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IoT-ENABLED ENERGY MANAGEMENT MONITORING SYSTEM FOR SUSTAINABLE RESOURCE OPTIMIZATION

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ABSTRACT: *This research, "IoT-Enabled Energy Management Monitoring System for Sustainable Resource Optimization," introduces an innovative IoT-enabled energy management monitoring system designed to address the escalating global energy demands and promote sustainable practices. By integrating smart controllers, advanced sensors, and a user-centric interface, the system empowers users with real-time insights into their energy consumption patterns, enabling informed decisions for energy optimization. Our experimental results demonstrate the system's ability to provide detailed energy consumption data with a high degree of accuracy, achieving a minimum percentage error of 0.03% in load measurements. This precision not only facilitates effective load management and energy conservation but also contributes to a greener environment by minimizing energy waste. The research aligns with the United Nations Sustainable Development Goal 7 (Affordable and Clean Energy) and Goal 13 (Climate Action) by promoting responsible energy consumption and contributing to the reduction of greenhouse gas emissions. The developed system offers a practical and cost-effective solution for residential settings, with potential for broader applications across various sectors, fostering a more sustainable energy future.*

KEYWORDS: Smart homes, Electricity, Load management, Energy conservation, Sensors, Home monitoring, Real-time information.



INTRODUCTION

The escalating global demand for energy has intensified the need for efficient and sustainable energy management systems, particularly in residential and industrial settings [1]. Traditional energy metering infrastructure often relies on outdated technologies, leading to inaccuracies in consumption data and billing, hindering effective energy conservation efforts [2, 3]. This is especially prevalent in regions like Nigeria, where reliance on electromechanical meters poses significant challenges to accurate energy monitoring and billing [4, 5].

This research addresses this critical need by introducing an innovative IoT-enabled energy management monitoring system designed to empower users with real-time insights into their energy consumption patterns. By leveraging smart controllers, advanced sensors, and a user-centric interface, the system enables informed decision-making for energy optimization and load management [6, 7]. This study is driven by the urgent global imperative to mitigate the energy crisis and promote resource efficiency [8]. Building upon existing research exploring diverse approaches, such as event-driven energy metering [9] and advanced signal processing techniques like the fast discrete Stockwell transform [10], this work delves into the critical domain of home energy monitoring systems.

A key innovation of this research lies in the meticulous integration of an IoT-enabled module (ESP) for precise energy monitoring, coupled with remote control capabilities via a GSM module [11, 12]. This not only facilitates energy conservation but also provides a cost-effective and efficient solution with broad applicability across various sectors. Furthermore, the incorporation of the ThingSpeak IoT platform enables automated data acquisition, providing regular updates on energy consumption patterns every 24 hours [13]. This user-friendly interface empowers users to actively participate in load management and adopt more conscious energy consumption behaviors.

The novelty of this system extends beyond its core functionalities to encompass features such as SMS-based recharging and overload protection. The system can automatically disconnect loads exceeding a predefined daily consumption threshold, ensuring responsible energy usage and preventing potential hazards [14]. This research contributes not only to technological advancement but also addresses critical societal and environmental challenges associated with energy consumption. By providing accurate, real-time energy usage data, the system promotes a mindful and responsible approach to energy consumption, aligning with global initiatives for carbon emission reduction and environmental sustainability [15].

LITERATURE REVIEW

This section delves into related works, projects, and the operational characteristics of components contributing to the design of the energy watt-hour meter. By discussing their significance, effects, and functionalities, a comprehensive understanding is established and research methodology employed in our system is described.



Recent Advancements in Energy Metering systems

In recent advancements in energy metering systems, an Intelligent Wireless Energy Meter was developed, employing a PIC16F887 microcontroller and RF module for enhanced data accuracy and digital display [3]. Concurrently, researchers explored the integration of an Energy Meter with wireless sensor network technology, showcasing progress in both wireless communication and energy measurement [4]. The synergy between these works underscores the significance of precision and connectivity in energy monitoring systems, aligning with the proposed IoT-enabled framework.

Investigating a Wireless AC Energy Monitor with diverse functionalities, including power supply, signal filtering, and microcontroller sections, researchers made substantial progress in comprehensive energy monitoring [5]. Simultaneously, a Smart Sensor design utilizing the ADE7753 contributed valuable insights into advanced sensing technologies for precise energy and power measurement [6]. Together, these works highlight the importance of multifaceted monitoring and advanced sensing capabilities in optimizing resource utilization.

A focus on simplifying energy monitoring and recharging through automatic systems is evident in the development of a GSM-Based Smart Energy Meter [7]. In parallel, the creation of a WSN-Based Smart Sensor System for real-time monitoring signifies a transition toward intelligent and automated energy management [8]. These works collectively emphasize the importance of remote management and real-time monitoring in enhancing the efficiency of energy systems.

Home Energy Monitoring systems

A comprehensive review addressed evolving technologies, challenges, and opportunities in the energy monitoring domain, considering data privacy and renewable energy integration [9]. Simultaneously, a research review on smart home energy management systems discussed configurations and technologies for optimal efficiency [10]. Both works ([9][10]) contribute to the conceptualization of the proposed system by providing a contextual understanding of the broader landscape of energy technologies. Proposing a smart home energy management system with a highly efficient Solar panel and Bluetooth application for load control, researchers emphasized the integration of renewable energy sources [11]. Additionally, an occupancy-based optimization approach for energy management in smart homes offered insights into efficient resource utilization [12]. These works collectively address the intersection of renewable energy integration and dynamic energy management in smart homes and also contribute insights into the technologies, algorithms, and challenges associated with home energy monitoring and management, providing a valuable foundation for the proposed research.

Limitations of Existing Works and Proposed Improvements

While the aforementioned studies have made significant contributions to the field of energy monitoring and management, some limitations need to be addressed. These include:

- **Cost:** Many existing systems rely on expensive hardware and software components, making them inaccessible to a wider range of users.



- **Complexity:** Some systems require complex installation and configuration processes, hindering their adoption by non-technical users.
- **User Engagement:** Several systems lack user-friendly interfaces, limiting user engagement and understanding of energy consumption patterns.
- **Functionality:** Some systems offer limited functionality, lacking features such as remote control and overload protection.

This research aims to overcome these limitations by developing a cost-effective, user-friendly, and feature-rich IoT-enabled energy management monitoring system. The proposed system will:

- Utilize low-cost, readily available components to reduce the overall cost.
- Simplify the installation and configuration process to enhance user experience.
- Provide a user-friendly interface for intuitive interaction and understanding of energy data.
- Incorporate advanced features such as remote control and overload protection to enhance functionality and value.

By addressing these limitations, this research aims to make a significant contribution to the field of energy monitoring and management, promoting energy efficiency and sustainability in residential and potentially industrial settings.

METHODOLOGY

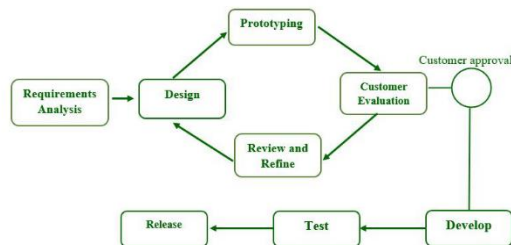
The research design for this project follows the prototyping model, which involves building a prototype, testing it, and refining it iteratively until a satisfactory outcome is achieved. This model is suitable for the development of systems where requirements are not well understood initially and can evolve through the development process. The choice of the prototyping model allows for flexibility and responsiveness to changes in the system requirements, ensuring that the final product aligns closely with user needs.

System design

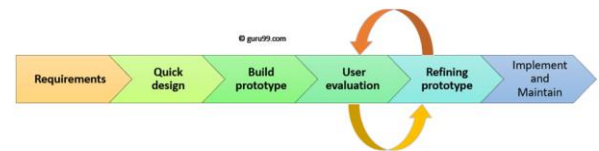
The system design model has the following six (6) Software Development Lifecycle:

- Requirements Gathering
- Quick Design
- Build Prototype
- Initial User Evaluation
- Refine Prototype

○ Product



(a)



(b)

Figure 1(a),(b). Prototyping methodology chart

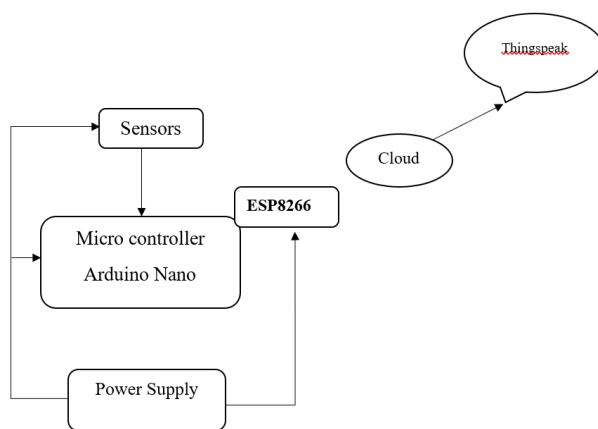


Figure 2: The Activity Diagram of the system

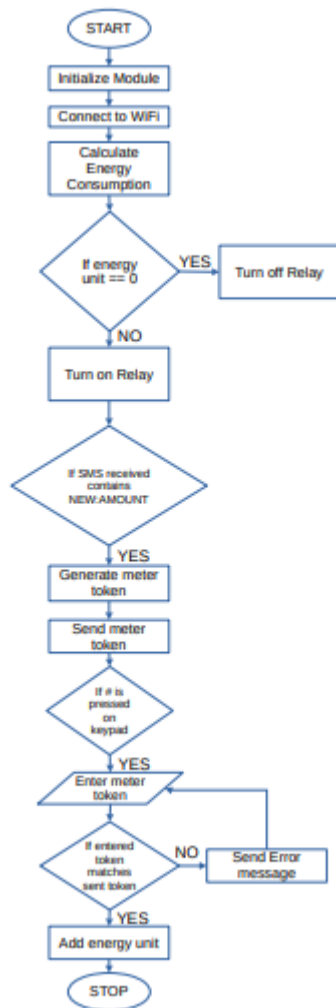


Figure 3: The flow chart of the System

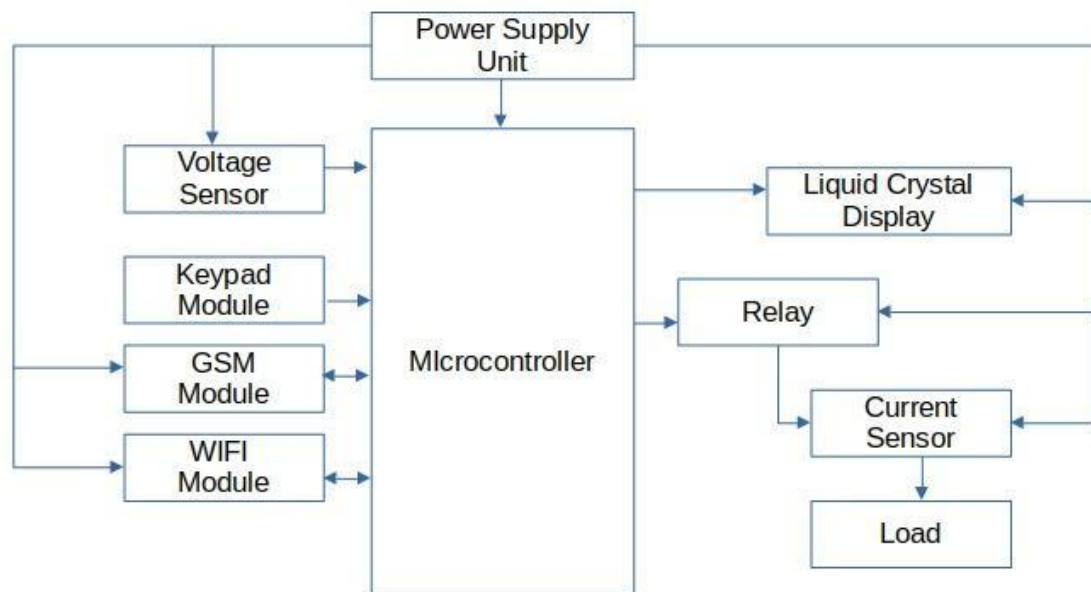


Figure 4: The Block Diagram of the System

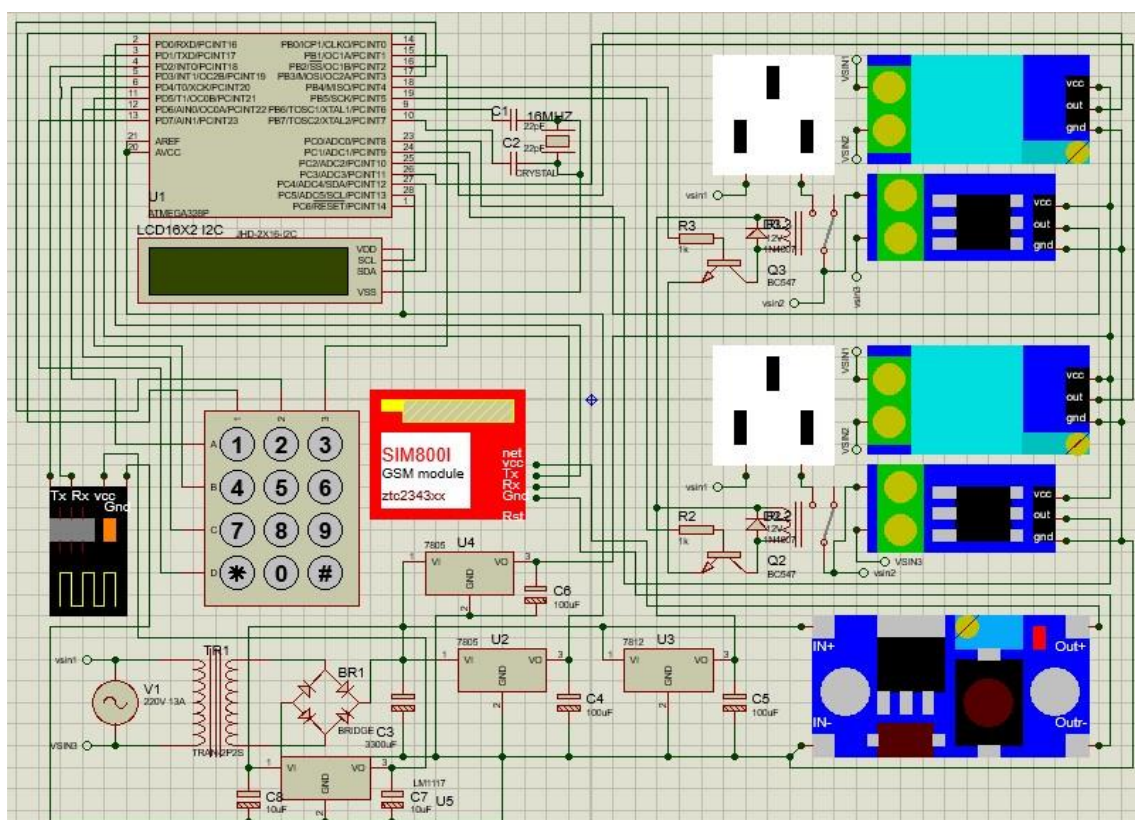


Figure 5: The simulated Diagram of the system



Hardware Design

The hardware design of the IoT-enabled energy management monitoring system involves the careful selection and integration of various components to achieve the desired functionality. The system comprises several key modules, each serving a specific purpose. As shown in figure 5 above of the electrical simulation.

- **Power Supply Module:** This module provides the necessary power to all the components of the system. It includes a step-down transformer, a bridge rectifier, a filter capacitor, and a voltage regulator. The transformer steps down the AC mains voltage to a lower level, which is then rectified and filtered to produce a stable DC voltage. The voltage regulator ensures a constant output voltage regardless of input voltage fluctuations or load variations.
- **Sensing Module:** This module is responsible for measuring the electrical parameters, namely voltage and current. It utilizes a current sensor (ACS712) and a voltage sensor (ZMPT101B) to accurately measure the current flowing through the load and the voltage across it. These sensors provide analog signals proportional to the measured values.
- **Microcontroller Module:** The microcontroller (ATmega328P) acts as the brain of the system. It receives the analog signals from the sensing module, converts them into digital values using its built-in analog-to-digital converter (ADC), and performs the necessary calculations to determine energy consumption. The microcontroller also controls the display module and the communication module.
- **Display Module:** The display module provides a visual representation of the energy consumption data. It utilizes an LCD (Liquid Crystal Display) to show the measured values of voltage, current, and energy consumption. The LCD is interfaced with the microcontroller using the I2C communication protocol, which reduces the number of pins required for communication.
- **Communication Module:** The communication module enables the system to transmit the energy consumption data to a remote server or cloud platform. It utilizes a GSM module (SIM800L) to send the data wirelessly over the cellular network. The GSM module is interfaced with the microcontroller using the UART communication protocol.

C. Software Design

The software design of the IoT-enabled energy management monitoring system involves programming the microcontroller to perform the following tasks:

- **Data Acquisition:** The microcontroller reads the analog signals from the current and voltage sensors and converts them into digital values using its ADC.
- **Energy Calculation:** The microcontroller performs the necessary calculations to determine the energy consumption based on the measured voltage and current values.
- **Display Update:** The microcontroller updates the LCD display with the measured values of voltage, current, and energy consumption.



- **Data Transmission:** The microcontroller transmits the energy consumption data to the GSM module for wireless transmission to the cloud platform.
- **Remote Control:** The microcontroller receives commands from the cloud platform via the GSM module and performs the corresponding actions, such as turning the load on or off.

The software is developed using the Arduino programming language, which provides a user-friendly environment for programming the microcontroller. The Arduino IDE (Integrated Development Environment) is used to write, compile, and upload the code to the microcontroller.

RESULTS AND DISCUSSION

The design project extensively utilized various tools for testing and collecting results, enabling informed decisions and system improvements. The tools employed included a Digital Multimeter, Breadboard, Light Emitting Diodes (LED) with appropriate limiting resistors, Flowcode programming language software, and Proteus ISIS 8.9 Professional. These tools were instrumental in validating the functionality of devices, assessing system performance, and ensuring that components operated as intended. The combination of these testing tools contributed to a comprehensive evaluation of the design project, facilitating iterative enhancements and confirming the proper operation of individual elements within the system.

Output voltage Testing

The output voltage was tested under two conditions:

- No-load condition and
- Full load condition

Readings taken at different points are:

- No load voltage, $V_{NL} = 5.07V$
- Full load voltage, $V_{FL} = 5.06V$
- Transformer output voltage, $V_{RMS} = 12.56V$
- Filtered output voltage, $V_{DC} = 10.02V$
- Peak voltage, $V_M = 15.59V$

The measured regulator output voltage under full load condition was 5.06V. The voltage regulation, V_R is given by the relationship below:

Where,

$$V_{NL} = 5.07$$



$$V_{FL} = 5.06$$

$$\begin{aligned} V_R &= \frac{V_{NL} - V_{FL}}{V_{NL}} \times 100\% \\ &= \frac{5.07 - 5.06}{5.07} \times 100\% \\ &= 0.197\% \end{aligned} \quad (1)$$

For the display section, the signal voltages required to switch on the LCD were supplied by a 7805 voltage regulator while the display was observed. From the program written, the display updates every 3 mins of the values of the energy consumed by the load. The user can also request the energy consumption by sending "STATUS" to the registered SIM inserted on the GSM module.

The microcontroller underwent software debugging using flow code programming language, ensuring each program section's accuracy through animated mode. Hardware testing involved programming the microcontroller to alter output states, validating functionality. Observations of the microcontroller's output pins connected to the display input pins confirmed its proper operation. Subsequently, the microcontroller, programmed with hex code, exhibited the expected responses when connected to LEDs configured as outputs.

At the end of the implementation, various loads were tested in order to compare with the standard measurements of these loads as shown in the table of results below.

Results

The performance of the IoT-enabled energy management monitoring system was evaluated through a series of tests. The accuracy of the system was assessed by comparing the measured energy consumption values with the standard values for different loads.

Test on loads

Standard time of 3mins was used during the period of energy consumption. The percentage error between the standard readings and the experimental readings was calculated using the following formula:

$$\text{Percentage Error} = \frac{\text{Standard Reading} - \text{Experimental Reading}}{\text{Standard Reading}} \times 100\%$$

Table 1: Standard and Experimental Energy Readings

LOADS (W)	STANDARD READING (KWh)	EXPERIMENTAL READING (KWh)	PERCENTAGE ERROR
30	0.0020	0.0033	0.03
60	0.0030	0.0035	0.05
100	0.0050	0.0073	0.23
200	0.0100	0.0150	0.50

The minimum percentage error achieved by the system was 0.03%, indicating a high degree of accuracy in the measurement of energy consumption. The results also demonstrate the system's ability to provide real-time monitoring and control of energy consumption, enabling users to make informed decisions about their energy usage.

Test on cloud Account

The data collected by the system was also transmitted to the ThingSpeak cloud platform for further analysis and visualization. The ThingSpeak platform provides a user-friendly interface for creating charts and graphs to visualize the energy consumption data over time. The graphs generated on the ThingSpeak platform are shown in Figures 5.1, 5.2, and 5.3.

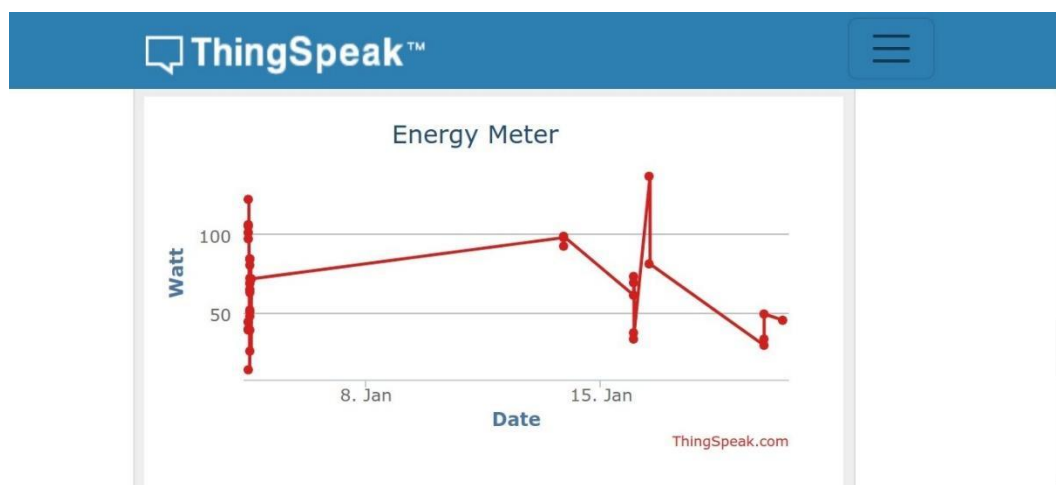


Figure 5.1: Thingspeak result showing the graph of power usage(watts) for January

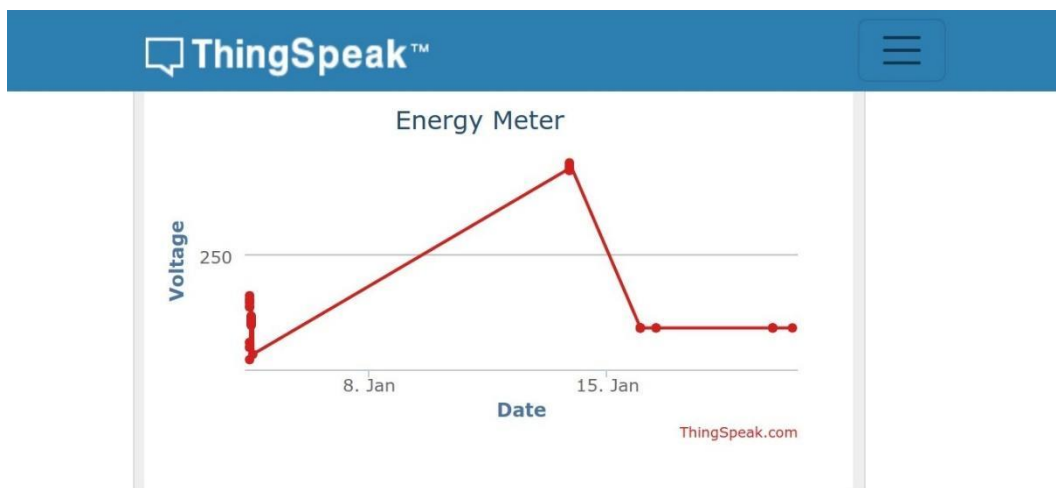


Figure 5.2: Thingspeak result showing the voltage supplied for the month of January

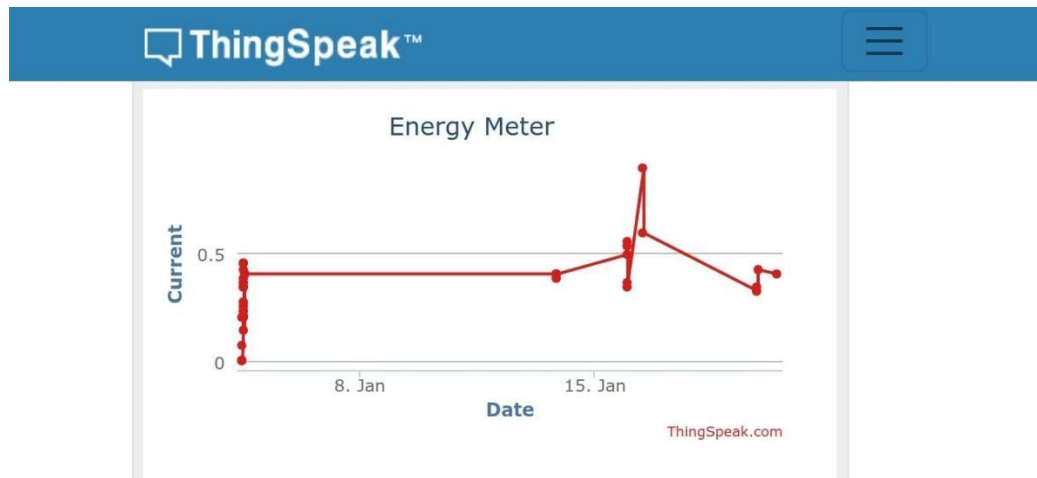


Figure 5.3: Thingspeak result showing the Current supplied for the month of January

The graphs show the variation of power consumption, voltage, and current over time. The data can be used to identify patterns of energy usage and to optimize energy consumption. The ThingSpeak platform also enables remote monitoring and control of the system, providing users with greater flexibility and convenience.

DISCUSSION

From the results obtained during the experiment, it was observed that the measurement of the various loads obtained to standard measurement of the same loads varied with a minimum percentage error as shown in table one above. This is due to the hardware implementation. Also it can be deduced from the graph that the microcontroller results displayed on the LCD tallies with the one on the cloud account. The circuit diagram shows the physical connections of the components and their interconnections with the microcontroller. I2C LCD was used for pin minimization as it requires only two pins for communication. Software serial function on the Arduino IDE was used for the GSM and Esp8266-01 serial communication. Real time monitoring and control was also observed with remote recharging of the meter.

CONCLUSION

This paper presented an innovative IoT-enabled energy management monitoring system designed to address the escalating global energy demands and promote sustainable practices. The system integrates smart controllers, advanced sensors, and a user-centric interface to provide real-time insights into energy consumption patterns, enabling informed decision-making for energy optimization. The experimental results demonstrate the system's ability to provide detailed energy consumption data with a high degree of accuracy, achieving a minimum percentage error of 0.03% in load measurements. This precision not only facilitates effective load management and energy conservation but also contributes to a greener environment by minimizing energy waste. The research aligns with the United Nations Sustainable Development Goal 7 (Affordable and Clean Energy) and Goal 13 (Climate Action) by promoting responsible energy consumption and contributing to the reduction of greenhouse



gas emissions. The developed system offers a practical and cost-effective solution for residential settings, with potential for broader applications across various sectors, fostering a more sustainable energy future.

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