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Design And Implementation of a Low-Cost IoT Based Smart Energy Meter

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Abstract

Power demand has surged exponentially over the past century. As energy consumption grows, there is a need to upgrade the traditional electricity transmission and distribution network into an interactive service system. To minimize energy wastage, effective metering infrastructure is essential. With advancements in communication technology, modern products are increasingly designed with smart functionalities. In recent years, the Internet of Things (IoT) has facilitated the seamless connection of devices using sensors. This paper proposes an alternative strategy for estimating and charging energy usage, moving away from conventional methods. As part of the smart grid, smart meters, equipped with advanced metering infrastructures (AMI), are extensively distributed and connected to communication networks. This project introduces a novel, low-cost IoT-based smart energy meter (SEM). The proposed system allows users to monitor real-time data on supply voltage, current, frequency, and power consumption directly on their smartphones. Energy usage is measured in kWh, and the system is simulated using Proteus 8.15 software. An IoT platform is developed for remote, real-time monitoring of the metering infrastructure. Additionally, the ESP32 microcontroller is utilized for the design, fabrication, and operation of the IoT-based smart meter. The proposed SEM can also help energy companies to detect potential thefts and faults, thereby ensuring reliable service for their customers

Keywords

Smart Energy Meter, IoT, Proteus, Smart Grid and Low-cost.

1. Introduction

A smart energy meter is an advanced electronic device that measures and records electricity consumption in real time while enabling two-way communication between consumers and utility providers (Devadhanishini, 2019). Unlike traditional meters that only provide cumulative readings and require manual data collection, smart meters transmit detailed information such as voltage, current, and power usage, allowing accurate monitoring, efficient billing, outage detection, and identification of energy wastage or system faults (A. A. Adhau, Apr. 2013). IoT-based smart energy metering further enhances this capability by integrating internet-connected sensors that send real-time energy data to cloud platforms for analysis, helping users track consumption patterns, optimize energy use, and reduce costs (S. S. Ali, Dec. 2010). As a key component of smart grid infrastructure, these systems improve service reliability and promote sustainable energy management (K. Ashna and S. N. George, 2013). This project presents a low-cost IoT-based smart energy meter using the ESP32 Development Kit-1, selected for its low power consumption and high processing speed. The system combines embedded hardware and software with Wi-Fi connectivity to transmit real-time energy usage and billing data to a web page or mobile app, providing both consumers and service providers with continuous access to meter status and recorded readings (S. S. Ali, Dec. 2010) (K. Ashna and S. N. George, 2013).

The long-term aim of this project is to create an IoT-based smart energy meter with a wide range of features and functionalities. The objectives are divided into two sections: primary and secondary. The primary and secondary objectives outline the essential conditions that need to be met for the successful design and implementation of the system. The goal of the "Design and Implementation of a Low-Cost IoT-Based Smart Energy Meter" project is to develop an affordable and efficient energy monitoring system that leverages IoT technology to enable real-time tracking, remote access, and automated data transmission of electricity usage.

Primary objectives

- To implement the proposed metering system using Proteus Software.
- To develop an affordable and efficient energy monitoring system.
- To utilize the ESP32 microcontroller for wireless communication of data via IoT/app.
- To ensure the system is simple and intuitive for general users to understand and operate.
- To ensure that the system prevents users from exceeding the designated maximum voltage, current, power consumption limit.

Secondary Objectives

- To develop and implement a Smart Energy Meter that can be easily integrated into any home or industrial setting.
- To enable remote monitoring of energy consumption via the Internet.
- To minimize overall system cost by selecting affordable components and optimizing design for mass production.
- To develop a user-friendly mobile app interface
- To conduct overall testing of the hardware implementation.

2. Literature Review

The increasing concern over energy consumption and its environmental impact has accelerated the development of IoT-based smart energy meters as a modern solution for efficient energy management. Unlike traditional systems that rely on manual readings and provide limited feedback, IoT-enabled meters deliver real-time monitoring, remote access, and two-way communication between consumers and utility providers, enhancing awareness and efficiency in electricity usage (S.-W. Lee, 1996) (P. A. V. Loss, 2021). The use of low-cost embedded components, such as microcontrollers and Wi-Fi modules like the ESP32, makes these systems more accessible and suitable for widespread adoption, especially in developing regions, while allowing users to monitor voltage, current, and power consumption through web or mobile applications (S.-W. Lee, 1996) (R.R. Mohassel, 2014). Historically, energy metering evolved from early 20th-century electromechanical meters requiring manual readings to digital meters with improved accuracy, and eventually to smart grid-integrated meters in the early 2000s that enabled two-way communication (A.Moreno-Munoz and J. J. Gonzalez De La Rosa, 2008) (A.Rashdi, 2013). With the rapid advancement of IoT technologies in the 2010s, smart energy meters began incorporating wireless communication and cloud computing for real-time data access and advanced energy management, playing a crucial role in promoting sustainability and efficient energy distribution (Z.I. Rana, 2014).

2.1 Historical Background

The evolution of energy metering has progressed from early 20th-century electromechanical meters with analog dials and manual readings, which were prone to errors and inefficiencies, to more advanced systems driven by the need for greater accuracy and reliability (A.Moreno-Munoz and J. J. Gonzalez De La Rosa, 2008). In the late 20th century, digital meters improved measurement precision and introduced limited remote reading features, though they still lacked real-time monitoring capabilities. The early 2000s marked the emergence of smart grids, enabling two-way communication between consumers and utility providers, with smart energy meters becoming a key component for improved data management and control (A.Rashdi, 2013). With the rapid growth of IoT technology in the 2010s, smart energy meters integrated microcontrollers, wireless communication, and cloud computing to provide real-time monitoring and remote access via mobile applications. This advancement enhances consumer awareness, supports efficient energy management, and contributes to sustainability efforts, reflecting the broader shift toward intelligent and optimized energy systems (A.Moreno-Munoz and J. J. Gonzalez De La Rosa, 2008) (A.Rashdi, 2013) (Z.I. Rana, 2014).

2.2 Related Research Works

Before conducting any research or review work, it is essential to thoroughly understand the methods and findings of others to gain a solid understanding of my own project. This literature review examines related studies in similar fields and draws a general comparative conclusion about my work in relation with the others.

Earlier Research

In the early days, electricity was a privilege available only to a select few. However, advancements in technology have since made it accessible to people worldwide, helping meet basic needs more easily. The history of electricity meters is closely connected to the work of early scholars. When electricity first emerged in the 1870s, it was mainly used for telegraphs and arc lamps. The invention of the electric lamp by Thomas Edison in 1879 opened up the power market to the general public. In 1888, Oliver B. Shallenberger invented the AC ampere-hour meter. As metering technology progressed, it led to greater enlightenment and eventually became widespread among the general population (Z.I. Rana, 2014).

Recent Research

In recent years, extensive research has focused on developing low-cost IoT-based smart energy meters to improve energy efficiency, promote sustainability, and enhance accessibility for residential and industrial users (H.G. R. Tan, 2007). Many studies integrate microcontrollers such as ESP32 and Raspberry Pi with voltage and current sensors to enable real-time monitoring of power consumption, with data transmitted to cloud platforms and accessed via mobile or web applications (B.Sivaneasan, 2021). Researchers have emphasized cost-effective hardware design and system scalability to support deployment in both developing regions and large-scale smart grid or smart city infrastructures, utilizing wireless technologies like Wi-Fi, LoRa, and Zigbee for seamless communication (B.Sivaneasan, 2021) (H.G. R. Tan, 2007).Furthermore, recent advancements incorporate data analytics and machine learning techniques to predict consumption trends, detect anomalies, and support intelligent energy management, enabling better load distribution and early fault detection (A.Zaballos, 2009) (B.Sivaneasan, 2021).

Conflicting Research Works

The deployment of smart meter technology as an advanced energy management solution is gradually expanding across developing countries, supporting the transition from unmetered electricity usage to intelligent monitoring systems. To design effective energy policies, it is essential to understand the factors influencing consumer acceptance, though current insights into user motivations remain limited (A. Kumar, 2018). Research highlights that customer satisfaction depends on service quality, with smart meters offering features such as real-time consumption monitoring, appliancelevel feedback, bill estimation, usage predictions, and direct communication with grid operators. Surveys across households have examined whether feedback mechanisms effectively promote energy conservation and behavioral change, while frameworks like the Technology Acceptance Model (TAM) assess perceived usefulness, ease of use, and user attitudes toward smart appliances. Studies also address privacy concerns and propose models to evaluate data protection levels, emphasizing benefits such as reduced metering costs, improved efficiency, and fraud detection (B.K. Barman, 2018). Smart meters can connect to domestic appliances through wireless, web-based, power-line, or dedicated communication systems and may integrate with mobile devices for real-time monitoring. Programs such as Hungary's Smart Meter initiative demonstrate the effectiveness of bidirectional communication, while technologies like Zigbee, WiMAX, and Home Area Networks (HAN) support secure data transmission within advanced Energy Management Systems, contributing to safer, more efficient, and sustainable electricity usage (M.Aboelmaged, 2017) (N. Fathima, 2017) (P.Corral, 2012).

3. System Design and Modeling

3.1 Introduction

The **System Design and Modeling** section provides a comprehensive overview of the architecture, development, and operational workflow of the proposed IoT-based smart energy meter. It begins with a block diagram that visually represents the key components, including the ESP32 DevKit V1 also covers the hardware and software requirements, highlighting the use of Proteus for circuit simulation and virtual testing prior to hardware deployment, allowing verification of system functionality and early identification of potential issues. Overall, this section emphasizes the seamless integration of hardware and software components to create a functional, cost-effective, and scalable smart energy meter, demonstrating its practical application, user-friendliness, and potential for adoption in residential and industrial energy monitoring systems.

3.2 Block Diagram

The simple block diagram represents the interaction of various components working together to measure, process, display, and wirelessly transmit energy consumption data (Figure 1).

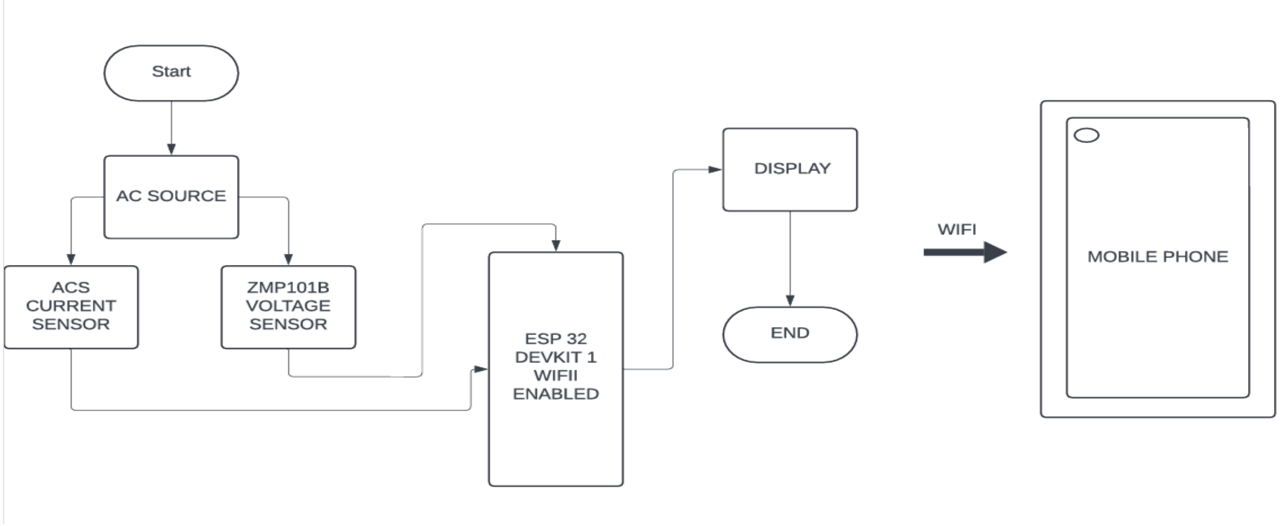

Figure 1: Block Diagram of the project

The diagram illustrates how the system starts by initializing the ESP32, sensors, and display. When the energy meter system is powered on, it begins at the start block where all components are initialized and calibrated to ensure accurate measurements. The system is connected to an AC source that supplies power to the electrical load (such as appliances), and this same source is continuously monitored to evaluate energy consumption. The core of the system is the ESP32 Development Kit, which functions as the main controller. It receives analog signals from the ACS712 Current Sensor and the ZMPT101B Voltage Sensor. The ACS712 measures the real-time current flowing through the circuit, while the ZMPT101B measures the real-time AC voltage. Using these two parameters, the ESP32 calculates electrical power using the formula $P = V \times I$ and determines total energy consumption over time. The processed data is then displayed locally on a 16x2 LCD Display, allowing users to directly view voltage, current, power, and cumulative energy readings. Simultaneously, the ESP32 uses its built-in Wi-Fi capability to transmit the collected data to a mobile application through an IoT platform, enabling users to remotely monitor their energy usage in real time, access historical consumption data, and receive alerts if preset energy limits are exceeded. Overall, the system integrates sensing, processing, display, and wireless communication to provide both local and remote energy monitoring.

3.3 Simulation

The simulation of the project was designed in Proteus 8.15 software. Due to the unavailability of the ESP32 microcontroller in Proteus, an Arduino Uno R3 was used as a substitute for the main controller. The Arduino Uno handled the processing of sensor data and the communication with the display and virtual terminal, replicating the role that the ESP32 would typically play in a real-world implementation (Figure 2).

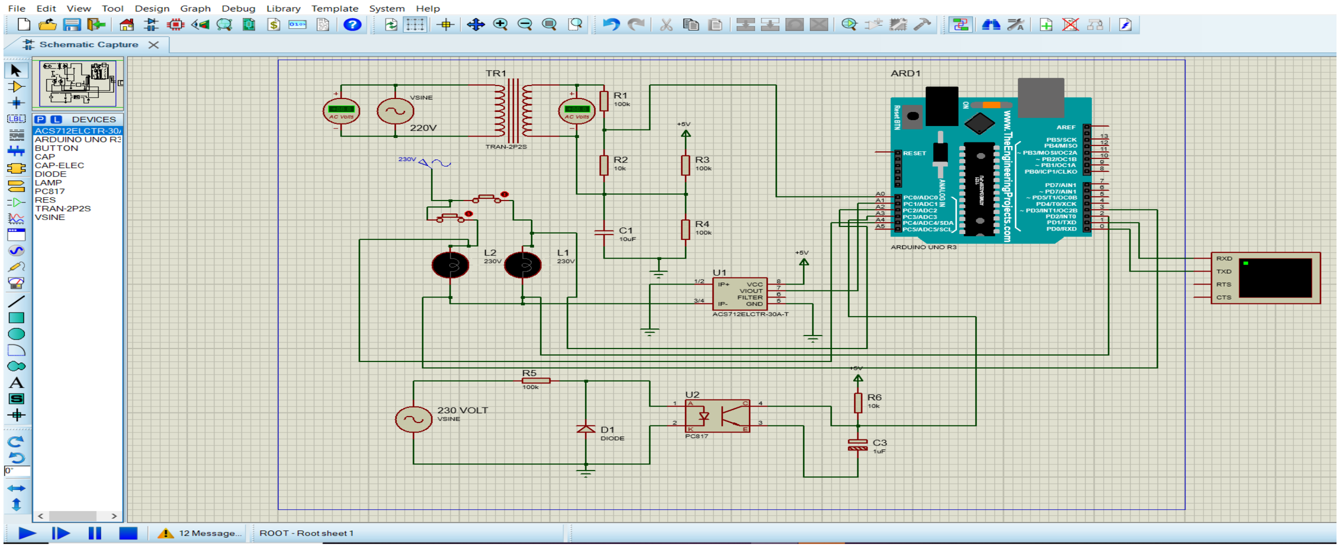

Figure 2: Simulation of the Project

In the simulation setup, a voltage sensor and a current sensor were used to measure the electrical parameters of the AC power flowing through a load (such as a light bulb or a motor). An optocoupler or photocoupler circuit is used in to verify frequency and simulate isolation between high and low voltage circuits, which is critical for protecting sensitive components from high voltage surges or spikes. A switch was incorporated to turn the load on or off, allowing for control over the energy consumption process. The sensors fed the voltage and current data to the Arduino Uno, which processed these signals and calculated the power consumption in real time. A virtual terminal was utilized in the simulation to display the calculated values, including voltage, current, frequency, power factor and power consumption. This terminal acted as a basic interface, allowing users to see the system's output. The simulation successfully demonstrated the functionality of the smart energy meter, providing real-time monitoring of power consumption using standard electronic components. Though the simulation was carried out with Arduino, the principles remain the same for the intended use of ESP32 in the final implementation.

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3.4 Circuit Diagram

The circuit diagram plays a critical role in this project, especially before hardware implementation. The circuit diagram aids in efficient resource planning and cost management (Figure 3).

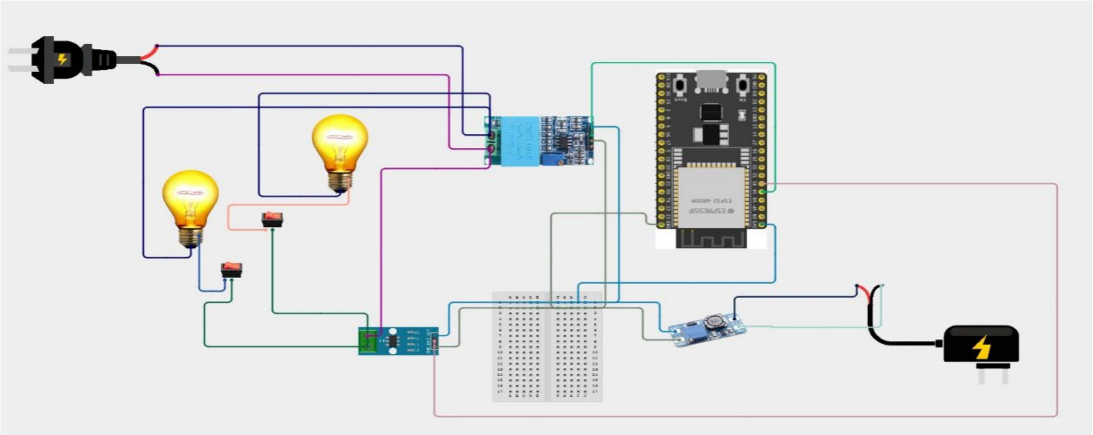


Figure 3: Circuit Diagram of the Project

This is picture of the final designed before hardware implementation of the project. By laying out all the required components visually, it becomes easier to estimate the exact number and type of components needed for the project. This helps in avoiding over-purchasing or underestimating essential parts, ensuring that the project remains low-cost, as intended. Additionally, the diagram facilitates smoother collaboration and communication among team members by providing a unified reference point, making it easier for engineers and technicians to understand and implement the project cohesively. Thus, the circuit diagram serves as a blueprint for hardware implementation, offering clarity, reducing errors, and enabling pre-hardware testing and simulations, which is vital for a successful, low-cost IoT-based project.

3.5 Hardware Implementation

This is the hardware implementation of the project (Figure 4 and 5).

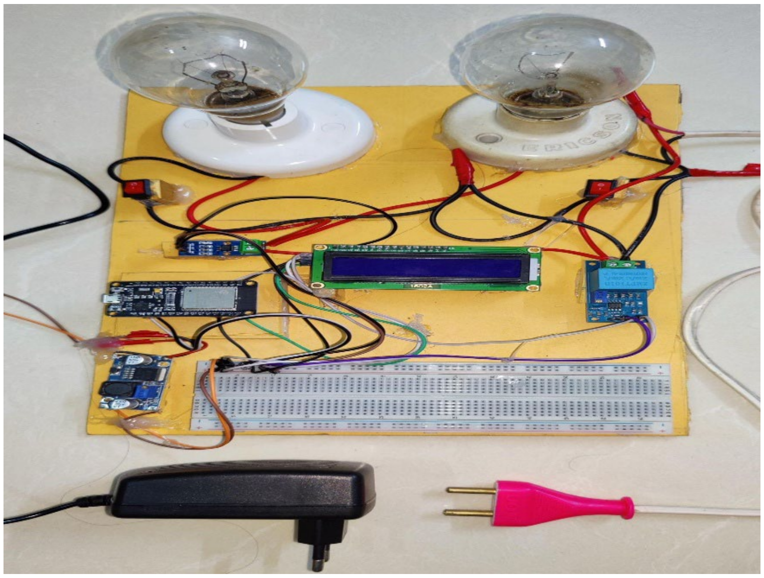


Figure 4: Top View indicating where different components have been placed

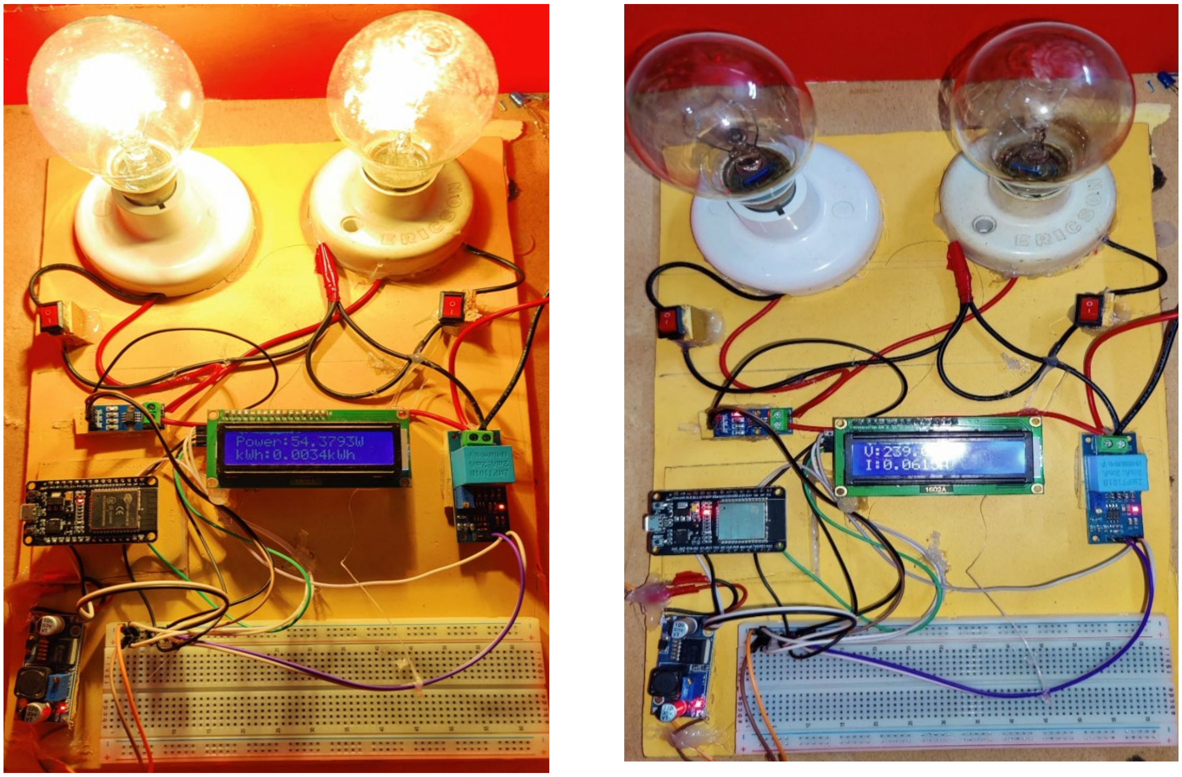


Figure 5: With and without activating the circuit's load

The operation of this project is heavily reliant on hardware components. The microcontrollers and sensors were tested before final implementation by constructing a test board and installing all of the sensors and modules based on the simulation model and operating the system. The sensor data was thoroughly examined. The IoT integration was further tested by comparing the data displayed on the LCD to the data displayed on the app. However, it is important to note that the hardware implementation of a system differs from its simulation.

4. Results and Analysis

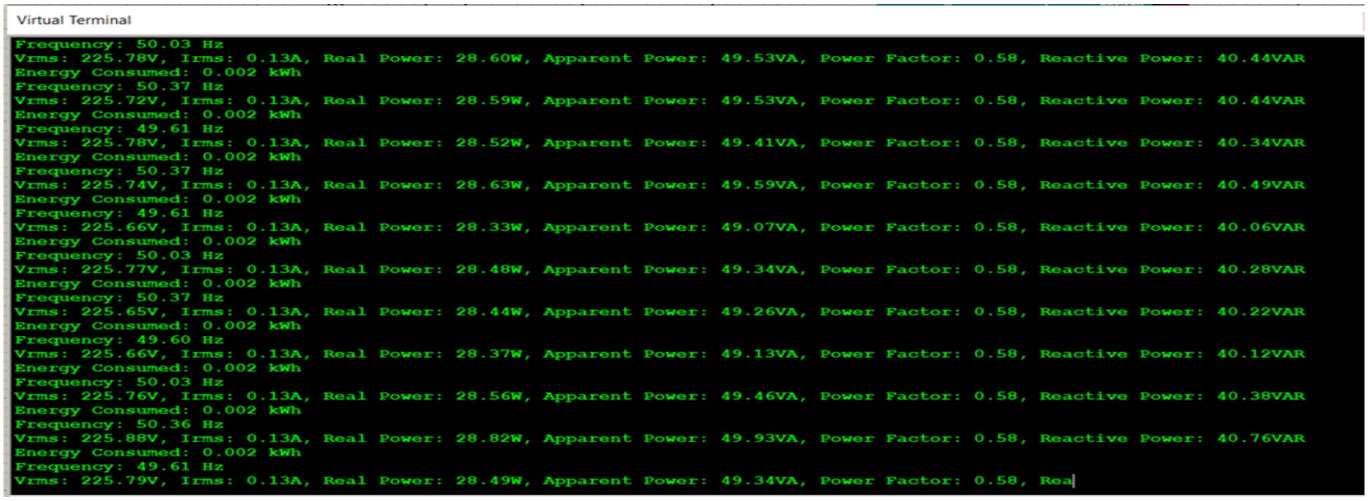
This section outlines the results and performance evaluation of the proposed low-cost IoT-based smart energy meter through both hardware implementation and circuit simulation using Proteus. The system is centered on the ESP32 DevKit V1, which performs data processing and Wi-Fi communication, enabling real-time transmission of measured electrical parameters to a mobile application for remote monitoring. The circuit was initially designed and tested in Proteus to validate functionality and minimize implementation errors before hardware deployment. Experimental findings from the prototype were compared with simulation results to assess measurement accuracy, communication performance, and overall system stability. Challenges such as sensor calibration, data latency, and reliability were addressed to enhance system efficiency. The evaluation confirms that the proposed design is cost-effective, scalable, and suitable for practical residential and small-scale industrial energy monitoring applications.

4.1 Simulated Results

During the simulation phase, the Arduino Uno R3 sends data, such as voltage, current, frequency and power usage, to the Proteus Virtual Terminal via serial communication. The following are the output results displayed on the Proteus Virtual Terminal (Figure 6, 7 and 8).

```
Frequency: 0.00 Hz
Vrms: 225.03V, Irms: 0.00A, Real Power: 0.00W, Apparent Power: 0.00VA, Power Factor: nan, Reactive Power: 0.00VAR
Energy Consumed: 0.000 kWh
Frequency: 0.00 Hz
Vrms: 224.95V, Irms: 0.00A, Real Power: 0.00W, Apparent Power: 0.00VA, Power Factor: nan, Reactive Power: 0.00VAR
Energy Consumed: 0.000 kWh
Frequency: 0.00 Hz
Vrms: 225.01V, Irms: 0.00A, Real Power: 0.00W, Apparent Power: 0.00VA, Power Factor: nan, Reactive Power: 0.00VAR
Energy Consumed: 0.000 kWh
Frequency: 0.00 Hz
Vrms: 224.91V, Irms: 0.00A, Real Power: 0.00W, Apparent Power: 0.00VA, Power Factor: nan, Reactive Power: 0.00VAR
Energy Consumed: 0.000 kWh
Frequency: 0.00 Hz
Vrms: 225.04V, Irms: 0.00A, Real Power: 0.00W, Apparent Power: 0.00VA, Power Factor: nan, Reactive Power: 0.00VAR
Energy Consumed: 0.000 kWh
Frequency: 0.00 Hz
Vrms: 224.88V, Irms: 0.00A, Real Power: 0.00W, Apparent Power: 0.00VA, Power Factor: nan, Reactive Power: 0.00VAR
Energy Consumed: 0.000 kWh
Frequency: 0.00 Hz
Vrms: 225.02V, Irms: 0.00A, Real Power: 0.00W, Apparent Power: 0.00VA, Power Factor: nan, Reactive Power: 0.00VAR
Energy Consumed: 0.000 kWh
Frequency: 0.00 Hz
Vrms: 224.91V, Irms: 0.00A, Real Power: 0.00W, Apparent Power: 0.00VA, Power Factor: nan, Reactive Power: 0.00VAR
Energy Consumed: 0.000 kWh
Frequency: 0.00 Hz
Vrms: 224.99V, Irms: 0.00A, Real Power: 0.00W, Apparent Power: 0.00VA, Power Factor: nan, Reactive Power: 0.00VAR
Energy Consumed: 0.000 kWh
Frequency: 0.00 Hz
Vrms: 224.93V, Irms: 0.00A, Real Power: 0.00W, Apparent Power: 0.00VA, Power Factor: nan, Reactive Power: 0.00VAR
Energy Consumed: 0.000 kWh
Frequency: 0.00 Hz
```

Figure 6: Without any load



```
Frequency: 50.03 Hz
Vrms: 225.78V, Irms: 0.13A, Real Power: 28.60W, Apparent Power: 49.53VA, Power Factor: 0.58, Reactive Power: 40.44VAR
Energy Consumed: 0.002 kWh
Frequency: 50.37 Hz
Vrms: 225.72V, Irms: 0.13A, Real Power: 28.59W, Apparent Power: 49.53VA, Power Factor: 0.58, Reactive Power: 40.44VAR
Energy Consumed: 0.002 kWh
Frequency: 49.61 Hz
Vrms: 225.78V, Irms: 0.13A, Real Power: 28.52W, Apparent Power: 49.41VA, Power Factor: 0.58, Reactive Power: 40.34VAR
Energy Consumed: 0.002 kWh
Frequency: 50.37 Hz
Vrms: 225.74V, Irms: 0.13A, Real Power: 28.63W, Apparent Power: 49.59VA, Power Factor: 0.58, Reactive Power: 40.49VAR
Energy Consumed: 0.002 kWh
Frequency: 49.61 Hz
Vrms: 225.66V, Irms: 0.13A, Real Power: 28.33W, Apparent Power: 49.07VA, Power Factor: 0.58, Reactive Power: 40.06VAR
Energy Consumed: 0.002 kWh
Frequency: 50.03 Hz
Vrms: 225.77V, Irms: 0.13A, Real Power: 28.48W, Apparent Power: 49.34VA, Power Factor: 0.58, Reactive Power: 40.28VAR
Energy Consumed: 0.002 kWh
Frequency: 50.37 Hz
Vrms: 225.65V, Irms: 0.13A, Real Power: 28.44W, Apparent Power: 49.26VA, Power Factor: 0.58, Reactive Power: 40.22VAR
Energy Consumed: 0.002 kWh
Frequency: 49.60 Hz
Vrms: 225.66V, Irms: 0.13A, Real Power: 28.37W, Apparent Power: 49.13VA, Power Factor: 0.58, Reactive Power: 40.12VAR
Energy Consumed: 0.002 kWh
Frequency: 50.03 Hz
Vrms: 225.76V, Irms: 0.13A, Real Power: 28.56W, Apparent Power: 49.46VA, Power Factor: 0.58, Reactive Power: 40.38VAR
Energy Consumed: 0.002 kWh
Frequency: 50.36 Hz
Vrms: 225.88V, Irms: 0.13A, Real Power: 28.82W, Apparent Power: 49.93VA, Power Factor: 0.58, Reactive Power: 40.76VAR
Energy Consumed: 0.002 kWh
Frequency: 49.61 Hz
Vrms: 225.79V, Irms: 0.13A, Real Power: 28.49W, Apparent Power: 49.34VA, Power Factor: 0.58, Rea
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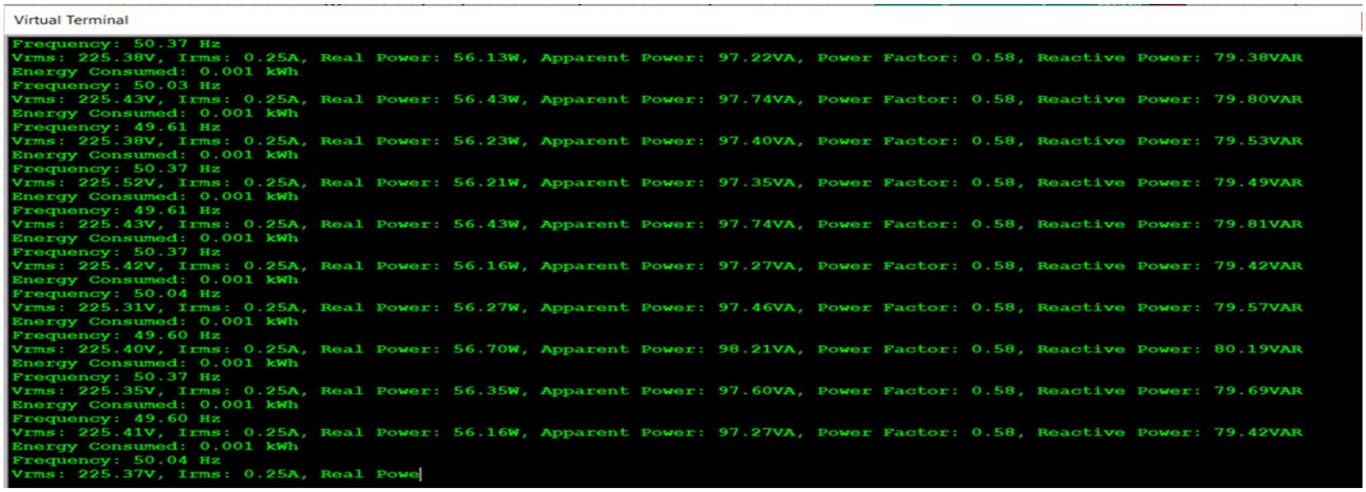
Figure 7: After turning on the single load



```
Frequency: 50.37 Hz
Vrms: 225.38V, Irms: 0.25A, Real Power: 56.13W, Apparent Power: 97.22VA, Power Factor: 0.58, Reactive Power: 79.38VAR
Energy Consumed: 0.001 kWh
Frequency: 50.03 Hz
Vrms: 225.43V, Irms: 0.25A, Real Power: 56.43W, Apparent Power: 97.74VA, Power Factor: 0.58, Reactive Power: 79.80VAR
Energy Consumed: 0.001 kWh
Frequency: 49.61 Hz
Vrms: 225.38V, Irms: 0.25A, Real Power: 56.23W, Apparent Power: 97.40VA, Power Factor: 0.58, Reactive Power: 79.53VAR
Energy Consumed: 0.001 kWh
Frequency: 50.37 Hz
Vrms: 225.52V, Irms: 0.25A, Real Power: 56.21W, Apparent Power: 97.35VA, Power Factor: 0.58, Reactive Power: 79.49VAR
Energy Consumed: 0.001 kWh
Frequency: 49.61 Hz
Vrms: 225.43V, Irms: 0.25A, Real Power: 56.43W, Apparent Power: 97.74VA, Power Factor: 0.58, Reactive Power: 79.81VAR
Energy Consumed: 0.001 kWh
Frequency: 50.37 Hz
Vrms: 225.42V, Irms: 0.25A, Real Power: 56.16W, Apparent Power: 97.27VA, Power Factor: 0.58, Reactive Power: 79.42VAR
Energy Consumed: 0.001 kWh
Frequency: 50.04 Hz
Vrms: 225.31V, Irms: 0.25A, Real Power: 56.27W, Apparent Power: 97.46VA, Power Factor: 0.58, Reactive Power: 79.57VAR
Energy Consumed: 0.001 kWh
Frequency: 49.60 Hz
Vrms: 225.40V, Irms: 0.25A, Real Power: 56.70W, Apparent Power: 98.21VA, Power Factor: 0.58, Reactive Power: 80.19VAR
Energy Consumed: 0.001 kWh
Frequency: 50.37 Hz
Vrms: 225.35V, Irms: 0.25A, Real Power: 56.35W, Apparent Power: 97.60VA, Power Factor: 0.58, Reactive Power: 79.69VAR
Energy Consumed: 0.001 kWh
Frequency: 49.60 Hz
Vrms: 225.41V, Irms: 0.25A, Real Power: 56.16W, Apparent Power: 97.27VA, Power Factor: 0.58, Reactive Power: 79.42VAR
Energy Consumed: 0.001 kWh
Frequency: 50.04 Hz
Vrms: 225.37V, Irms: 0.25A, Real Powe
```

Figure 8: After turning on the double load

4.2 Hardware Results

The hardware results focus on measuring and displaying key parameters such as voltage, current, and power consumption for a single load. These values are captured by sensors integrated with the ESP32 microcontroller and are displayed on a 16x2 LCD screen for real-time monitoring. In addition to the local display, the data is also transmitted to the Blynk mobile app, allowing users to remotely access the voltage, current, and power consumption values for the same load (Figure 9, 10 and 11.

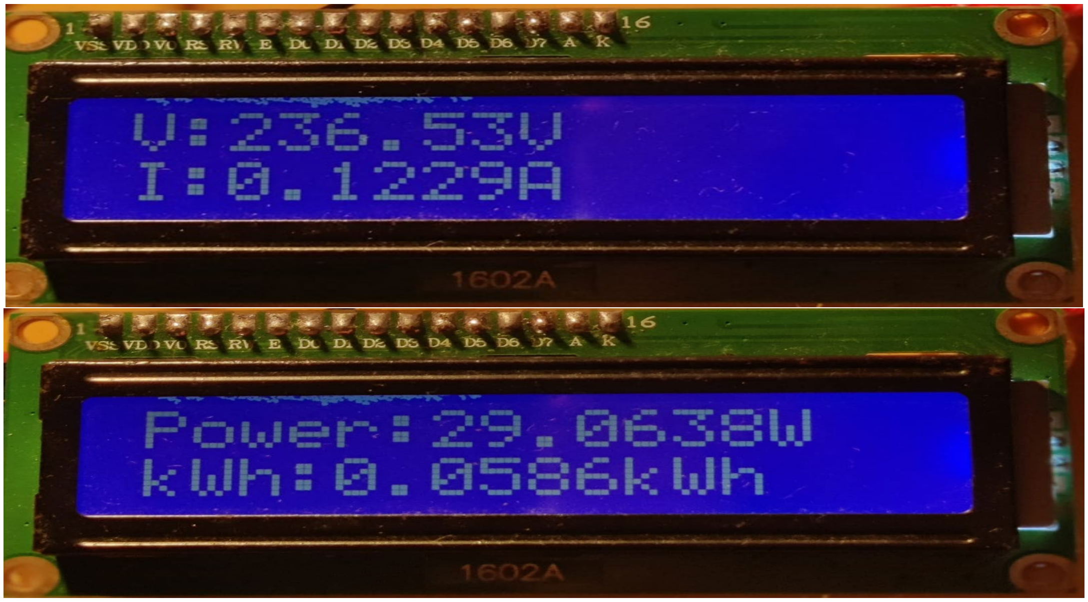


Figure 9: Value of Voltage and Current & Power Consumption for Single Load

Figure 10: Value of Voltage, Current Power & Consumption for Double Load

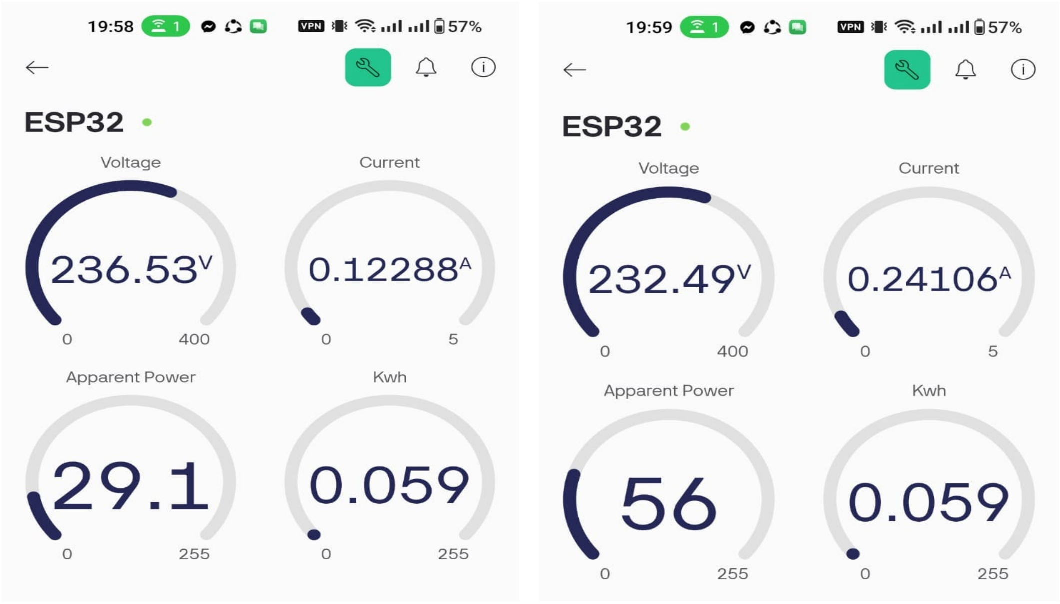


Figure 11: Blynk App Value for Single & Double Load

4.3 Result Analysis

In this project, comparing the values of voltage, current, and power consumption across the simulation, hardware implementation, and mobile app data is essential for evaluating the system's accuracy and performance.

During the simulation phase, ideal conditions are used, allowing for more precise and stable readings in terms of voltage and current. These values serve as a benchmark for testing the accuracy of the hardware and mobile app outputs. In the hardware implementation, small errors might occur due to sensor tolerances, electrical interference, or variations in real-world conditions (Table 1 and 2).

Table 1: Comparison Between Hardware, App & Simulated Value for Single Load

Comparison	Simulation	Hardware	App
Current (I)	0.13	0.1229	0.12288
Voltage (V)	225.78	236.53	236.53
Real Power (W)	28.60	29.0638	29.1
Power Consumption (Kwh)	0.01	0.0586	0.059

Table 2: Comparison Between Hardware, App & Simulated Value for Double Load

Comparison	Simulation	Hardware	App
Current (I)	0.25	0.2411	0.24106
Voltage (V)	225.38	232.49	232.49
Real Power (W)	56.13	56.0430	56.0
Power Consumption (Kwh)	0.02	0.0589	0.0589

This comparison helps in validating the system's performance and ensuring that the smart energy meter is accurate, consistent, and reliable across all platforms.

4.4 Cost Analysis

The cost analysis of the project details the components used to develop the low-cost IoT-based smart energy meter, along with their quantities and estimated prices in BDT Taka. The total quantity of components amounts to 29, with an overall estimated cost of 4320 BDT or 50 USD (approximately), demonstrating the affordability and feasibility of the proposed smart energy meter system for practical applications (Table 3).

Table 3 Cost of Components

Component	Quantity	Estimated Price (BDT)
ESP32 Development Kit 1.0	1	550
Display 16*2	1	350
Switch	2	80
ACS712 Current Sensor	1	150
ZMPT101b Voltage Sensor	1	300
LM22596 Buck Converter	1	120
Breadboard	1	160
Male - Male Jumper Wire (40pcs)	1	130
Incandescent Light Bulb (60W, 220-240V)	2	100
Male - Female Jumper Wire (40pcs)	1	130
Female - Feale Jumper Wire (40pcs)	1	130
9V 3A AC – DC Adapter	1	270
Multimeter	4	1350
PVC Board	1	200
Normal Wire	1	100
Light Holder	2	200
Total	29	4320

5. Discussions and Future Work

The "Design and Implementation of a Low-Cost IoT-Based Smart Energy Meter" project illustrates the significant impact of IoT technology on energy monitoring and management. This project was initiated to address the growing need for cost-effective solutions that empower users to track their energy consumption efficiently.

The project book encapsulates the comprehensive journey of designing and implementing the Low-Cost IoT-Based Smart Energy Meter. It begins with an introduction to the need for smart energy solutions in the context of rising energy costs and environmental concerns. The literature review outlines existing technologies and their limitations, paving the way for the proposed solution. Subsequent chapters detail the theory and methodology chapter, including the selection of components, circuit design, and software development. The project employs the ESP32 microcontroller as a versatile solution for processing and transmitting data. The integration of a 16x2 LCD display and the Blynk app is explored, emphasizing their roles in user interaction and data accessibility. The results section presents a thorough analysis of the hardware performance compared to simulation outputs. The discussion reflects on the project's successes and areas for improvement, particularly concerning data accuracy in the mobile app.

Future work for this project could include the addition of power factor and frequency monitoring to provide more comprehensive energy data. A fault detection system could also be integrated to identify issues such as voltage fluctuations or current spikes, enhancing system safety. Additionally, incorporating a cost calculation feature with an online billing system would allow users to track energy expenses in real-time, making the meter even more user-friendly and efficient. Through the system is performing as intended there are some sectors where this can be improved in the future. Those scopes are mentioned below:

- Single-phase smart energy meter system could be upgraded to a three-phase system.
- Frequency and power factor could be incorporated into the hardware of this project for improved monitoring and analysis of energy usage.

- Cost calculation and online billing system could be implemented to give users real-time insights into their energy costs based on actual consumption.
- The smartphone app can be developed from the ground up to work even better with the system and the app can be published to the app stores for the general people which enables them to observe the parameters of the energy meter.
- Introducing Artificial Intelligence features for advanced smart metering.
- Fault detection feature can be included to identify irregularities or issues in the electrical system, such as overloads, voltage fluctuations, or wiring faults.

These enhancements will position the smart energy meter as a more robust and versatile solution for energy management. While the current system is quite simple, there are numerous opportunities for future improvements to enhance its capabilities.

6. Conclusion

The proposed method has the ability to alleviate customer pain and raise user awareness of excessive electricity use as well as defective home equipment. Customers may simply view the voltage, current, power consumptions with this system. The technique is simple to understand and dependable. The implementation of this smart energy meter project paves the way for advanced energy management solutions, supporting a sustainable future for both consumers and energy providers. The ability to harness data effectively will not only empower users but also contribute to more sustainable energy practices, driving the transition towards a smarter and more efficient energy ecosystem. If the meter is enhanced with additional modern features, energy distribution companies such as DESCO and DPDC will be able to analyze usage patterns within specific regions. This valuable insight can then assist in optimizing load distribution in those areas.

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