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REAL-TIME ENERGY MONITORING AND COST ESTIMATION USING AN IOT-ENABLED SMART METERING SYSTEM

K. BHARATHI [1*] | K.VENU [2] | K.SRINIVASARAO [3] | M.MANOHAR [4] | R.NARAYANARAO [5]

[1] ASSISTANT PROFESSOR, DEPARTMENT OF EEE, AVANTHI INSTITUTE OF ENGINEERING AND TECHNOLOGY, TAGARAPUVALASA, INDIA.

[2,3, 4, 5] STUDENT, DEPARTMENT OF EEE, AVANTHI INSTITUTE OF ENGINEERING AND TECHNOLOGY, TAGARAPUVALASA, INDIA.

ABSTRACT:

The increasing demand for efficient energy utilization necessitates the development of intelligent monitoring systems capable of real-time data acquisition and analysis. Conventional energy meters lack the capability to provide continuous monitoring and remote accessibility, resulting in inefficient energy management. This paper presents the design and implementation of an Internet of Things (IoT)-enabled smart energy meter capable of real-time measurement of electrical parameters such as voltage, current, and energy consumption along with cost estimation. The proposed system integrates voltage and current sensors with a microcontroller-based processing unit to compute instantaneous power and cumulative energy consumption. The system transmits data through IoT communication modules, enabling remote monitoring via mobile or cloud platforms. Additionally, GSM-based communication is incorporated for user interaction and alert notifications. Experimental validation demonstrates accurate measurement and real-time visualization of electrical parameters. The developed system provides a cost-effective, scalable, and efficient solution for modern smart grid and energy management applications.

KEYWORDS:

IOT ENERGY METER, SMART METERING, REAL-TIME MONITORING, VOLTAGE SENSOR, CURRENT SENSOR, GSM COMMUNICATION, ENERGY COST ESTIMATION, EMBEDDED SYSTEMS.

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INTRODUCTION

The rapid growth in electrical energy consumption has intensified the need for intelligent monitoring and control systems to ensure efficient utilization of resources. Traditional energy meters primarily focus on cumulative energy measurement and require manual data collection, leading to inefficiencies and inaccuracies [1]. With the advancement of Internet of Things (IoT) technologies, energy monitoring systems have evolved toward automation, real-time data acquisition, and remote accessibility [2].

IoT-based smart energy meters enable continuous monitoring of electrical parameters such as voltage, current, and power consumption, thereby enhancing transparency and control over energy usage [3]. These systems utilize embedded processors and communication modules to transmit data to cloud platforms, allowing users to access consumption data from anywhere [4]. Real-time monitoring plays a crucial role in identifying energy wastage and optimizing consumption patterns in residential and industrial environments [5].

The integration of sensors such as ACS712 for current measurement and voltage divider circuits for voltage sensing has significantly improved measurement accuracy in low-cost systems [6]. Furthermore, GSM and Wi-Fi communication technologies enable reliable data transmission and remote interaction with users [7]. Cloud-based analytics platforms facilitate storage and visualization of large datasets, enabling long-term consumption analysis [8].

Modern smart meters also incorporate cost estimation features, allowing users to monitor electricity expenses based on tariff structures [9]. This capability promotes energy conservation by encouraging users to adopt efficient consumption practices. Additionally, IoT-enabled systems support smart grid applications, demand-side management, and renewable energy integration [10].

Despite these advancements, there remains a need for cost-effective and scalable solutions suitable for widespread deployment, particularly in developing regions. This paper addresses this gap by proposing a low-cost IoT-enabled energy meter with real-time monitoring and cost estimation capabilities.

MATERIALS AND METHODS:

The proposed system consists of sensing units, a processing unit, communication modules, and a display interface. The architecture integrates voltage and current sensors with a microcontroller to compute electrical parameters and transmit data to users.

HARDWARE COMPONENTS

1. Microcontroller (Arduino/ARM-based): Acts as the central processing unit for data acquisition and computation.
2. Voltage Sensor (ZMPT101B): Measures AC voltage and provides scaled analog output.
3. Current Sensor (ACS712): Measures load current using Hall-effect sensing.
4. Relay Module: Enables load control and protection.
5. LCD Display (16×2): Displays real-time voltage, current, and cost.
6. GSM Module: Provides communication through SMS commands.
7. Energy Meter Module: Measures actual energy consumption.

The system measures instantaneous voltage V and current I, and computes power using:

$$P = V \times I$$

Energy consumption is calculated as:

$$E = \int P(t)dt$$

Cost estimation is performed using:

$$Cost = E \times Tariff\ Rate$$

The system uses GSM communication for remote interaction. Users can send predefined SMS commands to retrieve energy usage and billing information. The IoT integration allows cloud-based monitoring for real-time analytics.

RESULTS:

The experimental setup shown in **Fig. 1** illustrates the complete hardware implementation of the proposed IoT-enabled energy meter. The system consists of interconnected modules including the microcontroller board, sensors, relay, LCD display, and energy meter unit. The wiring connections demonstrate proper interfacing between sensing and processing units.

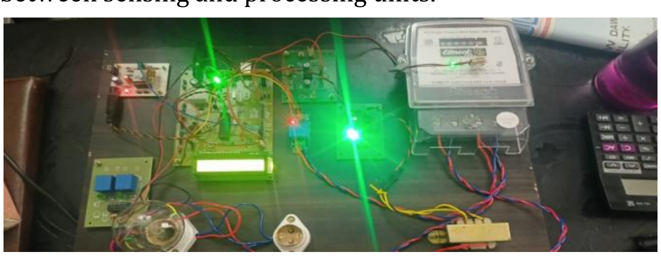

FIG. 1: EXPERIMENTAL SETUP OF IOT-BASED ENERGY METER SYSTEM.

The presence of LED indicators confirms active operation and signal flow within the system. The setup validates the feasibility of real-time monitoring and control of electrical parameters. The integration of GSM and IoT modules ensures remote accessibility. The compact design highlights its suitability for practical deployment. The system successfully demonstrates stable operation under real-time conditions.

FIG. 2: LCD DISPLAY SHOWING REAL-TIME VOLTAGE AND CURRENT MEASUREMENTS.

The LCD display in **Fig. 2** presents real-time electrical parameters measured by the system. The voltage reading of approximately 217 V indicates accurate sensing of supply voltage. The current measurement displayed confirms proper functioning of the ACS712 sensor. The continuous update of readings demonstrates real-time data acquisition capability. The display also shows system identifiers and operational status. The clarity of the display ensures user-friendly monitoring. The results validate the accuracy of sensor integration and microcontroller processing. This confirms the system's effectiveness in local monitoring applications.

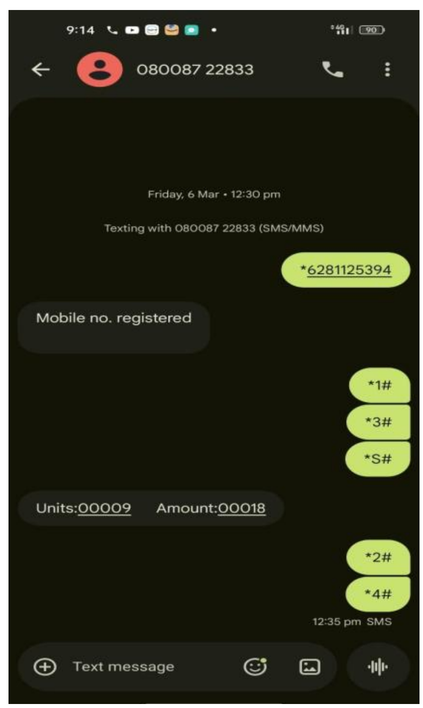

FIG. 3: GSM-BASED USER INTERACTION FOR ENERGY MONITORING

The GSM communication interface shown in **Fig. 3** demonstrates remote interaction between the user and the energy meter system. The user sends predefined SMS commands to retrieve energy consumption and cost information. The system responds with units consumed and corresponding billing amount. The successful exchange of messages confirms reliable communication. This feature eliminates the need for manual meter reading. It enhances user convenience by providing instant access to energy data. The GSM-based system is particularly useful in areas with limited internet connectivity. The results confirm the effectiveness of remote monitoring functionality.

DISCUSSION:

The results demonstrate that the proposed IoT-enabled energy meter provides accurate and reliable measurement of electrical parameters. The integration of voltage and current sensors ensures precise data acquisition, while the microcontroller efficiently processes and computes energy consumption. The real-time display and GSM communication significantly enhance user accessibility and convenience. Compared to traditional meters, the proposed system offers continuous monitoring and eliminates manual data collection. The cost estimation feature provides transparency in electricity usage, encouraging energy-saving behaviour. The system also supports remote monitoring, making it suitable for smart grid and demand-response applications. However, certain limitations exist, such as dependency on communication networks and sensor calibration accuracy. Future improvements may include cloud-based analytics, machine learning integration, and renewable energy monitoring capabilities.

CONCLUSIONS:

This paper presented the design and implementation of an IoT-enabled smart energy meter for real-time monitoring of voltage, current, energy consumption, and cost. The system successfully integrates sensing, processing, and communication modules to provide accurate and remote monitoring capabilities. Experimental results validate the effectiveness of the proposed system in real-world applications.

The developed solution is cost-effective, scalable, and suitable for residential and industrial deployment. It contributes to improved energy management, reduced wastage, and enhanced consumer awareness. Future work may focus on integrating advanced analytics, smart grid compatibility, and renewable energy systems for enhanced performance.

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