

Review on IOT-Enabled Smart Grid Energy Management and notification Systems with Integrating Renewable Energy Sources

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Abstract –

The increasing demand for electrical energy and the growing integration of renewable energy resources have accelerated the development of smart grid technologies for efficient energy management. This review paper presents a comprehensive study of an Internet of Things (IoT)-based Energy Management System (EMS) for smart grid applications utilizing ESP32 as the central controller. The proposed system integrates multiple energy sources, including conventional utility power supply (MSEB grid), solar photovoltaic generation, and wind energy systems, to ensure reliable and sustainable power delivery to connected loads.

The ESP32-based controller continuously monitors electrical parameters such as voltage, current, power consumption, and energy generation from renewable sources. Through intelligent source selection and load management strategies, the system optimizes energy utilization while reducing dependency on the conventional grid. IoT technology enables real-time monitoring, remote control, and cloud-based data visualization, allowing users to access system performance from anywhere. Additionally, a GSM communication module is incorporated to provide instant notifications and alerts regarding power source switching, fault conditions, overload situations, low battery status, and energy consumption patterns.

This review analyzes various IoT communication protocols, smart grid architectures, renewable energy integration techniques, and energy management algorithms reported in recent literature. The study highlights the advantages of combining solar and wind energy with smart grid infrastructure, including improved energy efficiency, enhanced reliability, reduced operational costs, and lower

carbon emissions. Furthermore, challenges related to communication security, renewable energy intermittency, and system scalability are discussed. The review concludes that IoT-enabled smart grid systems integrated with ESP32, renewable energy resources, and GSM-based alert mechanisms represent a promising solution for future intelligent and sustainable energy management applications in residential, commercial, and industrial sectors.

Key Words: Smart Grid, Internet of Things (IoT), Energy Management System, ESP32, Solar Energy, Wind Energy, GSM Module, Renewable Energy Integration, Load Management, Real-Time Monitoring.

1. INTRODUCTION

The rapid growths in energy demand, increasing environmental concerns, and the integration of renewable energy resources have accelerated the development of smart grid technologies worldwide. Traditional power distribution systems face challenges such as inefficient energy utilization, limited monitoring capabilities, and dependence on centralized power generation. To address these issues, smart grid systems have emerged as an intelligent solution that combines advanced communication technologies, automation, and distributed energy resources to improve the reliability, efficiency, and sustainability of electrical power networks.

The Internet of Things (IoT) has become a key enabling technology for smart grid implementation by facilitating real-time monitoring, control, and data analysis of power generation, transmission, and consumption. IoT-based energy management systems provide continuous information regarding energy production, load demand, and system performance, allowing efficient utilization of available energy resources. Among various embedded controllers, the ESP32

microcontroller has gained significant attention due to its built-in Wi-Fi connectivity, low power consumption, and capability to support real-time IoT applications.



Fig1:- Introduction To Smart Grid System

The integration of renewable energy sources such as solar photovoltaic (PV) systems and wind energy systems with conventional utility power supplies has become essential for achieving sustainable energy management. In India, the Maharashtra State Electricity Distribution Company Limited (MSEB) supply serves as the primary power source for residential and industrial consumers. However, combining MSEB supply with solar and wind energy sources through an intelligent energy management framework can significantly reduce grid dependency, improve energy efficiency, and enhance system reliability. Such hybrid energy systems can automatically select the most suitable power source based on availability, generation capacity, and load requirements.

In recent years, researchers have focused on developing IoT-enabled smart grid systems that can monitor renewable energy generation, manage load distribution, and provide remote access to users through cloud platforms and mobile applications. Furthermore, the incorporation of GSM communication modules enables the transmission of real-time notifications and alert messages regarding power source switching, fault conditions, energy consumption, and system status. This feature enhances user awareness and facilitates timely decision-making in case of abnormal operating conditions.

This review paper presents a comprehensive study of IoT-based Energy Management Systems (EMS) for smart grid applications utilizing ESP32 controllers, MSEB utility supply, solar photovoltaic generation, and wind energy resources. The paper examines various system architectures, communication technologies, energy optimization techniques, load management strategies, and GSM-based notification mechanisms reported in recent literature. Additionally, the challenges, advantages, and future research directions associated with IoT-enabled hybrid smart grid systems are discussed to provide a foundation for the development of efficient, reliable, and sustainable energy management solutions.

2. Literature Survey

1. Kirmani et al. (2023)

Kirmani, Mazid, Khan, and Abid presented a comprehensive survey on IoT-enabled smart grids. The authors discussed smart grid architecture, communication technologies, wireless sensor networks, and energy management strategies. Their study emphasized that IoT technologies improve real-time monitoring, demand-side management, and integration of renewable energy resources. The paper also highlighted challenges related to cybersecurity, interoperability, and communication reliability in smart grid environments. This work provides a strong foundation for developing IoT-based energy management systems using ESP32 controllers and cloud platforms.

2. Saleem et al. (2017)

Yasir Saleem, Noel Crespi, Mubashir Husain Rehmani, and Rebecca Copeland proposed an IoT-aided smart grid framework that integrates sensors, communication networks, and automation technologies. The study explained how IoT devices enable bidirectional communication between power generation, transmission, and distribution systems. Their work demonstrated the importance of intelligent monitoring and control for efficient energy utilization and renewable energy integration. The proposed concepts are directly applicable to smart grid projects involving MSEB supply, solar panels, wind turbines, and ESP32-based monitoring systems.

3. Pallavi Ashok Hiray (2018)

Pallavi Ashok Hiray reviewed IoT-based smart grid systems for monitoring and controlling renewable energy resources. The study focused on applications such as wind power prediction, smart home automation, asset management, and power monitoring. The author concluded that IoT significantly enhances the utilization efficiency of existing power infrastructure and supports renewable energy integration. This review supports the implementation of hybrid solar-wind smart grids with remote monitoring and control features.

4. Koushik Kumar Reddy et al. (2026)

Dareddy Koushik Kumar Reddy and colleagues developed a Smart IoT-Integrated Hybrid Solar-Wind Energy Management System using ESP32. The system monitored battery voltage, generation current, and load conditions while prioritizing critical and non-critical loads. Real-time monitoring was achieved through IoT connectivity. The study demonstrated stable power delivery and efficient utilization of renewable energy sources. Their work is highly relevant to the proposed smart grid system integrating MSEB supply, solar power, wind power, and IoT-based monitoring.

5. Chinedu Alex Ezeigweneme et al. (2024)

Chinedu Alex Ezeigweneme and co-authors developed and implemented an ESP32 IoT-based smart grid for enhanced energy efficiency and management. Their system employed real-time monitoring, load shedding, and adaptive control using ESP32 technology. The study demonstrated how smart grids can dynamically manage electrical loads and improve energy efficiency. The proposed architecture serves as a useful reference for implementing intelligent load management in hybrid renewable energy systems.

6. Huang et al. (2023)

Guang-Li Huang, Adnan Anwar, Seng W. Loke, Arkady Zaslavsky, and Jinho Choi reviewed IoT-based smart energy management systems and energy disaggregation techniques. Their research emphasized real-time monitoring, appliance-

level energy analysis, and intelligent decision-making for energy conservation. The study highlighted the importance of IoT-enabled data analytics in optimizing energy consumption and improving overall grid efficiency.

7. Nikpour et al. (2023)

Maryam Nikpour and co-authors investigated intelligent energy management frameworks in smart cities using IoT and machine learning technologies. The authors concluded that IoT-based energy management systems significantly improve energy efficiency, reduce operational costs, and enhance sustainability. Their work supports the incorporation of intelligent analytics into smart grid systems for better management of renewable energy resources and load scheduling.

8. Frontiers in Energy Research Review (2026)

A recent review article on IoT applications in modern power grids discussed the role of IoT in grid monitoring, renewable energy integration, fault detection, and demand-side management. The authors highlighted the increasing adoption of smart sensors, cloud platforms, and wireless communication technologies for improving grid reliability and operational efficiency. The findings support the use of ESP32, GSM modules, and IoT dashboards in modern smart grid applications.

9. Cabantog (2026)

Mark Angelo Cabantog critically reviewed an ESP32-based smart energy monitoring system that employed IoT and cloud technologies for energy usage monitoring. The study demonstrated the effectiveness of ESP32 in collecting and transmitting energy data while generating real-time alerts. The review suggested integrating GSM communication for enhanced reliability in areas with poor internet connectivity, which aligns closely with the proposed system's notification mechanism.

10. Al-Turjman and Abdulkadir

Fadi Al-Turjman and Abdulsalam Ahmed Abdulkadir reviewed energy harvesting and smart grid technologies for modern power systems. Their work emphasized the importance of integrating renewable energy sources and intelligent communication networks to create sustainable and efficient smart grids. The study provides theoretical support for hybrid solar-wind-grid energy management architectures.

3. METHODOLOGY

A. Proposed System Overview

The proposed Internet of Things (IoT)-based Energy Management System is designed to efficiently manage and monitor electrical energy generated from multiple energy sources, including the utility grid (MSEB supply), solar photovoltaic (PV) panels, and wind energy systems. The system functions as a smart grid by integrating renewable energy resources with conventional grid power and intelligently distributing energy to connected loads based on availability and demand.

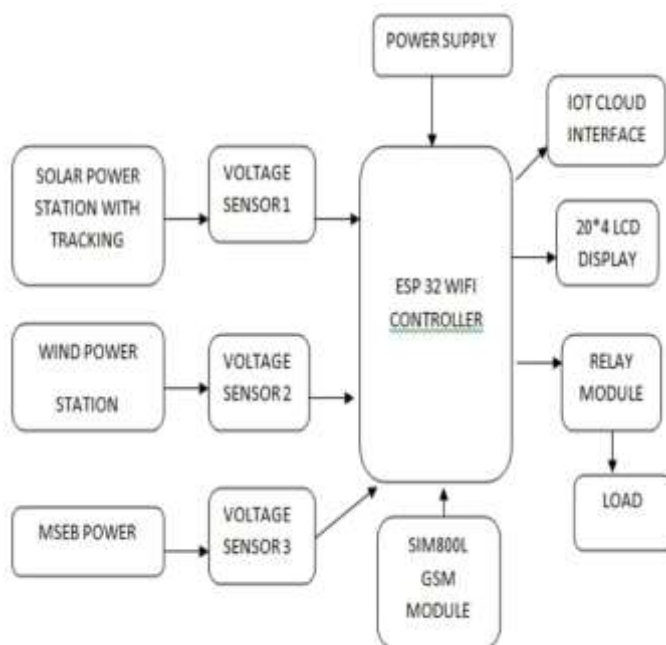


Fig2:- Block Diagram Of Proposed System

The core controller of the system is the ESP32 microcontroller, which performs real-time monitoring, data acquisition, source selection, load management, and

communication with cloud platforms. A GSM module is incorporated to provide instant notifications regarding power source status, energy consumption, fault conditions, and emergency alerts.

B. System Architecture

The proposed smart grid consists of the following major components:

1. MSEB Utility Power Supply
2. Solar Photovoltaic System
3. Wind Energy Generation Unit
4. ESP32-Based Energy Management Controller
5. Voltage and Current Sensors
6. Relay-Based Source Switching Unit
7. GSM Communication Module
8. IoT Cloud Monitoring Platform
9. Electrical Load Section

The ESP32 continuously monitors voltage, current, and power parameters from all energy sources. Based on predefined energy management algorithms, the controller selects the most suitable power source and supplies energy to the connected load while maintaining uninterrupted operation.

C. Data Acquisition and Monitoring

Voltage and current sensors are installed at the outputs of the MSEB supply, solar PV system, wind turbine generator, and load terminals. These sensors continuously measure electrical parameters such as:

- Voltage (V)
- Current (A)
- Power (W)
- Energy Consumption (kWh)

The ESP32 acquires these parameters through its analog-to-digital converter (ADC) channels and processes them in real time.

D. Smart Energy Management Algorithm

The energy management strategy prioritizes renewable energy utilization to reduce dependency on conventional utility power. The operating sequence is as follows:

1. Solar energy is given the highest priority when sufficient power is available.
2. Wind energy is utilized when solar power is unavailable or insufficient.
3. MSEB grid supply acts as a backup source during renewable energy shortages.
4. Automatic switching between sources is performed using relay modules controlled by the ESP32.
5. Load demand and source availability are continuously analyzed to optimize energy utilization.

The algorithm minimizes energy wastage and improves overall system efficiency.

E. IoT-Based Monitoring System

The ESP32 transmits real-time energy data to an IoT cloud platform through Wi-Fi connectivity. The cloud dashboard displays:

- Solar Power Generation
- Wind Power Generation
- Grid Power Consumption
- Load Demand
- Energy Source Status
- Daily and Monthly Energy Usage

Users can remotely monitor system performance through smart phones, tablets, or computers.

F. GSM Notification System

A GSM module is integrated to enhance system reliability and user awareness. SMS notifications are generated under the following conditions:

- Grid Power Failure
- Solar System Fault

- Wind System Fault
- Overload Conditions
- Source Switching Events
- Excessive Energy Consumption

These notifications enable prompt corrective actions and improve operational safety.

G. Load Management Strategy

The connected load is categorized according to priority levels. During energy shortages, non-critical loads can be disconnected automatically while critical loads continue to receive power. This intelligent load scheduling improves energy utilization and prevents system overload.

H. System Operation Flow

1. Energy is generated from solar and wind sources.
2. Utility power is monitored as a backup source.
3. Sensor data are collected by the ESP32.
4. Energy management algorithms evaluate source availability.
5. Appropriate relays are activated for source selection.
6. Electrical loads are supplied from the selected source.
7. System parameters are uploaded to the IoT platform.
8. GSM notifications are transmitted whenever abnormal conditions occur.
9. The process repeats continuously for real-time smart grid operation.

I. Performance Evaluation Parameters

The proposed system can be evaluated using the following parameters:

- Energy Utilization Efficiency (%)
- Renewable Energy Contribution (%)
- Power Switching Time (ms)
- Load Supply Reliability (%)
- IoT Communication Latency
- GSM Notification Response Time
- Energy Cost Reduction

- Carbon Emission Reduction

The collected data can be analyzed to determine the effectiveness of the smart grid energy management system in improving energy efficiency, reliability, and renewable energy integration.

4. CONCLUSIONS

The Internet of Things (IoT)-based Energy Management System for a Smart Grid integrating MSEB utility supply, solar energy, and wind energy presents an effective solution for modern energy management challenges. The proposed system utilizes an ESP32 microcontroller as the central controller to continuously monitor and manage multiple power sources while ensuring reliable power delivery to connected loads. By intelligently switching between renewable energy sources and the conventional grid supply, the system improves energy efficiency, reduces dependency on fossil fuels, and promotes sustainable energy utilization.

The integration of solar and wind energy sources enhances the reliability and availability of power, while the IoT platform enables real-time monitoring of voltage, current, power consumption, and source status from remote locations. Furthermore, the GSM module provides instant notifications and alerts regarding power source changes, fault conditions, load status, and system performance, thereby improving operational awareness and system reliability.

The review indicates that smart grid systems incorporating IoT technologies, renewable energy resources, and wireless communication networks offer significant advantages in terms of energy optimization, cost reduction, environmental sustainability, and user convenience. Such systems are well-suited for residential, commercial, and industrial applications where efficient energy management is essential.

Future research can focus on integrating artificial intelligence and machine learning algorithms for predictive energy management, demand forecasting, fault diagnosis, and adaptive load scheduling. The incorporation of battery energy storage systems and advanced communication technologies such as Lora WAN and 5G can further enhance the

performance, scalability, and resilience of IoT-enabled smart grid infrastructures.

REFERENCES

1. Sheeraz Kirmani, Abdul Mazid, Irfan Ahmad Khan and Manaullah Abid, "A Survey on IoT-Enabled Smart Grids: Technologies, Architectures, Applications, and Challenges," Sustainability, 2023.
2. Yasir Saleem, Noel Crespi, Mubashir Husain Rehmani and Rebecca Copeland, "Internet of Things-aided Smart Grid: Technologies, Architectures, Applications, Prototypes, and Future Research Directions," 2017.
3. Pallavi Ashok Hiray, "Review on Internet of Things Based Smart Grid to Monitor and Control Renewable Energy Sources," AJCT, 2018.
4. Dareddy Koushik Kumar Reddy et al., "Smart IoT-Integrated Hybrid Solar-Wind Energy Management System Using ESP32," IJERST, 2026.
5. Chinedu Alex Ezeigweneme et al., "Development and Implementation of an ESP32 IoT-Based Smart Grid for Enhanced Energy Efficiency and Management," 2024.
6. Guang-Li Huang et al., "IoT-based Analysis for Smart Energy Management," 2023.
7. Maryam Nikpour et al., "Intelligent Energy Management with IoT Framework in Smart Cities Using Intelligent Analysis," 2023.
8. "Internet-of-Things (IoT) Applications in Modern Power Grids," Frontiers in Energy Research, 2026.
9. Mark Angelo Cabantog, "A Critical Review of the ESP32-Based Smart Energy Monitoring System," 2026.
10. Fadi Al-Turjman and Abdulsalam Ahmed Abdulkadir, "Energy Harvesting in IoT-Based Grid: Literature Review," 2024.
11. A.S. Walde, "Wireless Intelligent Power Management System" International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 2016.