

SMART ENERGY METER WITH ENCRYPTED MOBILE CONNECTIVITY FOR REAL-TIME MONITORING AND CONTROL

Bhanu Shree K A
Dept of CSE
C Byregowda institute
of Technology
bhanushreeka2004@gmail.com

Bhumika R
Dept of CSE
C Byregowda institute
of Technology
bhumikar6604@gmail.com

Varsha M S
Dept of CSE
C Byregowda institute
of Technology
vvarshams2004@gmail.com

Varsha R J
Dept of CSE
C Byregowda institute
of Technology
varsharj05@gmail.com

Pavithra L
Asst. Prof Dept of CSE
C Byregowda institute of Technology
pavithra.cbit@gmail.com

Abstract: This paper presents a comprehensive IoT-based Smart Energy Meter system that enables real-time monitoring, secure communication, automated billing, and electricity theft detection. The system integrates ESP32 microcontroller, ACS712 current sensor, relay modules, and Firebase cloud infrastructure[1],[2] Android applications for administrators and users. The system ensures transparency, reduces manual intervention, and enhances efficiency in electricity management. Experimental results demonstrate accurate monitoring, fast response to abnormal conditions, and reliable cloud synchronization.

Keywords: IoT, Smart Meter, ESP32, Firebase, Energy Monitoring, Automation, Theft Detection

I. INTRODUCTION

Electricity consumption is rapidly increasing due to urbanization and digital transformation. Traditional metering systems rely on manual readings,

which introduce delays, inaccuracies, and lack of transparency. Consumers are unable to track real-time usage, leading to inefficient energy consumption and higher costs. Moreover, electricity theft remains a major challenge for utility providers. The integration of Internet of Things (IoT) technologies provides a powerful solution to these issues. The proposed smart energy meter system enables real-time monitoring, automated billing, and secure communication. It enhances user awareness, improves operational efficiency, and minimizes losses. This system is designed to support smart homes and scalable smart grid environments. Electricity consumption is rapidly increasing due to urbanization and digital transformation. Traditional metering systems rely on manual readings, which introduce delays, inaccuracies, and lack of transparency. Consumers are unable to track real-time usage, leading to inefficient energy consumption and higher costs. Moreover, electricity theft remains a major challenge for utility providers. The integration of Internet of Things (IoT) technologies provides a powerful solution to these issues. The proposed smart energy meter system enables real-time monitoring, automated billing, and secure communication. It enhances user awareness, improves operational efficiency, and minimizes losses. This system is designed to support smart homes and scalable smart grid environments. [1]

II. LITERATURE SURVEY

Existing research on IoT-based energy meters highlights significant advancements in monitoring technologies. Several systems utilize sensors and wireless communication to transmit energy data to cloud platforms. However, most existing solutions are limited to monitoring and lack integrated billing systems. Some systems focus on theft detection but fail to provide real-time alerts and user interaction. Other approaches rely on web dashboards instead of mobile applications, reducing accessibility. The proposed system addresses these limitations by integrating monitoring, control, billing, and security into a single platform. It ensures seamless interaction between hardware, cloud, and users. Existing research on IoT-based energy meters highlights significant advancements in monitoring technologies. Several systems utilize sensors and wireless communication to transmit energy data to cloud platforms. However, most existing solutions are limited to monitoring and lack integrated billing systems. Some systems focus on theft detection but fail to provide real-time alerts and user interaction [2]. Other approaches rely on web dashboards instead of mobile applications, reducing accessibility. The proposed system addresses these limitations by integrating monitoring, control, billing, and security into a single platform. It ensures seamless interaction between hardware, cloud, and users.

III. SYSTEM REQUIREMENTS

The system requires both hardware and software components to function effectively. Hardware components include ESP32 microcontroller, ACS712 current sensor, relay module, OLED display, and buzzer. Software components include Android Studio for mobile application development and Firebase for backend services. Functional requirements include real-time monitoring, automated billing, theft detection, and remote control. Non-functional requirements include performance, scalability, security, and reliability. The system must ensure low latency communication and accurate data synchronization. [6] The system requires both hardware and software components to function effectively. Hardware components include ESP32 microcontroller, ACS712 current sensor, relay module, OLED display, and buzzer. Software components include Android

Studio for mobile application development and Firebase for backend services. Functional requirements include real-time monitoring, automated billing, theft detection, and remote control. Non-functional requirements include performance, scalability, security, and reliability. The system must ensure low latency communication and accurate data synchronization.

IV. PROPOSED SYSTEM

The proposed system is designed using ESP32 microcontroller as the central unit. It continuously collects current data using ACS712 sensor and processes it to calculate energy consumption. The processed data is uploaded to Firebase cloud for real-time synchronization. The system supports two types of users: administrator and consumer. The administrator can control sessions, monitor multiple houses, and manage billing. The consumer can view real-time usage, receive alerts, and track payments. The system also includes theft detection, which identifies abnormal current spikes and triggers automatic disconnection. The proposed system is designed using ESP32 microcontroller as the central unit. It continuously collects current data using ACS712 sensor and processes it to calculate energy consumption. The processed data is uploaded to Firebase cloud for real-time synchronization. The system supports two types of users: administrator and consumer. The administrator can control sessions, monitor multiple houses, and manage billing. The consumer can view real-time usage, receive alerts, and track payments. The system also includes theft detection, which identifies abnormal current spikes and triggers automatic disconnection. [3]

V. SYSTEM DESIGN

The system architecture consists of three layers: hardware layer, cloud layer, and application layer. The hardware layer performs sensing and control operations. The cloud layer stores and synchronizes data using Firebase database. The application layer provides interfaces for users and administrators. Data flows from sensors to ESP32, then to Firebase, and finally to mobile applications. This layered approach ensures scalability, maintainability, and efficient communication. The system architecture consists of three layers: hardware layer, cloud layer, and application layer. The hardware layer performs sensing and control operations. The cloud layer stores and synchronizes data using Firebase database. [4][6] The application layer provides interfaces for users and administrators. Data flows from sensors to ESP32, then to Firebase, and finally to mobile applications. This layered approach ensures scalability, maintainability, and efficient communication. The three layers are explained below:

A. Device Layer

The device layer which constitutes the physical hardware foundation of the system. Built upon the ESP32 microcontroller and ACS712 current sensors, this layer is responsible for local edge computing tasks, including reading current parameters, executing theft detection logic, and controlling peripheral actuators such as relays, the OLED display.

B. Cloud Layer

The second layer is Cloud layer, which serves as the central communication bridge utilizing the Firebase Realtime Database. This layer is

responsible for storing all live data and system status flags pushed by the hardware, ensuring instantaneous synchronization across the network.

C. Application Layer

The Application layer encompasses the client-side interfaces and notification services. It includes custom Android Applications for both Administrators and Users, alongside an SMS gateway service. The admin app utilizes the cloud bridge to issue command signals such as session initiation or forced disconnection while the user app retrieves usage data for monitoring. Simultaneously, the notification service actively monitors Firebase database triggers to dispatch corresponding SMS alerts during critical events, completing the feedback loop as shown in the below Fig 1.

Flow of Fig 1:

The ESP32 Smart Meter reads current using ACS712, processes theft logic, and controls relays, OLED, and buzzer. It pushes real-time data (current, status flags) to Firebase. Admin App and User App read/write from Firebase: Admin sends session and disconnection commands. User primarily reads usage and status. A Notification/SMS Service (via Cloud Functions or external API) listens for specific changes in Firebase and sends corresponding SMS alerts.

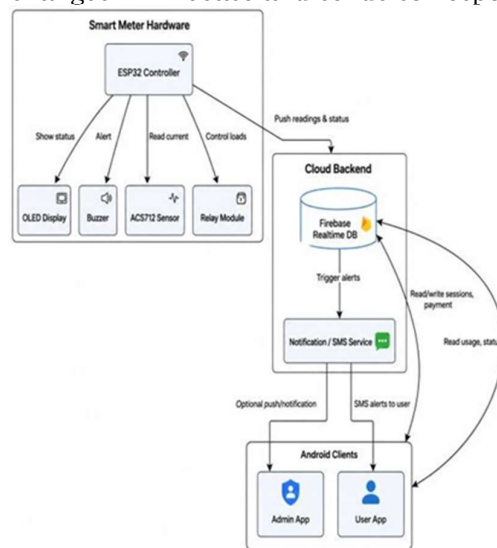


Fig 1: System design

VI. IMPLEMENTATION

The implementation involves integrating hardware components and developing software applications. The ESP32 is programmed using Arduino IDE to read sensor data and control relays. The ACS712 sensor measures current consumption and sends analog signals to ESP32. The Android application is developed using Android Studio with Java and XML. Firebase is used for real-time data storage and synchronization. The system is tested under various conditions

to ensure accuracy and reliability. The implementation involves integrating hardware components and developing software applications. The ESP32 is programmed using Arduino IDE to read sensor data and control relays. The ACS712 sensor measures current consumption and sends analog signals to ESP32. The Android application is developed using Android Studio with Java and XML. Firebase is used for real-time data storage and synchronization. The system is tested under various conditions to ensure accuracy and reliability. [3][5]

VII. TESTING

The system undergoes multiple testing phases to validate its functionality. Unit testing verifies individual components such as sensors and relays. Integration testing ensures proper communication between hardware and software. System testing evaluates the overall performance under real-world conditions. The results confirm that the system accurately monitors energy consumption and detects unauthorized usage. The system undergoes multiple testing phases to validate its functionality. Unit testing verifies individual components such as sensors and relays. Integration testing ensures proper communication between hardware and software. System testing evaluates the overall performance under real-world conditions. The results confirm that the system accurately monitors energy consumption and detects unauthorized usage. [7]

VIII. RESULTS AND DISCUSSION

The results demonstrate that the system provides accurate real-time monitoring of electricity usage. It successfully detects abnormal usage and triggers alerts. The automated billing system reduces manual effort and improves efficiency. The mobile application enhances user interaction and transparency. The system shows high reliability and scalability for real-world deployment. The results demonstrate that the system provides accurate real-time monitoring of electricity usage. It successfully detects abnormal usage and triggers alerts. The automated billing system reduces manual effort and improves efficiency. The mobile application enhances user interaction and transparency. The system shows high reliability and scalability for real-world deployment.

IX. CONCLUSION AND FUTURE WORK

The proposed smart energy meter system offers a comprehensive solution for modern energy management. It integrates monitoring, billing, and security features into a single platform. The system improves efficiency, reduces losses, and enhances user awareness. Future work includes integration with online payment systems, AI-based prediction models, and large-scale smart grid deployment. Further improvements can enhance security and system performance. The proposed smart energy meter system offers a comprehensive solution for modern energy management. It integrates monitoring, billing, and security features into a single platform. The system improves efficiency, reduces losses, and enhances user awareness. Future work includes integration with online payment systems, AI-based prediction models, and large-scale smart grid deployment. Further improvements can enhance security and system performance..

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