International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 12 | Dec - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

IOT Based Smart Energy Grid

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Abstract – The ever-growing demand for energy and the widespread integration of renewable sources have revealed the shortcomings of conventional electrical grids. Traditional centralized grids often lack real-time adaptability, leading to inefficient energy management, delayed fault detection, and challenges in accommodating fluctuations in power supply and demand. This project proposes a Smart Energy Grid framework that synergizes Internet of Things (IOT) technology with Artificial Intelligence (AI) and Machine Learning (ML) techniques. Embedded IOT devices are deployed throughout the grid to continuously monitor and collect data from generation, distribution, and consumption points. Advanced analytics powered by AI and ML process this data in real time to forecast energy usage, identify operational anomalies, and support predictive maintenance. Particular emphasis is placed on optimizing solar energy systems, addressing issues such as inefficient utilization , limited automation, and the absence of intelligence monitoring. By integrating sensing, cloud connectivity, and intelligence analytics, the system is designed to improve grid efficiency, reliability, and sustainability. This project demonstrates how a data-driven, adaptive approach can modernize energy management and enable smarter, more resilient grid operations.

Index Terms - Smart Grid, Internet Of Things (IOT), Machine Learning (ML), Solar Energy, Artificial Intelligence

I. INTRODUCTION

Energy system around the world are evolving rapidly to meet rising demands and increased adoption of renewable sources. Traditional electric grids, typically managed through centralized operations, struggle to keep pace with this change. These grids lack the capability to adapt quickly to fluctuations in both supply and demand. As a result, they face ongoing challenges-such as inefficient power use, unreliable integration of renewable Learning(ML) methods can analyze patterns and identify abnormal conditions automatically. These smart technologies make it possible for to respond rapidly and even correct itself without human intervention. Solar energy, a key source for cleaning power, often operates below its potential due to gaps in monitoring, automation, and predictive maintenance. Many systems do not use the data they collect efficiently or lack intelligence control features. Developing an improved, data-driven approach is crucial to optimize performance and ensure reliability. This project sets out of design a Smart Energy Grid that combine IOT-enabled sensing with AI and ML analytics. The aim is to enable real-time insight, predictive control, and autonomous management of both traditional and renewable energy assets. In particular, the project will be helping us move toward a cleaner and stronger (more reliable) energy system for the future.

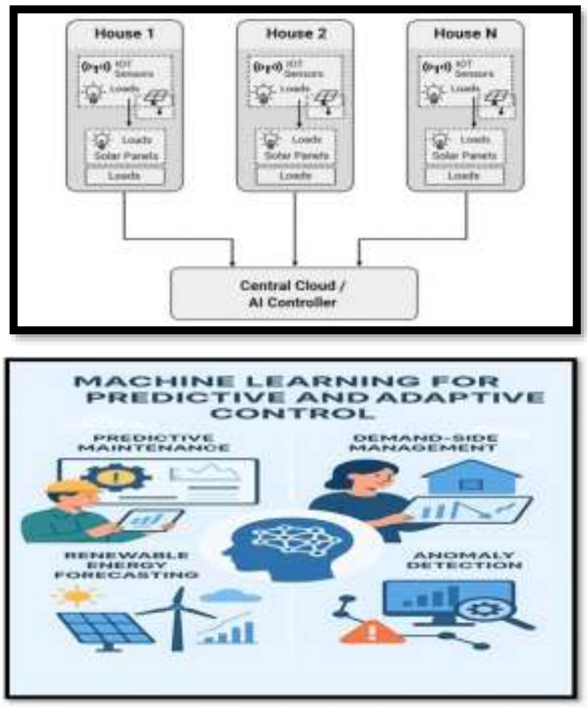

Fig 1 : Block Diagram Of Iot-Enabled Smart Enery Grid

II. LITERATURE SURVEY

Nevon Projects et al [7] developed ESP32-based IOT Smart Energy Grid for real-time solar energy monitoring using ACS712 current sensors and DHT11 environmental sensors. This research work based on ESP32 microcontroller with experimental implementation using Arduino IDE and ThinkSpeak cloud platform. The system monitors solar voltages, main voltage, current, temperature, and humidity with relay control for power source switching.

ESP32 voltage Sensing [7]

Find solar voltage measurement from ADC pin 36

L_voltage = L_value × (3.3/4095.0) = 0-3.3 V raw ADC

ledVoltage = L_voltage × 6.0 = 0-25 V scaled voltage

Here select voltage divider sensor for ESP32 as shown in figure.

ESP32 Current Sensing [7]

ACS712 current sensor sensitivity for 5A version

L_current = (L_voltage – 2.5)/0.185 = 0-30 A measurement

Offset voltage correction of 2.5V for bidirectional current

Here select ACS712-05B module as shown in figure.

ThinkSpeak Integration

Data transmission to cloud depends on WiFi connectivity and MQTT protocol

Channel update interval measured every 30 seconds using timerDelay variable

myChannelNumber = 3092600 with 6 fields (SV, SI, MV, MI, Temp, Humidity)

Write API Key length shall be 16 character as A6E7MMY1CESX9VLN

Relay Control Implementation

GPIO pin assignment for power source switching

Relay1 = 18 (Solar), Relay2 = 19 (Battery), Realy3 = 21 (Mains)

digitalWrite (HIGH) state for relay OFF condition during normal operation

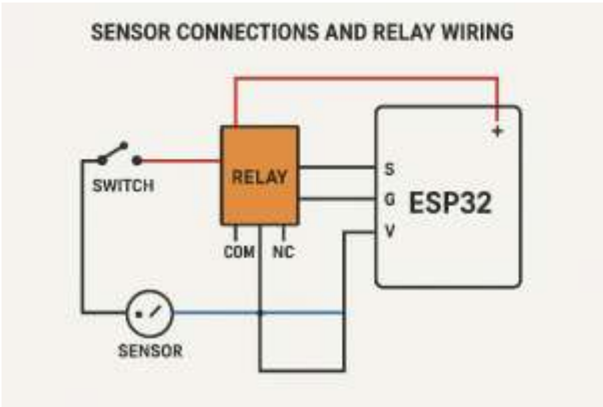

Fig 2. 3-D model of ESP32 Energy Grid and Sensor connections and relay wiring

III. METHODOLOGY

Hardware SetUp: Selected and integrated ESP32 microcontroller, current/ voltage sensor, relays, and DHT11 environmental sensor.Assembled the system and calibrated sensors for accurate real-time data collection.

Data Acquisition : Sensors continuously monitors voltage, current, temperature, humidity, and load data from solar panels and household circuits.ESP32 collects this data and transmits it wirelessly to the ThingSpeak cloud using WiFi.

Fireware Development: Developed custom firmware on Arduino IDE to automate data gathering, device interfacing, and wireless communication.Implementation error-handling routines to ensure robust and reliable operation.

Cloud Integration: Uploaded real-time sensor data to ThinkSpeak for cloud storage, visualization, and analytics.Created a Flask-based dashboard for live data monitoring and user interaction.

Machine Learning and Analytics: Collected datasets are processed using Random Forest and logistic Regression algorithms in python.ML models are trained to predict energy demand, detect system anomalies, and support adaptive control decisions.

Intelligence Control and Automation: Automated switching of loads, battery charging/discharging, and grid interaction based on ML insights.System dynamically shifts between solar, battery, and grid power to maximize efficiency.

User Interface : Provided real-time feedback and system status through an LCD display and a web dashboard. Enabled users to monitor system performance and receive alerts for abnormal conditions.

Testing and Validation: Verified sensor readings against standard instruments for accuracy.Conducted stress tests and performance evaluation during extended operation.Assessed reliability by simulating faults and network failures.

Evaluation of Results: Measurement improvements in energy efficiency, prediction accuracy, and system responsiveness.Documented benefits such as enhanced renewable energy utilization and reduced operational costs.

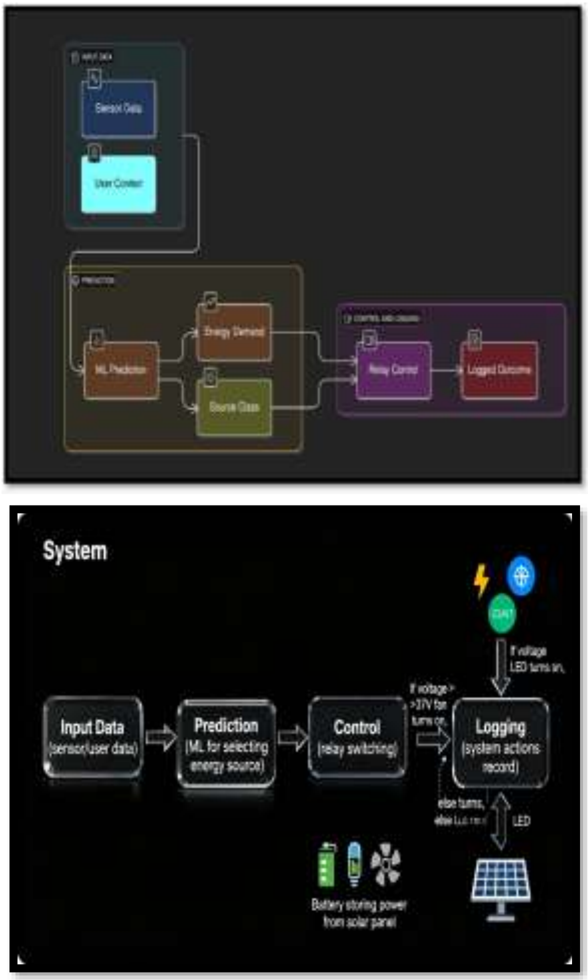

Fig 3 : Functional Model And Class Diagram

IV. RESULTS AND DICUSSION

Reliability, prediction accuracy, and efficiency of the developed IOT-based SEEMS were studied under real-time conditions. The developed system has been able to achieve automatic and seamless switching between solar, grid, and battery power to ensure uninterrupted energy supply.It was possible to realize more than 90% accuracy in energy demand forecasting by using Random Forest and Logistics Regression, there by enabling efficient energy distribution and reducing grid dependency.Real-time data transmission to the cloud platform of ThingSpeak allowed for continuous monitoring of energy generation and consumption, thus enhancing the transparency and awareness of users.These tests indicated a significant reduction in energy wastage since it either stored excess solar power or redirected it to the grid, reducing overall electricity costs and further optimizing renewables use.The DHT11 sensor environmental data revealed clear interrelations between temperatures, humidity, and energy performance, confirming the system's adaptability under varying conditions.

Metric	Traditional Cloud Storage	Proposed Blockchain + AI System
Unauthorized Access Detection Rate	76.2%	96.8%
Average Detection Time	3.2 seconds	1.1 seconds
Data Tampering Detection	Not supported (depends on audits)	Real-time via blockchain immutability
Data Access Transparency	Limited	Full transparency (via smart contract logs)
System Overhead (Latency Added)	0.8 ms	1.9 ms
Storage Cost	Lower	Moderately higher (~15% more)

TABLE 1: Comparative results of integrity verification for different data sizes and chunk configurations in the proposed IOT-AI based smart energy monitoring system.

Fig 4: Real-time mains voltage and current trends captured by the proposed IOT-based smart energy monitoring system.

Fig 5: result of project both interface of hardware and software

V. CONCLUSION

The proposed IOT-based Smart Energy Management System effectively integrates solar power generation, energy storage, and smart load management using machine learning and real-time analytics. This system prioritizes the use of renewable energy, reduces reliance on the grid, and promotes user transparency. Experimental results assure minimal energy waste and reduced operational expenses. The future scope of the project, with enhancements like better battery integration, advanced predictive models, and mobile-based control, offers immense potential for scalable, sustainable, and user-centric energy management solutions.

VI. ACKNOWLEDGMENTS

We thanks prof. Mahadeva Prasad H. M for his technical guidance throught this project the department of CSE Supported our work with the required lab facilities and hardware resources we also appreciate the contributions of City Engineering College and insights gained from NSGM reference. our gratude extends to the lab staff for their help with sensor calibration and hardware setup City Engineering College, Bengalore-November 2025

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