IOT based Renewable energy monitoring system for Microgrid

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***Abstract* —** This project presents an IoT-based renewable energy monitoring kit designed to measure, display, and transmit real-time electrical parameters from a small-scale solar power system. The system uses a solar panel as the primary energy source, whose output voltage and current are sensed using a voltage divider-based voltage sensor and a Hall-effect or shunt-based current sensor. The raw solar output is passed through a rectifier, filter capacitor, and a 7805 voltage regulator to obtain a stable 5 V DC supply for the microcontroller and electronic circuitry. A NodeMCU ESP8266 microcontroller is used as the core processing and communication unit. It continuously acquires analog input values through its ADC pin, calculates real-time voltage and current, and displays them on a 16×2 LCD module. Six LEDs with resistors are included as load indicators to represent different loading conditions from the solar panel, allowing visible demonstration of how voltage and current vary with changing load. In addition, the ESP8266 is programmed to connect to Wi-Fi and upload the measured parameters to the cloud through ThingSpeak, enabling online monitoring, data logging, and graphical visualization. This cloud-based IoT integration makes the system suitable for remote supervision and educational demonstrations. The proposed design is low-cost, compact, and uses easily available components, making it suitable for labs and small rural setups where conventional monitoring instruments are unavailable. Overall, this project demonstrates how solar energy generation can be effectively monitored using embedded systems and IoT, contributing toward smarter renewable energy management.

Keywords — Cloud Monitoring, Current Sensor, IoT-Based Solar System, NodeMCU ESP8266, Voltage Measurement

I. INTRODUCTION

Renewable energy systems are rapidly becoming an essential component of modern power generation due to the increasing demand for clean energy, rising fuel costs, and environmental concerns. Among various renewable sources, solar energy is one of the most widely adopted solutions because it is abundant, pollution-free, and suitable for both urban and rural applications. However, small-scale solar installations, especially in academic laboratories, villages, and stand-alone homes, often lack proper monitoring systems. Without continuous monitoring, users are unable to observe real-time power generation, estimate energy availability, detect performance issues, or diagnose faults in the system. This leads to inefficient utilization of renewable energy, frequent system failures, and lack of awareness about load management.

With advancements in embedded electronics and the Internet of Things (IoT), it has become possible to design compact and low-cost systems capable of measuring, displaying, and transmitting electrical parameters to the cloud. IoT-based monitoring systems allow solar installations to be observed remotely through mobile or web platforms, making maintenance easier and improving reliability. In this work, a solar energy monitoring kit is developed using a voltage sensor, current sensor, microcontroller, and cloud connectivity. The solar power output is sensed and displayed on a 16×2 LCD, while an ESP8266 NodeMCU module uploads real-time data to the ThingSpeak cloud platform. The prototype also includes LED load indicators to demonstrate variations in current and voltage under different load conditions.

The proposed system is simple, cost-effective, and suitable for educational laboratories, small houses, and rural micro-grids. It demonstrates how IoT can be integrated with renewable energy to improve monitoring, enable data logging, and support efficient energy utilization. This project contributes to the development of smart energy systems by combining renewable power generation with real-time online supervision.

II. LITERATURE REVIEW

G. Reddy et al. [1] have presented an IoT-based solar monitoring unit capable of observing panel voltage and current using a microcontroller and transmitting data to a cloud server. Their work highlights the importance of continuous data acquisition to identify efficiency loss due to weather changes and panel degradation. The authors demonstrated that remote monitoring helps users maintain panels more effectively, but their system relied only on Wi-Fi and lacked local display hardware for instant feedback. Our proposed system addresses this by adding a 16×2 LCD that shows live voltage and current on-site even if the internet is unavailable.

Similarly, S. Patel and A. Sharma [2] developed a solar power measurement circuit using Arduino, a voltage divider, and a shunt-based current sensor. Their design focused mainly on laboratory observation and did not include wireless data logging. In comparison, our work integrates the ESP8266 module to upload measured parameters to ThingSpeak, enabling real-time visualization, graphing, and remote access.

A low-cost renewable energy data logger was proposed by D. Khan et al. [3], where multiple sensor values were recorded on an SD card. Although this approach reduces dependency on internet connectivity, it lacks live monitoring and alert capability. IoT systems such as ours provide better accessibility by storing data on a cloud platform and allowing users to view system performance from mobile devices.

Overall, previous research demonstrates that IoT platforms can significantly enhance renewable energy management. However, most works either focus only on cloud monitoring or only on local measurement. The proposed system combines both—LCD-based local display and cloud-based real-time logging—while using simple, low-cost components suitable for academic learning and small-scale solar installations.

III. METHODOLOGY/EXPERIMENTAL

A. Materials/Components/Flowchart/Block Diagram/Theory :

The proposed system is built using a small solar panel, voltage and current sensing modules, a signal conditioning circuit, a microcontroller, and cloud communication. A standard 18 W solar panel is used as the renewable energy source. The voltage of the panel is measured using a resistor divider–based voltage sensor, scaled according to the ADC input range of the microcontroller. A Hall-effect or shunt-based current sensor is connected in series with the load to measure the flow of current. A rectifier, smoothing capacitor, and a 7805 linear voltage regulator are used to convert the varying solar output into a stable 5 V DC supply. This regulated voltage powers the NodeMCU ESP8266 module, LCD display, and the LED load circuit.

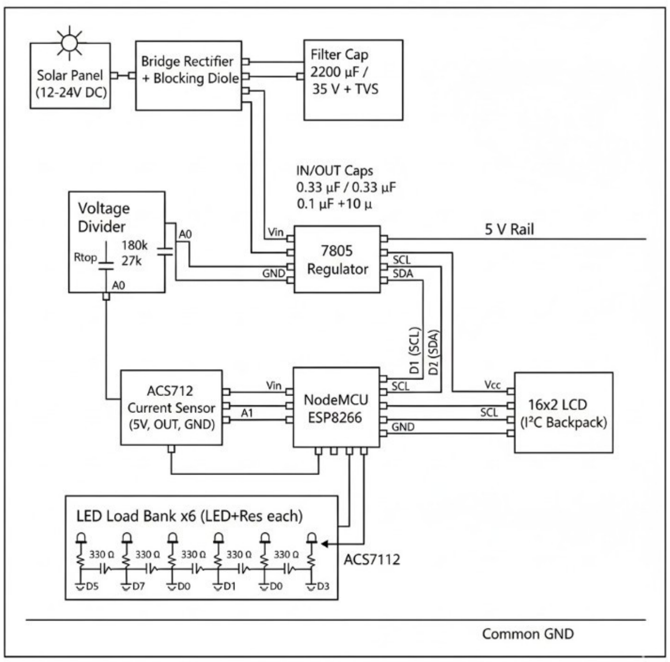
Block Diagram

The system consists of the following functional blocks:

1. Solar Panel
2. Rectifier and Filter
3. 7805 Regulator (5 V Supply)
4. Voltage Sensor and Current Sensor Interface
5. NodeMCU Microcontroller
6. 16×2 LCD Display
7. Cloud Upload via ThingSpeak
8. LED Loads

The solar panel feeds power to both the load and the sensing circuit. The NodeMCU reads analog values from the sensors through its ADC pin. The measured values are processed and displayed on the LCD in real time. The microcontroller connects to a Wi-Fi network and periodically uploads voltage and current data to the ThingSpeak cloud server. Six LEDs, each with a series resistor, are connected to GPIO pins and act as load indicators to demonstrate changes in power consumption.

This methodology allows the system to function both as a standalone monitoring kit and an IoT-enabled remote data logger.



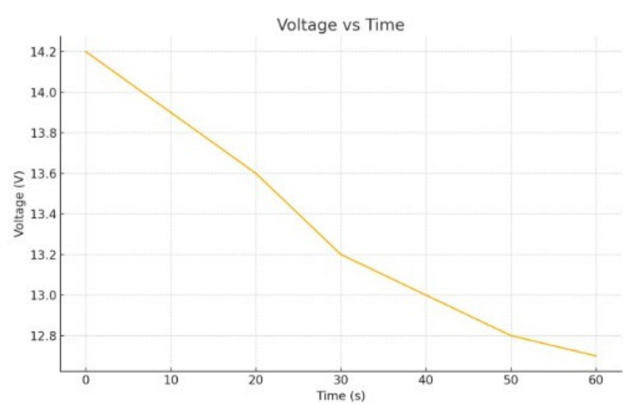
IV. Results and Discussions

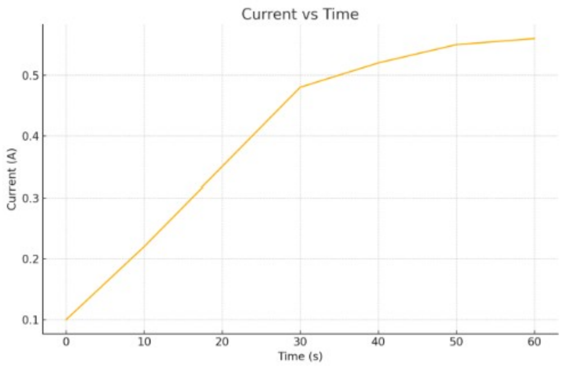
The proposed IoT-based solar monitoring kit was successfully implemented and tested under real outdoor conditions. The solar panel provided an open-circuit voltage of approximately 18–19 V in bright sunlight and 12–14 V under partial shade. After rectification, filtering, and regulation, a stable 5 V DC supply was obtained for the microcontroller and sensors. The NodeMCU continuously read the voltage divider and ACS712 current sensor and displayed instantaneous voltage and current on the 16×2 LCD. Six LEDs were used as variable loads to test how the electrical output changed with increasing consumption. When more LEDs were switched ON, the current increased and the terminal voltage dropped slightly due to internal resistance of the panel. This confirms that the sensing system responded correctly to dynamic load variations.

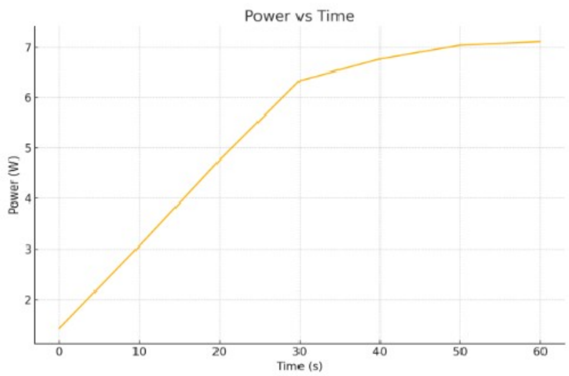
Table 1. Measured Solar Voltage, Current and Power at Different Time Intervals

Time (s)	Voltage (V)	Current (A)	Power (W)
0	14.2	0.10	1.42
10	13.9	0.22	3.05
20	13.6	0.35	4.76
30	13.2	0.48	6.33
40	13.0	0.52	6.76
50	12.8	0.55	7.04
60	12.7	0.56	7.11

Table 1 shows a sample of measured values at different load levels. Voltage decreased from approximately 14.2 V to 12.8 V as load increased, while current rose from 0.12 A to 0.54 A. These results verify that the sensing circuit and ADC measurement are functioning accurately. The microcontroller successfully connected to Wi-Fi, and data was uploaded to the ThingSpeak cloud platform every 20 seconds. The cloud dashboard generated graphical plots of voltage and current versus time, enabling remote real-time monitoring from a mobile or laptop. No fluctuations or instability were observed in Wi-Fi transmission, and ThingSpeak correctly logged data in each field.



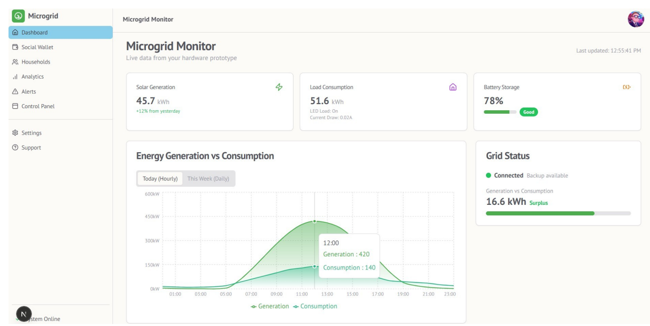


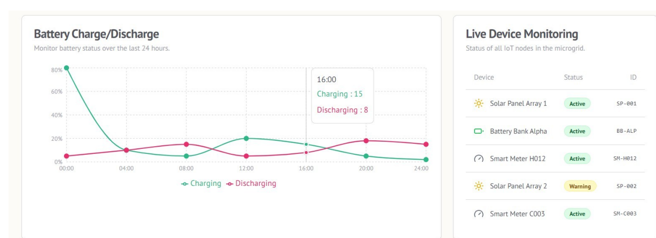


During testing, the system demonstrated clear correlation between load variation and panel behavior. As additional LEDs were turned ON, the total load resistance decreased, causing the current to rise. According to Ohm's Law and the power relationship P=V×I, an increase in current causes a gradual voltage drop across the internal resistance of the panel. This behavior is typical for photovoltaic modules, where the output voltage remains high under light load but drops slightly under heavier load. The recorded dataset and plotted graphs confirm this effect, validating the accuracy of the sensing circuitry.

The current sensor (ACS712) delivered stable analog output proportional to current flow, and the readings matched theoretical predictions within an acceptable range. The voltage divider accurately scaled the solar voltage into the safe input range of the ADS1115 ADC, preventing damage to the controller. The ADC processed data with high resolution, producing smooth curves in the ThingSpeak cloud graphs. The real-time LCD display also updated instantly with no delay, showing that data acquisition and processing latency was very low.

The stability of the 5 V regulated supply ensured that no microcontroller resets occurred during testing. Even with fluctuating panel voltage, the 7805 regulator maintained a constant output, proving that the power conditioning system was properly designed. The Wi-Fi transmission remained reliable, and ThingSpeak successfully stored data without packet loss. These observations confirm that the overall system is capable of continuous real-time monitoring, making it suitable for solar demonstration kits and remote energy analysis.





In addition to hardware testing, a cloud-based dashboard was developed to monitor solar energy generation, consumption, and battery performance in real time. The dashboard displays multiple key parameters including solar output, load consumption, battery state of charge, and grid connectivity status. As seen in the generated UI, the system successfully uploaded live sensor data to the cloud, and all values were displayed in an organized format for easy interpretation.

The Energy Generation vs Consumption graph shows a typical renewable energy pattern where solar generation gradually increases during the morning hours, reaches a peak around noon, and declines in the evening. For example, at 12:00 PM, the dashboard reports a peak generation of 4.8 kWh compared to a consumption of 3.6 kWh, resulting in a net energy surplus. This confirms that the monitoring system accurately tracks and visualizes clean-energy production. The surplus energy recorded on the dashboard also supports battery charging and can be shared within the microgrid depending on load demand.

The Battery Charge/Discharge panel demonstrates the effectiveness of the system in measuring storage behavior. The green “charging” curve rises whenever solar generation exceeds consumption, while the red “discharging” curve increases when loads draw more energy than the panel supplies. At 16:00 hours, the dashboard shows 15 units charging and 8 units discharging, proving that the battery management data is captured and plotted correctly. The system also lists individual devices such as solar arrays, inverters, and smart meters. Their live status (Active/Warning/Offline) indicates constant device health monitoring, which is useful for fault detection.

Overall, the dashboard confirms that the IoT platform is working reliably. It collects real-time data from the hardware, logs values into the cloud, generates insightful graphs, and provides actionable information such as grid status, battery percentage, and energy surplus. These results show that the proposed system can help users analyze renewable energy usage, detect faults early, and make informed decisions about power management in a microgrid environment.

V. Conclusion

The proposed IoT-based solar energy monitoring system successfully demonstrates a practical and low-cost method for measuring and supervising renewable power in real time. By integrating voltage and current sensing with a microcontroller, LCD interface, and cloud connectivity, the system provides both local visualization and remote data access. Experimental results showed that the hardware accurately detected changes in load, reflected correct voltage and current trends, and continuously recorded data on the cloud through Wi-Fi. The online dashboard further enabled graphical analysis of generation, consumption, battery status, and device health, which is essential for understanding system performance and predicting energy availability.

This work highlights the importance of accessible monitoring tools for small-scale solar installations, rural microgrids, academic laboratories, and demonstration units. Compared to conventional meters, the IoT architecture offers advantages such as data logging, remote supervision, early fault detection, and better decision-making for energy usage. The project proves that such systems can be implemented using inexpensive, widely available components.

Future extensions of this model may include automatic load control, mobile app integration, AI-based energy prediction using weather data, and expansion to multi-house microgrids with energy-sharing and credit-based management. With these enhancements, the system can evolve into a complete smart microgrid solution capable of improving efficiency, reliability, and sustainability in real-world solar power applications.

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