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Sensor-Based IOT Platform for Real-Time Monitoring and Cloud Visualization of Solar PV Generation and Battery Energy Storage System

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Abstract - Solar photovoltaic (PV) systems with battery storage are spreading quickly, yet many installations still rely on handheld meters and local displays that give no remote access, no historical record and little battery information. This paper presents a sensor-based Internet of Things (IoT) platform for real-time monitoring and cloud analytics of a solar PV generation and battery energy storage system. The architecture senses PV voltage and current, battery voltage, charging current and temperature, ambient temperature, humidity and solar irradiance, and estimates battery state of charge (SoC) by Coulomb counting. Conditioned data are sent over Wi-Fi or a GSM link to the ThingSpeak cloud, where live dashboards and exportable records build a historical dataset. A prototype based on a NodeMCU ESP8266, a DHT22 sensor, a light sensor and a voltage channel was tested outdoors. Every reading was uploaded to ThingSpeak, temperature stayed between about 31 °C and 32.5 °C, humidity between 61 % and 66 %, and the solar voltage rose with light intensity. The platform offers a low-cost, expandable base for fault detection, forecasting and battery analytics using machine learning.

Key Words: Solar PV monitoring, Internet of Things, ThingSpeak, battery energy storage, state of charge, cloud analytics.

1. INTRODUCTION

Solar photovoltaic (PV) installations are growing rapidly in residential, commercial and industrial sectors. A PV array is rarely used alone: a battery energy storage system (BESS) is added to supply loads when sunlight is unavailable, and the pair has to be watched together because panel output, battery charging and battery ageing all depend on irradiance and temperature.

In many laboratories and small installations, monitoring still means a digital multimeter, the display of a charge controller and a separate battery indicator, with values written down by hand. This gives no remote access, no cloud storage, no unified dashboard and no time-stamped history, so long-term performance analysis, fault diagnosis and battery health estimation are difficult.

Advances in Industrial IoT now allow electrical and environmental parameters to be acquired continuously, stored in the cloud and later analysed with artificial intelligence (AI). This paper describes a sensor-based IoT platform that measures PV and battery parameters in real time, uploads them to the ThingSpeak cloud and builds a historical dataset for machine learning (ML) research. The main contributions are: (i) a complete sensing architecture for PV, battery and weather parameters; (ii) a working prototype with live cloud upload; and (iii) a logged dataset that supports future forecasting, fault detection and battery analytics.

2. LITERATURE REVIEW

IoT-based monitoring of renewable energy has been studied widely in recent years. Nkinyam et al. [1] developed a low-cost IoT monitoring device for solar PV systems, showing that inexpensive sensors and a microcontroller can replace costly commercial data loggers. Rao et al. [2] proposed a smart cloud-based monitoring system for solar PV energy generation, which moves data storage and visualisation off the site and into the cloud. In the same direction, Bufwoj et al. [3] presented the design and implementation of a smart solar generation and IoT-enabled power monitoring system.

Wireless sensing has also been applied at the power-system level. Velvizhi and Anbarasan [4] studied real-time energy monitoring for renewable power systems using IoT-based wireless sensor networks, with attention to stability and efficiency, while Khan et al. [5] considered real-time monitoring and control of renewable energy systems with energy storage using wireless telecommunication and signal processing for smart grids. An earlier IoT-based remote monitoring and control unit for solar PV was reported by Adhya et al. [6], which shows that the idea is well established and that current work is moving towards cloud services and analytics.

Battery monitoring is the other half of the problem. Coulomb counting is the most direct way to track SoC, and Ng et al. [7] described an enhanced Coulomb counting method that also estimates state of health (SoH) of lithium-ion batteries. Model-based observers, such as the extended Kalman filter approach of Plett [8], reduce drift but need more computation and a battery model. Both lines of work need good voltage, current and temperature records, which is what a monitoring platform should supply.

From this review, three points stand out. First, low-cost sensors, microcontrollers and cloud dashboards are now practical for PV monitoring. Second, PV monitoring and battery state estimation are usually treated separately. Third, historical data are often shown on dashboards but are not prepared as a dataset for ML. The present work treats the PV array, the battery and the surrounding weather as one monitored system and logs time-stamped records intended for later AI use.

3. PROBLEM STATEMENT AND OBJECTIVES

The limitations of present PV set-ups are: lack of continuous monitoring, no centralised cloud database, limited battery health information, difficult fault diagnosis, no historical dataset for AI, poor predictive maintenance and manual data recording. The primary objective is to develop a real-time Industrial IoT monitoring system for solar PV and battery energy storage. The specific objectives are to measure PV voltage and current, battery voltage and charging current, battery temperature and solar irradiance; to estimate battery SoC; to upload data to

ThingSpeak; to generate a historical database; and to support future AI and ML research.

4. SYSTEM DESIGN AND METHODOLOGY

4.1 System Architecture

Fig. 1 shows the block diagram. Voltage, current, temperature and irradiance sensors on the solar PV panel, and voltage, current and temperature sensors on the battery, feed an STM32 controller that performs data acquisition and control. A data-processing stage applies filtering, scaling, validation and feature extraction. The processed values are sent through a GSM or Wi-Fi module to the ThingSpeak cloud for visualisation and storage, and then to a database (MySQL or cloud storage) for historical analysis. ML and deep learning (DL) models trained on this database are intended for forecasting, fault detection and battery analytics.

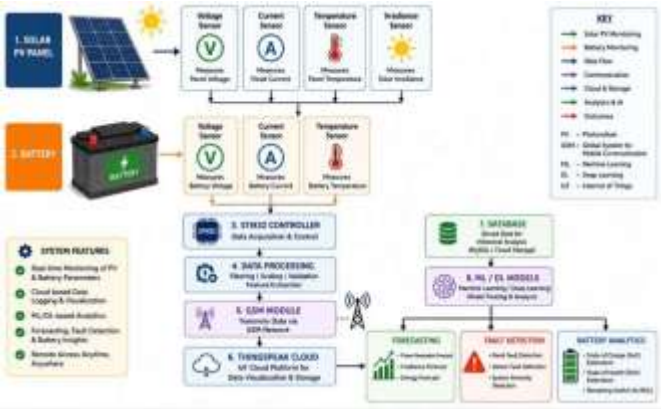


Fig -1: Block diagram of the proposed IoT-based monitoring system for solar PV and battery storage.

4.2 Sensing and Signal Conditioning

Table 1 lists the parameters and sensors. PV and battery voltages exceed the input range of a microcontroller analogue-to-digital converter (ADC), so a resistive divider is used. With resistors R_1 and R_2, the ADC input is

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

and the measured voltage is recovered as $V_{in} = V_{out} (R_1 + R_2) / R_2$. Currents are measured with ACS758 or INA219 modules, panel and battery temperatures with DS18B20 sensors, ambient temperature and humidity with a DHT22, and irradiance with a BH1750 or light-dependent resistor (LDR) in the prototype (a pyranometer is the ideal reference). Wind speed, dust level and panel tilt (MPU6050) are optional extensions.

Table -1: Parameters and sensors used.

Parameter	Sensor	Method
PV / battery voltage	Voltage divider	Divider and ADC
PV / battery current	ACS758 / INA219	Hall or shunt sensing
Panel / battery temp.	DS18B20	One-wire digital
Ambient temp., humidity	DHT22	Single-wire digital
Solar irradiance	BH1750 / LDR	Light intensity (lux)
Battery SoC	Voltage + current	Coulomb counting

4.3 Battery State of Charge Estimation

Battery SoC is estimated from the measured voltage and current by Coulomb counting, in which the current is integrated over time:

$$SoC(t) = SoC(t_0) + (\eta / C_n) \int I_b(\tau)\, d\tau \times 100\ \% \quad (2)$$

where I_b is the battery current (positive while charging), C_n is the rated capacity and η is the charging efficiency. Voltage readings are used to set the initial SoC and to correct drift when the battery is at rest [7].

4.4 Controller and Communication

An STM32 microcontroller handles acquisition and processing, and an ESP8266 Wi-Fi module sends data to the cloud; a SIM800L or SIM7600 GSM module provides a cellular link where Wi-Fi is not available. In the prototype reported here, a NodeMCU (ESP-12E) board reads the sensors and uploads directly over Wi-Fi.

4.5 Cloud Platform and Software Tools

ThingSpeak stores the data in channel fields and provides live charts. The board connects to Wi-Fi and posts each reading to api.thingspeak.com with the channel write key. Firmware for the prototype is written in the Arduino IDE using the DHT library; the STM32 design uses STM32CubeMX for peripheral configuration (GPIO, I²C, UART, timers and clocks) and STM32CubeIDE for Embedded C. A serial terminal such as PuTTY or Tera Term is used for debugging, and the exported ThingSpeak data are handled in Excel.

5. HARDWARE IMPLEMENTATION

Fig. 2 shows the prototype. A small solar panel is mounted above a breadboard carrying the NodeMCU ESP8266, the DHT22 temperature and humidity sensor, the light sensor and the voltage-sensing module. A lithium-ion cell in a holder represents the battery, and a laptop running the Arduino IDE serial monitor displays the readings. The prototype was then taken outdoors and tested under sunlight with the laptop connected, as part of the testing stage.

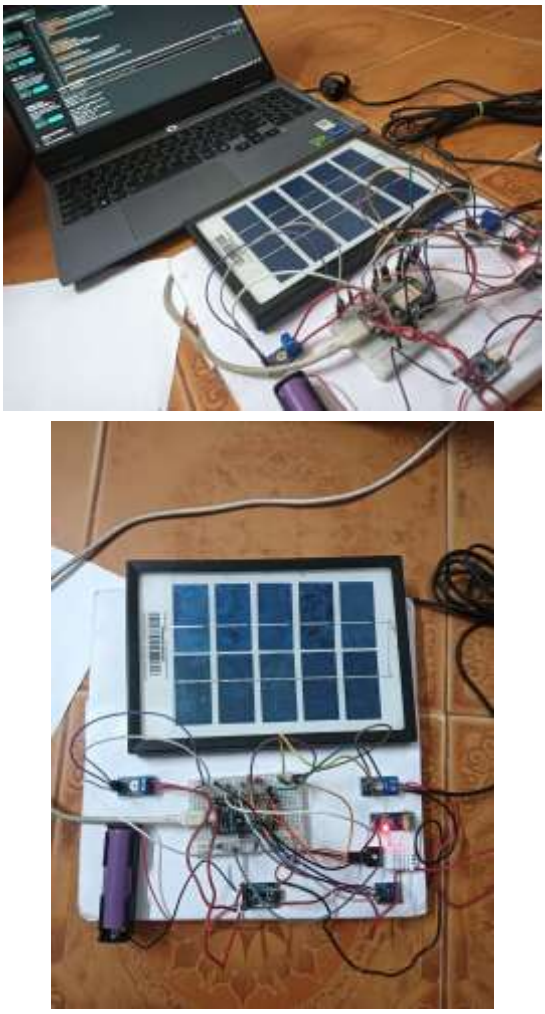


Fig -2: Prototype hardware: (a) bench set-up with laptop running the serial monitor; (b) top view of the solar panel, sensor modules, NodeMCU and battery holder.

The estimated cost of the complete design, including the STM32 board, GSM module, voltage and current sensors, DS18B20 and DHT22 sensors, BH1750, buck converter, PCB and enclosure, is about Rs. 7,800.

6. RESULTS AND DISCUSSION

6.1 Serial Monitor Output

Fig. 3 shows the Arduino IDE serial monitor at 115200 baud. For every reading the NodeMCU prints a "SOLAR MONITORING" block containing voltage, light intensity (lux), temperature and humidity, followed by the message "ThingSpeak upload successful", which confirms that each reading reached the cloud. When the light intensity rose from 23.33 lux to 16278.33 lux, the measured voltage changed from 0.08 V to 0.14 V, while temperature stayed near 31.1–31.3 °C and humidity near 64.5–65.4 %.



Fig -3: Serial monitor output showing voltage, light intensity, temperature, humidity and upload status.

6.2 Cloud Monitoring on ThingSpeak

Fig. 4 shows the temperature chart (Field 1) of the ThingSpeak channel. Each dot is one reading uploaded by the ESP8266. From about 09:43 to 10:04 the temperature stayed between 32.1 °C and 32.5 °C. It was steady near 32.1–32.2 °C until about 09:55, rose to a peak of 32.5 °C near 10:01 and settled at 32.3 °C. The humidity chart (Field 2) fell from about 64.1 % to 62.5 % between 09:45 and 10:02 and then rose slightly to about 62.8 %; in a later window (10:00–10:18) it ranged from 61.2 % to 63.5 %. Humidity therefore tended to fall as temperature rose. Because the charts update live, the readings can be followed remotely.

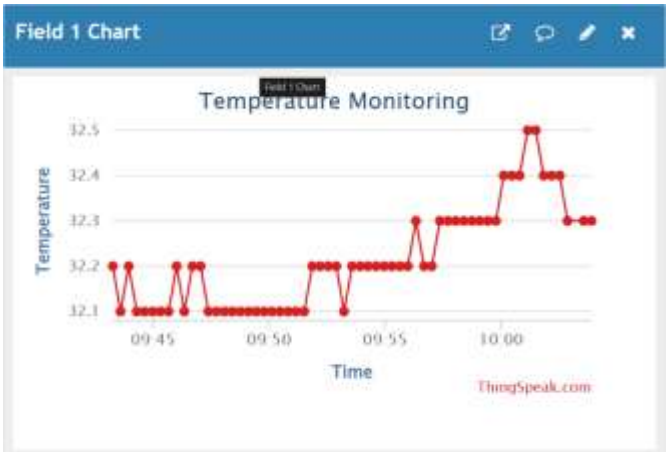


Fig -4: ThingSpeak Field 1 chart of temperature monitoring.

6.3 Logged Dataset

ThingSpeak data were exported to Excel with four columns: date, entry_id, temperature and humidity. Each row is one upload with its own entry ID. In the 41 entries examined, temperature lay between 31.9 °C and 32.1 °C and humidity between 65.0 % and 65.8 %. Table 2 summarises the observations. This record is the start of the historical dataset needed for later analysis and AI/ML work.

Table -2: Summary of observed values.

Source	Parameter	Observed range
Serial monitor	Light / Voltage	23.33→16278.33 lux / 0.08→0.14 V
Serial monitor	Temp. / Humidity	31.1–31.3 °C / 64.5–65.4 %
ThingSpeak (09:43–10:04)	Temperature	32.1–32.5 °C (peak 32.5 °C)
ThingSpeak (09:45–10:18)	Humidity	61.2–64.1 %
Excel log (41 entries)	Temp. / Humidity	31.9–32.1 °C / 65.0–65.8 %

6.4 Discussion

The tests show that the sensing, processing, Wi-Fi transmission and cloud storage chain works end to end, and that the platform records a time-stamped history. The solar voltage values are small and depend on the conditioning circuit and test set-up, so calibration against a reference multimeter and tests under full sunlight and load are still needed. Battery current, battery temperature and SoC estimation, the STM32 controller and the GSM link belong to the full design and are to be validated in the next stage.

7. CONCLUSIONS AND FUTURE SCOPE

A sensor-based IoT platform for real-time monitoring and cloud analytics of a solar PV and battery storage system was designed and a prototype was built and tested. The prototype

measured light intensity, voltage, temperature and humidity, uploaded every reading to ThingSpeak and produced live charts and an exportable dataset, replacing manual recording with remote, continuous monitoring.

Future work includes adding battery current and temperature channels, completing SoC estimation by Coulomb counting, integrating the STM32 controller and GSM link, calibrating all sensors, and collecting a longer dataset. This dataset can then be used to train ML and DL models for power and irradiance forecasting, panel and sensor fault detection, and battery SoC, SoH and remaining useful life estimation.

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