Design And Implementation of a Real-Time Energy Monitoring System Using Hc-12 Wireless Communication and Esp8266-Based Iot Cloud Integration

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***Abstract*—This paper presents the development of a wireless real-time energy monitoring system that integrates long-range communication with Internet of Things (IoT) technology. The system is designed to measure key electrical parameters such as voltage and current and to compute power consumption continuously. An Arduino-based transmitter unit acquires sensor data and transmits it using HC-12 wireless modules, enabling reliable communication over extended distances. At the receiver end, the data is processed and displayed locally, and further transmitted to a cloud platform using an ESP8266 module for remote monitoring. This dual-level monitoring approach ensures both on-site and remote accessibility of energy data. The proposed system reduces dependency on manual data collection and improves the efficiency of energy management through continuous monitoring and data logging. The implementation demonstrates a cost-effective and scalable solution suitable for residential and industrial applications. The system enhances usability by combining simple hardware architecture with reliable communication and cloud-based visualization.**

***Index Terms*—Real-Time Energy Monitoring, Internet of Things, Arduino Uno, HC-12 Wireless Module, ESP8266, ThingSpeak, Power Measurement, Wireless Communication**

I. INTRODUCTION

The increasing demand for electrical energy in residential, industrial, and commercial sectors has made efficient energy monitoring an essential requirement. Conventional monitoring systems rely on periodic manual readings, which do not provide continuous insight into energy consumption patterns. This lack of real-time visibility limits the ability to optimize energy usage and detect abnormalities at an early stage.

With the advancement of Internet of Things (IoT) technologies, energy monitoring systems have evolved to support real-time data acquisition, remote accessibility, and automated analysis. IoT-enabled systems allow electrical parameters to be monitored continuously and accessed from anywhere through cloud platforms, thereby improving operational efficiency and decision-making. However, many existing solutions depend on short-range communication methods, which restrict their applicability in large-scale or remote environments.

The primary problem addressed in this work is the absence of a reliable and cost-effective system that can provide both long-range wireless communication and real-time cloud-based monitoring. Traditional approaches either lack remote accessibility or require complex and expensive infrastructure.

To overcome these challenges, this paper proposes a wireless energy monitoring system that combines long-range communication using HC-12 modules with

IoT-based cloud integration through the ESP8266. The objective of this work is to design and implement a system capable of accurately measuring electrical parameters, transmitting data over extended distances, and enabling real-time monitoring through a cloud platform. The proposed approach aims to enhance energy management by providing continuous, accessible, and reliable monitoring.

II. RELATED WORK

Recent developments in energy monitoring systems have focused on integrating Internet of Things (IoT) technologies to enable real-time data acquisition and remote access. IoT-based architectures allow seamless communication between sensing devices and cloud platforms, improving system efficiency and accessibility. Several studies have implemented Arduino- and microcontroller-based systems to measure electrical parameters such as voltage, current, and power, with data transmitted to cloud platforms for visualization and analysis [1], [7]. These approaches significantly reduce manual intervention and enhance monitoring capabilities.

Wireless communication technologies such as ZigBee, Bluetooth, and Wi-Fi have been widely used in earlier energy monitoring systems. These technologies are suitable for short-range applications and provide efficient data transfer within limited coverage areas. However, they often face challenges related to communication range, reliability, and dependency on network infrastructure [3], [16]. To overcome range limitations, some researchers have explored GSM-based communication systems for remote monitoring. While GSM enables long-distance communication, it introduces higher operational costs and increased system complexity [14].

In addition, several works have utilized cloud platforms to store and analyze energy data, enabling remote monitoring through web or mobile interfaces. IoT frameworks for smart environments and energy systems have demonstrated improved data management and user accessibility [8], [9]. Despite these advancements, many systems rely on a single communication technology, which restricts flexibility and scalability in practical deployments.

However, several research gaps still exist. Most existing systems either focus on short-range communication or depend entirely on internet-based transmission, limiting their applicability in remote or infrastructure-limited environments. Furthermore, many solutions do not provide an integrated approach that combines local monitoring, long-range wireless communication, and cloud connectivity. There is also a need for cost-effective and simplified systems that can deliver reliable performance without complex configurations.

To address these limitations, the proposed system integrates HC-12-based long-range wireless communication with ESP8266-based IoT connectivity. This hybrid approach enables efficient data transmission over extended distances while maintaining real-time cloud monitoring capabilities. The system provides a balanced solution in terms of performance, cost, and scalability, making it suitable for a wide range of energy monitoring applications.

III. PROPOSED SYSTEM

The proposed system is a wireless and IoT-enabled energy monitoring solution designed to measure, transmit, and analyze electrical parameters in real time. The system is structured into two main units, namely the transmitter unit and the receiver unit, along with cloud integration for remote access. In the transmitter unit, voltage and current sensors are used to acquire electrical parameters from the connected load. These signals are processed by a microcontroller, which computes values such as voltage, current, and power. The processed data is displayed locally and then transmitted wirelessly using an HC-12 module, enabling reliable long-distance communication.

The overall architecture of the system is illustrated in Fig. 1, which shows the flow of data from the sensing unit to the cloud platform. The diagram highlights the interaction between the transmitter, receiver, and IoT modules.

At the receiver end, the transmitted data is captured by another HC-12 module and forwarded to a microcontroller for processing. The received values are displayed on a local display for immediate monitoring. In addition to local visualization, the data is transmitted to an ESP8266 module, which provides internet connectivity and uploads the data to a cloud platform. This enables users to monitor energy consumption remotely through a web-based interface. The system ensures continuous operation and provides real-time updates, making it suitable for efficient energy management.

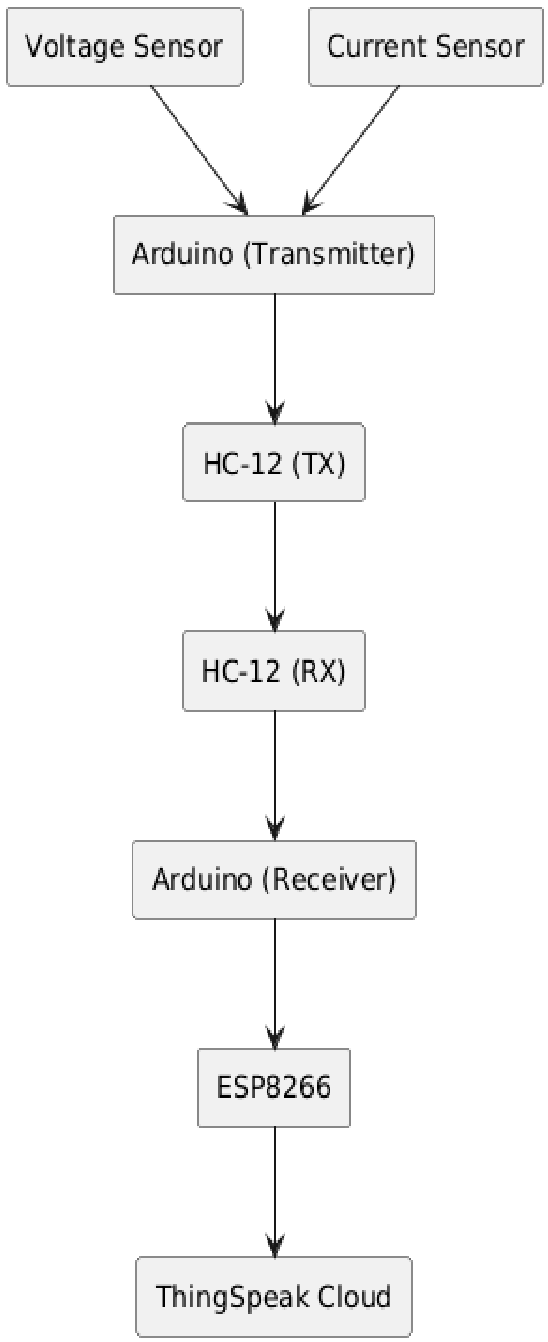

Fig. 1. Block Diagram of Proposed Energy Monitoring System

The proposed system offers several advantages over traditional approaches. It eliminates the need for manual data collection by enabling automated monitoring and transmission of electrical parameters. The use of long-range wireless communication enhances flexibility and allows deployment in areas where short-range technologies are not effective. Furthermore, the integration of IoT technology enables remote accessibility, data logging, and analysis. The system is cost-effective, easy to implement, and scalable, making it suitable for applications in residential, industrial, and smart energy systems.

IV. IMPLEMENTATION

The system design integrates sensing, processing, wireless communication, and cloud connectivity to achieve real-time energy monitoring. The architecture is divided into three functional stages: data acquisition, wireless transmission, and cloud-based monitoring. The voltage and current sensors are used to measure electrical parameters from the load, and the acquired signals are processed using a microcontroller to compute voltage, current, and power values.

The overall workflow of the system is illustrated in Fig. 2, which represents the step-by-step operation from data acquisition to cloud visualization. The methodology begins with continuous sensing of electrical parameters, followed by signal processing and local display. The processed data is then transmitted wirelessly using HC-12 modules, ensuring reliable long-distance communication between the transmitter and receiver units.

At the receiver end, the incoming data is decoded and displayed for local monitoring. The processed data is further transmitted to the ESP8266 module through serial communication. The ESP8266 establishes a Wi-Fi connection and sends the data to a cloud platform using API-based communication. This enables real-time visualization and storage of energy parameters, allowing users to monitor the system remotely.

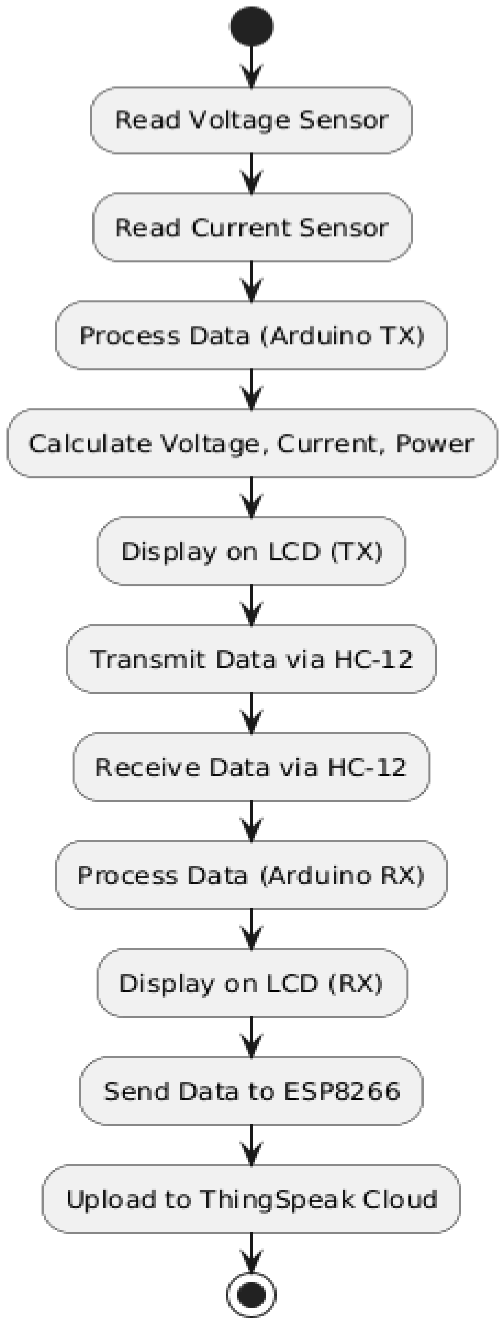

Fig. 2. Flowchart of System Operation

The methodology ensures a continuous and synchronized flow of data across all stages. Proper data formatting and communication protocols are maintained to avoid transmission errors and ensure reliability. The combination of long-range wireless communication and IoT-based cloud integration provides an efficient and scalable solution for energy monitoring applications.

V. RESULTS AND DISCUSSION

The implementation of the proposed system involves the practical realization of the hardware and software components to achieve real-time energy monitoring. The system is developed by integrating sensing units, microcontrollers, wireless communication modules, and IoT connectivity into a unified framework. The complete hardware setup is designed to ensure accurate measurement, reliable communication, and continuous operation.

The hardware configuration of the system is illustrated in Fig. 3, which shows the interconnection of sensors, microcontrollers, HC-12 modules, and the ESP8266 unit. The voltage sensor and current sensor are connected to the transmitter microcontroller, where the analog signals are acquired and processed. The computed values are displayed locally and transmitted wirelessly using the HC-12 module. At the receiver side, the data is received, processed, and displayed before being forwarded to the ESP8266 module for cloud transmission.

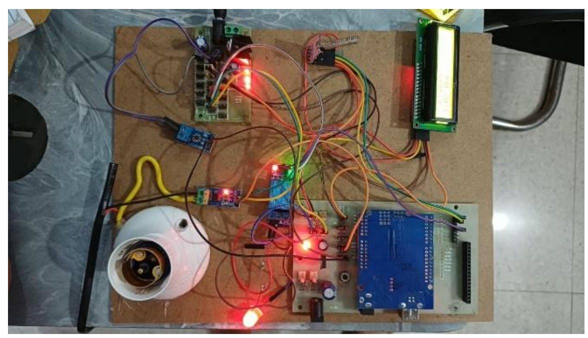

Fig. 3. Hardware Implementation of the Proposed System

The system is implemented using embedded programming in the Arduino environment. The transmitter unit is programmed to read sensor values, perform necessary calculations, and format the data for transmission. The receiver unit is programmed to decode the received data and manage display operations. Serial communication is established between modules to ensure synchronized data transfer.

The ESP8266 module is configured to connect to a Wi-Fi network and communicate with the cloud platform using API-based requests. The received data is periodically uploaded to the cloud, enabling real-time visualization and storage. Proper testing and validation are carried out to ensure accurate sensor readings, stable wireless communication, and reliable cloud connectivity.

The implementation demonstrates that the system operates effectively in real-time conditions, providing continuous monitoring and seamless integration between hardware and software components.

VI. RESULTS AND DISCUSSION

The performance of the proposed energy monitoring system is evaluated based on its ability to measure, transmit, and display electrical parameters in real time. The system is tested under different load conditions to verify the accuracy and consistency of voltage, current, and power measurements. The obtained results demonstrate that the system operates reliably, with minimal delay in data acquisition and transmission.

The measured electrical parameters for different load conditions are presented in Table I, which shows the variation of voltage, current, and calculated power. The results indicate that the system provides consistent and accurate readings, validating the effectiveness of the sensing and processing units.

TABLE I. MEASURED ELECTRICAL PARAMETERS

Load Type	Voltage (V)	Current (A)	Power (W)
Bulb 1	220	0.18	39.6
Bulb 2	220	0.25	55.0
Fan	220	0.30	66.0
Mixed Load	220	0.45	99.0

The real-time output of the system is visualized through the cloud platform, as shown in Fig. 4, where electrical parameters are represented graphically. The cloud interface provides continuous updates, enabling users to monitor variations in energy consumption over time. The graphical representation helps in identifying usage patterns and detecting abnormal conditions such as sudden increases in load.

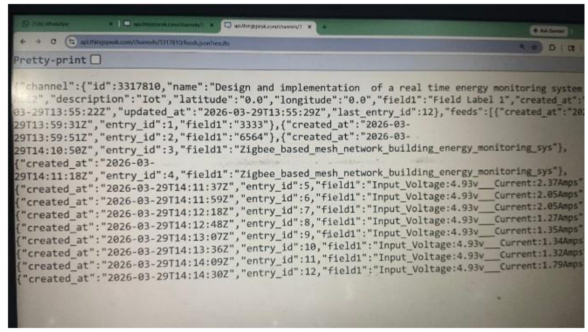

Fig. 4. Real-Time Energy Monitoring from Cloud Platform

In addition to graphical visualization, the system also provides a web-based interface for displaying real-time electrical parameters in numerical format, as shown in Fig. 5. The developed HTML interface presents voltage, current, and power values in a simple and user-friendly manner, enabling easy monitoring without the need for graphical interpretation.

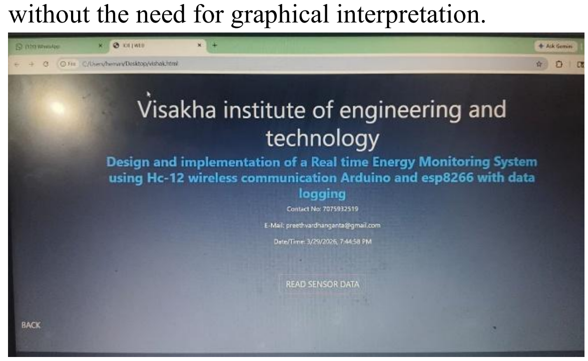

Fig. 5. Web-Based Interface for Real-Time Energy Monitoring

The system also provides local monitoring through LCD displays at both transmitter and receiver units, ensuring data availability even in the absence of internet connectivity. The HC-12 wireless communication module demonstrates stable long-range communication with minimal data loss. Furthermore, the ESP8266 module enables efficient cloud communication with low latency.Overall, the results confirm that the proposed system is accurate, reliable, and suitable for real-time energy monitoring applications in both residential and industrial environments.

VII.CONCLUSION AND FUTURE WORK

The proposed system successfully demonstrates a reliable and efficient approach for real-time energy monitoring using wireless communication and IoT technology. By integrating voltage and current sensing with microcontroller-based processing, the system accurately measures electrical parameters and computes power consumption. The use of HC-12 modules enables stable long-range wireless communication between the transmitter and receiver units, while the ESP8266 module facilitates seamless cloud connectivity for remote monitoring.

The implementation confirms that the system provides consistent performance with minimal delay in data transmission. The inclusion of both local display and a web-based interface enhances accessibility, allowing users to monitor energy parameters in real time. The developed HTML interface, which displays numerical values in a simple format, ensures lightweight operation and ease of use, especially in low-bandwidth conditions. The adoption of a point-to-point topology simplifies system design and ensures reliable communication for the current implementation.

Future work can focus on enhancing the scalability and intelligence of the system. The current point-to-point topology can be extended to a star topology, enabling multiple transmitter nodes to communicate with a central receiver or cloud gateway for large-scale monitoring. Additional features such as graphical dashboards, mobile application integration, and real-time alert systems can further improve user interaction and system responsiveness. Moreover, incorporating data analytics and machine learning techniques for energy consumption prediction and anomaly detection can significantly enhance the system's capability. Integration with renewable energy sources and smart grid infrastructure can also be explored to expand the applicability of the system.

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