IoT-Enabled Real-Time Monitoring System for Electricity Consumption in Maritime SMEs: Design and Evaluation

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Abstract. The growing demand for electrical energy in Small and Medium Enterprises (SMEs) within the maritime sector, necessitates efficient and cost-effective monitoring systems. This paper presents the design and implementation of an Internet of Things (IoT)-based real-time monitoring system for electricity consumption, specifically aimed at maritime SMEs. Using SCT-013-000 and ZMPT101B sensors for current and voltage measurements, the system enables remote monitoring through the Cayenne IoT platform. Experimental results demonstrate an average accuracy rate of 93.94% for current measurement and 98.50% for voltage measurement. Data transmission success rates were 74.00% and 99.02% in two consecutive tests. The proposed system provides an affordable and practical solution for maritime SMEs, contributing to improved energy management, reduced operational costs, and the promotion of sustainable practices. Future work includes the integration of predictive analytics and smart grid technology to further enhance energy efficiency and sustainability in maritime operations.

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1 Introduction

Electricity is a critical infrastructure for economic development, influencing industrial growth, job creation, and investment within maritime sectors. With modern industries requiring stable and uninterrupted power, effective energy management is crucial for sustained growth, especially in emerging economies like Indonesia. However, despite the growing demand, the nation faces challenges in rassemblement the increasing electricity requirements. Small and Medium Enterprises (SMEs), which play a significant role in the local economy, are particularly affected by these limitations.

Energy efficiency within maritime SMEs aligns with the goals of the Sustainable Development Goals (SDGs), which promote responsible consumption, life below water, affordable and clean energy, innovation, and sustainable infrastructure development [1,2]. However, maritime SMEs often struggle with real-time monitoring of electricity consumption, limiting their ability to optimize energy use and implement effective conservation strategies. The removal of electricity subsidies in regions like Indonesia has further raised operational costs for these enterprises, highlighting the need for more affordable and efficient energy solutions. [3].

Research [4]also mentions that individual and organizational behavior significantly affect electricity consumption and energy conversion. The conventional methods used by maritime SMEs to monitor electricity consumption are manual and lack real-time data, which limits their ability to make timely decisions regarding energy use. These methods do not provide detailed insights into the consumption of individual electrical devices, which could help identify inefficiencies and potential areas for cost savings. As electricity costs continue to rise, especially for post-subsidy maritime SMEs, there is a pressing need for innovative solutions that can offer more granular and real-time monitoring of electricity usage.

This study aims to develop a low-cost, IoT-based electricity consumption monitoring system that provides real-time data on current and voltage usage in maritime SMEs, offering a practical and scalable solution that aligns with the SDGs. IoT is defined as intelligent nodes and interconnected interoperability in a dynamic global infrastructure network implementing any connectivity concept from anywhere at any time to carry out information exchange and communication to achieve recognition, positioning, tracking, monitoring, and intelligent administration [5,6]. The system is designed to monitor electricity consumption via a smartphone or PC using the Cayenne IoT platform. By integrating sensors for both voltage and current measurement, the system enables real-time monitoring, providing maritime SMEs with critical insights into their energy consumption patterns and helping them to make informed decisions that contribute to cost savings and operational efficiency.

The primary contribution of this research is the design and implementation of an IoT-enabled monitoring system that is capable of tracking electrical parameters with high accuracy and reliability. The system's performance, in terms of accuracy and data transmission efficiency, offers a practical solution for maritime SMEs, particularly in regions with limited access to sophisticated monitoring technologies. Unlike existing solutions, the proposed system integrates both current and voltage measurement sensors and allows remote monitoring through an intuitive interface, making it highly scalable and user-friendly for maritime SMEs.

The subsequent sections of this work are organized as follows: Section 2 provides an overview of pertinent literature on IoT-based electricity monitoring systems. Section 3 delineates the design and methods of the proposed system, encompassing both the hardware and software components. Section 4 delineates the experimental configuration and findings. Section 5 ultimately finishes the work by summarizing the principal findings and proposing avenues for future research.

2 Related work

IoT devices for monitoring electrical energy consumption have been widely reported in various kinds of literature. Several solutions are delivered by applying the concept of open-source technology based on IoT, which is low cost, integrated, real-time, visualized, and effective in analyzing data. The system can monitor energy consumption through the android application by predicting the bill every month by connecting hardware, software, and cloud [7]. Electrical energy consumption records can be monitored in real-time by providing billing information and monthly usage statistics via a web server [8]. IoT-based energy measurement eliminates human involvement in maintaining electrical energy consumption [9]. The applied flexibility provides solutions for users by utilizing IoT-based technology.

IoT is here to transfer energy consumption information efficiently using wireless to detect household appliance electricity usage and generate electricity bills [10]. IoT applies a distributed network topology that can dynamically absorb various energy sources. This is done to manage the energy demand side and various fields of electricity production in a sustainable manner. IoT-based energy monitoring systems can be analyzed based on microcontrollers, sensors, communication protocols, and applications [11]. The system architecture connects all sensors and modules to the microcontroller. The microcontroller transmits data to the cloud via a communication protocol linked to the internet network. Data transmitted to the cloud is retained on storage devices/servers and processed as required. The processed data will ultimately be presented on the client-side, including websites, mobile applications, and APIs.

The design of an IoT-based energy consumption monitoring and billing system helps to reduce energy waste and prevent electricity shortages. Users can perform power management by knowing energy usage over time [12]. The system design incorporates several essential components such as a microcontroller (ARM7-

LPC2138), USB to TTL converter, GSM system, Relay, and interfacing. Electrical energy consumption is obtained by counting the calibration pulses from the electric energy meter to generate measurement data. The measurement result data is sent to a central server that can be accessed anywhere in the android application connected to the internet [13]. The data displayed on the android application is energy consumption, frequency, voltage, and power fluctuations.

A *smart energy meter* is used to monitor and control an electric energy meter when using linear loads based on the Internet of Things (IoT) [14]. This device works by controlling and calculating energy consumption using Fast Fourier Transform (FFT). The measurement results of the voltage and current values from the sensor input obtained are uploaded to the Thingspeak cloud platform. The sensor input value is used to calculate the instantaneous power to control efficient energy consumption.

Despite these advancements, several gaps still exist in current IoT-based solutions, particularly regarding accuracy, cost efficiency, and ease of use. Most existing systems focus on household applications, neglecting the specific needs of maritime SMEs. Additionally, while several systems offer real-time monitoring capabilities, issues with data transmission and scalability are often reported. Therefore, this study addresses these gaps by designing a low-cost, highly accurate IoT-enabled monitoring system specifically for maritime SMEs, with robust real-time data transmission through the Cayenne platform. The proposed system combines the strengths of previous solutions—real-time monitoring, ease of use, and low-cost implementation—while improving accuracy and data transmission rates in environments with variable internet connectivity.

3 Methodology

This section presents the design and development of an Internet of Things (IoT)-based system for monitoring electricity consumption. The system measures both current and voltage in real-time, enabling users to monitor energy consumption remotely through the Cayenne IoT platform. The key hardware components include current and voltage sensors, a microcontroller, and a wireless communication module. The data is transmitted and visualized on the Cayenne dashboard, providing an intuitive user interface.

3.1 System architecture

The system is divided into three main units: input, processing, and output units. The input unit consists of current and voltage sensors, the processing unit includes a microcontroller for data collection and transmission, and the output unit visualizes the data on a remote dashboard.

3.1.1 Input unit

SCT-013-000 current sensor measures the AC current by applying the current transformer principle, ensuring galvanic isolation between the primary and secondary circuits. It can measure currents up to 100A with a high accuracy of ±1%. ZMPT101B voltage sensor measures AC voltage up to 250V. It is known for its precision and stability, making it ideal for real-time voltage monitoring.

3.1.2 Processing unit

ADS1115 Analog to Digital Converter (ADC): This ADC module transforms the analog signals from the sensors into digital data for subsequent processing. It provides 16-bit precision and operates at up to 860 samples per second, ensuring accurate data collection.

Arduino Pro Mini: This microcontroller processes the data collected from the sensors and communicates with the wireless module.

Wemos D1 Mini (ESP8266): Equipped with the ESP8266 Wi-Fi chipset, this module connects the system to the internet, allowing data transmission to the Cayenne platform. It operates on the IEEE 802.11b/g/n protocol and supports real-time communication.

3.1.3 Output unit

Cayenne IoT Platform acts as a user interface where real-time data on voltage, current, and power consumption is visualized. The platform supports drag-and-drop functionality, simplifying the user experience.

3.2 System design and configuration

The proposed system's architecture is shown in Figure 1, illustrating how the sensors, microcontroller, and wireless module interact. The SCT-013-000 sensor measures the current and the ZMPT101B sensor measures voltage. Both sensors send their data to the ADS1115 module, which converts the analog signals into digital inputs. The Arduino Pro Mini processes these inputs and sends the data to the Wemos D1 Mini module. This module transmits the data wirelessly to the Cayenne IoT platform for real-time monitoring.

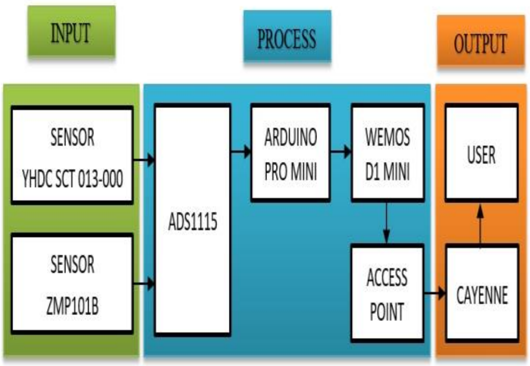

Fig. 1. System architecture

3.3 Data transmission and visualization

The data collected by the sensors is transmitted at one-minute intervals. The Wemos D1 Mini sends the data to the Cayenne platform, where it is stored and visualized in the form of real-time graphs and metrics. Users can access this data through their smartphones or PCs. The Cayenne platform enables the user to monitor key parameters such as: Current (A), Voltage (V), and Power Consumption (W). The platform also supports historical data visualization, enabling users to track usage trends over time. The Cayenne dashboard's drag-and-drop functionality allows easy customization of the interface according to the user's preferences.

3.4 Calibration and testing procedure

Two tests were conducted to evaluate the performance and accuracy of the system: sensor calibration and data transmission tests.

3.4.1 Sensor calibration

Calibration was performed to ensure the accuracy of the current and voltage measurements. The SCT-013-000 sensor's current readings were compared against a standard amperage pliers device, while the ZMPT101B voltage sensor was compared against a digital multimeter. Both sensors were tested with varying loads, and the results were plotted to determine linearity and accuracy.

3.4.2 Data transmission testing

The data transmission capability of the system was evaluated by running the system for extended periods. Two tests were performed. In the first test, the system was operated for 6 hours, with data being transmitted every minute. The test results showed a data transmission success rate of 74%, with most failures attributed to poor internet connectivity. In the second test, conducted over 8 hours, the system achieved a data transmission success rate of 99.02%, demonstrating improved reliability with better internet conditions.

3.5 Experimental setup

The hardware components were assembled as shown in Figure 2, and the system was connected to a customer's KWH meter for real-world testing. The system was designed to fetch data every minute and store it on a micro SD card. Data was also sent to the Cayenne platform, where it could be visualized in real-time. During the tests, users monitored the data through the Cayenne interface on both smartphones and PCs, observing variations in voltage and current values under different load conditions.

Fig. 2. Hardware components connected to the customer

3.6 Data analysis

The collected data was analyzed for both accuracy and transmission performance. The current sensor SCT-013-000 achieved an average accuracy rate of 93.94%, with minimal deviations across different load levels. The voltage sensor ZMPT101B showed a higher accuracy rate of 98.50%, further validating the precision of the system. The data transmission tests confirmed that the system is highly reliable in environments with stable internet connections, with transmission rates improving from 74% in the first test to 99.02% in the second.

4 Results and discussion

This section presents the experimental results and analysis of the IoT-based electricity consumption monitoring system. The performance of the system was evaluated based on the accuracy of current and voltage measurements, data transmission rates, and the system's overall reliability in real-time monitoring.

4.1 Calibration results

The system's current and voltage sensors were calibrated to verify their accuracy. The calibration process involved comparing sensor readings to standard measuring devices (amperage pliers and multimeter) under varying load conditions.

4.1.1 Current sensor calibration

The SCT-013-000 current sensor was tested with loads ranging from 0A to 10A. The comparison between the sensor and the standard device showed high linearity, as illustrated in Figure 3. The sensor demonstrated an average accuracy of 93.94%, with the highest accuracy observed at 0.1A (100%) and the lowest at 4.8A (86.88%). These results are consistent with the manufacturer's specification of ±1% accuracy, confirming the sensor's reliability for real-time current measurement in small and medium enterprise (SME) environments.

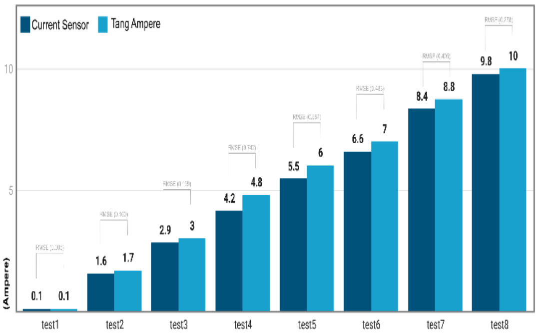

Fig. 3. Graph of comparison SCT-013-000 and Tang Ampere

4.1.2 Voltage sensor calibration

The ZMPT101B voltage sensor was tested with input voltages ranging from 147V to 229V. The calibration results, shown in Figure 4, indicate an average accuracy of 98.50%. The highest accuracy was observed at 215V (99.86%), while the lowest was recorded at 165V (95.45%). These results demonstrate the sensor's high precision in voltage measurement, making it suitable for real-time monitoring applications where voltage stability is critical.

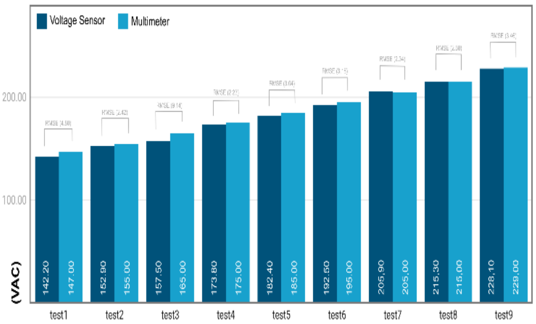

Fig. 4. Graph of comparison ZMPT101B and multimeter

4.2 Data transmission and reliability

Two tests were conducted to evaluate the system's data transmission performance over the internet, focusing on the success rate of data sent to the Cayenne IoT platform.

4.2.1 First test – 6 hours

In the first test, the system operated continuously for 6 hours. The data transmission success rate was 74%, with 287 out of 389 data points successfully sent to the Cayenne platform. Figure 5 and Figure 6 illustrate the time-series data for current and voltage measurements, respectively. The analysis indicates that most transmission failures occurred due to unstable internet connectivity during the test, which resulted in data loss. The peak current value during this test was 19A, while the highest recorded voltage was 230V at specific times during the day.

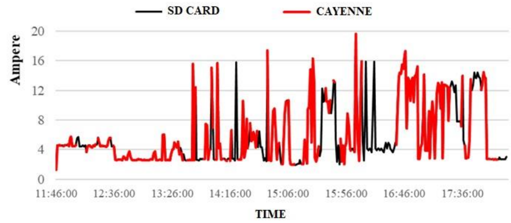

Fig. 5. Graph of current measurement in the first test carried out

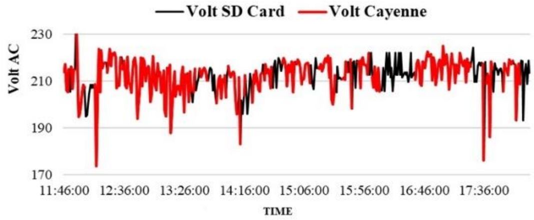

Fig. 6. Graph of voltage measurement in the first test carried out

4.2.2 Second test – 8 hours

The second test, conducted over a longer period (8 hours), resulted in a significantly higher data transmission success rate of 99.02%, with only 5 out of 511 data points unsent. Figures 7 and 8 display the current and voltage measurement graphs for the second test. The peak current reached 46A, and the voltage stabilized at 225V during the test period. The improved data transmission reliability in this test can be attributed to the use of a more stable internet connection (Telkomsel provider), as opposed to the IM3 Ooredoo provider used in the first test. This highlights the importance of internet stability in the successful implementation of IoT-based monitoring systems.

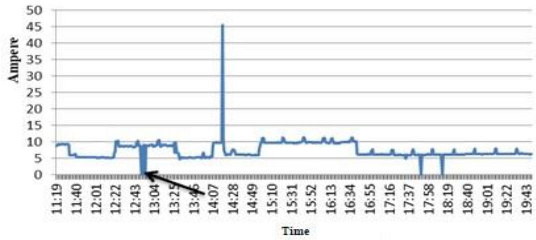

Fig. 7. Graph of current measurement in the second test carried out

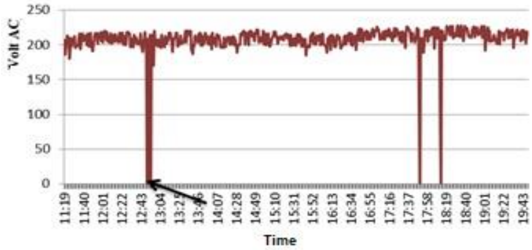

Fig. 8. Graph of voltage measurement in the second test carried out

4.3 Data visualization and user experience

The system's data visualization capabilities, powered by the Cayenne platform, allow users to monitor electricity consumption in real time. Figure 9 shows the Cayenne dashboard, where users can view live data on current, voltage, and power consumption. The system enables users to track changes in electricity usage trends and analyze consumption patterns over time, providing valuable insights into operational efficiency.

Additionally, users can access historical data, allowing them to identify periods of high consumption and adjust their energy usage accordingly. The Cayenne platform's drag-and-drop interface simplifies the customization of data views, making the system accessible even for users with limited technical knowledge. This ease of use is crucial for maritime SMEs, which often lack specialized personnel for energy management.

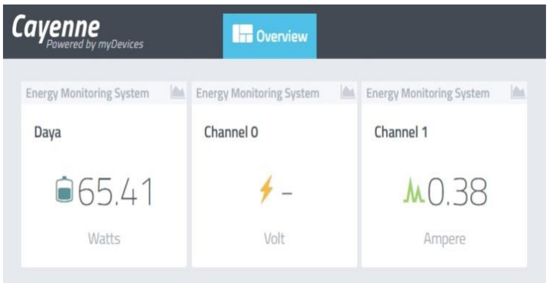

Fig. 9. Cayenne dashboard

4.4 System performance analysis

The IoT-based monitoring system performed well across the tests, demonstrating high accuracy in both current and voltage measurements. The system's data transmission capabilities, while dependent on the quality of the internet connection, proved robust in environments with stable connectivity. These results confirm the feasibility of implementing the system in maritime SMEs for real-time electricity monitoring.

4.4.1 Accuracy

The system's accuracy rates of 93.94% for current measurement and 98.50% for voltage measurement indicate that it is suitable for applications requiring precise energy monitoring. The high accuracy rates, especially for voltage, underscore the reliability of the system in providing critical insights into electricity consumption trends.

4.4.2 Reliability

The significant improvement in data transmission from 74% to 99.02% between the two tests highlights the role of internet stability in system performance. This suggests that in regions with strong internet infrastructure, the system will reliably transmit data to cloud-based platforms, ensuring real-time monitoring without significant data loss.

4.5 Discussion of Limitations and Future Improvements

4.5.1 Limitations

Although the system demonstrated reliable performance, certain limitations were identified:

Dependence on Internet Connectivity: The success of data transmission is heavily reliant on the quality of the internet connection. In areas with intermittent or weak connectivity, data loss may occur, limiting the system's effectiveness. A potential improvement could involve adding local storage backup, where data can be stored during periods of poor connectivity and transmitted once a stable connection is re-established.

Scalability: While the current system is designed for maritime SMEs, scaling the solution to larger enterprises with more complex energy requirements may require additional sensors and enhanced data processing capabilities. Future iterations of the system could incorporate more advanced data analytics and machine learning algorithms to predict consumption patterns and optimize energy usage dynamically.

4.5.2 Future Work

Future developments could focus on:

Predictive Analytics: By integrating machine learning algorithms, the system could forecast future energy consumption patterns based on historical data, facilitating improved energy management.

Smart Grid Integration: Incorporating smart grid technology would allow for more dynamic energy management, adjusting consumption based on grid conditions.

Cost Estimation: Adding real-time cost estimation for electricity usage could help maritime SMEs manage their energy expenses more effectively.

5 Conclusion

This study successfully developed an IoT-based electricity monitoring system for maritime SMEs. The system achieved high accuracy in measuring current and voltage, with reliable data transmission to the Cayenne platform. This real-time monitoring solution helps maritime SMEs optimize energy use and reduce costs. In terms of practical implications, this system is scalable, cost-effective, and user-friendly, making it a valuable tool for maritime SMEs that operate on limited budgets but require real-time insights into energy consumption patterns. Moreover, it aligns with the goals of sustainable development by promoting energy efficiency and supporting maritime SMEs in optimizing their energy use. Future enhancements will include the integration of predictive analytics, local data storage, and smart grid technology to further improve energy management.

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