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Internet of things based smart photovoltaic panel monitoring system

Arcot Ramakrishnan Kalaiarasi, Ayyadurai Chinnadurai Vasunthira Devi, Vijayan Yeshwanth, Samuthiraraj Pravinraj, Muthu Prabakaran
Department of Electronics and Instrumentation, Saveetha Engineering College, Chennai, India

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ABSTRACT

Solar energy has the potential to meet the entire world's energy requirements. Previous study revealed that photovoltaic (PV) panel monitoring methods are far more difficult and exclusive. This study examines and proposes an automated internet of things (IoT)-based PV panel monitoring system that allows autonomous monitoring of solar panel properties such as voltage, temperature, humidity, and sun irradiation from anywhere over the internet. Excessive human demand can be reduced by collecting data from solar panels. Many data sets can be collected frequently; for example, thousands of data points can be collected each minute. Continuous monitoring is achievable by gathering real-time data. Because there is no possibility of human error, highly accurate data can be generated.

Corresponding Author:

Arcot Ramakrishnan Kalaiarasi
Department of Electronics and Instrumentation, Saveetha Engineering College
Chennai, Tamil Nādu, India
Email: kalaiarasi@saveetha.ac.in

1. INTRODUCTION

Electricity is a part of life for everyone in the present day. To meet their energy needs, developed countries have already adopted renewable energy resources and smart technology [1], [2]. Recently, sunlight is now recognised as the most popular renewable energy source, filling the difference between electricity production and consumption as shown by Eisapour *et al.* [3]. Because of advancements in solar panel technology and cost reductions, solar panels have advanced in power generation. The device continually monitors the photovoltaic (PV) panel and transmits the output by using the internet using an internet of things (IoT) network. The primary goal of solar panel monitoring system is to maintain the optimum power output as mentioned earlier [4]. By monitoring the maximum output power of the solar power station to spot faulty connections and dust or pollutants deposited on the PV panels, these contaminants have an impact on the PV panels' performance [5].

Monitoring the system using human efforts takes more time and is considered a difficult task. As a result, sensing components and their peripheral units helps to simplify the monitoring process as mentioned earlier [6]. Most likely, the sensors are modest in size and operate in any climatic situation with minimal power needs. The IoT is a system that runs without a large portion of wire connections for system monitoring as shown by Keerthana *et al.* [7]. The flowchart of the suggested method for integrating the system is displayed in Figure 1. Moreover, the IoT can measure readings via wireless connections using Bluetooth and Wi-Fi modules. Because of their ease of installation, cost-effectiveness, and space constraints, the IoT is attempting to adapt itself to a variety of applications [8], [9]. While monitoring the PV panels, poor connections and dust accumulate on the panels, resulting in decreased output and other difficulties affecting the functioning of the solar panels.

However still, hardly a backup data is available to the current researchers. Consequently, this work provides a simple and reasonable IoT-based system for monitoring PV panel parameters, with an extra backup data preserved on a cloud storage system. The IoT-based solar panel monitoring system collects data from sensors such as the voltage sensor, digital humidity and temperature (DHT11) sensor, and GY-302 sensor and stores it in the cloud-based application to monitor PV panel parameters such as voltage, temperature, humidity, and solar irradiation [10].

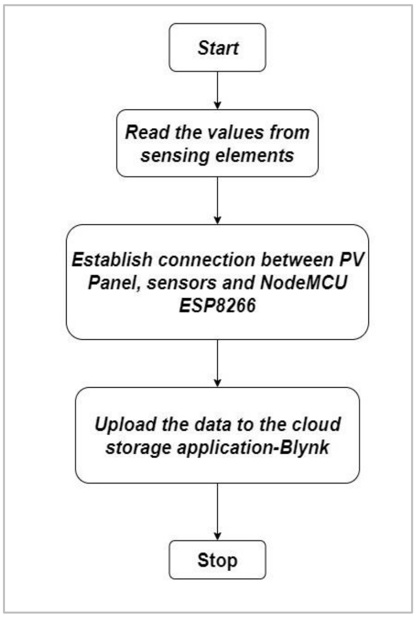

Figure 1. Project flowchart

2. PROPOSED SYSTEM

A fundamental goal of the proposed work is to monitor the temperature, humidity, voltage, and solar irradiation of the PV panel. PV panels are now used in a variety of fields to generate electricity as shown by Rani *et al.* [11]. Solar radiation falling on the panel diminishes as the humidity in the solar panel rises and the output voltage falls as well. As a result, high humidity reduces ideal power. The solar panel is linked to a microcontroller called NodeMCU ESP8266. The block diagram of the suggested method for integrating the system is displayed in Figure 2.

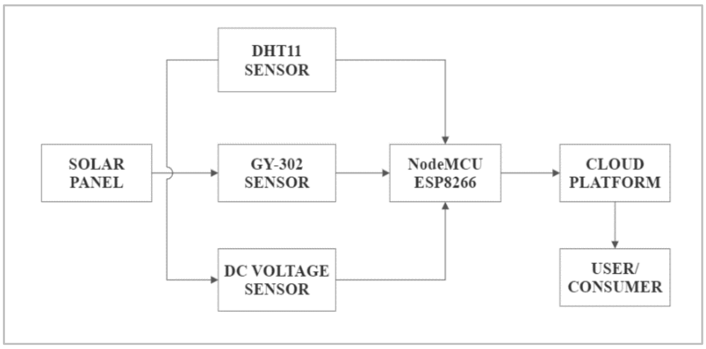

Figure 2. Block diagram of the proposed structure

Monitoring the system's output voltage is made possible by the voltage sensor's interface to the solar panel. Voltage sensors are beneficial in rapidly identifying the problems in systems. Subsequently, a connection is made between the DHT11 sensor and the solar panel to detect the humidity and temperature of the system, the DHT11 sensor is referred to as a digital humidity and temperature sensor as mentioned earlier [12]. PV panel is linked with a GY-302 BH1750 digital light intensity module, the irradiance of the solar panel is observed. The irradiation unit of measurement is used to describe radiation that is falling on the surface. The circuit design of the suggested method for integrating the system is displayed in Figure 3.

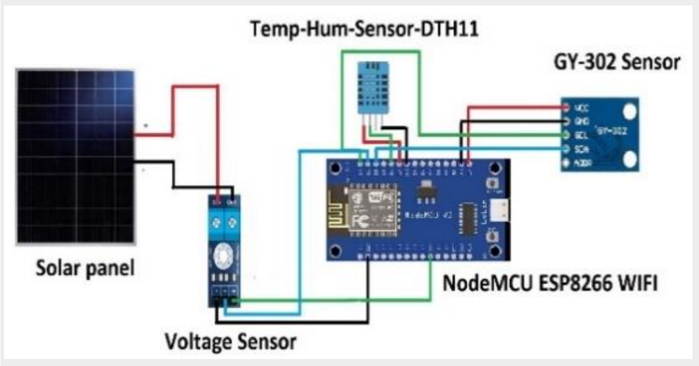

Figure 3. Circuit diagram of proposed structure

With the Wi-Fi module, an interface is shared between the controller and the cloud server, and subsequently, the panel's parameters, such as voltage, temperature, humidity and solar irradiation, are sent to the server. The panel's parameters are recorded on the server every hour and day, allowing for scrutiny and comparison [13]. Data from various solar panels is combined via an IoT platform, which applies analytics to communicate the most crucial data with applications created to satisfy particular requirements. The schematic design of the suggested method for integrating the system is displayed in Figure 4.

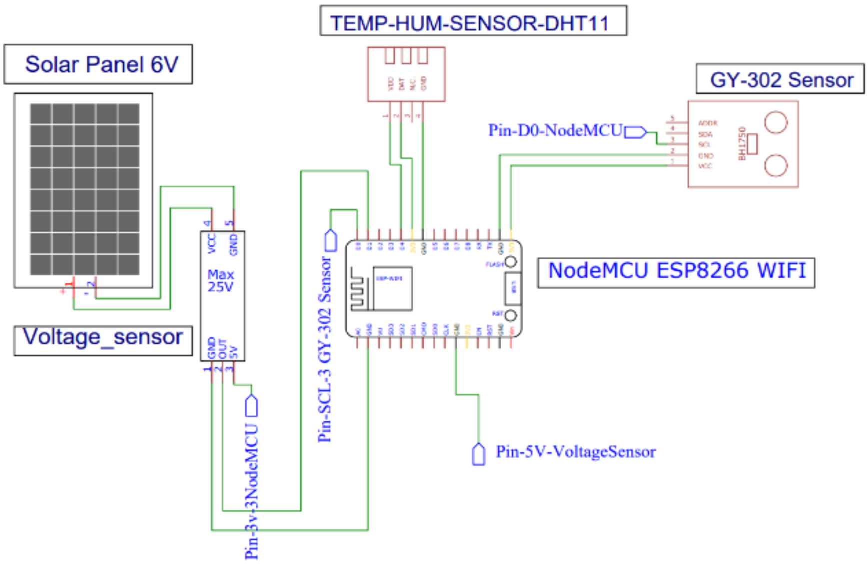

Figure 4. Schematic diagram of proposed structure

3. HARDWARE USED FOR IMPLEMENTATION

3.1. Voltage sensor

A voltage sensor is a device that detects changes in external stimuli and reacts to the system's output in the form of voltage. There are numerous voltage sensor ranges, in which authors uses sensor ranges of 0-25 [14]. It is used to monitor the direct current (DC) or alternating current (AC) voltage of a solar panel. The voltage sensor is designed simply, yet it may be utilised in a variety of applications. It has two resistors with resistance values of 30 KΩ and 7.5 KΩ. Figure 5 illustrates the voltage sensor that was utilising in this setup. The voltage sensor is works on the principle of "voltage divider" as (1):

$$V_O = R_2 /(R_1 + R_2) \times V_i \quad (1)$$

where, V_O: O/P voltage (V), V_i: I/P voltage (V), R_1: first resistor's resistance (Ω), R_2: second resistor's resistance (Ω)/

3.2. DHT11 sensor

The DHT11 sensor is a low-cost sensor that is used to monitor the humidity and temperature of a solar panel system. The DHT11 sensor has a temperatures ranging from 0 °C to 50 °C, and humidity levels ranging from 20% to 90%. Temperature precision is + or -1°, while humidity accuracy is + or -1%. This sensor is easily connected to the NodeMCU ESP8266 microcontroller device. To measure temperature, DHT11 has negative temperature coefficient (NTC). It means that when resistance decreases, temperature rises. The resistance between the electrodes is measured by the DHT11 sensor to compute relative humidity for more details [15]. Figure 6 illustrates the DHT11 sensor that was utilising in this setup. The DHT11 sensor translates resistance measurements to relative humidity and transmits humidity and temperature information to the NodeMCU ESP8266 microcontroller device.

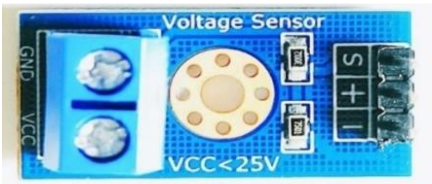

Figure 5. Top view of voltage sensor

Figure 6. Top view of DHT11 sensor

– Relative humidity:

$$H_r = \frac{P_{H2O}}{P_{SAT}} \times 100 \quad (2)$$

where, H_r: relative humidity, P_{H2O}: vapour pressure of water molecule, P_{SAT}: vapour saturation pressure of water.

– Absolute humidity:

$$H_a = \frac{Pe^{-h/RT}M}{RT} \times \frac{H_r}{100} \quad (3)$$

where, H_a: absolute humidity, P: partial pressure, H: enthalpy of water evaporation, R: gas constant, M: molecular mass, T: temperature, H_r: relative humidity. P: 1.002×10^{11} Newton/metre^2, H: 42809 Joule/mol, R: 8.3145 Joule/Kelvin×mol, M: 0.0180153 Kg.

3.3. GY-302 BH1750 sensor

A GY-302 BH1750 sensor is used to measure light intensity, also known as solar irradiation, which is the quantity of light received from the region of the PV panel [16], [17]:

– Solar constant: amount of radiation reaches the earth surface.
– Solar zenith angle: the angle formed between the sun's beam and a line perpendicular to the surface of the earth.

The GY-302 sensor has a 3 to 5 DC voltage operating range and a 16-bit analogue to digital (A/D) converter built in. The I2C bus interface is appropriate for receiving ambient light. The analogue and digital signals from the GY-302 sensor module will be received and shown on the Arduino IDE's serial monitor. Figure 7 illustrates the GY-302 BH1750 sensor that was utilising in this setup.

$$Solar\ Irradiation = Solar\ Constant \times Cosine$$

$$(Solar\ zenith\ angle) \times Transmittance \tag{4}$$

where, $Solar\ Constant$: 1361 (W/m^2), $Solar\ zenith\ angle$: 60 (degrees) and $Transmittance$: 0.75.

3.4. NODEMCU ESP8266

Node micro controller unit (NodeMCU) is a free and open IoT platform's low-cost microcontroller. The ESP8266 system on chip (SoC) Wi-Fi module powers the NodeMCU. It connects to the object and sends data via the Wi-Fi protocol [18], [19]. Figure 8 illustrates the WI-FI Module-ESP8266 that was utilising in this setup.

It is the most cost-effective and accessible IoT platform since it is open source. As compared to the Arduino UNO, the NodeMCU ESP8266 microprocessor consumes extremely low power as shown by Cheragee *et al.* [20]. To programme the NodeMCU, the Arduino IDE is typically used. Because of its small size and built-in Wi-Fi module, this device is mostly utilised for IoT-based applications [21].

3.5. Photovoltaic panel

A solar panel is a device that transform the energy of light (solar rays) into electrical energy. The maximum power (Pmax) is 3 watts, and the nominal voltage is 6 DC volts. A solar panel with a voltage at maximum power of (Vmp) 7.5 volts is to be employed. Figure 9 illustrates the PV panel that was utilising in this setup. For the suggested technique, a polycrystalline solar panel is required [19]. The optimal output power, depending on the availability of sunlight, is 3 watts per day. An ultraviolet (UV) and scratch resistant coating are applied to the solar panel. It is a 9×2-cell array built of polycrystalline silicon material [22], [23].

Figure 7. Top view of GY-302 BH1750 sensor

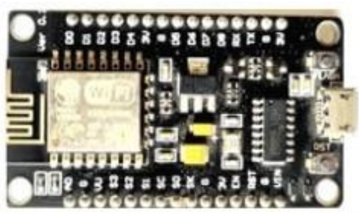

Figure 8. Top view of NodeMCU ESP8266

Figure 9. Top view of PV panel

4. SOFTWARE USED FOR IMPLEMENTATION

4.1. Arduino (IDE)

The Arduino (IDE) software application has a "text editor for writing code" section where we may input the necessary code. The C programming language is used in the proposed model. Then comes the "message area," in which if the code is possibly wrong, it will be displayed. The Arduino software is compatible with all Arduino boards, including the Arduino Uno, Arduino Nano, and NodeMCU ESP8266. This software simplifies the process of writing code and uploading it to the Arduino board [24]. The "toolbar with buttons" provides a variety of features such as run, upload, download, and debugging the code. The Arduino IDE software is connected to the microcontroller board and simply feeds the code to it. It is simple to download and install. Install any required drivers, then connect the microcontroller board to your computer through USB. Simply chose the used board, then the serial port, and finally upload the application.

4.2. Blynk application

Blynk is a software application for the IoT platform. Blynk server is an open-source network that is in responsible for sharing data from the NodeMCU ESP8266 microcontroller board to the Blynk mobile application [25]. Blynk is simple to use; simply run the Arduino IDE software and import the Blynk libraries. Next, choose the template ID and device name before uploading the program to the microcontroller board [26]. Overall, Blynk is the best software since IoT models may be launched for free at any time. The subsequent Figure 10 shows the before and after connecting to the microcontroller. The proposed system (Blynk) is connected to a microcontroller board and the Arduino IDE software, letting us to monitor voltage, temperature, humidity, and solar irradiation data from PV panels [27].

Figure 10. The before and after connecting to the microcontroller

5. RESULTS AND DISCUSSION

The project's outcome is exhibited utilising the Blynk IoT platform. The following results were achieved by integrating several sensors on the Blynk mobile application. Every one-minute, the values of the DHT11 sensor, voltage sensor, and GY-302 BH1750 sensors are updated. Begins at 7:30 AM. and ends at 4:30 PM, the authors gathered data for nine hours. To get the information acquired on November 26, 2022 by Table 1 [28]. The super chart of the proposed structure and data stream of the Blynk application is displayed in Figure 11. Remotely monitored solar panel characteristics include voltage, temperature, humidity, and irradiance.

Table 1. Final data [28]

Date and time	Voltage (v)	Temperature (℃)	Temperature (℉)	Humidity (%)	Irradiation (lx)	Irradiation (W/m^2)
11/26/22 04:32:00 PM	4 V	30 ℃	86 ℉	58%	3037 lx	24 W/m^2
11/26/22 04:31:00 PM	4 V	30 ℃	86 ℉	58%	3177 lx	25 W/m^2
11/26/22 04:30:00 PM	4 V	30 ℃	86 ℉	58%	3360 lx	27 W/m^2
11/26/22 04:29:00 PM	4 V	31 ℃	87 ℉	57%	3540 lx	28 W/m^2
11/26/22 04:28:00 PM	4 V	31 ℃	88 ℉	57%	3560 lx	28 W/m^2
…	…	…	…	…	…	…
…	…	…	…	…	…	…
11/26/22 07:31:00 AM	2 V	28 ℃	82 ℉	84%	56 lx	0 W/m^2
11/26/22 07:30:00 AM	2 V	28 ℃	82 ℉	84%	44 lx	0 W/m^2
11/26/22 07:29:00 AM	3 V	28 ℃	82 ℉	84%	50 lx	0 W/m^2
11/26/22 07:28:00 AM	3 V	28 ℃	82 ℉	84%	29 lx	0 W/m^2

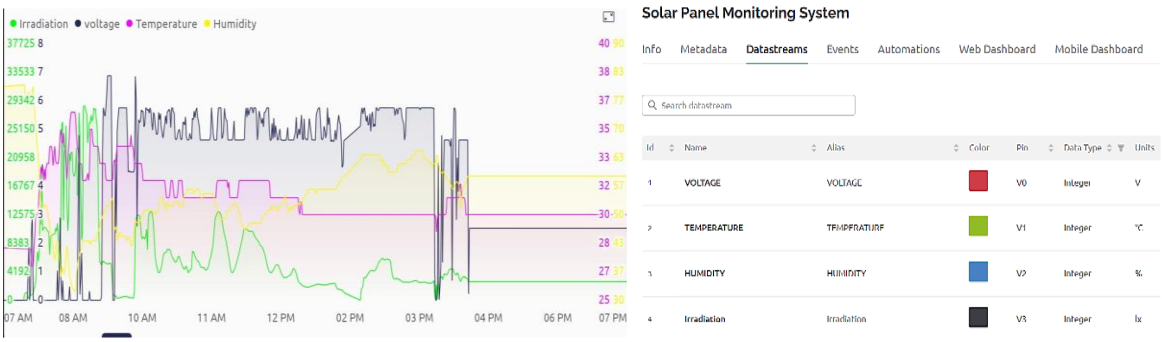

Figure 11. Super chart of the proposed structure and data stream of the Blynk application

The DHT11 sensor is used to monitor the temperature on the surface of a solar panel. The temperature of the solar panels was recorded on November 26, 2022, from 7:30 AM to 4:31 PM at 7:31 AM, the temperature is 30.42 °C, at 12:30 PM, the temperature is 31.04 °C, and at 4:30 PM, the temperature is 30 °C. The curve of temperature in the solar panel is shown in Figure 12.

Figure 12. Solar panel output temperature gauge and graph obtained using Blynk application

A DC voltage sensor measures the output voltage of the solar panel. On November 26, 2022, from 7:30 AM to 4:30 PM, solar panel voltage is monitored. Every hour at 7:30 AM, the voltage is 0.28 V; at 12:30 PM, the voltage is 5.29 V; and at 4:30 PM, the voltage is 3.63 V. The curve of voltage in the solar panel is shown in Figure 13.

The DHT11 sensor measures the humidity of the solar panel. Solar panel humidity monitoring on November 26, 2022 from 7:31 AM to 4:31 PM at 7:31 AM, the humidity is 64.11%; at 12:31 PM, the humidity is 51.96%; and at 4:31 PM, the humidity is 58.55%. The curve of humidity in the solar panel is shown in Figure 14.

Figure 13. Solar panel output voltage gauge and graph obtained using Blynk application

Figure 14. Solar panel output humidity gauge and graph obtained using Blynk application

The GY-302 BH1750 sensor is used to measure solar irradiation. Monitoring of solar panel irradiation on November 26, 2022 from 7:31 AM to 4:31 PM at 7:31 AM, the irradiation is 6,160.05 lx (48.66 W/m^2); at 12:31 PM, the irradiation is 4,291.86 lx (33.90 W/m^2); and at 4:31 PM, the irradiation is 3,046.06 lx (24.06 W/m^2). The curve of irradiance in the solar panel is shown in Figure 15.

Figure 15. Solar panel output irradiation gauge and graph obtained using Blynk application

6. CONCLUSION

In this work, researchers successfully established an IoT-based PV panel monitoring system, which gives significant insights into environmental conditions and PV panel performance. The IoT-based PV panel monitoring system was created by methodically integrating a network of sensors capable of recording real-time data on the surrounding environment and PV panel functionality. One of the the system's most distinguishing characteristics was its intuitive design, which was available via online dashboard and apps for mobile devices. However, the study is constrained to a limited time frame and sensor set, which limits its generalizability. Future research should look at long-term data trends, increase sensor variety, and apply predictive analytics to improve real-time monitoring and maintenance of solar panel systems.

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BIOGRAPHIES OF AUTHORS

Dr. Arcot Ramakrishnan Kalaiarasi has completed her Ph.D. in the year 2014 from Anna University, Chennai, Tamil Nadu, India. She is currently working as professor in the Department of Electronics and Instrumentation, Saveetha Engineering College, Chennai, Tamil Nadu, India. She is having more than 21 years of teaching experience. She has published more than 10 peer reviewed journals, and more than 20 conferences. She has guided nearly 100 UG Students and 20 PG Students. She is an active member of IEI India for the past 20 years. Her areas of research interest are MEMS, control systems, IoT, electrical drives and control, photovoltaics systems. She can be contacted at email: kalaiarasi@saveetha.ac.in.

Ayyadurai Chinnadurai Vasunthira Devi is an enthusiastic and dedicated undergraduate student pursuing a bachelor's degree in electronics and instrumentation engineering at Saveetha Engineering College, located in Chennai, Tamil Nadu, India. She has a deep understanding of the core principles of electronics and instrumentation, which she has applied to create innovative IoT prototypes and solutions. She can be contacted at email: vasunthira2001@gmail.com.

Vijayan Yeshwanth is a dedicated undergraduate student pursuing electronics and instrumentation engineering at Saveetha Engineering College, located in Chennai, Tamil Nadu, India. With a profound passion for the intersection of technology and innovation, he has delved deep into the realm of internet of things (IoT) during her academic journey. He can be contacted at email: yeshwanth2748481@gmail.com.

Samuthiraraj Pravinraj is a dedicated student at Saveetha Engineering College, located in Chennai, Tamil Nadu, India. His academic pursuits primarily revolve around internet of things. With a passion for IoT, he is committed to contributing valuable insights to the academic community. His academic focus and commitment to excellence make him a promising contributor to the field. He can be contacted at email: emailrajprawin@gmail.com.

Muthu Prabakaran currently working towards the Ph.D. degree at Anna University, Chennai. He is currently working as an assistant professor in the Department of Electronics and Instrumentation, Saveetha Engineering College, Chennai, Tamil Nadu, India. He is having more than 4 years of teaching experience. He has guided nearly 20 UG Students. His areas of research interest are IoT, power electronics and drives, photovoltaic systems. He can be contacted at email: smprabakaran.sm@gmail.com.