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Wireless IoT-Based Smart Monitoring System with Power Theft Detection

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ABSTRACT

Electricity is a crucial part of modern life, but traditional billing methods rely on manual meter readings, leading to inefficiencies, errors, and delays. This project introduces an IoT-based smart energy metering system that automates data collection, billing, and theft detection. The system integrates a microcontroller with an energy meter to monitor power consumption in real time. A centralized database securely stores usage data, allowing both consumers and electricity providers to access it via a web interface or mobile application. This enables users to track their daily electricity consumption and manage energy usage efficiently. The system also enhances security by detecting unauthorized tampering or electricity theft. If irregularities or violations occur, alerts are sent to both the consumer and the service provider. In cases of excessive consumption or unauthorized access, the system can automatically disconnect the power supply to prevent misuse. By leveraging IoT and automation, this solution improves accuracy, transparency, and efficiency in energy management while reducing operational costs for electricity providers. It ensures a seamless billing process and promotes responsible energy consumption.

KEYWORDS

Android, Web development, IOT, Metering Solution

1. INTRODUCTION

Efficient energy management and monitoring are essential for optimizing power usage and distribution. Traditional metering systems require manual readings, which can be prone to errors and inefficiencies. Consumers may face billing inaccuracies due to misread meter values, leading to disputes or unexpected fines [1]. Additionally, adverse weather conditions and the absence of residents during meter reading visits make the process cumbersome and unreliable.

To overcome these limitations, we propose a Wireless IoT-Based Smart Metering System with Power Theft Detection that introduces four key features aimed at enhancing energy efficiency and security:

1.1 Power Theft Detection with Instant Alerts: Unauthorized electricity usage is automatically detected, triggering immediate notifications to the consumer's mobile device and relevant authorities, facilitating swift action.

1.2 Automated Power Cutoff for Overuse:

The system continuously monitors energy consumption, and if it exceeds a predefined threshold, power is automatically disconnected to prevent overloading and potential hazards.

1.3 Prepaid Smart Metering System:

Unlike conventional postpaid meters, this system operates on a prepaid basis, where users receive electricity based on the amount they have paid. Once the balance is depleted, power is suspended until further payment is made, ensuring responsible usage and reducing unpaid bills.

1.4 Automated Billing and Web-Based Monitoring:

The system generates electricity bills automatically and transmits them to the user, municipal authorities, and relevant officials. A web-based platform is provided to allow real-time monitoring of energy consumption, enabling users to track usage, balance, and alerts regarding power theft or excessive consumption.

Our system leverages NodeMCU, an IoT-enabled microcontroller that utilizes Wi-Fi for real-time data transmission to the cloud. This eliminates the need for SIM-based GSM modules, reducing operational costs and enhancing efficiency [2]. Consumers can view live electricity readings on an LCD display, while updates and alerts are accessible through an online dashboard and mobile notifications.

In Section II evaluates important literature on smart metering and current energy management methods. Section III explains the system architecture, including its design and essential components. Section IV describes the methodology, including working concepts and implementation strategies. Section V outlines the hardware configuration and its capabilities. Section VI displays and analyses the results to determine system performance. Section VII discusses major findings and recommends further improvements. Finally, Section VIII refers to the sources employed in this study. This structure maintains a logical flow of information throughout the work.

2. LITERATURE SURVEY

Traditional electro-mechanical meters, commonly used in energy monitoring, degrade over time, leading to inaccuracies and frequent maintenance issues. To improve efficiency, digital energy meters were introduced, offering greater precision. The development of Automated Meter Reading (AMR) systems further enhanced metering by leveraging communication technologies such as Bluetooth, GSM, ZigBee, and Power Line Communication (PLC) for remote data acquisition.

Among these technologies, GSM-based metering provides real-time billing but is prone to network failures, leading to delayed or lost messages. PLC-based systems utilize existing power lines for data transmission but often suffer from interference and reliability concerns. Short-range communication technologies like ZigBee and Bluetooth have limited range, making them unsuitable for large-scale implementations.

Existing metering solutions [3] typically provide energy consumption feedback at the end of the billing cycle, preventing real-time tracking and proactive energy management. Additionally, meter tampering and electricity theft remain major challenges, causing financial losses for utility providers. To address these limitations, our proposed IoT-based smart metering system with NodeMCU enables real-time monitoring, prepaid billing, and theft detection. By leveraging Wi-Fi connectivity instead of GSM, the system ensures cost-effective, secure, and reliable data transmission, significantly improving energy efficiency and consumer control.

3. SYSTEM ARCHITECTURE

The system design of the smart energy meter is illustrated in Figure 1. It involves Arduino, optocoupler, 16×2 LCD Inductive Bulb, NodeMCU and other essential Components.

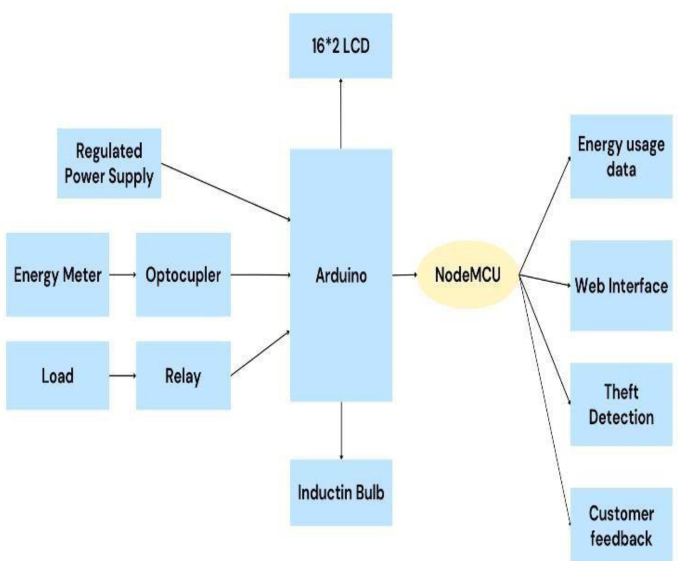

Figure 1 Block Diagram of IoT-Based Smart Metering System with Power Theft Detection

3.1 Arduino Uno

The Arduino Uno is use for processing input signals and controlling output devices. It is a microcontroller borad. Its features multiple digital and analog pins, a USB port for programming, and a power input jack. The board is programmed using the Arduino IDE, making it easy to integrate with sensors, displays, and communication modules.

3.2 16×2 LCD Display

The 16×2 LCD module displays essential data such as electricity consumption, alerts, and system status. It has two rows with 16 character spaces each. The display receives commands from the microcontroller and updates in real time, providing clear visual feedback.

3.3 NodeMCU (ESP8266)

NodeMCU is a microcontroller with built-in Wi-Fi for wireless communication. It transmits power consumption data to an online platform, enabling remote monitoring. It also sends real-time notifications and alerts for electricity usage, billing, and tampering detection.

3.4 Relay Module

The relay module acts as an electrically controlled switch, enabling automatic power control. If unauthorized usage or overload is detected, the relay disconnects the circuit to prevent damage and ensure safety.

3.5 Inductive Energy Meter

This meter measures electricity consumption and sends readings to the microcontroller. The data is used for billing calculations and theft detection, ensuring accurate power tracking.

3.6 Indication Bulb

The indication bulb provides visual alerts for system events. It signals power status, warnings, and unauthorized access detection.

4. METHODOLOGY

The Wireless IoT-based Smart Metering System with Power Theft Detection is designed for efficient energy monitoring, automated billing, and enhanced security against unauthorized electricity usage. The system integrates Arduino Uno[4] [5] [6], NodeMCU (ESP8266), ESP32, a 16×2 LCD display, a relay module, and an inductive energy meter to facilitate effective power management.

NodeMCU enables wireless communication, allowing real-time monitoring and data transmission to an online platform. The Arduino Uno processes energy consumption data and controls the relay module, which disconnects the power supply in cases of excessive usage or unauthorized access. The ESP32 enhances data processing capabilities and ensures smooth system performance. The LCD display provides real-time feedback on electricity usage and alerts users about system events.

All collected data is securely stored in a MySQL database on the service provider's server. If the recorded energy consumption exceeds a predefined threshold, automated actions are triggered to regulate usage and maintain system stability. MySQL is chosen for its efficiency, reliability, and ease of integration, making it suitable for real-time data handling[7].

4.1 Key Features:

4.1.1 IoT-Based Connectivity – Uses Wi-Fi for seamless data transmission, eliminating GSM dependency .

4.1.2 Pay-Per-Use System – Ensures electricity is provided only for the amount paid by the user[8][9].

4.1.3 Automatic Power Cut-off – Disconnects power in case of excessive consumption or tampering

4.1.4 Theft Detection – Detects unauthorized electricity usage and triggers instant alerts[10][11].

4.1.5 Live Monitoring – Displays real-time electricity usage on an LCD screen and updates the web platform.

4.1.6 Automated Billing – Calculates and sends electricity bills digitally based on actual consumption [12][13].

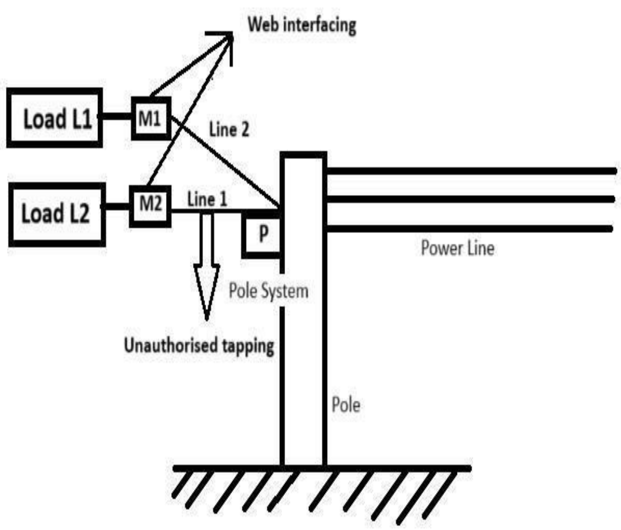

Figure 2 Power theft detection

5. HARDWARE IMPLEMENTATION

The hardware implementation integrates various components to enable real-time energy monitoring, automated billing, theft detection, and secure power management. The power supply unit, comprising a step-down transformer, rectifier, and voltage regulator, provides a stable 5V supply to power the Arduino Uno and other components. The Arduino Uno acts as the central controller, processing energy data and managing components like the relay, LCD, and communication modules. The NodeMCU (ESP8266) ensures IoT connectivity by transmitting real-time data, such as energy usage and alerts, to a web server. The ESP32 module supports advanced processing and faster communication. The energy meter, isolated by an optocoupler, measures electricity consumption, while the relay module disconnects power during excessive use or theft detection. A 16×2 LCD display provides local feedback on energy usage, and an indication bulb serves as a visual alert for key events.[14]

Data transmitted accessible via a web interface. Theft detection compares pole meter readings with individual consumption to identify discrepancies, triggering alerts for immediate action. This system ensures efficient, secure, and user-friendly energy management. [15]

6. RESULTS AND DISCUSSIONS

The proposed IoT-based smart metering system enhances energy monitoring, automates billing, and improves security against unauthorized electricity use.

Figure 3 represent the complete hardware implementation of the smart metering system, showcasing its various components and their integration. This model efficiently detects overload conditions, automates bill generation, and incorporates theft detection mechanisms. Unauthorized power access is immediately identified, triggering alerts and disconnecting the supply to prevent misuse.

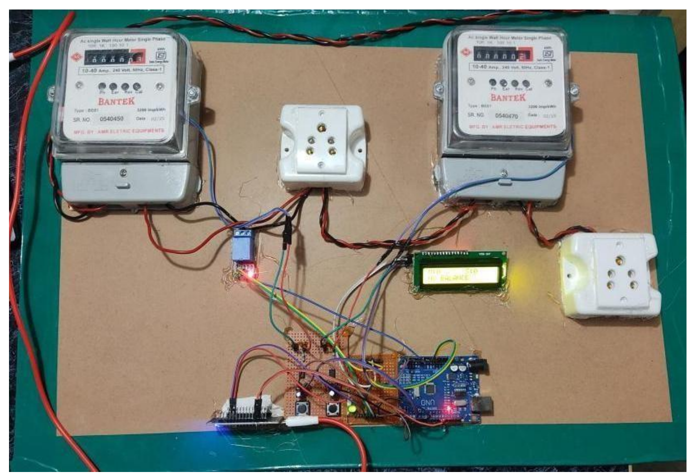

Figure 3 Hardware implementation of the smart metering system

Figure 4 illustrates the main interface of the smart energy meter, displaying real-time voltage, current, power consumption, and available balance. It allows users to monitor energy usage and check their remaining balance.

Figure 4 Web Dashboard Interface

Figure 5 showcases the theft detection mechanism, which identifies unauthorized power access, triggers alerts, and disconnects the supply to prevent theft.

Figure 5 Theft Detection Message

Figure 6 illustrates the overload detection mechanism, where the system continuously monitors power consumption and automatically disconnects the supply if it exceeds the predefined threshold. This ensures the protection of electrical appliances and prevents potential hazards like overheating or circuit damage.

Figure 6 Overload Detection Message

7. CONCLUSION

The proposed Wireless IoT-Based Smart Metering System offers an efficient and intelligent approach to energy management by incorporating real-time monitoring, automated billing, and power theft detection. By utilizing Arduino, NodeMCU, and an inductive energy meter, the system ensures accurate energy tracking and secure power distribution. The integration of IoT technology allows users and authorities to remotely monitor energy usage, enhancing transparency and efficiency. Key functionalities such as overload detection, pay-per-use billing, and automatic disconnection help in preventing energy wastage and unauthorized usage. This system not only reduces manual effort but also promotes sustainable energy consumption. Future improvements may include advanced data analytics and machine learning for predictive energy management.

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