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Smart Power Monitoring System for Home Appliances

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Abstract- — Rapid growth in residential electricity consumption has created a strong need for intelligent and user-friendly monitoring solutions that can help users understand and control their energy usage. Traditional energy meters provide only cumulative readings and do not offer real-time insights into appliance-level consumption. This paper presents the design and implementation of an IoT-based Smart Power Monitoring System for home appliances that enables continuous monitoring and remote access to electrical parameters. The proposed system measures real-time voltage, current, power, and energy consumption using ZMPT101B voltage and ACS712 current sensors interfaced with an ESP32 microcontroller. The ESP32 processes sensor data and transmits it securely to cloud platforms such as ThingSpeak and Blynk via Wi-Fi, allowing users to visualize and analyze energy usage through mobile or web dashboards. In addition, the system incorporates a relay-based protection mechanism that automatically disconnects the load during abnormal conditions such as overcurrent, voltage fluctuations, or excessive power consumption. This feature helps prevent electrical damage and improves system safety. The proposed solution is low-cost, scal-able, and energy-efficient, making it suitable for residential envi-ronments as well as small industrial applications. By providing real-time monitoring, data analytics, and remote accessibility, the system promotes energy awareness, reduces electricity wastage, and supports the development of smarter and more sustainable energy management systems.

Index Terms—IoT, ESP32, Smart Energy Monitoring, Power Monitoring System, Home Automation.

I. INTRODUCTION

Energy consumption in modern households is continuously increasing due to the widespread use of electrical and electronic appliances such as air conditioners, refrigerators, washing machines, and smart devices. While these appliances improve comfort and convenience, they also contribute to higher electricity demand and rising energy costs. Traditional energy meters provide only cumulative monthly readings and lack real-time visibility into how individual appliances consume electricity. This limitation often results in energy wastage, increased electricity bills, and difficulty in identifying abnormal usage patterns or potential electrical faults.With the rapid development of Internet of Things (IoT) technology, new opportunities have emerged to improve energy monitoring and management.

IoT enables electrical devices and sensors to communicate with cloud platforms, allowing real-time data collection, remote monitoring, and intelligent control of energy systems. By providing instant access to power consumption information, users can make informed decisions about their energy usage and reduce unnecessary consumption.The proposed Smart Power Monitoring System addresses these challenges by integrating IoT technology with real-time sensing, cloud- based analytics, and automatic protection mechanisms. The system measures key electrical parameters such as voltage, current, power, and energy consumption, and transmits this information to cloud platforms for visualization and analysis. In addition, a relay-based protection system ensures safe operation by disconnecting loads during abnormal conditions. This approach enhances user awareness, improves electrical safety, and promotes efficient and sustainable energy utilization.

II. PROBLEM STATEMENT

Most residential users lack clear visibility into appliance-level energy consumption, making it difficult to understand how electricity is used within their homes. Traditional energy meters only provide cumulative readings and do not offer real- time monitoring or detailed analysis. Existing monitoring solutions often provide limited real-time alerts, minimal automation, and weak integration with mobile or cloud platforms. As a result, users are unable to quickly detect abnormal power usage, overload conditions, or inefficient energy consumption. In addition, the absence of automatic protection mechanisms increases the risk of electrical damage, safety hazards, and potential power theft. Therefore, a smart, connected, and intelligent monitoring solution is required to ensure efficient energy management, enhanced safety, and real-time accessibility for users.

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III. OBJECTIVES

The primary objective of the proposed Smart Power Monitoring System is to develop an intelligent and efficient solution for monitoring and managing electrical energy consumption. The system aims to monitor real-time electrical parameters such as voltage, current, power, and energy consumption of home appliances. It provides remote access to users through mobile and web-based dashboards for convenient monitoring. Another objective is to generate instant alerts during abnormal load conditions to ensure safety and prevent electrical damage. The system also enables relay-based automatic load disconnec- tion during overload situations. Additionally, it stores historical energy data for analysis and optimization while promoting energy efficiency and reducing electricity costs.

- Monitor real-time voltage, current, power, and energy consumption.
- Provide remote access through mobile and web dash- boards.
- Generate instant alerts during abnormal load conditions.
- Enable relay-based automatic load disconnection.
- Store historical data for energy analysis.
- Promote energy efficiency and reduce electricity costs.

IV. LITERATURE REVIEW

Table I Literature Survey

Ref	Author / Year	System / Approach	Key Features	Limitations
1	Sharma et al., 2020	IoT-based smart energy meter using NodeMCU	Real-time monitoring, Blynk dashboard	Limited measurement accuracy and no protection system
2	Kumar et al., 2021	Arduino-based power monitoring system	Basic IoT connectivity and energy tracking	No predictive alerts and limited mobile integration
3	Lee et al., 2019	Smart home energy management using IoT devices	Automated control and energy monitoring	Complex implementation and calibration issues
4	Zhang et al., 2022	Cloud-based energy monitoring platform	Data analytics and remote monitoring	High cost and less suitable for small homes
5	Patel et al., 2023	Wi-Fi enabled smart plug monitoring system	Real-time power tracking and cloud storage	Lack of relay protection and limited scalability

V. PROPOSED SYSTEM ARCHITECTURE

The proposed system architecture is designed to monitor and control household electrical appliances using an IoT-based smart monitoring system. The system mainly consists of sensors, a microcontroller, cloud connectivity, and a user interface. Voltage is measured using the ZMPT101B sensor, while current is measured using the ACS712 sensor. These sensors send real-time electrical parameters to the ESP32 microcontroller for processing.

The ESP32 processes the data and transmits it to cloud platforms through secure Wi-Fi communication. Users can monitor voltage, current, power, and energy consumption through mobile or web dashboards. In case of abnormal load conditions, the system generates instant alerts and activates a relay module to automatically disconnect the load, ensuring safety, energy efficiency, and protection of home appliances.

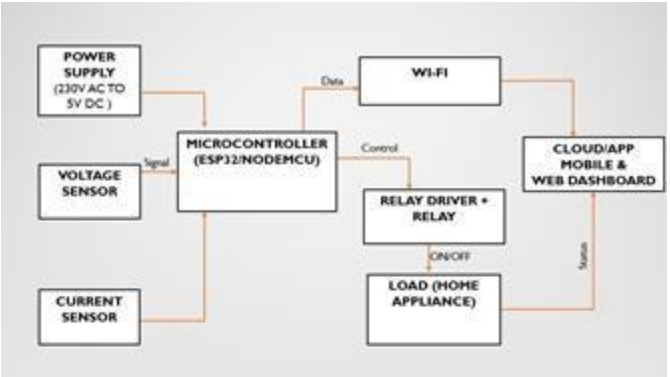

Fig.1. Proposed System Architecture

VI. METHODOLOGY

The proposed IoT-based Smart Power Monitoring System follows a structured methodology for accurate monitoring, data processing, and protection of home electrical appliances. The methodology consists of several stages including sensing, data processing, cloud communication, alert generation, and automated protection.

1. Data Sensing:
Voltage and current from the household electrical line are measured using sensors. The ZMPT101B voltage sensor measures the AC voltage, while the ACS712 current sensor measures the current drawn by connected appliances. These sensors convert electrical parameters into analog signals that can be read by the microcontroller.

2. Data Processing:
The analog signals from the sensors are sent to the ESP32 microcontroller, which converts them into digital values using its built-in ADC (Analog-to-Digital Converter). The ESP32 then calculates electrical parameters such as voltage, current, power, and energy consumption using programmed algorithms.

3. Data Transmission:
After processing, the ESP32 transmits the data to cloud platforms through Wi-Fi communication. Platforms such as ThingSpeak or Blynk are used to store, visualize, and monitor the data remotely.

4. Real-Time Monitoring:
Users can access real-time electrical data through mobile applications or web dashboards. This allows homeowners to track appliance-level energy consumption and identify high power usage.

5. Alert Generation:
If the system detects abnormal conditions such as overload, excessive current, or unusual power usage, the ESP32 automatically generates instant alerts. Notifications are sent to the user through the connected mobile application.

6. Automatic Protection:
A relay module is integrated into the system to provide automatic protection. When abnormal load conditions are detected, the relay disconnects the power supply to prevent damage to appliances and reduce safety risks.

7. Data Storage and Analysis:
The collected data is stored in the cloud for future analysis. Historical data helps users understand their electricity consumption patterns and implement energy-saving strategies.

8. System Optimization:
Sensor calibration and stable Wi-Fi communication are implemented to improve measurement accuracy and system reliability, ensuring consistent and efficient performance.
This methodology ensures accurate monitoring, real-time alerts, remote accessibility, and automatic protection, making the system an effective solution for smart energy management in residential environments.

VII. HARDWARE IMPLEMENTATION

The hardware implementation of the IoT-based Smart Power Monitoring System consists of several electronic components working together to measure electrical parameters, process data, and provide protection. Each component plays a specific role in ensuring accurate monitoring and safe operation.

1. ESP32 Microcontroller:
The ESP32 acts as the central processing unit of the system. It receives analog signals from the voltage and current sensors, processes the data, and calculates electrical parameters such as voltage, current, power, and energy consumption. The ESP32 also provides built-in Wi-Fi connectivity, allowing the system to transmit data to cloud platforms for remote monitoring.

2. ACS712 Current Sensor:
The ACS712 current sensor is used to measure the current flowing through the electrical load. It works based on the Hall-effect principle and provides an analog output proportional to the current passing through it. This sensor enables the system to detect load variations and abnormal current conditions.

3. ZMPT101B Voltage Sensor:
The ZMPT101B module is used for accurate AC voltage measurement. It contains a precision voltage transformer that safely steps down the input voltage and converts it into a measurable signal for the microcontroller. This ensures reliable voltage monitoring while maintaining electrical isolation.

4. Relay Module:

A relay module is integrated to provide automatic protection. When the ESP32 detects abnormal conditions such as overload or excessive current, it activates the relay to disconnect the power supply, preventing damage to appliances and enhancing electrical safety.

5. LCD Display:
An LCD display is used to show real-time electrical parameters such as voltage, current, power, and energy consumption. This allows users to view system data locally without needing to access the mobile dashboard.

6. Regulated Power Supply Module:
A regulated power supply converts AC mains voltage into stable 5V or 3.3V DC required by the ESP32 and other components. Proper voltage regulation ensures stable and reliable operation of the entire system.

During the development stage, the circuit was first assembled on a breadboard for testing and debugging. Sensor calibration was carefully performed to improve measurement accuracy. Proper insulation and safety precautions were taken while working with AC power. After successful testing and validation, the circuit can be transferred to a printed circuit board (PCB) for a more compact and reliable final implementation.

VIII. SOFTWARE IMPLEMENTATION

The software for the system was developed using the Arduino IDE, which provides an easy platform for programming microcontrollers such as the ESP32. The firmware is responsible for reading sensor data, processing electrical parameters, controlling the relay module, and sending data to cloud platforms.

1. Data Acquisition:
The ESP32 continuously reads analog signals from the ACS712 current sensor and ZMPT101B voltage sensor through its built-in Analog-to-Digital Converter (ADC). Multiple samples are taken in short intervals to ensure accurate measurement of voltage and current values.

2. Signal Filtering and Processing:
To improve accuracy, the software applies noise filtering techniques such as averaging multiple readings. This reduces fluctuations caused by electrical noise and ensures stable sensor measurements.

3. Power and Energy Calculation:
After obtaining voltage and current values, the firmware calculates power using the formula:

Power (P) = Voltage (V) × Current (I)
Energy consumption is then calculated by integrating power over time. These calculations allow the system to estimate the total electricity consumed by the connected appliances.

4. Wi-Fi Connectivity and Data Transmission:
The ESP32 connects to a Wi-Fi network and transmits the processed data to cloud platforms such as ThingSpeak or Blynk. This enables real-time monitoring of electrical parameters through mobile applications or web dashboards.

5. Auto Wi-Fi Reconnection Logic:
The program includes an automatic reconnection feature that reconnects the ESP32 to the Wi-Fi network if the connection is lost. This ensures continuous data transmission without manual intervention.

6. Cloud Upload Optimization:
To prevent network congestion and reduce unnecessary data usage, the system uploads data to the cloud at optimized intervals rather than continuously. This improves efficiency while maintaining real-time monitoring capability.

7. Threshold-Based Relay Control:
The software continuously checks the measured current and power values against predefined safety thresholds. If the load exceeds safe limits, the ESP32 triggers the relay module to disconnect the power supply automatically. This helps prevent overheating, electrical faults, and appliance damage.

Overall, the software implementation enables real-time monitoring, intelligent decision-making, remote accessibility, and automatic safety control, making the system a reliable smart energy management solution.

IX. CHALLENGES AND SOLUTIONS

Several challenges were encountered during development.

- Wi-Fi disconnection solved using auto-reconnection algorithms.
- Sensor calibration errors solved through software
- adjustments.
- Electrical noise reduced using filtering techniques.

- Cloud transmission delay optimized by controlling upload intervals.

X. EXPECTED OUTCOMES

The proposed system provides:

- Real-time monitoring of electricity usage
- Instant alerts for abnormal conditions
- Improved energy transparency
- Enhanced electrical safety

XI. APPLICATIONS

The system can be used in:

- Residential energy monitoring
- Industrial load supervision
- Smart grid systems
- Commercial energy analytics
- Renewable energy monitoring

XII. CONCLUSION

The proposed IoT-based Smart Power Monitoring System provides an effective solution for real-time monitoring and management of electrical energy consumption. The system measures voltage, current, power, and energy usage and transmits this data to cloud platforms for remote access.
The relay-based protection mechanism improves safety by automatically disconnecting loads during abnormal conditions. The system is cost-effective, scalable, and suitable for smart homes and small industrial environments.

Future improvements may include artificial intelligence for energy prediction and monitoring multiple appliances for complete smart home energy management.

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