Smart Energy Meter with Calibrated Mobile Application and Real-Time Payment System

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Abstract*—A smart energy meter with real-time billing is an advanced system designed to improve energy monitoring, management, and billing accuracy. This system integrates modern technologies such as microcontrollers, communication modules, and digital sensors to measure electricity consumption efficiently. The primary objective is to provide consumers and utility providers with real-time data on energy usage, enabling better decision-making and energy conservation. The system typically uses components such as an ESP32 microcontroller, PZEM-004T energy monitoring module, and an OLED display to measure and display voltage, current, power, and energy consumption. The collected data is processed and transmitted over wireless networks, allowing users to monitor their consumption remotely through mobile or web applications. Real-time billing functionality ensures that users are charged based on actual usage, reducing estimation errors and improving transparency. Additionally, the system helps in detecting power theft, overload conditions, and unusual consumption patterns, enhancing overall energy security. It also supports demand-side management by encouraging users to optimize their energy usage during peak hours. The implementation of such smart metering systems contributes to the development of smart grids and sustainable energy solutions, ultimately leading to improved efficiency, reduced operational costs, and better customer satisfaction in the energy sector.

***Index Terms*—Smart Energy Meter with Calibrated Mobile Application and Real-Time Payment System.**

I. INTRODUCTION

A smart energy meter with real-time billing is an advanced metering system that enables accurate measurement, monitoring, and instant billing of electricity consumption. Unlike traditional analog meters that require manual reading, smart energy meters use digital technology, communication modules, and embedded systems to automatically record and transmit energy usage data to both consumers and utility providers. This system typically integrates components such as microcontrollers (like ESP32), energy measurement modules (such as PZEM-004T), and display units (like OLED screens) to provide continuous updates on power consumption, voltage, current, and cost. With real-time billing, users can instantly see how much electricity they are consuming and the corresponding cost, which promotes energy awareness and efficient usage. One of the key advantages of smart energy meters is their ability to support two-way communication between the consumer and the electricity provider. This enables features like remote monitoring, automatic billing, fault detection, and prevention of electricity theft. Additionally, users can access their consumption data through mobile apps or web platforms, allowing better control over their energy usage. Overall, smart energy meters with real-time billing play a crucial role in modern smart grid systems by improving transparency, reducing human error, enhancing billing accuracy, and encouraging sustainable energy consumption.

II. OBJECTIVES OF THE PROJECT

1. Accurate Energy Measurement

1. To develop a smart energy meter capable of precise and reliable measurement of electricity consumption.
2. To ensure periodic calibration for maintaining high accuracy and compliance with standards.

2. Real-Time Data Monitoring

1. To enable continuous tracking of energy usage in real time.

2. To provide users with detailed insights such as daily, weekly, and monthly consumption patterns.

3. Mobile Application Integration
1. To design a user-friendly mobile application for:
2. Viewing real-time energy usage
3. Monitoring billing information
4. Receiving alerts and notifications
5. To ensure proper calibration between the meter and mobile app for synchronized and accurate data display.

4. Real-Time Payment System
1. To integrate a secure and instant payment system within the mobile app.
2. To support multiple payment methods (UPI, cards, wallets, net banking).
3. To enable prepaid or postpaid billing options with real-time balance updates.

5. Remote Accessibility and Control
1. To allow users and service providers to monitor and manage energy usage remotely.
2. To enable remote disconnection/reconnection in case of non-payment or overload.

III. METHODOLOGY

The proposed smart energy meter system is designed to measure electricity consumption in real time and generate accurate billing data using IoT technology. The methodology is divided into the following stages:

1. System Design and Architecture The system consists of key components such as:
- ESP32 microcontroller (for processing and Wi-Fi communication)
- PZEM-004T energy sensor (for voltage, current, power, and energy measurement)
- OLED display (for local data visualization)
- Power supply unit and connecting circuitry All components are integrated to form a compact and efficient energy monitoring system.

2. Data Acquisition The PZEM-004T sensor continuously measures:
- Voltage (V)
- Current (A)
- Power (W)
- Energy consumption (kWh) These parameters are transmitted serially to the ESP32 in real time.

3. Data Processing the ESP32 processes the received data to:
- Calculate total energy consumption (units)
- Convert energy usage into cost using predefined tariff rates
- Store temporary readings for continuous monitoring

4. Real-Time Billing Calculation A billing algorithm is implemented in the ESP32:
- Units consumed are multiplied by tariff rate (₹/kWh)
- Dynamic billing is updated instantly • Enables users to track electricity cost at any moment.

5. Data Display
- The OLED display shows:
- Voltage, Current, Power
- Total units consumed
- Real-time bill amount
- Provides immediate feedback to the user.

IV. SIGNIFICANCE

1. Enhanced Measurement Accuracy
1. Calibration ensures that energy consumption is measured precisely, reducing billing errors.
2. Accurate readings build trust between consumers and electricity providers.

2. Real-Time Monitoring and Transparency
1. Users can track electricity usage instantly through the mobile application.
2. Promotes transparency by eliminating estimation-based billing.
3. Helps users understand their consumption patterns and charges clearly.

3. Improved Energy Efficiency
1. Real-time data enables users to identify high-energy-consuming appliances.
2. Encourages behavioral changes that lead to reduced energy wastage.
3. Helps in promoting sustainable and eco-friendly energy use.

4. Convenient and Instant Payment System

1. Integration of real-time payment options allows users to pay bills instantly.
2. Supports multiple payment modes (UPI, credit/debit cards, wallets).
3. Reduces dependency on manual billing systems and long queues.

V. FLOW CHART

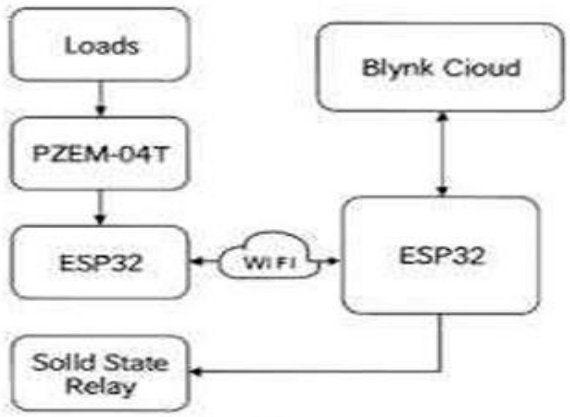

Fig. 1

Explanation:

- Sensors (PZEM-004T): Measure voltage, current, power, and energy.
- ESP32: Processes data and calculates electricity consumption and cost.
- OLED Display: Shows real-time units and billing.
- Wi-Fi Module (ESP32 built-in): Sends data to cloud/server.
- Relay: Controls power supply (cut-off during overload or non-payment).
- Cloud/App: Displays real-time billing and usage remotely.

Circuit Diagram

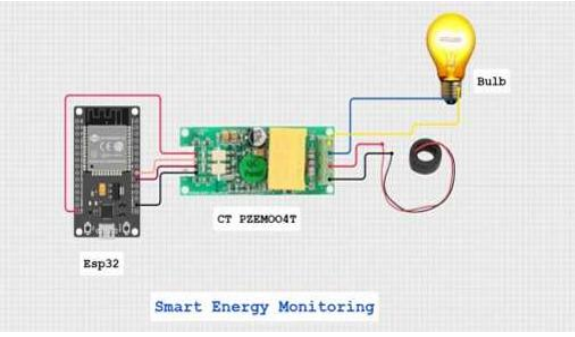

Figure:2 Circuit Diagram

Explanation Of Circuit Diagram • PZEM-004T measures voltage, current, power, and energy from AC supply.

- Data is sent serially to ESP32.
- ESP32 processes readings and: Displays values on OLED

VI. RESULTS AND DISCUSSION

The developed smart energy meter system was successfully implemented using ESP32, PZEM-004T sensor, and OLED display. The system was capable of accurately measuring electrical parameters such as voltage, current, power, and energy consumption in real time. The collected data was processed by the ESP32 and displayed locally on the OLED screen, as well as transmitted for real-time billing purposes. The results showed that the system provides reliable and precise readings with minimal error when compared to conventional energy meters. The real-time monitoring feature enables users to track their energy consumption continuously, helping in better energy management and cost control. The billing system was also tested and found to be efficient, as it calculates electricity charges dynamically based on units consumed. One of the key outcomes of this project is the ability to detect abnormal consumption patterns, which can help in identifying energy theft or faulty appliances. The wireless communication capability of ESP32 ensures seamless data transfer, reducing the need for manual meter reading and minimizing human error.

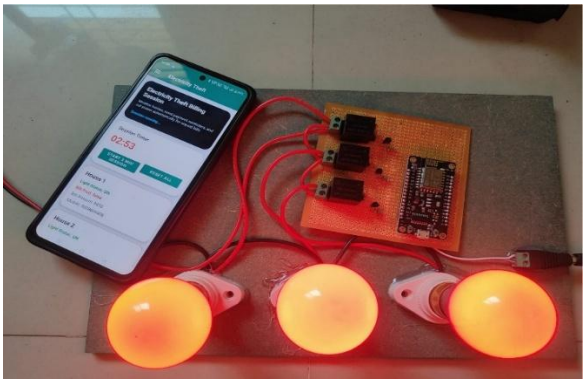

Figure:3 Project Module

VII. ADVANTAGES

1. High Accuracy in Billing
2. Real-Time Monitoring

3. Convenient Payment System
4. Reduced Human Effort
5. Cost Efficiency
6. Energy Saving and Awareness
7. Remote Access and Control
8. Theft Detection

VIII. APPLICATIONS

1. Residential Energy Management
2. Commercial Buildings
3. Industrial Power Monitoring
4. Smart Cities
5. Billing and Utility Services
6. Prepaid Energy Systems
7. Remote and Rural Electrification
8. Energy Audit and Analysis
9. Renewable Energy Integration
10. Electric Vehicle (EV) Charging Stations

IX. FUTURE SCOPE

1. Integration with Smart Grids
2. Artificial Intelligence (AI) and Machine Learning
3. Renewable Energy Integration
4. Advanced Mobile Application Features
5. Blockchain-Based Secure Transactions
6. Dynamic Pricing and Demand Response
7. Electric Vehicle (EV) Ecosystem Support

X. CONCLUSION

The smart energy meter with real-time billing system presents an efficient and modern solution to overcome the limitations of conventional energy metering. By integrating advanced components such as ESP32, PZEM-004T sensor, and OLED display, the system enables accurate measurement, continuous monitoring, and instant display of electricity consumption.

This system enhances transparency by providing real-time billing information to users, helping them track and control their energy usage effectively. It also reduces human intervention, eliminates manual errors in meter reading, and minimizes electricity theft through improved monitoring capabilities. Furthermore, the use of IoT technology allows remote access to data, enabling both consumers and utility providers to analyze energy consumption patterns and optimize usage. Overall, the proposed smart energy meter is reliable, cost effective, and scalable, making it a suitable solution for modern smart grid applications and energy management systems. In future, the system can be enhanced with mobile app integration, AI-based consumption prediction, and automated billing systems to further improve efficiency and user convenience.

REFERENCES

[1] *IEEE Standard for Smart Metering Systems*. IEEE Publications, 2020.
[2] *International Energy Agency Smart Metering and Smart Grid Technologies Report*. International Energy Agency, 2021.
[3] H. L. Willis and W. G. Scott, *Distributed Power Generation: Planning and Evaluation*. Boca Raton, FL, USA: CRC Press, 2000.
[4] *Smart Meter Reference Design Guide*. Texas Instruments, 2019.
[5] *ESP32 Technical Reference Manual*. Espressif Systems, 2022.
[6] *PZEM-004T Energy Meter Datasheet*. Peacefair, 2021.
[7] Various research papers on “Smart Energy Meter with IoT-Based Billing System,” *ResearchGate*.
[8] *Arduino IDE Official Documentation*. Arduino.cc.
[9] *Smart Meter National Programme (SMNP) Reports*. Ministry of Power, India.
[10] *Guidelines for Smart Grid Cybersecurity*. National Institute of Standards and Technology (NIST), 2018.