

# IoT-Enabled AI-Based Solar Energy Forecasting and Battery Optimization System

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## Abstract:

*The AI Powered Solar Energy Management System (AI-SEMS) is an intelligent solution designed to optimize solar energy generation, storage, and utilization using Artificial Intelligence (AI), Battery Management System (BMS), MPPT control, and IoT technologies. The system integrates solar panels, a MOSFET-based MPPT charging circuit, a 12V battery, inverter, sensors, and cloud monitoring for efficient operation. A Raspberry Pi is used as the main controller to process real-time data collected from voltage, current, temperature, humidity, and light sensors. The system calculates key battery parameters such as State of Charge (SOC) and State of Health (SOH) to ensure safe and efficient battery usage. Additionally, a SARIMAX model is implemented to predict solar energy generation and system performance based on historical and environmental data. This predictive capability enables intelligent decision-making, improves energy efficiency, and enhances battery life. All system data is monitored and visualized remotely through the ThingSpeak cloud platform. The proposed system is suitable for smart energy applications, renewable energy systems, and sustainable power management.*

**Keywords:** Artificial Intelligence, Solar Energy,MPPT, BMS, Raspberry Pi,IoT, ThingSpeak, Smart Energy Management,SOC, SOH, SARIMAX model, Predictive Analytics, Energy Optimization.

## 1. INTRODUCTION

Solar energy is a widely used renewable energy source, but efficient management is required to maximize its performance. This paper proposes an AI Powered Solar Energy Management System using a Raspberry Pi to monitor and control energy flow. The system integrates AI, MPPT, and IoT for improved efficiency and smart energy management.

Patel (2019), in “*Battery Management Systems and Renewable Energy Integration,*” emphasizes the importance of efficient energy storage in renewable energy systems. The study explains how Battery Management Systems (BMS) ensure safe charging and discharging, prevent overvoltage,

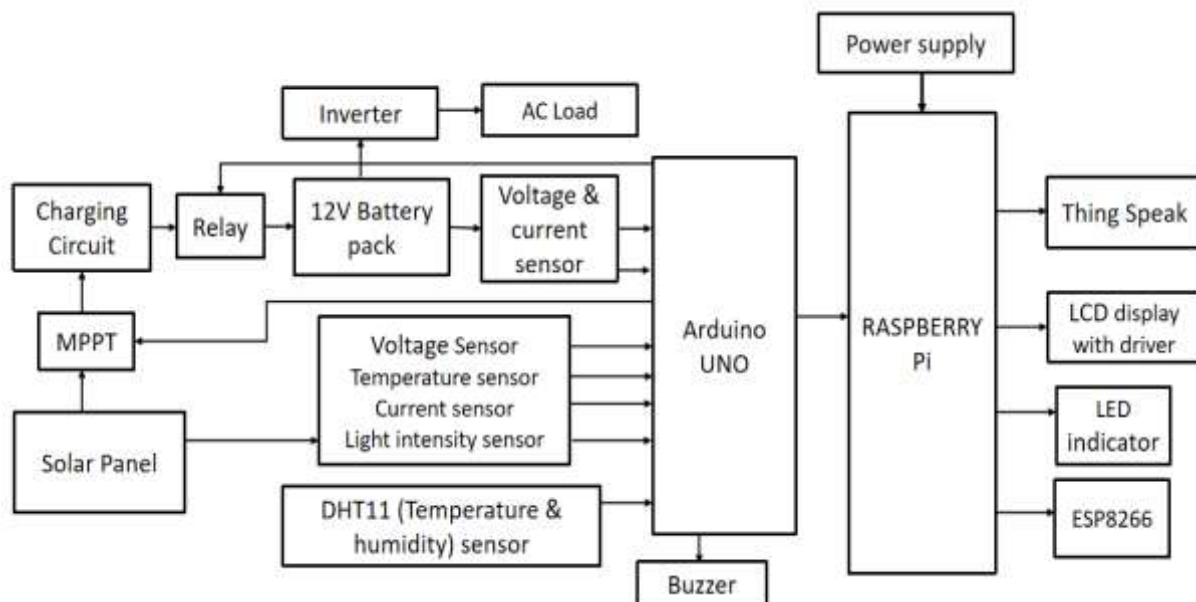
and improve battery lifespan. It also highlights the integration of BMS with microcontrollers and AI for automated energy control, which is relevant to IoT-based solar applications [1]. Green (2020), in “*Solar Energy: Principles and Technologies,*” provides a fundamental understanding of photovoltaic systems, including solar cell operation, efficiency factors, and solar radiation modeling. The work also discusses advancements in smart grids and hybrid renewable systems, forming a strong theoretical base for solar energy projects [2].

Jayanth S., Poorvi M. B., and Sunil M. P. (2020) proposed a *Raspberry Pi-based Energy Management System* for real-time monitoring of solar parameters. Their system enabled accurate measurement of voltage, current, and power, improving energy tracking and system efficiency [3].

Smith and Brown (2021), in their paper “*AI-Driven Optimization of Solar Energy Systems,*” explored the application of Artificial Intelligence in solar power management. Their research demonstrated that machine learning algorithms can predict solar irradiance, optimize energy storage, and manage load distribution efficiently. The study showed that AI-based systems can improve photovoltaic system efficiency by 15–20% [4].

## 2. BLOCK DIAGRAM

The block diagram For AI-Powered Solar Energy Management System Using Raspberry Pi as shown in fig.1



**Fig.1 Block Diagram**

The core function is to harvest energy from a Solar Panel, store it in a 12V Battery pack, and use it to power an AC Load, all while monitoring critical parameters and controlling the system with a RASPBERRY Pi.

**Energy Generation:** The system starts with the Solar Panel, which converts sunlight into electrical energy.

**Charging:** This energy flows to the Charging Circuit, which manages the charge going into the 12V Battery pack, ensuring optimal and safe charging.

**Power Switching:** A Relay acts as an electronic switch, likely controlling the connection between the charging circuit/solar panel and the battery, and possibly between the battery and the load/inverter, often used to prevent overcharging or deep discharge.

**Power Conversion:** The stored 12V DC power from the battery is fed to an Inverter, which converts the DC power into standard AC power to run the AC Load (e.g., household appliances).

**Main Power:** A separate Power supply provides the necessary regulated power to the main control unit, the RASPBERRY Pi, and associated electronics. Multiple sensors are used to monitor the status of the solar system and the environment. All analog sensor signals are first processed by an ADC Converter (Analog-to-Digital Converter) before being read by the Raspberry Pi, as the Pi's GPIO pins typically only read digital inputs.

**Solar Panel Monitoring:** A block containing a Voltage Sensor, Temperature sensor, Current sensor, and Light intensity sensor monitors the solar panel's output and environmental conditions. This data is crucial for calculating the panel's efficiency.

**Battery/Load Monitoring:** A dedicated Voltage & current sensor monitors the battery pack's output and the current being drawn by the load, allowing for state-of-charge calculation and load management.

**Environmental Monitoring:** A DHT11 (Temperature & humidity) sensor measures the ambient temperature and humidity, which can affect system performance and is useful for environmental logging.

The RASPBERRY Pi is the central processing unit, taking in the digital data from the ADC Converter and the DHT11 sensor (which is often a digital sensor).

**Data Processing:** The Raspberry Pi runs the control logic, processing the sensor data to perform calculations (like power/efficiency), manage the relay, and decide on alarm conditions.

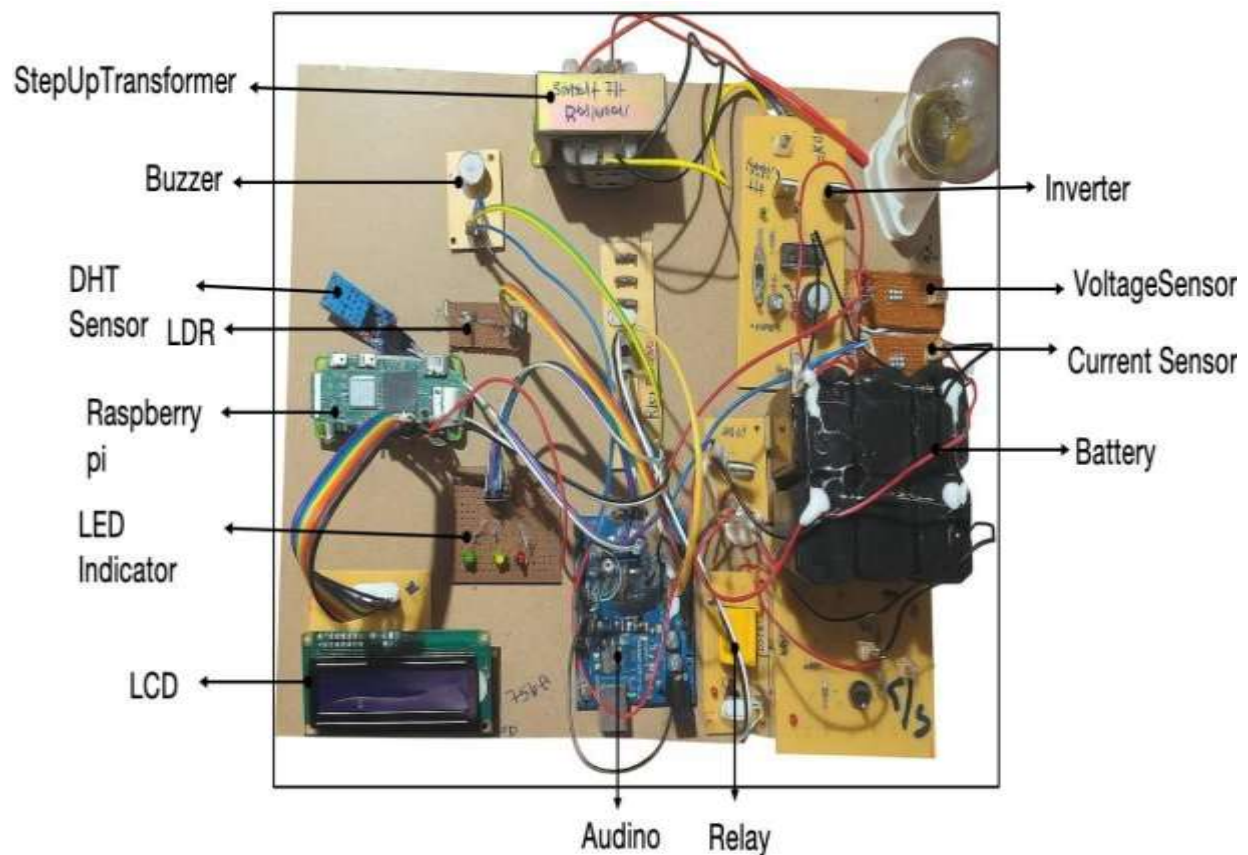
**Local Display:** An LCD display with driver is connected to the Pi to provide a local, real-time interface for users to view monitored parameters (voltage, current, temperature, etc.).

**Alarms and Status:** A Buzzer and LED indicator are connected to the Pi to provide immediate local alerts (e.g., low battery, over-current) and system status feedback.

**IoT and Remote Monitoring:** The Pi is connected to ThingSpeak, which is an IoT analytics platform. This enables the system to publish real-time data to the internet, allowing for remote monitoring, data storage, and trend analysis via a web browser or mobile app.

### 3. HARDWARE MODULE

The hardware module built for the AI Powered Solar Energy Management System using Raspberry Pi is shown in Fig.2



**Fig.2 Hardware Module**

The hardware module, labeled as Fig. 2, represents the AI-Powered Solar Energy Management System using a Raspberry Pi. The system integrates multiple sensors and control components to ensure efficient energy generation, monitoring, and utilization. The DHT11 sensor measures environmental parameters such as temperature and humidity, which affect solar panel performance, while an LDR (Light Dependent Resistor) detects sunlight intensity to determine optimal charging conditions. Solar energy is captured from the panel and processed through a MOSFET-based MPPT circuit to extract maximum power, and the energy is stored in a lead-acid

battery. The stored DC power is converted into AC using an inverter to supply electrical loads, with a step-up transformer used for voltage boosting and isolation. The system is controlled by a Raspberry Pi along with an Arduino, where the Raspberry Pi performs data processing and intelligent decision-making, and the Arduino handles real-time control operations. Voltage and current sensors continuously monitor system parameters to ensure efficient performance. In addition to real-time monitoring, a SARIMAX model is implemented in the Raspberry Pi to predict solar energy generation and system behaviour based on historical data and environmental conditions, enabling proactive energy management and improved system efficiency. A relay module is used for switching loads, while an LCD display provides real-time system status, and a buzzer with LED indicators gives alerts during abnormal conditions such as overvoltage, overheating, or low battery levels. Overall, the hardware module ensures efficient, intelligent, and safe operation of the solar energy management system

## **4. TESTING AND RESULTS**

### **4.1 TESTING WITH THINGSPEAK APP**

ThingSpeak is a cloud-based IoT platform developed by MathWorks that allows users to collect, store, analyze, and visualize real-time data from connected devices like Raspberry Pi and Arduino. It enables users to create channels for sensor data such as voltage, temperature, and humidity, displaying them through live graphical charts. Integrated with MATLAB, ThingSpeak supports advanced data analysis and automation. It is widely used in projects like AI-powered solar energy management systems to monitor and optimize energy use. With its user-friendly interface and real-time updates, ThingSpeak is a powerful tool for IoT research and smart system applications.

#### **Step 1: Create ThingSpeak Account**

- Open ThingSpeak
- Sign in or create a new account using MathWorks

#### **Step 2: Create a Channel**

- Click on “New Channel”
- Enter channel name.
- Add fields like:
  - Solar Voltage
  - Solar Current

- Battery Voltage
- Battery Current
- SOC, SOH, Temperature, etc.
- Click Save Channel



**Fig.3 Home Page of ThingSpeak**



**Fig.4 ThingSpeak Platform After Login**

### **Step 3: Connect Raspberry Pi**

- Use internet (Wi-Fi) connection
- Write a program in Raspberry Pi
- Send sensor data using API key to ThingSpeak

### **Step 4: Data Upload**

- Sensor data (voltage, current, temperature, etc.) is sent continuously

- Data gets stored in respective field.

#### Step 5: Data Visualisation

- ThingSpeak automatically creates graphs for each parameter
- Helps to analyse system performance

#### Step 6: Data Analysis & Prediction

- Use MATLAB analytics in ThingSpeak
- Apply AI model like theSARIMAX model
- Predict solar energy and system behavior

#### Step 7: Remote Monitoring

- Access data from anywhere using internet
- Monitor system in real-time.

The following graphs represent the real-time performance of the AI Powered Solar Energy Management System.



Fig.5 Temperature

- There is an inverse relationship between temperature and humidity:
  - When temperature decreases, humidity increases.
  - When temperature increases, humidity decreases.

- This behavior is typical in environmental systems where hotter air holds less relative humidity as shown in above fig.5 and 6.



Fig.6 Humidity



Fig.7 Solar Voltage

- When voltage is stable and sunlight is strong, the current increases significantly.
- The low current despite moderate voltage on earlier days suggests low solar intensity or inefficiency.



**Fig.8 Solar Current**

- The sudden drop in voltage and spike in current variation indicates inconsistent solar conditions (clouds, shading, or load variation) as shown in above fig 7 and 8.



**Fig.9 Battery Voltage**



**Fig.10 Battery Current**

- When battery voltage increases, it indicates charging, and current flow supports this.
- The drop in voltage with varying current suggests battery is supplying power to loads.
- The low voltage (~6–7V) is a concern, indicating possible over-discharge, which can damage the battery. As shown in fig.9 and 10 Fluctuations indicate unstable energy management or inconsistent solar input.



**Fig.11 Light Intensity**

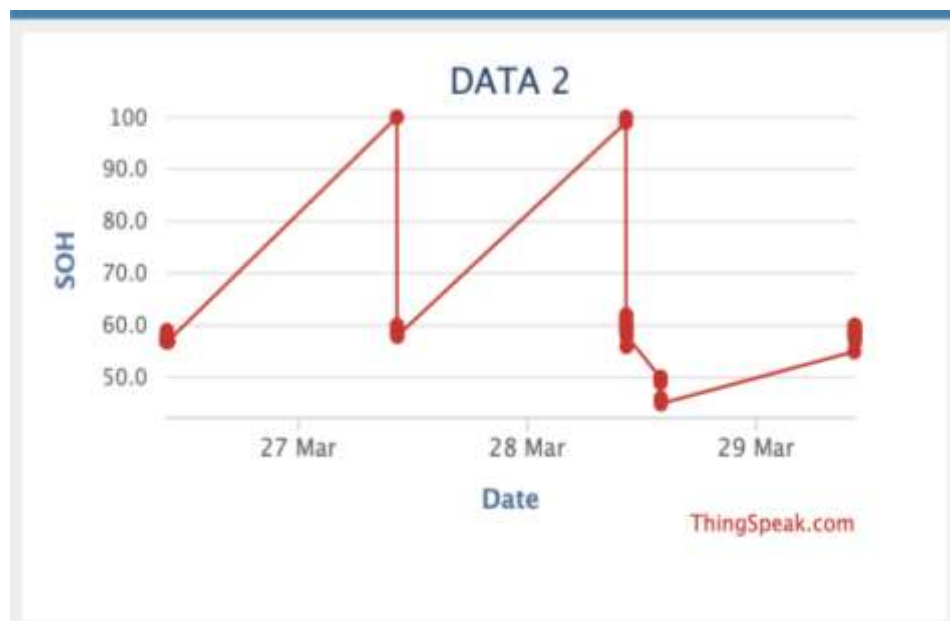
The system performs efficiently under high light intensity, but its performance drops drastically during low light conditions as shown in fig.11 and 12.

- Efficiency is directly dependent on light intensity.



**Fig.12 Efficiency**

- When light intensity is high, efficiency is also high.
- When light intensity drops sharply, efficiency also drops significantly.



**Fig.13 State of Health (SOH)**

The battery system shows unstable behavior, with repeated full charging and dangerous deep discharging (0%). This can lead to battery degradation and reduced lifespan.

- SOC reaching 0% indicates complete battery drain, which is harmful.



**Fig.14 State of Charge (SOC)**



**Fig.15 Pulse Width Modulation (PWM)**

- SOH variations suggest the battery may be experiencing stress or aging effects.
- Frequent full charge and deep discharge cycles can reduce battery lifespan.
- As shown in Fig.13 and 14 the SOH and SOC trends indicate accelerated wear due to extreme cycling.

As shown in Fig.15 the PWM (%) initially exhibits a very low negative value around March 27, followed by a sharp increase to near-zero levels. After this sudden rise, the PWM stabilizes with minor fluctuations and maintains a nearly constant positive trend from March 28 to March 29, indicating improved and steady system performance over time.

## 4.2 RESULT

This updated table summarizes the key performance metrics and sensor data trends recorded between March 27th and March 29<sup>th</sup>.

**Table 1: Performance Metrics and Sensor Data Trends**

Parameters	Ranges	Result and System Impact
Temperature	32°C to 42°C	Shows an inverse relationship with humidity.
Humidity	18% to 42%	Typical environmental fluctuation; decreases as temperature rises.
Solar Voltage	3.0V to 22.0V	Fluctuations indicate inconsistent solar conditions.
Solar Current	0.02A to 0.19A	Spikes significantly when sunlight is strong.
Battery Voltage	6.5V to 15.0V	Increases during charging; lows near 6V suggest a dangerous deep-discharge state.
Battery Current	0.90A to 2.05A	Higher values indicate active charging or heavy load demand.
Light Intensity	50% to 99%	The primary driver for energy generation; drops sharply during low-light periods.
Efficiency	25% to 260%	Directly dependent on light intensity.
State of Charge (SOC)	0% to 100%	Shows unstable behavior with repeated full charges and complete drains.
State of Health (SOH)	45% to 100%	Variations suggest the battery is experiencing stress from frequent cycling.
PWM %	PWM %   -800 to 100%	Represents the modulation used for charging control; shows significant variations over the recording period.

### 4.3 FUTURE PREDICTION TABLE

Fields	Time (Future)			
	T+1	T+2	T+3	T+4
Temperature	26.5	27.8	29.2	30.5
Humidity	45.2	43.8	42.5	41.0
Solar Voltage	760.5	758	762.3	765
Solar Current	1.8	2.5	1.9	1.5
Battery Voltage	13.2	12.6	13.8	14
Battery Current	2.1	1.9	2.3	2.6
Light Intensity	0.9	1.2	1.5	1.3
Efficiency	320	300	340	360
SOC	18	20	22	25
SOH	58	56	55	57
PWM%	20	40	60	50

### 5. CONCLUSION

The development of an advanced and reliable blackboard erasing system addresses critical challenges related to time consumption and manual effort in traditional teaching environments, significantly enhancing classroom efficiency. By using components like DC motors, limit switches, Bluetooth and RF modules, the system ensures real-time, flexible control for automated erasing tasks. The integration of limit switches, Bluetooth module, RF receiver, and manual switches allows for prompt response and smooth operation, while features like speed control and boundary detection ensure safe and effective performance. The system operates through multiple control modes, providing convenience and adaptability for different users.

This hardware was tested in various scenarios, including left-right movement, speed variations, edge detection through limit switches, and wireless command execution via Bluetooth and RF. It met all defined functional requirements and performed efficiently under all tested conditions.

It demonstrates a successful application of embedded systems and automation technology to improve classroom operations, providing educational institutions with a practical and robust solution to enhance teaching convenience and reduce physical workload.

## 6. ACKNOWLEDGMENT

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## REFERENCES

- [1] G. Priya, "Design and Fabrication of Automated Board Cleaner," *International Journal of Scientific Research in Science, Engineering and Technology*, vol. 2, no. 3, pp. 131–133, Mar. 2015.
- [2] A. S. Rajput and P. V. Sutar, "Automated Blackboard Cleaner Using Microcontroller," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 6, no. 3, pp. 1234–1238, 2017.
- [3] M. S. Patil, S. R. Tamboli, P. R. Dunke, and N. D. Batwal, "Automatic Blackboard Cleaner," *International Journal of Advance Engineering and Research Development (IJAERD)*, vol. 5, no. 16, 2018.
- [4] D. Ghodasara, M. Aghera, and S. Rayjada, "Automatic Board Duster," *International Journal of Research in Engineering, Science and Management*, vol. 2, no. 3, pp. 316–318, Mar. 2019.
- [5] K. Yadav, S. Verma, and N. Sharma, "Automated Smart Duster Using Arduino for Teaching Boards", vol. 7, no. 4, 2020.
- [6] S. Vignesh K., Vinith K., Mouleswaran H., and M. Sanjay, "Automatic Blackboard Duster to Reduce Health Hazards," 2021.
- [7] Sanjay S. Tippannavar and Preethi G., "Design and Implementation of a Dust Remover from a Conventional Blackboard Duster to Prevent Respiratory Problems," 2023.