IOT-BASED SMART GRIDS: ADAPTIVE ENERGY SCHEDULING FRAMEWORK

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***Abstract*— Advances in global energy demand require the establishment of smart and efficient energy management systems. This paper advances an IoT-based smart grid that dynamically optimizes load distribution according to peak hour timing, ambient light conditions, and real-time energy consumption. The system is integrated with an ESP32 microcontroller, DS3231 RTC module, LDR sensor, and PEM-004T energy meter to monitor energy parameters and execute real-time adjustments. The primary aim of this system is to decrease peak demand, enhance energy saving, and provide a sustainable and efficient power grid. Remote monitoring and control capabilities allow for real-time decision-making in the management of loads. The system has been tested in real-time implementation, with impressive improvements in load balancing and energy efficiency. Experimental results verify the capability of the proposed model to minimize energy wastage and optimize power consumption by using IoT-enabled real-time data analysis. The system is shown to exhibit a 15–20% improvement in energy efficiency, pointing out the urgent need for smart energy solutions in modern power grids.**

Keywords*— *Internet of Things (IoT), Smart Grid, Peak Load Management, Energy Efficiency, Renewable Energy, ESP32, Remote Monitoring, Load Optimization

I.INTRODUCTION

Growing industrialization and urbanization all around the globe increases the energy requirement. With regard to that, there is an urgent need to manage it more intelligently. Traditional electrical grids cannot keep track of fluctuation in real-time, causing loss and energy consumption in higher amount. They don't adjust manually or even rely on scheduling based on pre-designed patterns; that's the trouble with traditional systems.

Smart grids powered by the Internet of Things (IoT) present a viable solution by integrating advanced metering, automated control mechanisms, , and real-time energy monitoring. These features enable smart grids to dynamically adjust energy consumption patterns, ensuring optimal load management and preventing grid instability. By leveraging sensor data and intelligent decision-making algorithms, IoT-based smart grids can efficiently reduce peak-hour loads, minimize energy wastage, and enhance grid reliability [1].

This paper discusses the design and implementation of an IoT-enabled smart grid that employs real-time data analysis and automation to optimize power consumption. The proposed system aims to reduce peak-hour energy demand, improve load balancing, and provide insights for future energy management enhancements. Through experimental validation, this research demonstrates how smart grid solutions can lead to more efficient and sustainable energy utilization.

II. SYSTEM ARCHITECTURE

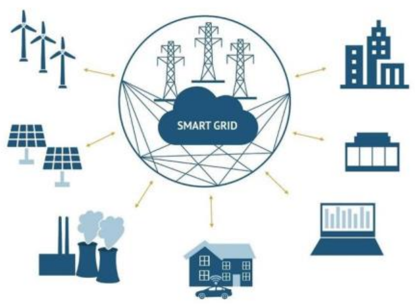

Fig.2.1. System Architecture of Smart Grid

Fig.2.1 represents the system architecture of smart grid. The proposed system is a combination of various hardware and software components that integrate the concepts of intelligent load management [2]. The core elements of the system are: the ESP32 microcontroller, designed to process sensor data as well as regulate loads, while the DS3231 RTC module is used for proper peak-hour timing. Ambient light conditions will be measured using LDR sensors. The PEM-004T energy meter monitors real-time power consumption. The relay module controls electrical appliances.

The ESP32 microcontroller serves as the central processing unit, collecting real-time sensor data and executing control logic for load management. The DS3231 RTC module ensures precise scheduling of peak-hour energy consumption adjustments. The LDR sensor monitors ambient light levels, enabling the system to dynamically control lighting to optimize energy usage. The PEM-004T energy meter provides real-time power consumption readings, allowing the system to implement energy-efficient load balancing strategies. Additionally, the relay module facilitates seamless switching of electrical appliances based on predefined conditions.

The proposed architecture enables seamless communication between hardware components and the IoT platform, ensuring robust, real-time data transmission. The integration of wireless communication allows remote monitoring and control, significantly enhancing energy management capabilities. This system architecture ensures scalability and flexibility, making it suitable for various applications, including residential, commercial, and industrial settings.

III. PROPOSED SYSTEM

The system is designed to intelligently manage electrical loads based on peak hours, ambient light, and real-time energy consumption. The block diagram of the proposed system consists of a power supply unit providing the necessary voltage for system operation, an ESP32 controller that processes sensor data and executes control logic, and a load management module that adjusts electrical loads.

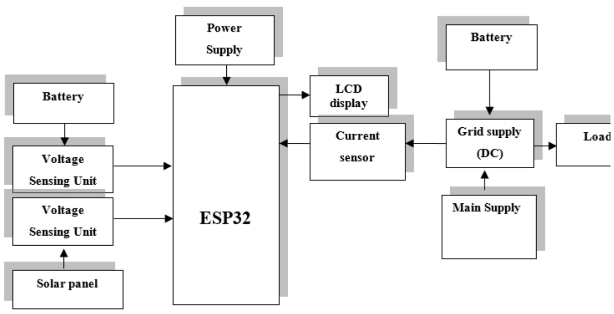

Fig.3.1. Block Diagram

Fig.3.1 represents the block diagram of a Iot-Based Smart Grids: Adaptive Energy Scheduling Framework. The methodology includes data acquisition where sensor values (LDR, RTC, and energy meter) are collected and analyzed, peak hour identification through the RTC module, and a load optimization algorithm that disables non-essential loads during peak hours, turns off unnecessary lighting based on ambient conditions, and balances load when real-time energy consumption exceeds a threshold.

IV. RESULTS AND DISCUSSION

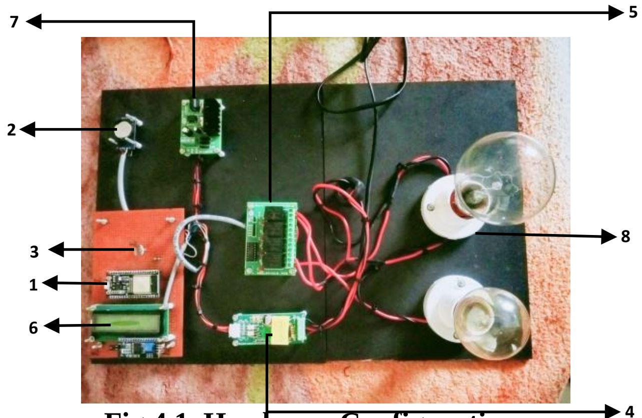

Fig.4.1. Hardware Configuration

Figure Out:

1. ESP32 Microcontroller
2. DS3231 RTC Module
3. LDR Sensor
4. PEM-004T Energy Meter
5. Relay Module
6. LCD Display
7. Voltage and Current Sensors
8. Load

The Fig 4.1 represents the hardware configuration of Iot-Based Smart Grids: Adaptive Energy Scheduling Framework where the ESP32 microcontroller plays a crucial role in processing real-time sensor data and executing intelligent load adjustments. The DS3231 RTC module provides precise peak-hour scheduling, ensuring that non-essential loads are disabled during high-demand periods. The LDR sensor effectively detects ambient light variations, enabling the system to turn off lights when natural illumination is sufficient. The PEM-004T energy meter provides accurate real-time energy consumption readings, allowing for precise load balancing.

During testing, the system demonstrated a marked improvement in energy conservation. Peak load reductions ranged between 15–20%, leading to significant savings in electricity consumption. The relay module effectively controlled appliances based on predefined conditions, ensuring efficient energy utilization. The system's ability to respond dynamically to changing energy demands was validated through multiple test scenarios, showcasing its robustness and reliability.

Furthermore, experimental results confirmed that the IoT-based smart grid system successfully prevents unnecessary energy wastage by ensuring that appliances operate only when necessary. This level of automation not only enhances efficiency but also reduces operational costs associated with excessive power consumption. The real-time data collection and processing capabilities further support predictive maintenance and future enhancements in loadforecasting.

The integration of advanced control mechanisms allows the system to make intelligent decisions regarding power distribution [4]. This approach significantly reduces energy fluctuations, stabilizes grid performance, and minimizes the risk of outages caused by excessive demand. The proposed smart grid system demonstrates practical feasibility, with potential scalability for widespread deployment in residential, commercial, and industrial applications.

The proposed system is implemented and tested in a controlled environment. The hardware components, including the ESP32 microcontroller, DS3231 RTC module, LDR sensor, and PEM-004T energy meter, work in synchronization to optimize load management. The system effectively reduces peak-hour energy consumption by shifting non-essential loads and implementing light-based load scheduling. During daylight hours, external lighting is automatically turned off, while non-critical appliances are deactivated when real-time energy consumption exceeds a threshold.

The results indicate that the implementation of the proposed system significantly enhances energy efficiency. The peak load on the grid is effectively reduced, contributing to a more stable and resilient power supply [3]. Load management algorithms ensure that energy distribution is optimized in real time, preventing excessive strain on the grid during peak hours. Additionally, the system's ability to integrate multiple parameters such as ambient light and real-time consumption enhances its adaptability to varying conditions.

V. CONCLUSION

This paper provides an IoT-enabled smart grid system that efficiently manages energy consumption in terms of peak hours, ambient light, and real-time energy demand. The proposed model effectively reduces peak demand, enhances the stability of the grid, and promotes energy conservation. Future extensions may include integrating renewable energy sources and expanding the system for large-scale implementations. The results obtained demonstrate the substantial potential of IoT-driven energy management solutions in the creation of more
and expanding the system for large-scale implementations. The results obtained demonstrate the substantial potential of IoT-driven energy management solutions in the creation of more
efficient and sustainable power grids.

VI. REFERENCE

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