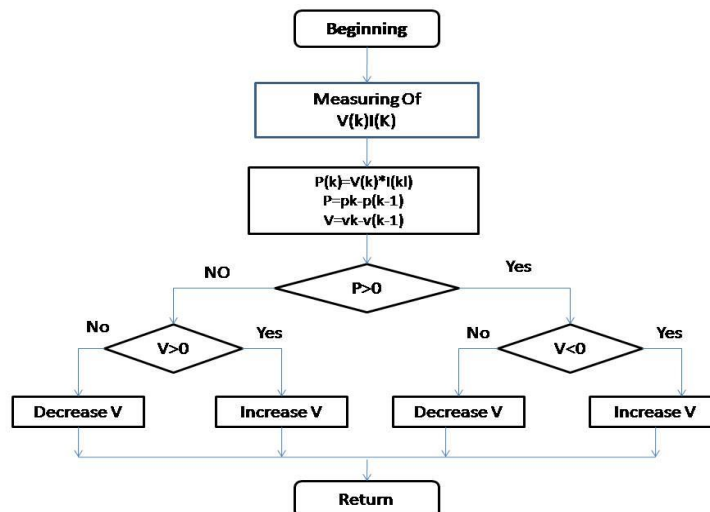


Fig. 3 MPPT workflow architecture

Utilizing fitting voltage and current sensors, the recommended system first assesses the voltage and current output by the Photovoltaic (PV) panel. The solar energy system's production is evaluated by scrutinizing the data, frequently by calculating the product of the documented voltage and the relevant current.

After calculating the power, the system calculates the change in power by comparing the current power value to the prior recorded value. Based on this adjustment, the system follows the decision-making process to assess whether the PV output has increased or decreased. It has been shown in the above Figure 3). If the power is raised ($P > 0$), the system recognizes that the operating conditions have improved and proceeds in the direction of higher power generation. If power is reduced ($P < 0$), the system modifies the operating conditions to achieve a higher power level.

After reaching the necessary upon selection, the system reverts to the measurement phase, during which voltage and current are re-evaluated. This constant process of monitoring, computation, comparison, and decision-making enables the system to follow changes in PV power while improving operating performance. The proposed method utilizes the Maximum Power Point Tracking algorithm to optimize solar energy production efficiency. MPPT is a technology applied in Photovoltaic (PV) systems to augment the power generation of solar panels.

Energy is delivered as Direct Current (DC) and is not converted into alternating current. The PV panel supplies DC power to the system sensing and control module. The converter module is involved in this process. The sensor continually monitors the panel's attributes. Quickly measure quantities such as voltage and current. The MPPT controller receives the measured data and processes it.

9. Wi-Fi Configuration

The TCP/IP convention, which can access any kind of remote availability organization, limits the ESP8266EX Wi-Fi module. The ESP8266 Wi-Fi Module has the lowest circuit requirements, is the most cost-effective, and performs exceptionally well in terms of capacity and data handling. The GPIO pins allow different sensors to be connected to the Wi-Fi module.

The least amount of time is spent processing the sensor data. It uses a single chip with self-adjusted radio frequency, allowing to function in different conditions. Information is handled by a microcontroller that is fixed with the Wi-Fi module CPU. It also serves as a transporter, transferring data to the server built with the ESP8266 serial port, a Wi-Fi wireless transceiver module from sensors and other connection frameworks. Through information lines or

information-interfacing components such as beneficiary and moving ports to the Server, the detected information is processed by matched codes and transferred remotely.

The integrated 10-bit ADC that operates within the module and its recurrence range, which varies from 2.4GHz to 2.5GHz, are the key components of the ESP8266 Wi-Fi module. Express if Systems manufactures the highly integrated, inexpensive, and low-power ESP8266 Wi-Fi module. On a single chip, this System-on-Chip (SoC) combines a microcontroller, Wi-Fi transceiver, and additional peripherals. WIFI microcontrollers or modules are responsible for sending and receiving data over Wi-Fi. They are also able must be installed in the Arduino IDE before may utilize an ESP8266 board with it. To start the installation of the ESP8266 board package via the Boards Manager, it is necessary to first include a URL into the "Additional Boards Manager URLs" in the IDE options to allow Wi-Fi functionality. Devices communicate with one another over Wi-Fi modules.

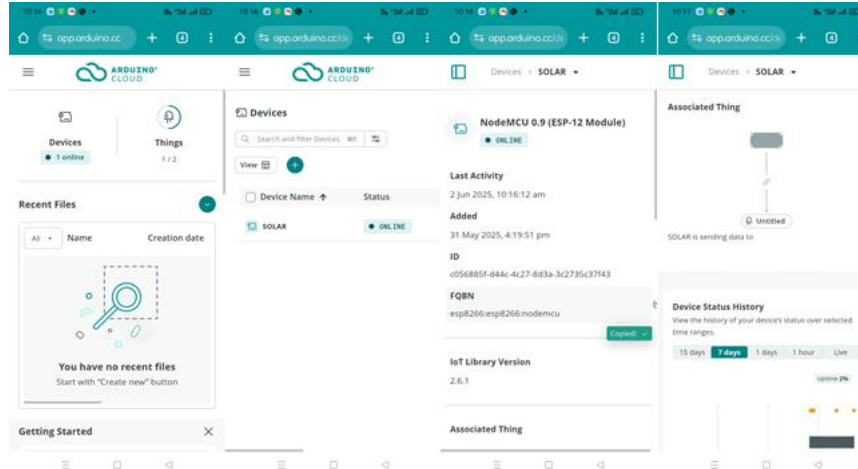
10. Arduino IoT Cloud

Arduino IoT Cloud - that effortlessly connects, operates, and monitor the gadgets from anywhere in the globe using the Arduino Cloud desktop or mobile platform. With Arduino Cloud, write the program the gadget automatically with any code that choose; simply add a few lines to personalize it. There are examples of code for hundreds of sensors and Actuators.

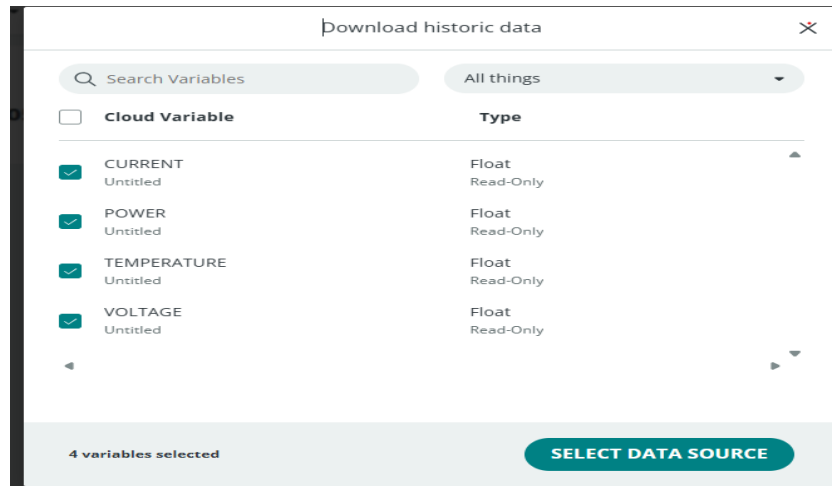
To commence utilizing the Arduino Cloud, adhere to the following procedures:

- The Arduino Create Agent plugin must be installed first.
- Verify whether the board is cloud-compatible. Every official Arduino board that is compatible is depicted in the graphic below.
- Sign up with Arduino to create an account.
- To gain access to the Arduino Cloud, press the bento menu (9-dots) situated in the top right corner of any Arduino webpage. Courtesy copy.
- Alternatively, then enter the Arduino Cloud directly.

A dashboard editor opens when select create new dashboard. Here, the ability to make widgets. It is also necessary to attach widgets to variables while creating them. This is accomplished by picking a variable that wish to link, clicking on a widget to construct, and then choosing a Thing. Once connected, and use it to monitor a value from a sensor or to interact with it, like a button. The data will update automatically as long as the board is linked to the cloud. The data are transferred to your registered mail id the below Figure 4(a) and (b)) shows Arduino IoT Cloud sample dashboard and cloud variables visuals.



(a)

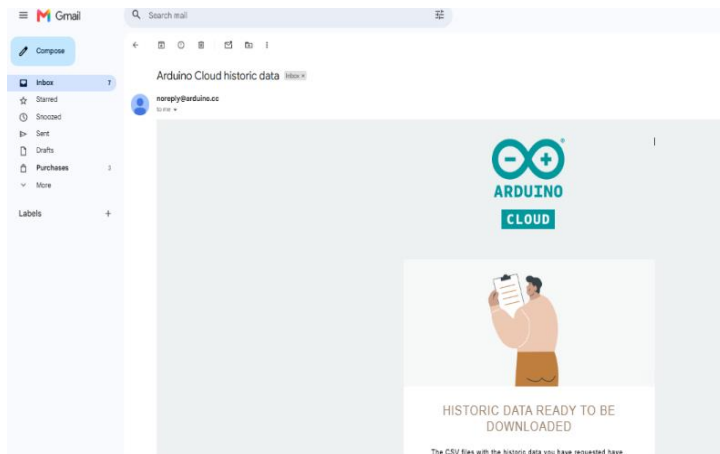


(b)

Fig. 4 (a) Arduino IoT cloud sample dashboard, and (b) Arduino IoT cloud variables.

The cloud dashboard shows past voltage, current, power and temperature information that comes from the PV system. The data that is collected is also sent to the email address that has been registered through the Arduino IoT Cloud.

This makes it simple for users to get the data that is being watched without having to connect to the real system. Figure 5 displays the PV data stored in a personal database and accessible through the Arduino IoT Cloud platform.



DATE & TIME	CURRENT	POWER	TEMP	VOLTAGE
2026-08-04T03:12:27.	0.09	0.7389	27	8.21
2026-08-04T03:12:28.	0.1	0.824	27.4	8.24
2026-08-04T03:12:29.	0.11	0.8899	27.2	8.09
2026-08-04T03:12:30.	0.1	0.833	27.3	8.33
2026-08-04T03:12:31.	0.08	0.6608	27.1	8.26
2026-08-04T03:12:32.	0.1	0.829	27.6	8.29
2026-08-04T03:12:33.	0.11	0.9163	27.1	8.33
2026-08-04T03:12:34.	0.11	0.8954	27.2	8.14
2026-08-04T03:12:35.	0.09	0.7479	27.1	8.31
2026-08-04T03:12:36.	0.1	0.811	27	8.11
2026-08-04T03:12:37.	0.08	0.6592	27.2	8.24
2026-08-04T03:12:38.	0.09	0.7461	27.3	8.29
2026-08-04T03:12:39.	0.1	0.811	27.2	8.11
2026-08-04T03:12:40.	0.09	0.7416	27.4	8.24

Fig. 5 Arduino cloud historic data

11. Result and Discussion

The proposed Arduino Uno-based real time PV Panel monitoring system with IoT was effectively put into practice to maximize a Photovoltaic (PV) panel's power output in the face of shifting weather conditions. In addition to sending real-time performance data to the IoT platform, the system

continuously monitored PV voltage and current. According to experimental findings, the controller could effectively follow the maximum power point and continue to operate steadily in spite of changes in the weather condition. The IoT module successfully sent real-time PV parameters to the cloud platform, enabling for remote monitoring via a web dashboard or mobile application.

Table 1. Voltage, current, power and temperature measurements

Voltage, Current, Power & Temperature Analysis						
S.NO	DATE	TIME	Voltage	Current	Power	Temp.
			(V)	(C)	(P)	(T)
1	04/08/2026	03:12:27	8.21	0.09	0.73	27
2	04/08/2026	03:12:28	8.24	0.1	0.82	27.4
3	04/08/2026	03:12:29	8.09	0.11	0.88	27.2
4	04/08/2026	03:12:30	8.33	0.1	0.83	27.3
5	04/08/2026	03:12:31	8.26	0.08	0.66	27.1
6	04/08/2026	03:12:32	8.29	0.1	0.82	27.6
7	04/08/2026	03:12:33	8.33	0.11	0.91	27.1

The monitored parameters included the following:

- Voltage of the solar panels
- Output current
- Output power
- The panel temperature

The data obtained allowed users to remotely monitor system operation and compare energy output patterns over time. The sample stored values are displayed in Table 1 above.

The voltage, current, power and temperature may vary every time depends on the sunlight. A serial plotter monitor allows the PV panel's real-time values to be shown on the LCD and concurrently stored in the database.

The measurements are all included. In Figure 6 the graph displays the values of Voltage, Current, Power & Temperature analysis are below.

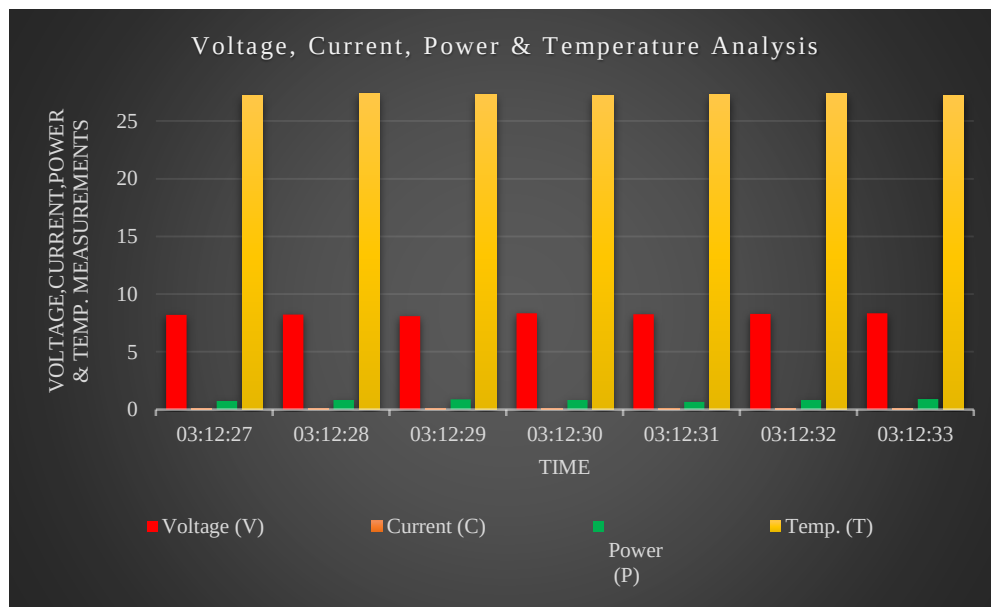


Fig. 6 Voltage, current, power and temperature analysis

The availability of operational data allows users to oversee the system's status, detect defects swiftly, and conduct preventative maintenance for real-time monitoring of voltage, current, and power metrics with the IoT platform. The PV

installation's functionality was enhanced by the IoT-enabled monitoring solution, which offered constant the experimental results demonstrate that integrating system.

12. Conclusion

This paper adeptly presented the formulation and advancement of a cloud-integrated system for evaluating the functionality of photovoltaic solar panels employing an Arduino UNO and a Wi-Fi module. The suggested IoT-based panel monitoring system, which uses an Arduino Uno and a Wi-Fi module, offers a straightforward and reasonably priced method of assessing the performance of solar panels. The system accurately keeps track of important factors like voltage, current, power and temperature, and the data that is collected can be accessed from a distance through the IoT platform. The data that was gathered shows that the system can recognize changes in the output of the photovoltaic panels in operating conditions. In total the system that was presented offers an option, for monitoring and analyzing the performance of solar photovoltaic systems in real time.

12.1. Future Scope of Work

The solar unit generates enough electricity to correspond with the controller's power input, but it still depends on an external source for operation. The highest power point can be tracked thanks to large solar panels. With the data, future parameters may be predicted. Diverse artificial intelligence and machine learning strategies can facilitate the system in making decisions based on data and delivering outcomes. The future IoT-based PV Solar Panel Monitoring System will eventually include a GPS module, enable location-based monitoring and track of solar installations. GPS integration provides real-time location data; this enhancement improves the system's intelligence, scalability, and adaptability for globally distributed renewable energy applications. Arduino UNO with IoT considerably enhances solar system performance and usability. The Arduino Uno successfully.

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