

Smart Energy Meter with Real-Time Cost Display Using IoT

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Abstract: Energy monitoring and management have become essential in modern electrical systems due to increasing power demand and the need for efficient utilization. This paper presents the design and implementation of a smart energy meter using Arduino and ESP8266 for real-time monitoring of electrical parameters and cost estimation. The system measures voltage, current, power, and energy consumption and displays the results on a 16×2 LCD and a mobile application through Wi-Fi communication. The proposed system also incorporates protection mechanisms such as overvoltage and overcurrent protection using a relay module. Additionally, energy theft detection is implemented by comparing main and sub-meter readings. The system is cost-effective, reliable, and suitable for smart grid and home automation applications.

Key Word: IoT, Smart Energy Meter, Arduino, ESP8266, Energy Monitoring, Cost Estimation

I. Introduction

The rapid growth in electrical energy consumption has led to the development of intelligent monitoring systems to ensure efficient utilization of power resources. Conventional energy meters lack the capability of real-time monitoring and remote access, which limits user awareness regarding energy usage and cost.

With the advancement of Internet of Things (IoT) technology, smart energy meters have emerged as an effective solution for monitoring and controlling energy consumption. These systems provide real-time data, enabling users to analyze their usage patterns and optimize energy consumption.

The proposed system focuses on developing a smart energy meter using Arduino and ESP8266, which enables real-time monitoring of electrical parameters and displays data both locally and remotely. The system also enhances safety and reliability through automated protection mechanisms.

II. Material And Methods

This experimental hardware-based study was carried out in the Department of Electrical & Electronics Engineering at G. Pulla Reddy Engineering College, Kurnool, India during the academic year 2025–2026. The system was developed and tested using embedded hardware components and IoT communication modules. The study focuses on real-time monitoring of electrical parameters and cost estimation using a smart energy meter system.

Study Design: Experimental hardware implementation of an IoT-based energy monitoring system

Study Location: This study was conducted in the Electrical & Electronics Engineering laboratory at G. Pulla Reddy Engineering College, Kurnool, Andhra Pradesh, India

Study Duration: Academic year 2025–2026

Sample size: Prototype-based system (single hardware setup)

System design consideration: The system was designed based on real-time monitoring requirements using embedded systems and wireless communication. The components were selected based on availability, cost-effectiveness, and compatibility with Arduino and ESP8266 modules.

Subjects & system configuration method: The system consists of an Arduino Uno microcontroller interfaced with voltage and current sensors to measure electrical parameters. The ESP8266 Wi-Fi module is used to transmit data to a mobile device through TCP Telnet communication. A 16×2 LCD is used for local display of measured parameters. A relay module is included to control the load during abnormal conditions such as overvoltage and overcurrent.

The system operates under different load conditions to analyze performance. The measured parameters include voltage, current, power, and energy consumption. The calculated energy cost is displayed in real time. The system also compares main supply readings with load conditions to detect energy theft.

The system configuration is as follows:

System A: Arduino-based energy monitoring unit with voltage and current sensing
System B: ESP8266-based wireless communication module for mobile data transmission
System C: Protection and control unit using relay for load management

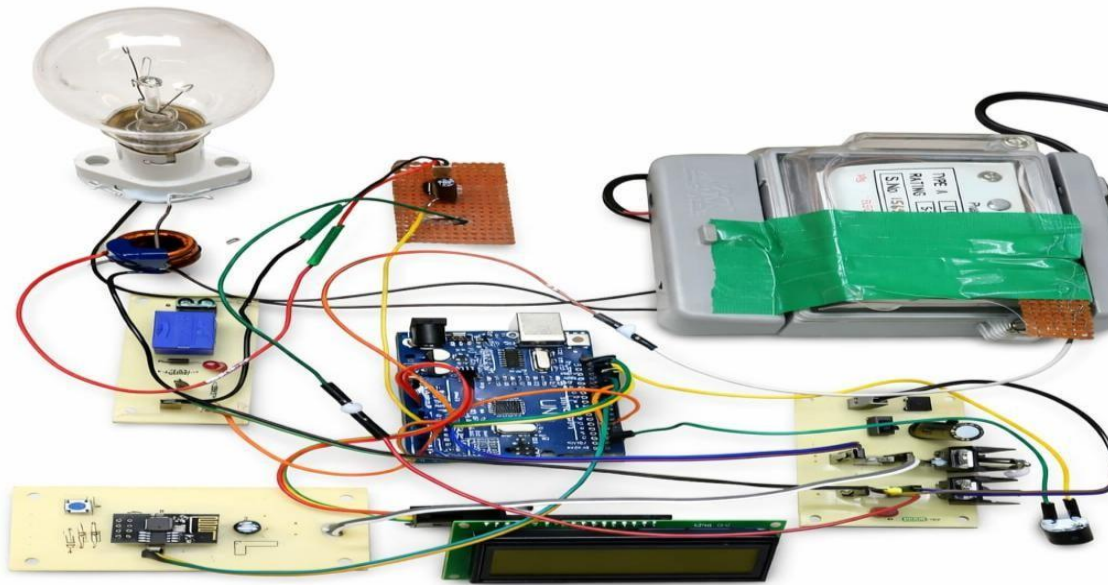
Procedure methodology

The system continuously acquires voltage and current measurements using appropriate sensors interfaced with the Arduino microcontroller. The acquired signals are processed to compute electrical parameters such as power and energy consumption. The corresponding energy cost is determined based on predefined tariff rates.

The processed data is displayed locally on a 16×2 LCD module and simultaneously transmitted to a mobile device through the ESP8266 Wi-Fi module using TCP Telnet communication. The system operates in real time and enables remote monitoring of energy parameters.

Additionally, the system incorporates protection mechanisms to detect abnormal operating conditions such as overvoltage and overcurrent. Upon detection of such conditions, the relay module automatically disconnects the load to ensure system safety.

Furthermore, an energy theft detection mechanism is implemented by comparing the measured values of the main supply and the load-side consumption. Any significant discrepancy between these values is identified as a potential theft condition, and an alert is generated and displayed on both the LCD and mobile interface.



Circuit Model



Display of ESP8266 IP Address on LCD Screen

Statistical analysis

The performance of the proposed system is evaluated in terms of accuracy, response time, and operational reliability. The measured electrical parameters, including voltage, current, power, and energy consumption, are validated by comparison with standard reference meter readings to ensure measurement accuracy.

The system efficiency and consistency are further assessed through repeated experimental trials conducted under varying load conditions. The results demonstrate stable performance, reliable data acquisition, and accurate real-time monitoring across different operating scenarios.

III. Result

The developed smart energy meter successfully measures electrical parameters such as voltage, current, power, and energy consumption in real time. The measured values are accurately displayed on the 16×2 LCD module, while the mobile interface enables effective remote monitoring through wireless communication.

The system performs real-time energy cost estimation based on the measured consumption and predefined tariff rates. The results indicate consistent and reliable operation under different load conditions.

Furthermore, the protection mechanism operates effectively by disconnecting the load during abnormal conditions such as overvoltage and overcurrent. The energy theft detection feature also demonstrates reliable performance by accurately identifying discrepancies between supply and load measurements under test conditions.

```
Connecting to 10.141.12.194 port 80, please wait...
```

```
Uts:4Bil:13.60CT:1LDR:646
```

```
AT+CIPSEND=0,4
```

```
Uts:6Bil:20.40CT:1LDR:836
```

```
AT+CIPSEND=0,4
```

```
Uts:8Bil:27.20CT:1LDR:833
```

```
AT+CIPSEND=0,4
```

```
Uts:10Bil:34.00CT:1LDR:839
```

```
AT+CIPSEND=0,
```

```
Uts:11Bil:37.40CT:0LDR:1023
```

Output Display on Mobile using TCP Telnet Application



Real-Time Data Display on LCD Screen

IV. Discussion

The implementation of the IoT-based smart energy meter demonstrates the effectiveness of integrating embedded systems with wireless communication technologies for real-time energy monitoring applications. In comparison with conventional energy meters, the proposed system offers enhanced functionalities, including real-time data acquisition, remote accessibility, and automated protection mechanisms.

The integration of the ESP8266 Wi-Fi module enables efficient and reliable wireless data transmission, while the Arduino microcontroller ensures accurate and stable processing of sensor data. The system exhibits consistent performance under varying operating conditions and supports real-time monitoring with minimal latency.

Furthermore, the proposed system is scalable and can be extended for advanced applications such as cloud-based data storage, predictive analytics, and integration with smart grid infrastructures, thereby enhancing its applicability in modern energy management systems.

V. Conclusion

The proposed IoT-based smart energy meter provides an efficient and reliable solution for real-time monitoring and cost estimation of electrical energy consumption. The integration of the Arduino microcontroller with the ESP8266 Wi-Fi module enhances system functionality by enabling remote data access and control capabilities.

The system demonstrates stable performance, accurate measurement of electrical parameters, and effective operation under varying load conditions. Its cost-effective design and ease of implementation make it suitable for practical deployment in residential and industrial energy management applications.

References

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