RENEWABLE ENERGY SMART MONITOR WITH SOURCES AND LOAD PREDICTION USING AI MODELS

Mr. A. Balaji, K. Ravi Teja, P. Padmavathi, B. P. Parameswara Rao
Assistant professor, Dept. of EEE, Usha Rama College of Engineering & Technology, Telaprolu, A.P, India
UG Students, Dept. of EEE, Usha Rama College of Engineering & Technology, Telaprolu, A.P, India

ABSTRACT: The increasing demand for sustainable power and efficient energy utilization has accelerated the adoption of renewable energy systems. This project presents a Renewable Energy Smart Monitor with Source and Load Prediction using AI Models, designed to monitor renewable energy generation and intelligently manage connected loads. The system integrates a solar panel and a mini windmill model as renewable energy sources. ESP32-based monitoring unit with DC voltage and current sensors measures the power generated from both sources and stores the energy in batteries. The system also monitors the power consumed by different DC loads such as a motor, light, and fan by measuring their current consumption. All the real-time sensor data related to source generation and load consumption is transmitted to a laptop for further analysis.
An AI-based prediction model running on the laptop collects the sensor data and analyzes the energy generation patterns and load requirements. Based on the available renewable energy and predefined load priority levels, the AI model predicts which loads should be turned ON or OFF to ensure efficient energy usage and battery management. In addition, the system includes a mobile application for remote monitoring, allowing users to view real-time information such as source voltage, current, battery status, and load conditions from anywhere. The mobile interface enables users to monitor system performance easily and supports smart energy management. This integrated solution improves renewable energy utilization, enhances reliability, and provides an intelligent and user-friendly monitoring platform for hybrid renewable energy systems.

KEYWORDS: Renewable Energy Systems, Solar-wind Hybrid system, Smart Energy Monitoring, Load Prediction, Artificial Intelligence (AI), Machine Learning (Ml), ESP32 Micro Controller, IoT -Based Monitoring, Battery Management System (BMS), Lithium -Ion Battery, Real -Time Data Acquisition, Load priority control.

I. INTRODUCTION

The increasing global demand for energy, along with the depletion of fossil fuels and rising environmental concerns, has driven the adoption of renewable energy sources such as solar and wind. These sources are clean and sustainable, but their power generation is highly dependent on environmental conditions, making them intermittent and unpredictable. This creates challenges in maintaining a stable energy supply and efficiently managing energy usage.
Hybrid renewable energy systems, which combine multiple sources like solar and wind, offer a more reliable solution. However, conventional systems often lack real-time monitoring and intelligent control, leading to inefficient energy utilization, battery issues, and poor load management. To address these limitations, an advanced monitoring and management system is required.
The proposed Renewable Energy Smart Monitor integrates sensors, embedded systems, and AI models to monitor energy generation and consumption in real time. It predicts future energy availability and load demand, enabling efficient and automated load control. By prioritizing essential loads and optimizing energy usage, the system improves reliability, reduces wastage, and enhances overall performance.
Additionally, the integration of IoT enables remote monitoring and data visualization through mobile applications, making the system more accessible and user-friendly. This approach not only improves energy efficiency but also supports sustainable and intelligent energy management for future applications such as smart homes and microgrids.

II. LITERATURE REVIEW

The rapid integration of renewable energy sources such as solar and wind into modern energy systems has created a need for intelligent monitoring, prediction, and control mechanisms. Recent research focuses on combining Artificial Intelligence (AI), Machine Learning (ML), and IoT technologies to improve energy forecasting, optimize load management, and enhance system efficiency. This section reviews five recent works (2024–2026) related to renewable energy monitoring and AI-based prediction systems.

2.1 Generative AI in Renewable Energy Systems:

A comprehensive review on the role of Generative AI (Gen-AI) in renewable energy forecasting and optimization. The study highlights that renewable energy systems face challenges such as non-linearity, intermittency, and uncertainty, which can be effectively addressed using advanced AI models.

The research demonstrates that AI techniques such as GANs, VAEs, and hybrid models significantly improve solar and wind forecasting accuracy, reduce prediction errors, and enhance energy efficiency. The study also shows that AI-driven models can improve energy system performance by up to 15–20% in forecasting accuracy.

However, the work mainly focuses on large-scale systems and advanced AI architectures, making it complex for small-scale implementations. The proposed system improves upon this by using a simplified AI model integrated with Arduino-based monitoring.

2.2 Machine Learning-Based Microgrid Energy Management:

A machine learning-based energy management framework for microgrids that predicts both renewable energy generation and load demand. The study integrates solar and wind forecasting with battery state-of-charge (SoC) estimation.

The research highlights that accurate load forecasting is critical for efficient energy management and decision-making in renewable systems. It compares multiple ML models such as Random Forest, LSTM, and ANN, concluding that these models provide high prediction accuracy for energy generation and load demand.

While the system provides accurate predictions, it is primarily designed for large commercial microgrids and involves complex implementation. The proposed project simplifies this approach by focusing on a compact, low-cost monitoring and prediction system.

2.3 AI-Driven Renewable Energy Optimization:

Investigated the use of AI and deep learning techniques for optimizing renewable energy systems. The study applied models such as Support Vector Regression (SVR), LSTM, and Random Forest for forecasting solar and wind energy.

The results show that Random Forest achieved high accuracy (up to 99%) in energy prediction tasks, demonstrating its effectiveness in handling complex datasets. The study emphasizes that AI can significantly improve energy efficiency, system reliability, and renewable integration.

However, the research mainly focuses on prediction and does not include real-time load control or embedded system implementation. The proposed system addresses this gap by integrating prediction with relay-based load control and real-time monitoring.

2.4 AI-Based IoT Energy Management System:

Developed an AI-based IoT system for energy forecasting and load management. The system collects real-time data from sensors and uses AI algorithms to optimize energy usage by adjusting consumption based on demand.

The study highlights the importance of combining IoT data acquisition with AI-based decision-making to improve energy efficiency and reduce operational costs. It demonstrates that intelligent systems can dynamically adapt energy consumption to user requirements. Despite its advantages, the system does not focus on hybrid renewable sources (solar + wind) or detailed battery management. The proposed system enhances this by integrating multiple renewable sources and battery monitoring.

2.5 AI Energy Management Review:

Recent studies on AI-based energy management systems (2025) emphasize the use of machine learning, deep learning, and optimization techniques for renewable energy forecasting and load control. These systems improve energy efficiency, demand response, and system reliability by analyzing real-time and historical data.

The research highlights that AI enables dynamic energy distribution, predictive maintenance, and smart grid optimization, making it a key technology for modern energy systems.

However, many of these systems are theoretical or require high computational resources, making them less suitable for low-cost embedded implementations. The proposed project overcomes this limitation by using a lightweight AI model with Arduino-based hardware.

III. PROPOSED METHODOLOGY

3.1 System Overview:

The proposed is an **AI Powered Renewable Energy Sources and Load Prediction** integrates multiple energy sources, intelligent monitoring, and predictive analytics to improve efficiency and reliability. The complete system consists of the following major components:

3.1.1 Solar Energy Unit:

The solar energy subsystem captures sunlight using photovoltaic (PV) panels and converts it into electrical energy. A charge controller (preferably MPPT) regulates the power flow, ensuring stable charging of the battery while preventing overcharging. Real-time voltage and current data from the solar unit are continuously monitored and transferred to the ESP32 microcontroller for performance analysis and prediction.

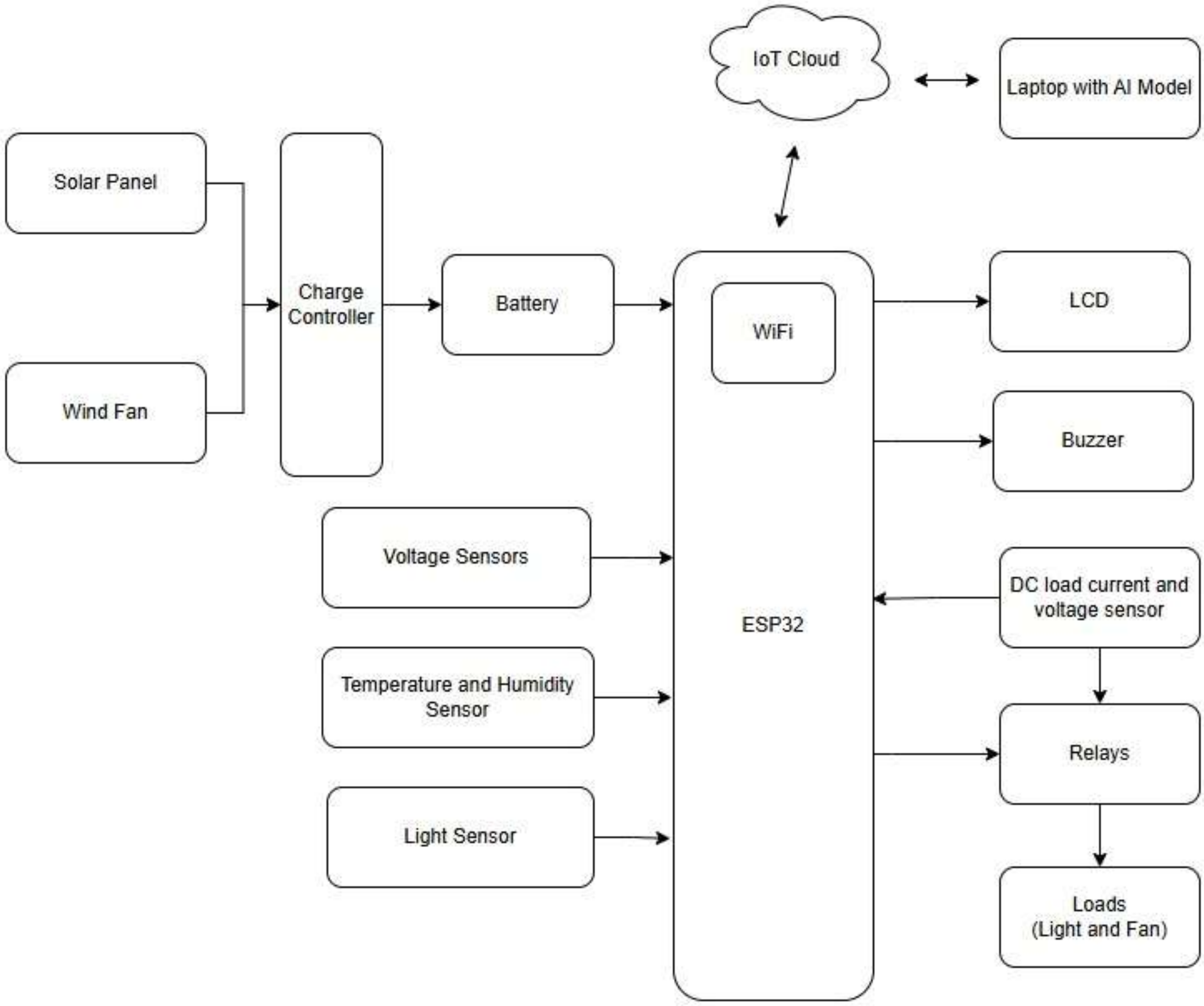

Fig1: Proposed Block Diagram

3.1.2 Wind Energy Unit:

The wind energy subsystem uses a small-scale wind turbine to generate power based on wind speed variations. The generated AC output is rectified and regulated before being supplied to the battery or loads. Integrating wind and solar helps maintain continuous power availability even during low-light or non-windy conditions, thus improving system reliability.

3.1.3 Battery Storage & Management:

A lithium-ion battery bank serves as the primary energy storage unit. A Battery Management System (BMS) monitors key parameters such as State of Charge (SOC), voltage, current, and temperature. It protects the battery from overcharging, deep discharge, and thermal issues. The battery acts as a buffer, supplying energy to loads when solar and wind inputs are insufficient.

3.1.4 ESP32 Data Acquisition Unit:

The ESP32 microcontroller functions as the central processing and control unit. It collects real-time data from sensors connected to solar, wind, and battery units. ESP32 also processes this data to compute power flow, energy usage, and system efficiency. The processed data is then transmitted to the IoT dashboard for user monitoring and fed into AI models for prediction.

3.1.5 IoT Monitoring Dashboard:

The system includes an IoT-based web or mobile dashboard that displays real-time energy data such as voltage, current, generated power, battery SOC, load consumption, and system status. Users can monitor performance remotely and receive alerts for critical events. The dashboard enhances system usability and provides transparency in energy management.

3.1.6 AI-Based Load & Source Prediction:

A machine learning model is integrated into the system to predict future load demand and renewable energy generation. Using historical and real-time data, AI algorithms forecast the availability of solar/wind power and expected consumption patterns. These predictions help optimize energy distribution, prevent shortages, and improve overall system efficiency.

3.1.7 Load Priority Control:

The system classifies loads into different priority levels such as critical, semi-critical, and non-critical. Based on battery status, predicted energy generation, and predicted load demand, ESP32 automatically controls the loads. High-priority loads always get power, while low-priority loads may be shed during shortages. This ensures stable and efficient power usage.

3.2 System Architecture:

The system architecture is divided into two main sections: the input hardware layer and the output functional layer. The input side includes energy sources, sensors, storage units, and the ESP32 controller, which collect and process real-time data. The output side represents the system functionalities such as monitoring, prediction, decision-making, and load control. This two-sided architecture clearly illustrates the flow of energy and information from generation to intelligent utilization.

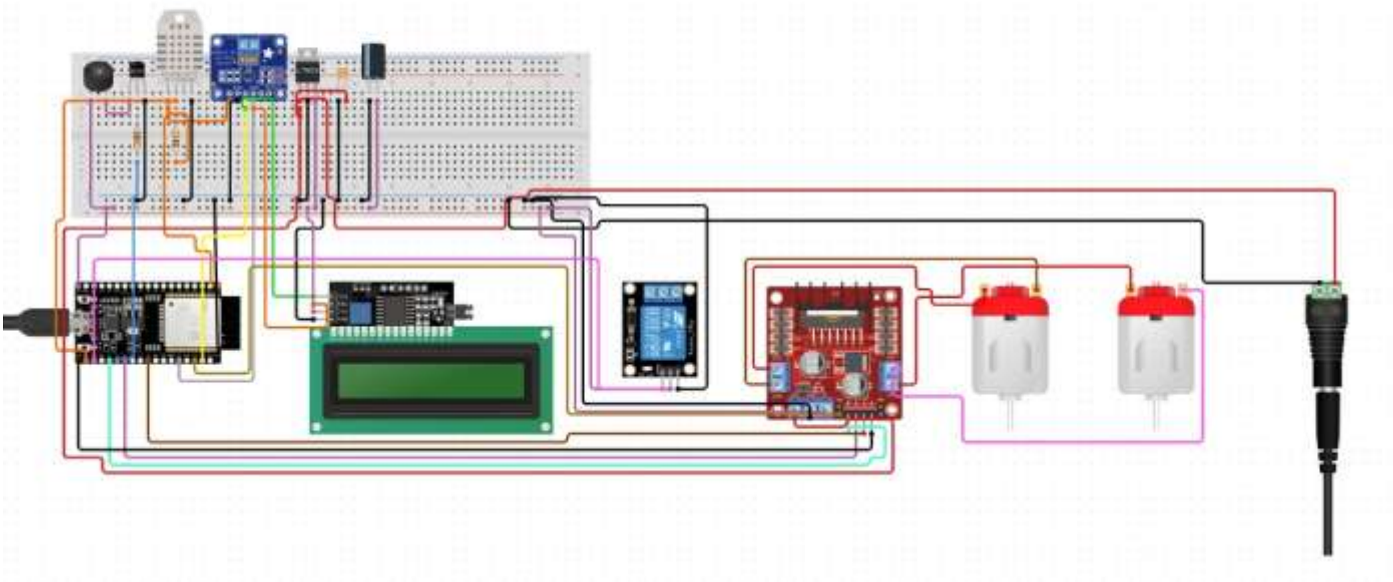

Fig2: Proposed Methodology Circuit Diagram

3.3 System Simulation and Performance Analysis:

3.3.1 Solar Power Simulation:

1. **The solar module is simulated using:**
   - PV panel characteristics
   - Irradiance changes
   - Temperature variations
2. **Simulation outputs:**
   - Generated power (W)
   - Panel voltage & current
   - Effect of shading or cloudy weather

Fig3: Solar Power Simulation

3.3.2 Wind Energy Simulation:

1. **Wind turbine simulation includes:**
   - Wind speed variations
   - Turbine rotor speed
   - AC to DC conversion behaviour
2. **Key results obtained:**
   - Power vs. wind speed curve
   - Turbine stability under low/high winds
   - This helps size the turbine correctly

Fig4: Wind Energy Simulation

3.3.3 Load Simulation:

1. **Loads are simulated as:**
   - Critical loads
   - Semi-critical loads
   - Non-critical loads
2. **The simulation evaluates:**
   - Power fluctuations
   - Priority-based load shedding
   - Energy balancing
   - Load switching delay

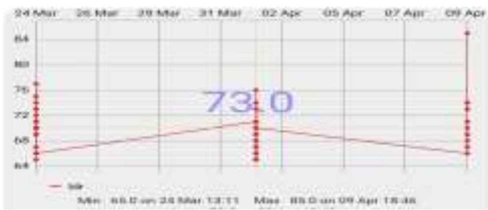

Fig5: Load Simulation

3.3.4 Temperature Simulation

- Temperature plays a critical role in the performance of solar panels, batteries, and sensor accuracy
- Ambient temperature variations
- PV temperature coefficient
- Battery thermal stability
- Sensor calibration under heat
- Electronic component heating

1. **Simulation Outcomes:**
   - PV panel voltage drop at high temperature
   - Battery heating during high current charging
   - Temperature impact on SOC estimation
   - ESP32 and sensor temperature drift

Fig5: Temperature Simulation

3.3.5 Current Simulation

1. **Current simulation analyzes how much current is generated, consumed, and stored at different time intervals:**
   - Parameters Considered
   - PV short-circuit current (ISC)
   - Wind turbine output current
   - Battery charging/discharging current
   - Load current consumption
   - Sensor response accuracy
2. **Simulation Outcomes:**
   - Current rise with increased sunlight
   - Wind turbine current response to speed changes
   - Battery charging current under MPPT
   - Load current spikes during switching
   - Energy flow comparison (input vs output currents)
3. **Current simulation ensures:**
   - Safe current limits for sensors and BMS
   - Efficient renewable power harvesting
   - Prevention of overload conditions

Fig6: Current Simulation

3.3.6 Voltage Simulation

1. **Voltage simulation determines how solar panels, wind turbines, and batteries perform under fluctuating operating conditions:**
   - Parameters Considered
   - Solar irradiance (W/m²)
   - Wind speed (m/s)
   - Battery State of Charge (SOC)
   - Load variations
   - Temperature effects on PV voltage
2. **Simulation Outcomes:**
   - Open-circuit voltage (VOC) changes with sunlight
   - Voltage drop during cloudy/windy fluctuations
   - System-level voltage stability during load switching
3. **Voltage simulation ensures:**
   - Prevention of over-voltage conditions
   - Stable charging of the battery

Fig7: Voltage Simulation

IV. RESULTS AND DISCUSSION

4.1 Experimental Setup

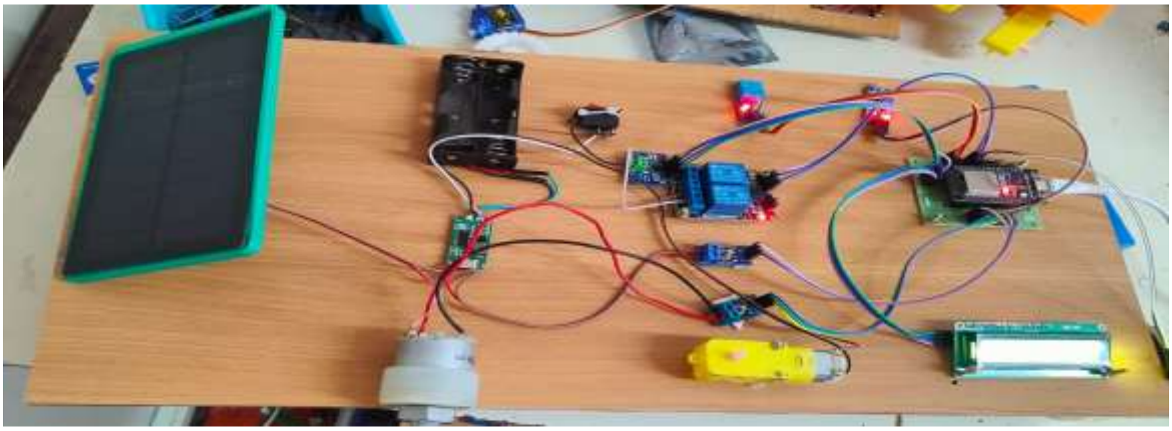

Fig8: Experimental Setup

The proposed Renewable Energy Smart Monitor with Source and Load Prediction using AI Models was successfully implemented and tested under varying environmental and load conditions to evaluate its monitoring accuracy, prediction performance, and intelligent load control capability. The system demonstrated reliable operation in terms of real-time data acquisition, energy prediction, and adaptive load management.

During experimentation, the solar panel and mini wind turbine generated variable electrical output depending on environmental conditions such as light intensity and airflow. The voltage and current sensors accurately measured the generated power from both sources. It was observed that solar output varied significantly with time of day, while wind output fluctuated based on wind availability. The hybrid combination of both sources improved overall energy availability, ensuring a more stable power supply compared to using a single source.

The battery system effectively stored excess energy during peak generation periods and supplied power during low generation conditions. The system successfully monitored battery voltage and prevented deep discharge by controlling load operation. This indicates proper implementation of battery management strategies, which are essential for improving battery lifespan and system reliability.

The load monitoring subsystem accurately measured current consumption of connected DC loads such as motor, light, and fan. The system was able to distinguish between different load conditions and calculate total power consumption in real time. The ESP32 microcontroller efficiently collected and transmitted all sensor data to the computing unit and IoT platform without significant delay, ensuring reliable data flow for analysis.

The Random Forest-based AI model demonstrated high prediction accuracy for both energy generation and load demand. By analyzing historical and real-time data, the model successfully predicted future energy availability under different conditions. The predicted values closely matched actual measurements, with minimal deviation. This confirms the effectiveness of the Random Forest algorithm in handling non-linear relationships and dynamic variations in renewable energy systems.

Based on AI predictions, the system performed intelligent load management using relay-based switching. When sufficient energy was available, all loads operated normally. During low energy conditions, the system automatically turned OFF non-essential loads based on predefined priority levels, ensuring that critical loads remained active. This dynamic allocation significantly reduced energy wastage and prevented battery over-discharge. The response time of the control system was fast, demonstrating efficient coordination between prediction and control mechanisms.

The LCD display provided real-time information about system parameters such as source voltage, current, battery level, and load status. The display was clear and updated continuously, improving user interaction and system transparency. The optional buzzer alert system effectively notified users during abnormal conditions such as low battery or overload.

4.1.1 ThingSpeak IoT Platform

- ThingSpeak is IoT platform for user to gather real-time data; for instance, climate information, location data and other device data. In different channels in ThingSpeak, you can summarize information and visualize data online in charts and analyze useful information.
- ThingSpeak can integrate IoT:bit (micro:bit) and other software/ hardware platforms. Through IoT:bit, you can upload sensors data to ThingSpeak (e.g. temperature, humidity, light intensity, noise, motion, raindrop, distance and other device information).

The integration with the ThingSpeak IoT platform enabled remote monitoring and data visualization. Sensor data, predicted values, and load status were successfully uploaded and displayed in graphical format. Users were able to monitor system performance through a mobile application, which enhanced accessibility and usability. The IoT system showed stable performance with minimal latency.

From an overall performance perspective, the system achieved significant improvements in energy efficiency, reliability, and intelligent control. The hybrid renewable system ensured better energy availability, while the AI model enabled predictive decision-making. The system effectively minimized energy wastage and optimized load utilization.

However, some limitations were observed, including minor variations in sensor accuracy and dependency on stable internet connectivity for IoT communication. These issues can be improved by using high-precision sensors and more robust communication protocols.

4.2 Output Readings:

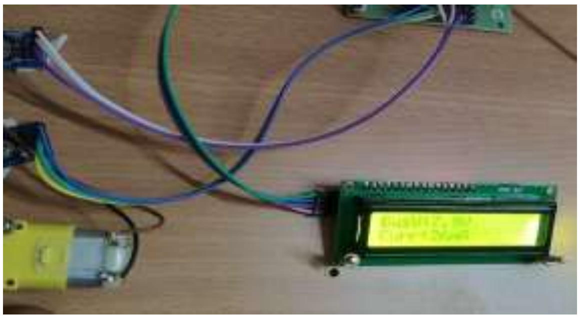

Fig9: Bus Voltage & Current readings

Fig10: Temp & LDR readings

- The DC bus voltage is the central electrical node that interconnects solar energy, wind power, battery storage, and loads.
- Bus current simulation determines how much current flows through the DC bus under different operating conditions.
- Temperature affects the performance of solar panels, batteries, sensors, and bus components.
- The LDR sensor monitors ambient light intensity, which directly influences solar generation and AI prediction models.

4.3 System Output:

The system is successfully fetching sensor data from ThingSpeak.

- The AI model analyzes the sensor data and predicts whether the system is normal or abnormal.

In both cases, the model detected abnormal conditions due to either:

- Zero voltage/current (no power flow), or
- Corrupted temperature sensor data.

- A missing Python library (requests) is causing an import error.
- Sensor calibration and communication need improvement.

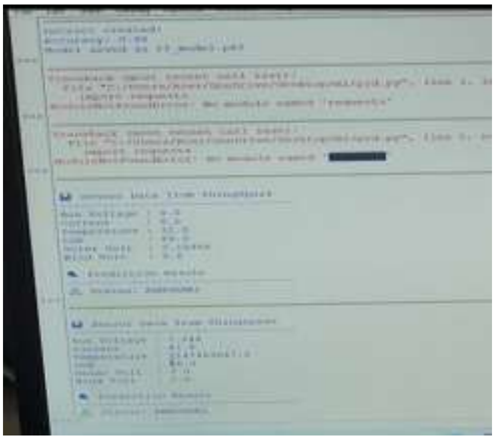

Fig11: Real-Time Monitoring

V. CONCLUSION

The project "Renewable Energy Smart Monitor with Sources and Load Prediction using AI Models" successfully implements a smart system for real-time monitoring and analysis of solar and wind energy data using an ESP32 and ThingSpeak platform. The integration of a Random Forest AI model enables accurate detection of normal and abnormal system conditions based on sensor data. The system effectively identifies issues such as power loss, overload, and sensor faults, improving reliability and efficiency. Overall, the project provides a cost-effective and scalable solution for intelligent energy monitoring and future smart grid applications.

REFERENCES

[1] M. Mamat, N. A. Rahman, and S. A. Ahmad, "Generative AI applications in renewable energy forecasting and optimization," *Energy Reports*, vol. 11, pp. 1025–1038, 2025.

[2] R. Onteru, S. Reddy, and P. Kumar, "Machine learning-based energy management for hybrid microgrid systems," *Journal of Electrical Systems and Information Technology*, vol. 11, no. 2, pp. 1–14, 2024.

[3] M. Talaat, A. El-Shahat, and H. Hassan, "AI-driven optimization techniques for renewable energy forecasting," *Sustainable Energy Technologies and Assessments*, vol. 63, pp. 101–115, 2025.

[4] M. Beshley, O. Yaremko, and I. Klymash, "IoT-based energy management system using artificial intelligence," in *Proc. Int. Conf. Advanced Information and Communication Technologies*, 2024, pp. 45–50.

[5] M. Abd'Azeez, T. Bello, and A. Yusuf, "Artificial intelligence in renewable energy forecasting and smart grid optimization," *International Journal of Smart Energy Systems*, vol. 9, no. 1, pp. 55–68, 2025.

[6] L. Breiman, "Random forests," *Machine Learning*, vol. 45, no. 1, pp. 5–32, 2001.

[7] T. Hastie, R. Tibshirani, and J. Friedman, *The Elements of Statistical Learning*, 2nd ed. New York, NY, USA: Springer, 2009.

[8] Espressif Systems, "ESP32 Series Datasheet," Espressif Systems, 2023.

[9] Allegro Microsystems, "ACS712 Current Sensor Datasheet," 2021.

[10] Texas Instruments, "INA219 Voltage and Current Sensor Datasheet," 2022.

[11] MathWorks, "ThingSpeak IoT Analytics Platform Documentation," 2023.

[12] S. Haykin, *Neural Networks and Learning Machines*, 3rd ed. Upper Saddle River, NJ, USA: Pearson, 2009.

About Author:

Mr. A. Balaji is working as an Assistant Professor at Usha Rama College of Engineering and Technology, an autonomous institution in Telaprolu, Vijayawada. He holds an M.Tech degree from JNTU Kakinada. He has 16 years of teaching experience and has published 10 international research papers, including those indexed in ESCI, Scopus, and IEEE.

Mr. K. Ravi Teja is a fourth-year Electrical and Electronics Engineering (EEE) student at Usha Rama College of Engineering and Technology, an autonomous institution in Telaprolu, Vijayawada. He has demonstrated strong academic performance throughout his engineering studies. He has successfully completed three APSSDC certification courses and has actively participated in two national-level workshops. Additionally, he completed a long-term internship at the Central Institute of Tool Design (CITD), Auto Nagar, Vijayawada, Andhra Pradesh.

Ms. P. Padmavathi is a fourth-year Electrical and Electronics Engineering (EEE) student at Usha Rama College of Engineering and Technology, an autonomous institution in Telaprolu, Vijayawada. She has maintained strong academic performance, particularly excelling in core electrical subjects. She served as a class representative for one year, demonstrating leadership and responsibility. She has successfully completed three APSSDC certification courses and participated in two national-level workshops. Additionally, she completed a long-term internship at Schneider Electric, Hyderabad, Telangana.

 **Mr. B. P. Parameswara Rao** is a fourth-year Electrical and Electronics Engineering (EEE) student at Usha Rama College of Engineering and Technology, an autonomous institution in Telaprolu, Vijayawada. He has maintained good academic performance, with a strong focus on core electrical subjects. He has successfully completed three APSSDC certification courses. Additionally, he completed a long-term internship at Bonfiglioli, Thirumudivakkam, Chennai, Tamil Nadu.