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Secure IoT Smart Energy Monitoring with AI Billing and NILM

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Abstract: This project presents a Secure Smart Energy Monitoring and Protection System using IoT with encrypted communication. The system is designed to measure electrical parameters such as voltage, current, and power consumption in real time using an energy sensing module interfaced with a microcontroller. A protection mechanism using a relay is implemented to handle overload and short-circuit conditions effectively. To ensure secure data transmission, the Advanced Encryption Standard (AES) algorithm is used to encrypt energy data before sending it to the cloud platform. The encrypted data is transmitted through an IoT module and decrypted for remote monitoring and analysis. The system also incorporates Non-Intrusive Load Monitoring (NILM) for appliance-level estimation and an AI-based model for predicting electricity consumption. The overall system demonstrates accurate monitoring, enhanced safety, and secure communication, making it suitable for smart energy applications.
Keywords: IoT, Energy Monitoring, AES Encryption, NILM, Smart Meter, ESP32, Protection System.

I. INTRODUCTION

In recent years, the demand for efficient energy management systems has increased significantly due to rising electricity consumption and the need for energy conservation. Traditional energy meters provide only basic readings and lack intelligent analysis, prediction capabilities, and security features. These limitations make it difficult for users to monitor energy usage effectively and prevent electrical hazards. With the advancement of Internet of Things (IoT) and Artificial With the advancement of Internet of Things (IoT) technology, smart energy monitoring systems can now provide real-time data, remote access, and automation. This project proposes a Secure Smart Energy Monitoring and Protection System that integrates IoT, encryption, and intelligent analysis. The system not only monitors energy consumption but also ensures safety through overload protection and enhances data security using AES encryption. The system incorporates Non-Intrusive Load Monitoring (NILM) to estimate appliance-wise energy usage without installing multiple sensors. An AI-based prediction model is also included to forecast electricity bills based on consumption patterns. This integrated approach provides a comprehensive solution for modern energy management. To overcome these limitations, this project proposes a Secure Smart Energy Monitoring and Protection System using IoT technology. The system enables real-time monitoring of voltage, current, and power consumption, along with protection against overload and short-circuit conditions. It also uses AES encryption to ensure secure data communication.

Additionally, intelligent features such as appliance-level energy estimation and electricity bill prediction make the system more efficient and user-friendly. They also do not ensure secure data transmission, making them less suitable for modern smart applications. The system enables real-time monitoring of voltage, current, and power consumption, along with protection against overload and short-circuit conditions

II. OBJECTIVE

The primary objective of this project is to design and develop a Secure Smart Energy Monitoring and Protection System that integrates real-time data acquisition, intelligent analysis, and secure communication using IoT technology. The system aims to accurately measure electrical parameters such as voltage, current, power, and energy consumption using suitable sensing modules interfaced with a microcontroller. This enables continuous monitoring of energy usage and provides users with precise and reliable information for effective energy management. Another important objective is to ensure electrical safety by implementing protection mechanisms such as overload and short-circuit detection. A relay-based control system is used to automatically disconnect the load during fault conditions, thereby preventing damage to electrical appliances and reducing the risk of hazards such as fire or equipment failure. This enhances the reliability and safety of the overall system.

The project also focuses on securing energy data during transmission. To achieve this, the Advanced Encryption Standard (AES) algorithm is implemented to encrypt the collected data before sending it through the IoT communication module. This ensures that the data remains protected from unauthorized access, tampering, or cyber threats, making the system suitable for modern smart grid and IoT-based applications.

In addition to monitoring and protection, the system aims to incorporate intelligent features for better energy analysis. Non-Intrusive Load Monitoring (NILM) techniques are used to estimate appliance-wise energy consumption without requiring additional hardware sensors for each device. This reduces system complexity and cost while still providing detailed insights into energy usage patterns.

Furthermore, an AI-based prediction model is implemented to a historical energy consumption data and forecast future electricity usage and billing. This helps users in planning their energy consumption more efficiently and avoiding excessive electricity costs. The system also aims to support tariff-based billing calculations to make it more practical for real-world applications.

III.PROPOSED SYSTEM

The proposed system presents a Secure Smart Energy Monitoring and Protection System that integrates real-time sensing, intelligent processing, secure communication, and automated protection using IoT technology. The system is designed to continuously monitor electrical parameters such as voltage, current, power, and energy consumption using an energy measurement module connected to a microcontroller. The microcontroller acts as the central processing unit, where all sensor data is collected, processed, and analyses to provide accurate energy readings.

A key feature of the proposed system is the integration of a protection mechanism using a relay module. The system continuously checks for abnormal conditions such as overload and short circuits. Whenever the measured current or power exceeds the predefined threshold values, the relay is automatically triggered to disconnect the load. This prevents damage to electrical appliances and enhances the safety of the system. Once the fault condition is cleared, the system can restore normal operation, ensuring reliable performance.

To enable remote monitoring and control, the system incorporates an IoT communication module such as ESP32 with built-in WIFI capability. The processed energy data is transmitted to a cloud platform where it can be accessed by users through a mobile or web-based dashboard.

IV.PROCEDURE

The procedure of the proposed system begins with the initialization of all hardware components connected to the microcontroller. When the system is powered on, modules such as the energy sensor (PZEM-004T), ESP32 microcontroller, relay unit, LCD display, Real-Time Clock (RTC), and IoT communication interface are activated and configured. The ESP32 acts as the central controller, ensuring proper communication between all components and coordinating the overall system operation.

In the next stage, the energy sensing module continuously measures electrical parameters such as voltage and current from the power supply line. These analog/digital signals are sent to the microcontroller, where they are processed to calculate important values such as power and energy consumption. The system updates these readings in real time and displays them on the LCD screen for local monitoring.

Simultaneously, the system checks for abnormal conditions such as overload and short circuit. Predefined threshold values are set for current and power. If the measured values exceed these limits, the microcontroller immediately activates the relay module to disconnect the load. This automatic protection mechanism prevents damage to electrical appliances and ensures user safety. Once the system returns to normal conditions, the relay can restore the connection.

After processing and validation, the collected energy data is prepared for transmission. Before sending the data to the cloud, the system applies the Advanced Encryption Standard (AES) algorithm to encrypt the information. This step ensures that the data remains secure during transmission and cannot be accessed or modified by unauthorized users.

V. EXISTING SYSTEM

In the current scenario, conventional energy monitoring systems are primarily designed to measure and display basic electrical parameters such as voltage, current, and total energy consumption. These systems are commonly used in residential and industrial applications in the form of standard energy meters. However, they provide only limited functionality and do not offer advanced features required for efficient energy management. One of the major limitations of existing systems is the absence of appliance-level energy monitoring. Traditional meters can only provide overall energy consumption and cannot identify how much energy is consumed by individual devices. To achieve appliance-level monitoring, additional sensors and complex hardware setups are required, which increases system cost and complexity.

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Another significant drawback is the lack of intelligent analysis and prediction capabilities. Most existing systems do not analyses energy consumption patterns or provide insights into future usage. As a result, users are unable to predict electricity bills or optimize their energy consumption effectively. The absence of AI-based models further limits the system's ability to provide smart recommendations or automation.

Existing systems also have limited or no built-in protection mechanisms. While some electrical installations use separate protection devices such as circuit breakers or fuses, they are not integrated with the monitoring system. This lack of integration makes it difficult to achieve a unified solution for both monitoring and protection, reducing the overall efficiency and reliability of the system. In addition, data security is often not considered in conventional energy monitoring systems.

VI. EXECUATION OF THE SYSTEM\

The execution of the proposed system begins when all hardware components are powered on and initialized. The ESP32 microcontroller acts as the central processing unit that controls and coordinates the entire system. Modules such as the PZEM-004T energy sensor, relay unit, LCD display, RTC (DS3231), SD card module, and IoT communication interface are activated and configured for operation. The system ensures proper communication between all components before starting the monitoring process.

Once the system is initialized, the energy sensing module continuously measures electrical parameters such as voltage, current, power, and energy consumption from the connected load. These values are transmitted to the ESP32, where they are processed and calculated in real time. The measured parameters are displayed on the LCD screen, allowing users to monitor energy usage locally.

During operation, the system continuously checks for abnormal conditions such as overload and short circuits. Predefined threshold values are set within the microcontroller. If the measured current or power exceeds these limits, the ESP32 immediately sends a signal to the relay module to disconnect the load. This automatic protection mechanism ensures safety and prevents damage to electrical appliances. Once the system detects that the fault condition has been resolved, it can restore the connection and resume normal operation.

At the same time, the system prepares the collected data for remote monitoring. Before transmission, the data is encrypted using the Advanced Encryption Standard (AES) algorithm to ensure secure communication. The encrypted data is then transmitted to the cloud platform via the ESP32's WiFi module.

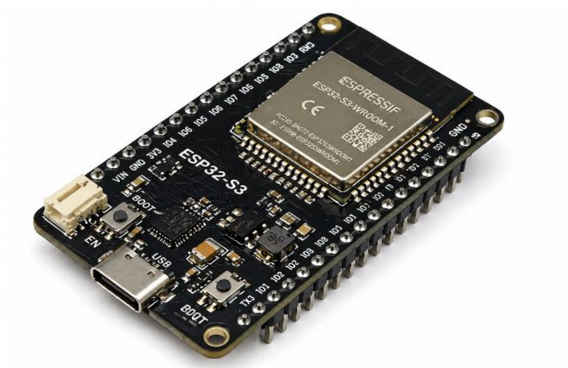

FIG:1 ESP 32 -S3

FIG: 2 PZEM-004T

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FIG: 3 2 CHANNEL RELAY

FIG: 4 RTC MODULE

FIG: 5 LCD DISPLAY

FIG: 6 BUCK CONVERTOR

VII. CONCLUSION

One of the major achievements of the system is the integration of an automatic protection mechanism using a relay module. The system effectively detects abnormal conditions such as overload and short circuits and immediately disconnects the load to prevent damage to electrical appliances and ensure user safety. This combination of monitoring and protection in a single system enhances reliability and makes it more practical for real-world applications.

Another important aspect of the project is secure data communication. By implementing the Advanced Encryption Standard (AES) algorithm, the system ensures that energy data is encrypted before transmission to the cloud. This protects the data from unauthorized access and cyber threats, making the system suitable for IoT-based smart grid environments where data security is a critical concern.

In addition to basic monitoring, the system incorporates intelligent features such as Non-Intrusive Load Monitoring (NILM) and AI-based prediction. NILM enables appliance-level energy estimation without the need for additional sensors, reducing system complexity and cost. The AI-based model analyses historical data to predict future energy consumption and electricity billing, helping users plan their energy usage more efficiently.

The integration of IoT technology allows users to monitor energy data remotely through cloud platforms, providing convenience and flexibility. Features such as data logging, time-based billing using RTC, and real-time display further enhance the functionality of the system.

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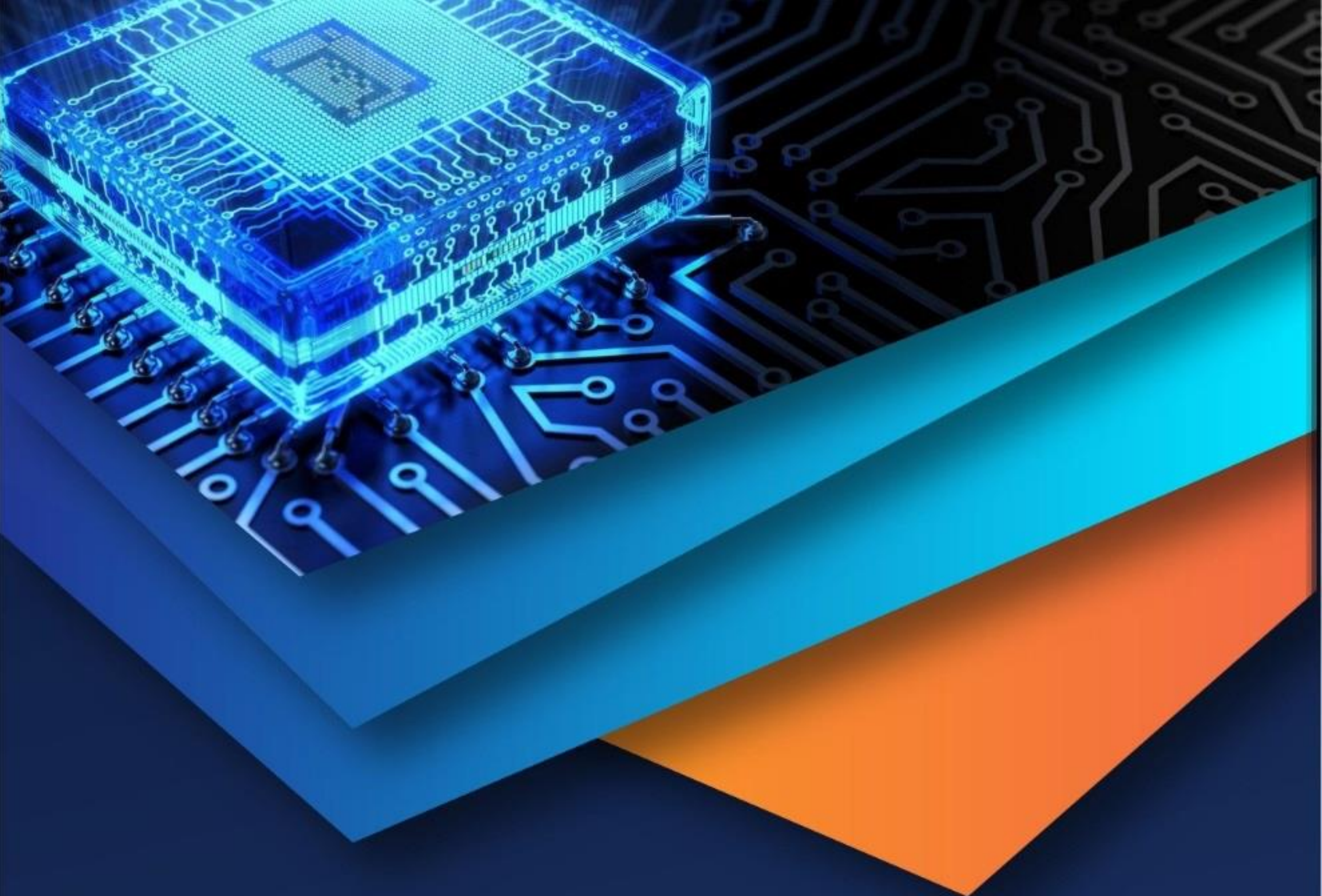

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