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ESP32-Based Smart System with Energy Monitoring and Scheduling via Android App for Industrial Applications

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Abstract - The rapid increase in energy consumption and the need for efficient utilization of electrical appliances have motivated the development of smart energy management systems. This paper presents an ESP32-based smart system integrating IoT technology for real-time energy monitoring, automated load control, and safety management in industrial applications. The system uses a PZEM-004T module to measure voltage, current, power, and energy consumption; a DS18B20 temperature sensor for environmental monitoring; MQ135 gas sensor and flame sensor for hazard detection; and relay modules for controlling AC loads. All monitored parameters are transmitted to the Blynk IoT cloud platform and accessed remotely via an Android application, enabling manual control, scheduling, and instant alerts during abnormal conditions. Results demonstrate reliable fire and gas detection, overload protection, and remote appliance control. The proposed system offers improved energy efficiency, enhanced safety response, and a cost-effective solution for industrial automation.

Key Words: ESP32, IoT, Energy Monitoring, PZEM-004T, Blynk, Android Application, Smart System, Industrial Automation.

1. INTRODUCTION

The rapid advancement of Internet of Things (IoT) technology has transformed conventional electrical systems into intelligent, automated, and remotely manageable solutions. In modern homes and industries, efficient energy management, real-time monitoring, and enhanced safety mechanisms are essential to reduce power consumption, prevent hazards, and improve operational reliability. Traditional electrical systems rely on manual switches and mechanical regulators, lacking real-time monitoring, automation, or smart connectivity. This results in energy wastage, poor hazard response, and limited operational control. The proposed system addresses these limitations by leveraging the ESP32 microcontroller as the central processing unit, integrating a PZEM-004T energy monitoring module, DS18B20 temperature sensor, MQ135 gas sensor, flame sensor, relay modules, and a DC heater. All monitored data is transmitted to the Blynk IoT cloud platform for remote access and control via an Android application. The system supports both manual and automatic operation modes and sends instant alerts under abnormal conditions such as voltage fluctuations, overloads, gas leaks, or fire events.

2. EXISTING METHODS AND LIMITATIONS

Traditional electrical systems lack real-time energy monitoring, automation, and safety mechanisms. Users rely on manual switches and monthly electricity bills, which prevents detailed power usage analysis. There is no provision for remote monitoring, intelligent scheduling, or hazard detection. Literature review highlights that IoT-based systems using ESP32 and cloud platforms such as Blynk significantly outperform conventional approaches in terms of energy efficiency, safety, and remote accessibility. Prior works by Kumar and Sharma (2021) on IoT-based energy monitoring, and Reddy and Rao (2022) on PZEM-004T integration, confirm the feasibility and effectiveness of sensor-based smart energy management systems.

3. PROPOSED METHOD

The proposed system is built around the ESP32 microcontroller, which provides dual-core processing and built-in Wi-Fi. The PZEM-004T module interfaces via TTL serial communication to measure AC voltage (80-260V), current (0-100A), active power, and cumulative energy. The DS18B20 digital temperature sensor uses the 1-Wire protocol with accuracy of +-0.5 degrees C over a range of -55 to +125 degrees C. The MQ135 gas sensor detects harmful gases including NH3, NOx, benzene, smoke, and CO2 with a detection range of 10-10,000 ppm. The flame sensor detects infrared radiation in the 760-1100 nm wavelength range from up to 100 cm. Relay modules provide electrical isolation between the ESP32 (3.3V logic) and AC loads (220V). A DC heater (12V, 2A) is used for temperature maintenance. All sensor data is processed by the ESP32 and transmitted to the Blynk IoT cloud platform via Wi-Fi. The Android application provides real-time dashboards, manual controls, and instant push notifications.

The system operates in a continuous monitoring loop. Upon initialization, the ESP32 connects to Wi-Fi and configures all GPIO pins and serial interfaces. The PZEM module continuously reads electrical parameters every second. If current exceeds a preset threshold, an overload alert is sent to the Android application and the load relay is triggered. The DS18B20 sensor reads temperature at regular intervals; if it falls below 25 degrees C, the heater relay is activated automatically. The MQ135 gas sensor monitors air quality continuously; if hazardous gas concentration exceeds the threshold, an alert notification is triggered. The flame sensor

outputs a digital signal upon fire detection, immediately activating the water pump relay and sending a Blynk notification. All sensor readings and device states are continuously updated on the Blynk dashboard, allowing remote monitoring and manual override at any time.

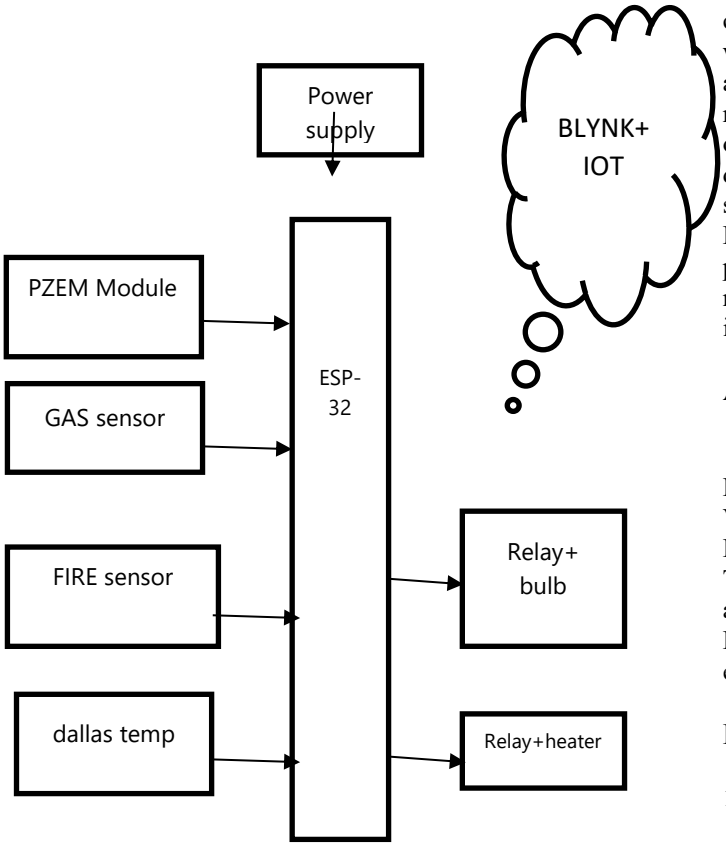

Fig.1:Block Diagram of Proposed Method

4. RESULTS AND DISCUSSION

The system was tested under various conditions to validate functionality. In the fire detection test, the flame sensor successfully detected fire within a 100 cm range and triggered the water pump relay within milliseconds while sending a Blynk notification. In the overload test, the PZEM-004T accurately detected a current of 0.45A exceeding the set threshold and displayed an overload warning on both the serial monitor and Blynk dashboard. In the gas detection test, the MQ135 sensor detected elevated gas concentration and triggered the alert system instantly. Temperature monitoring showed the DS18B20 reading stable values (approx. 29-30 degrees C) and activating the heater relay when temperature fell below the set threshold. Remote control via the Android application successfully toggled the load relay and heater relay in both automatic and manual modes. The Blynk dashboard displayed real-time gauge readings for voltage (245V), current (0.04-0.5A), power, energy, temperature, frequency (49 Hz), and power factor (1), confirming accurate data transmission.

5. CONCLUSIONS

The ESP32-based smart energy management system successfully integrates IoT technology, real-time energy monitoring, automated safety mechanisms, and remote control into a single cost-effective platform. The PZEM-004T ensures accurate measurement of electrical parameters, while the DS18B20, MQ135, and flame sensor collectively provide comprehensive environmental safety monitoring. Integration with the Blynk IoT cloud platform enables seamless remote access and control via an Android application. Experimental results confirm reliable detection of fire, gas hazards, and overloads with rapid automated response. The system demonstrates significant improvements over traditional manual systems in energy efficiency, safety, and user convenience. Future enhancements include integration with AI/ML for predictive analytics, cloud-based historical data storage, multi-node networking for large-scale industrial deployment, and integration with renewable energy sources.

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