

IOT-Driven Smart Energy Monitoring: Development of SIMONDE In Telecommunication Laboratory

Ade Irfansyah*, Yuyun Suprpto, Nyaris Pambudiyatno, Bambang Bagus Hariyanto, Teguh Imam Suharto

Politeknik Penerbangan Surabaya, Jl. Jemur Andayani I No.73, Surabaya, Jawa Timur 60236, Indonesia
ade_irfansyah@poltekbangsby.ac.id*
*corresponding author

ARTICLE INFO	ABSTRACT
<p>Article history Received April 18, 2025 Revised May 15, 2025 Accepted June 29, 2025</p> <hr/> <p>Keywords IoT Energy Monitoring Power Management Educational Laboratories Real-Time Monitoring</p>	<p>Accurate electrical energy monitoring is essential for effectively managing its usage. The Internet of Things (IoT) technology offers an optimal solution for real-time monitoring. This study aims to design and implement an IoT-based Power and Energy Monitoring System (SiMONDE) that efficiently monitors real-time electrical energy usage in a telecommunications laboratory. The research employs a research and development methodology with the ADDIE model approach, encompassing three phases: (1) analysis, (2) design, and (3) development. The results indicate significant errors in SiMONDE when measuring current in the range of 0.3 to 0.12 Amperes, compared to a clamp meter. However, when measuring currents between 1.6 and 3.7 Amperes, SiMONDE exhibits a low error margin. SiMONDE's media and usage feasibility percentages are also 97.5 percent and 96.87 percent, respectively. The study concludes that SiMONDE is not sufficiently accurate for low-current measurements yet demonstrates high usability feasibility according to user needs.</p>

I. Introduction

The increasing electricity consumption in educational environments requires a more efficient system to monitor and manage energy usage, particularly in educational labs where equipment use fluctuates significantly. This project aims to develop an IoT-based energy management system that monitors, controls, and optimises energy use in real-time. IoT technology enables continuous tracking and analysis of energy consumption patterns, providing insights for administrators to reduce waste and enhance efficiency. According to several studies, IoT-based energy management systems have been successfully applied in various sectors, such as smart green buildings and industrial systems, providing real-time data for improved energy efficiency and reduced operational costs [1], [2]. However, while IoT applications have been well-explored in general contexts, their specific implementation in educational environments remains under-researched, making this a promising area for future exploration.

Implementing the SiMONDE (Integrated Monitoring System for Educational Devices) in the telecommunications laboratory at Poltekbang Surabaya has brought numerous benefits to the educational and operational processes. One of the main advantages is the ability to monitor equipment usage in real-time, allowing the institution to track energy consumption and optimise the usage of resources more efficiently. This significantly reduces operational costs as the system helps identify periods of excessive energy use and opportunities to minimise wastage. Furthermore, by integrating IoT-based solutions like SiMONDE, the laboratory can collect data on equipment performance, helping with preventive

maintenance and extending the lifespan of costly technical assets [1], [2].

In addition to resource optimisation, SiMONDE enhances the learning environment for students. The system provides a practical example of how IoT technologies can manage complex systems, offering hands-on experience with cutting-edge energy management solutions. Students gain insights into real-time monitoring, data analysis, and the overall efficiency of telecommunication infrastructure, thus aligning their skills with industry demands. This kind of active learning prepares students for future roles in the telecommunication field, providing them with theoretical knowledge and practical competencies [3], [4]

This research aims to develop a comprehensive system to more precisely monitor and calculate the monthly electrical load cost, incorporating power factor ($\cos \phi$) into the equation. By analysing the $\cos \phi$, the system aims to improve energy efficiency by reducing reactive power and thus lowering electricity costs. Additionally, the study introduces a predictive model using simple linear regression to forecast electricity consumption for the upcoming months. This predictive approach provides valuable insights for better energy management and budgeting, helping institutions plan their future electricity needs while minimising costs and wastage.

A. Electrical Energy Management

The theoretical review for this research will cover several key concepts related to SiMONDE (Power and Energy Monitoring System), electrical energy management, and Internet of Things (IoT) technology.

Electrical energy management monitors, measures, and controls electricity use to improve efficiency and effectiveness [5]. This process involves implementing effective strategies to reduce energy waste and operational costs while ensuring more environmentally friendly and sustainable energy usage. Energy management programs are also systematically planned and implemented to optimise energy use through technology and continuous monitoring.

Moreover, electrical energy management can be applied across various industrial and educational sectors. In academic institutions, energy management programs are necessary to ensure that electricity is used effectively and efficiently, reducing operational costs and enhancing the quality of educational facilities. These efforts include minimising energy consumption per production unit and improving energy infrastructure management.

B. Monitoring System

The definition of a Monitoring System is a service that collects and analyses data to optimise all available resources. Monitoring systems are divided into two parts: (1) connection monitoring, and (2) traffic monitoring. Connection monitoring is a network monitoring technique that can be done by performing ping tests between the monitoring station and the target device. On the other hand, traffic monitoring is a technique used to observe the packet traffic on a network. The purpose of a monitoring system is to gather helpful information and data from a network so that it can be managed and controlled. In a monitoring system, there is often a tool that can control the monitoring process [6].

C. Internet of Things

IoT, short for the Internet of Things, refers to the concept that everything can be connected through the internet. This means that when an object is equipped with sensors and software, it can communicate, share data, and connect with other devices over the internet. This illustrates the active role of the internet in daily digital activities, facilitating data transfer and communication with others while connected to the internet. IoT is closely related to M2M (machine-to-machine), where devices used in M2M communication are called smart devices. The primary goal of creating these smart devices is to provide assistance and solutions for solving various problems, tasks, and daily challenges humans face. In line with this, IoT emerges as an innovation created to facilitate individual tasks [7].

IoT has become relevant because it enables integrating electronic devices with the internet to collect, process, and analyse data in real time [8]. The application of IoT in energy management has opened doors for the development of devices like SiMONDE, which uses voltage and current sensors to collect energy data accurately. Related research has shown that implementing IoT technology in electrical energy management can

improve energy savings, reduce costs, and increase user awareness of energy consumption [9]. Thus, IoT is a trusted technology today for monitoring and controlling electrical devices. However, data security and network reliability challenges remain primary concerns in developing and implementing IoT solutions like SiMONDE.

D. SiMONDE

SiMONDE (Sistem Monitoring Daya dan Energi) is designed with a robust architecture combining hardware and software components. The hardware includes IoT-based sensors for voltage and current measurements and controllers that manage the collection of real-time energy data. These sensors are installed across various points in the laboratory's electrical system, transmitting data through the internet. The software component is a cloud-based platform that stores, processes, and analyses the data. This platform is connected to a user-friendly mobile application, allowing users to monitor energy usage remotely and control the system as needed. The software can also provide real-time alerts and reports on energy consumption patterns.

SiMONDE's key features include real-time monitoring, which enables users to view live data on energy usage, thereby helping identify energy inefficiencies. The system also provides remote control through a mobile app, allowing users to manage and control electrical appliances anywhere. Furthermore, the data analytics feature offers insights into energy consumption trends over time, helping optimise energy use, reduce waste, and lower operational costs.

The technology stack used in SiMONDE includes IoT sensors that collect energy data and communicate with cloud platforms for real-time monitoring. The cloud infrastructure supports storing and analysing large datasets, enabling quick access and scalability. Additionally, a mobile application is the interface through which users can interact with the system, control devices, and view detailed energy reports. This combination of IoT technology, cloud computing, and mobile apps creates an interactive and efficient system for managing energy consumption in the telecommunications lab of Poltekbang Surabaya.

The research on SiMONDE (Sistem Monitoring Daya dan Energi) is built upon the theory of energy management and the Internet of Things (IoT). Energy management theory emphasises the need for efficient monitoring, measurement, and control of energy use, which SiMONDE addresses by utilising IoT technology to monitor and control energy consumption in real-time.

The IoT theory, which refers to the interconnectivity of devices through the Internet, forms the backbone of SiMONDE's functionality, enabling seamless data collection, analysis, and remote control of energy systems.

Previous research that serves as the foundation for this study includes work by Furqon et al. [8], who developed a similar energy monitoring system using IoT to track power usage in boarding houses. The study showed the effectiveness of real-time monitoring and demonstrated a significant margin of error in energy measurement compared to traditional methods. Another relevant study is by Istiana [10], who developed the PEMoS system, which utilised IoT to control and monitor energy in a more generalised residential context. These studies provide crucial insights into the application of IoT for energy management, helping to shape the development of SiMONDE.

The study conducted by Furqon and colleagues in 2019, titled "Design and Development of an Electrical Power Monitoring and Control System for Boarding Houses Using NodeMCU and Android-Based Firebase," aimed to create a system that monitors the electricity usage of boarding house residents, measures the energy consumed, and calculates the associated costs. The sensor measurements showed an error accuracy rate of $\pm 1.8\%$ compared to a digital multimeter as a benchmark. System application testing demonstrated that the application could monitor the electrical power usage in each boarding room in real-time [8].

The following study, conducted by Istiana [10], titled "Design of an IoT-Based Power Monitoring and Control System," developed a system called PEMoS, an acronym for Power and Energy Monitoring System. PEMoS operates by transmitting signals received from sensors through a server before being sent to the cloud [10]. It also includes an Android application used to control clients and monitor the electricity from PLN. Test results showed a voltage reading error rate of 1.60% and a current error rate of 9.93%. However, the client and server had a data transmission delay of approximately +6 seconds [10].

The research conducted by Subrata and colleagues in 2023, titled "IoT-based Single-Phase Power Factor and Control Panel Monitoring System," aimed to monitor the power factor on control panels. The system developed is integrated with IoT technology, allowing it to monitor and record data automatically anytime, anywhere. The system achieved an error percentage of 1.53% for voltage sensors and 5.02% for current sensors [11].

II. Method

In this study, the development model used is the ADDIE model, a systematic approach for developing instructional tools and other educational products. The ADDIE model comprises five main stages: Analysis, Design, Development, Implementation, and Evaluation. Each stage has a specific objective; for instance, in the Analysis stage, researchers identify needs and issues, while the Evaluation stage focuses on assessing the

product's effectiveness and making improvements based on the results obtained.

This study used development research using the ADDIE model approach (Analysis, Design, Development, Implementation, Evaluation). The ADDIE model is a systematic approach used in instructional design to develop educational programs or courses. It comprises five main stages: Analysis, Design, Development, Implementation, and Evaluation. However, this study did not conduct the Implementation and Evaluation stages due to time and resource constraints.

In this research, several key tools and components are utilised to ensure the proper functioning of SiMONDE. The NodeMCU V3 is the primary controller, enabling the system to communicate with various sensors and process data in real-time. The NodeMCU Board is used as the core board controller, facilitating the integration of IoT components and ensuring smooth data transmission. For measuring energy parameters such as voltage, current, power, and frequency, the PZEM-004T V3 energy meter sensor is employed. This sensor is critical in capturing real-time energy consumption data, which is then displayed for monitoring.

An LCD 16x2 display visualises the collected data, allowing users to view essential information such as the system's current energy usage directly. The I2C LCD Module is used alongside the LCD to simplify wiring and reduce the number of pins required for the display, improving system efficiency. Lastly, a Tang Ampere Meter is utilised to compare and validate the current measurement from the PZEM-004 T V3, ensuring accuracy in the readings and providing a reliable reference for system calibration.

The measurement data captured by the SiMONDE system, in addition to being displayed on the LCD screen, is also output as serial data. This serial data is transmitted to a computer and imported into a spreadsheet application like Excel. Once in Excel, the data undergoes statistical regression analysis to predict future energy consumption and estimate the associated costs. By applying linear regression analysis, it is possible to identify trends and patterns in energy usage, enabling more accurate forecasts for upcoming periods. This method gives users insights into current energy consumption and how much energy and cost can be expected based on historical data trends [12].

A. SiMONDE Needs Analysis Stage

The first stage in the ADDIE model is Analysis, which forms an essential foundation to ensure that the development process meets existing needs. In this stage, the researcher identifies the research needs and thoroughly understands the issues or challenges in energy management. These needs may include problems related to energy waste, lack of monitoring, and inefficiency in controlling energy usage in laboratories or other settings.

Data collection methods for this needs analysis are conducted through observations and interviews. Observations focus on monitoring energy usage in laboratories that do not yet have a monitoring system. Interviews are conducted with several groups, including:

(1) lecturers, (2) students, and (3) management. Lecturers are responsible for laboratory management and the learning process. Students, on the other hand, are the users of the laboratory facilities for academic activities. Finally, management is responsible for operational efficiency and energy budget management. The data collected through these methods provides a basis for designing the SiMONDE system to match user needs.

Once the needs are identified, the researcher sets the goals and objectives for this study, such as designing an effective Internet of Things (IoT)-based Power and Energy Monitoring System (SiMONDE). The goal-setting process includes technical aspects, like the expected capabilities of the system (for example, real-time energy usage monitoring and integration with other devices). Additionally, this analysis must consider user needs, including the technical staff in the laboratory and facility management who will use SiMONDE. This involves understanding how they will interact with the system, their required technological knowledge, and their expectations for efficiency and ease of use.

This study aims to design an IoT-based Power and Energy Monitoring System (SiMONDE) using the ESP8266 and Blynk application to monitor real-time electricity usage in laboratories. With SiMONDE, technical staff and management personnel can easily view energy consumption data through a simple, user-friendly interface, helping them identify energy waste and improve electricity efficiency. This system is also designed to be flexible and integrate with other laboratory devices, allowing for more comprehensive monitoring. SiMONDE is expected to simplify energy management by providing accurate information that is easily accessible to all users, regardless of their technical background.

Furthermore, this analysis includes a review of relevant literature. The researcher examines previous studies on electrical energy management and IoT technology for monitoring energy consumption, while also evaluating gaps or deficiencies in prior research. Previous studies have shown limited focus on educational environments or laboratories, which allows this research to contribute more specifically within that context. This analysis stage is critical to ensuring that each subsequent development step is relevant, measurable, and addresses fundamental needs in the field.

To analyse the error percentage in current measurements between the clamp meter and SiMONDE, the following equation can be used:

$$D = M1 - M2$$

D: Difference

M1: SiMONDE Reading M2: Clamp Meter Reading

The difference refers to the variation in current measurement readings between SiMONDE and the clamp meter. This calculation is then used to determine the percentage error of SiMONDE measurements relative to the clamp meter. The smaller the error percentage obtained, the more accurate SiMONDE performs the measurements. The error percentage of SiMONDE can be calculated using the following equation:

$$\text{Error \%} = (D / M2) \times 100\%$$

The error percentage can be determined by dividing the difference between the SiMONDE and clamp meter measurements by the clamp meter reading, then multiplying by 100%. If the error percentage obtained from the calculation is small, or below 5%, the SiMONDE measurements are considered accurate. However, if the calculated error is significant, SiMONDE is deemed insufficiently precise. A calibration process is necessary to ensure measurement accuracy, which returns the measurement results to their standard reference values.

Evaluating SiMONDE's media feasibility and usability involves collecting data through questionnaires distributed to respondents. These questionnaires are designed to measure two main aspects: media feasibility in terms of design, display, and system functionality and usability in terms of ease of use, efficiency, and reliability for the users.

After testing the measurement results, an expert feasibility evaluation of SiMONDE is also required. This feasibility test is conducted to determine the level of feasibility based on several specified criteria: (1) media feasibility, and (2) usability. The following explains each indicator and the items involved in the measurement.

The media feasibility assessment aspects are measured using several indicators: (1) visual display, (2) ease of navigation, and (3) information quality.

(4) design consistency, and (5) access speed. The visual display aspect evaluates how the SiMONDE interface on the LCD screen and smartphone provides users clear and easily understandable information. In a study on IoT-based devices utilising Arduino, ESP, and Android for monitoring household electrical energy, data visualisation through mobile applications helps enhance users' understanding of their energy consumption, highlighting the importance of informative and appealing visuals [13]. Using a system that integrates IoT-based backup power devices demonstrates that presenting data in an engaging format can strengthen users' comprehension and interest in the power monitoring system [14].

Ease of navigation is evaluated based on the accessibility of SiMONDE features, enabling users to

locate and use specific functions efficiently. Intuitive navigation can reduce users' cognitive load and improve usage efficiency [15]. Next, the information quality indicator assesses the reliability and accuracy of the data presented by SiMONDE. Accurate and precise information is essential in a monitoring system, as this data underpins user decisions. The references come from international journal articles from the last five years [16], [17], [18].

Furthermore, design consistency is evaluated by assessing the consistency of SiMONDE's interface appearance and feature layout. A consistent design enhances aesthetics and helps users form familiar and predictable interaction patterns. Finally, the access speed aspect assesses how quickly SiMONDE responds to user inputs. System responsiveness is critical to user experience, especially in real-time monitoring applications [19].

The evaluation score based on feasibility of use is measured by several indicators as follows: (1) ease of use, (2) system reliability, (3) user benefits, and (4) accuracy. Ease of use assesses the simplicity of operating SiMONDE, including its quick response to voltage and current inputs. Ease of use is essential to ensure users of varying skill levels can operate the tool without complex training [20].

Meanwhile, the system reliability indicator examines the consistency of SiMONDE's measurements under similar conditions and its durability in various environmental conditions. Reliability is crucial in a monitoring system as it involves the accuracy and continuity of the generated data [21]. The next indicator is user benefits, which evaluates how well the monitoring features assist users, for example, in efforts to save electrical energy. Based on the data provided, this aspect assesses the direct impact on user decision-making [22].

The final indicator of feasibility is accuracy, which assesses how precisely SiMONDE measures voltage and current compared to conventional measurement tools. This is an essential indicator in determining the quality of the measuring tool as it directly relates to the validity of the data produced [23].

To explain the results of the SiMONDE feasibility test using a questionnaire, the following steps can be taken: (1) data collection, (2) data analysis, (3) score and percentage calculation, and (4) feasibility conclusion. The questionnaire is distributed to some respondents, who may include primary users such as lecturers, students, or management personnel. The questionnaire contains questions evaluating various aspects of SiMONDE, such as visual display, ease of navigation, information quality, design consistency, and access speed. Each response is rated based on a Likert or another suitable scale, allowing average score calculations for each measured aspect. This

data is then used to determine the system's suitability and user acceptance.

Each item in the questionnaire is calculated as a percentage to determine the extent to which respondents deem the system feasible. A commonly used formula is:

$$\text{Feasibility \%} = (\text{AS} / \text{MS}) \times 100\%$$

AS: Achieve Score

MS: Maksimum Score

This percentage score provides insight into how well SiMONDE meets user needs. The final step is to draw a feasibility conclusion based on the percentage score. For instance, if the feasibility percentage is above 80%, SiMONDE can be considered highly feasible, while if it is below 60%, further improvements may be required in specific areas. This approach allows SiMONDE. The feasibility test results will be presented objectively and measurably, helping to identify areas needing further development based on user feedback.

B. SiMONDE Result Design Stage

After completing the analysis stage, the researcher will proceed to the design stage, where the overall concept and structure of SiMONDE will be carefully planned. This design involves detailed planning on how SiMONDE will be built, beginning with creating a system architecture that accommodates its main feature, real-time monitoring.

The research flowchart, as shown in Figure 1, illustrates the main stages of the system development process, from literature review to evaluation. The research begins with a literature review to understand the concepts and technology underlying the Power and Energy Monitoring System (SiMONDE). Next, a needs analysis is conducted to identify the required features and potential technical challenges.

At this stage, the researcher will determine the main features to be included in the system: a mobile application-based monitoring interface. The design of the user interface is crucial, as it will serve as the bridge between the system and its users. This interface is designed to be intuitive and easy for users of varying skill levels to use. Additionally, the researcher will consider how IoT technology can be integrated, which includes using sensors and devices that connect to the internet to collect and transmit data to the server in real-time. The researcher will also develop an instructional framework to guide the development and implementation process, ensuring each step is executed effectively and measured according to plan.

The research flowchart, as shown in Figure 1, illustrates the main stages of the system development process, from the literature review to the evaluation. The research begins with a literature review to understand the concepts and technology underlying the Power and

Energy Monitoring System (SiMONDE). Next, a needs analysis is conducted to identify the necessary features and any technical challenges that may arise.

C. SiMONDE Development Stage

In this study, the development model used is the ADDIE model, a systematic approach for developing instructional tools and other educational products. The ADDIE model comprises five main stages: Analysis, Design, Development, Implementation, and Evaluation. Each stage has a specific objective; for instance, in the Analysis stage, researchers identify needs and issues, while the Evaluation stage focuses on assessing the product's effectiveness and making improvements based on the results obtained.

The research method used in this study is development research using the ADDIE model approach (Analysis, Design, Development, Implementation, Evaluation). The ADDIE model is a systematic approach used in instructional design to develop educational programs or courses. It comprises five main stages: Analysis, Design, Development, Implementation, and Evaluation; however, the Implementation and Evaluation stages are limited due to time and resource constraints.

In this research, several key tools and components are utilised to ensure the proper functioning of SiMONDE. The NodeMCU V3 is the primary controller, enabling the system to communicate with various sensors and process data in real-time. The NodeMCU Board is used as the core board controller, facilitating the integration of IoT components and ensuring smooth data transmission. For measuring energy parameters such as voltage, current, power, and frequency, the PZEM-004T V3 energy meter sensor is employed. This sensor is critical in capturing real-time energy consumption data, which is then displayed for monitoring.

An LCD 16x2 display visualises the collected data, allowing users to view essential information such as the system's current energy usage directly. The I2C LCD Module is used alongside the LCD to simplify wiring and reduce the number of pins required for the display, improving system efficiency. Lastly, a Tang Ampere Meter is utilised to compare and validate the current measurement from the PZEM-004 TV3, ensuring accuracy in the readings and providing a reliable reference for system calibration.

The measurement data captured by the SiMONDE system, in addition to being displayed on the LCD screen, is also output as serial data. This serial data is transmitted to a computer and imported into a spreadsheet application like Excel. Once in Excel, the data undergoes statistical regression analysis to predict future energy consumption and estimate the associated costs. By applying linear regression analysis, it is possible to identify trends and patterns in energy usage, enabling more accurate forecasts for upcoming periods. This method gives users insights

into current energy consumption and how much energy and cost can be expected based on historical data trends [12].

The studies electrical energy monitoring in boarding houses and IoT-based power monitoring systems with Android applications; however, their research contexts did not include the educational laboratory environment [8], [10]. This study introduces a novel focus on energy management in academic laboratories, which requires a different approach due to the higher intensity of electricity use and the complexity of devices involved.

Additionally, this study employs SiMONDE, which is designed to improve energy efficiency, specifically in laboratories, through real-time IoT analysis. The research by Subrata et al. [11] focused on monitoring the power factor on control panels, also using IoT. Still, their goal was more about panel monitoring than comprehensive electrical energy management in a laboratory setting. Therefore, the novelty of this study lies in the development of SiMONDE, which not only monitors but also controls energy usage efficiently within an educational laboratory environment, offering a solution focused on energy savings and increasing user awareness in academic institutions.

III. Results and Discussion

A. SiMONDE Needs Analysis Result

Based on the data collection, two basic needs were identified: (1) technical and (2) user requirements. The technical requirements include: (1) real-time monitoring, (2) integration with other devices, and (3) system reliability. Real-time monitoring in SiMONDE should be capable of monitoring electricity usage in real-time to provide accurate data on power consumption in the laboratory. This data will be transmitted via Wi-Fi using ESP8266 and displayed through the Blynk application. Additionally, integration with other devices in the lab, such as equipment requiring specific power monitoring, is essential. This needs flexibility and system capability to detect and communicate with these devices. Lastly, system reliability is a critical technical requirement. SiMONDE should be able to operate over long periods with minimal technical intervention and handle network or power failures.

User requirements can also be observed through several factors: (1) technical staff, (2) facility management staff, and (3) user efficiency and ease of use. Laboratory technical staff must be able to use SiMONDE to monitor electricity usage effectively. The technological knowledge required includes basic use of the Blynk application and access to data transmitted by ESP8266. Meanwhile, facility management staff expect easy reading of energy usage reports to enhance efficiency and optimise electricity costs. The system should have a simple and easy-to-understand interface that does not require

advanced technical skills. Finally, users expect an efficient system with easy navigation and a user-friendly interface for quick access to energy usage data. This needs analysis highlights the necessity of this research, as the current laboratory lacks an energy monitoring system, thus lacking effective control over electricity consumption in the laboratory.

B. SiMONDE Result Design Result

The block diagram shown in Figure 2 illustrates the design of the SiMONDE system, an IoT-based power and energy monitoring system specifically designed for laboratory settings. The system starts with an AC 220V power source, serving as the primary energy source for the monitoring equipment and laboratory devices. This voltage is directed to the Current and Voltage Sensor (PZEM-004T V3), which measures electrical parameters such as current and voltage from the loads used in the laboratory. A DC +5V power source is also supplied for sensor operation, typically obtained from an adapter or other compatible power source.

The Current and Voltage Sensor then transmits the measurement data to the NodeMCU V3 microcontroller. The NodeMCU functions as the control centre, processing data from the sensor, managing communication, and sending this data to the monitoring platform. Additionally, the NodeMCU is connected to a 16x2 LCD Display, which provides users with a real-time visual display of the data on-site. This allows users to easily monitor power consumption without opening an application.

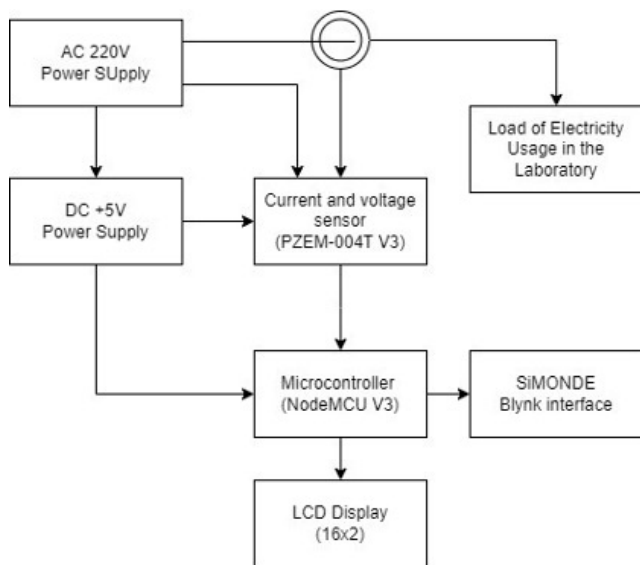


Fig. 1. SiMONDE block diagram

Furthermore, the NodeMCU is integrated with the Blynk interface, enabling users to monitor power usage remotely via the Blynk application. Through this interface, data can be accessed on a smartphone, providing convenience and flexibility for users, especially laboratory staff and facility management, to control and monitor electricity usage anytime and anywhere. This design

leverages IoT technology to create a modern, efficient, user-friendly monitoring system.

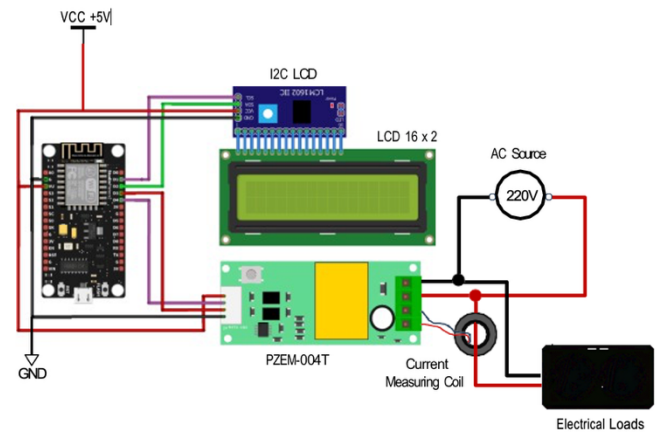


Fig. 2. SiMONDE Wiring Diagram

In Figure 2, a wiring diagram of SiMONDE is shown, detailing the component connections within the electrical power monitoring system using the NodeMCU ESP8266, the PZEM-004T V3 sensor, a 16x2 LCD with I2C interface, and an electrical load. The primary power source comes from 220V AC, which is used to measure the power consumption of the connected load. This AC voltage is fed into the PZEM-004T V3 sensor, which measures current and voltage, then transmits this data to the microcontroller.

The NodeMCU ESP8266, serving as the system's control centre, receives data from the PZEM-004T V3 sensor via the RX and TX pins, which are directly connected to the corresponding pins on the NodeMCU, specifically, pin D7 (TX) and pin D6 (RX). These pins enable serial communication between the NodeMCU and the sensor. The NodeMCU also draws power from a 5V source (through the Vin pin), which additionally powers the I2C LCD module to operate the display.

With this configuration, the system can display real-time electrical power usage data on the LCD and monitor energy consumption from connected devices, allowing users to control and monitor electricity usage via the Blynk application, which is based on the Internet of Things (IoT) technology. This system's energy consumption data is displayed in real-time on a smartphone, enabling users to monitor power consumption remotely. The loads monitored in this system include telecommunications laboratory equipment, such as AC units, lights, oscilloscopes, and experimenters. Thus, users can supervise the energy usage of these devices, ensure efficient power consumption, and detect potential energy waste in the laboratory.

The SiMONDE design phase involves designing a box to house the components. These components include the ESP8266, PZEM-004T sensor, LCD, and a DC +5V power supply. Figure 3 shows the panel box design that will be used to house these components.

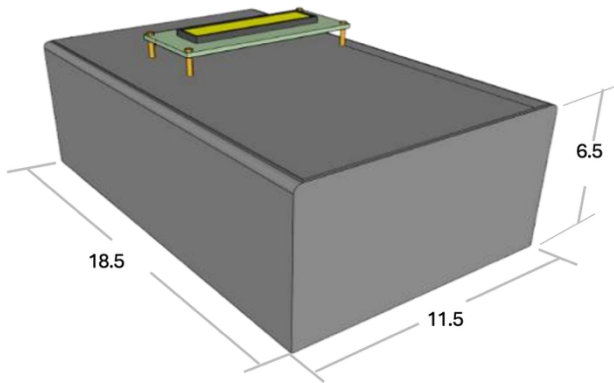


Fig. 3. SiMONDE toolbox design

C. SiMONDE Development Result

The SiMONDE hardware is built based on the block diagram shown in Figure 2. All components, including the DC +5V power supply, NodeMCU V3, its board, and the PZEM-004T, are assembled and connected through several pins according to the wiring diagram in Figure 3. The assembly of these components is done within a box that serves to protect the device from water. This box also acts as a safeguard for users against electric shocks from the 220V current. The 16x2 LCD component is mounted outside the box and securely attached to allow users to view SiMONDE's measurements and calculations, including electrical energy usage and associated costs.

In developing this research, creating the Blynk interface is critical to effectively connecting the monitoring system with users. The Blynk platform enables real-time tracking and control over energy consumption data, making it particularly useful for applications such as intelligent energy monitoring systems. Below is a detailed outline of creating the Blynk interface for monitoring electricity consumption.



Fig. 4. (a) 16x2 LCD installation, (b) SiMONDE component placement in the packaging box

Begin by setting up a Blynk account and creating a new project template, as shown in Figure 5. This template will be the foundation for the monitoring interface, where you can define widgets, data streams, and dashboards for mobile and web applications.

Create New Template

Fig. 5. Create a new template on Blynk

Configure the physical device (e.g., PZEM-004T sensor and NodeMCU ESP8266) to communicate with Blynk using virtual pins. These virtual pins allow you to map data from the device to the interface, enabling remote control and monitoring through the Blynk App. Blynk's virtual pin system helps organise data streams for different measurements, such as voltage, current, and power.

Use the Blynk App to set up a mobile dashboard where widgets like gauges, graphs, and labels can be added, as shown in Figure 6. This step involves customising the user interface to display electricity consumption data visually, providing the user with a real-time view of energy usage. Widgets can be configured to update dynamically based on incoming data from the connected sensors.

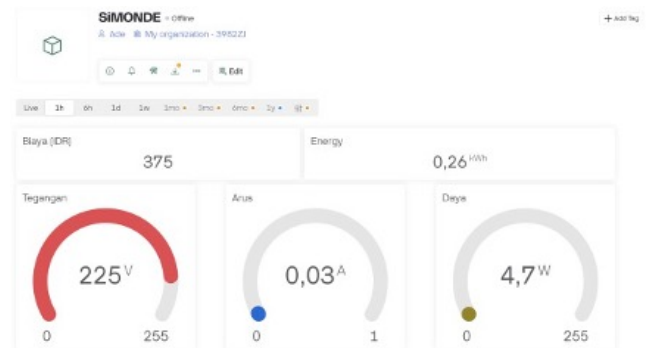


Fig. 6. Blynk mobile dashboard

Use the Arduino IDE to program the ESP8266 microcontroller and connect it to the Blynk server. Include the necessary libraries for Blynk and power monitoring sensors such as the PZEM-004T. This programming stage ensures accurate transmission of energy consumption data to the Blynk interface.

After setup, test the interface to ensure sensor data is correctly displayed on the Blynk App. Calibration may be necessary to verify that the data (e.g., kilowatt-hour measurements) accurately reflect actual energy consumption. This testing phase is critical to ensure the system's reliability and usability in real-world applications. Following these steps, the Blynk interface will allow users to monitor and analyse their electricity

consumption in real-time, providing valuable insights and improving energy efficiency.

Software development is also a key component at this stage. Researchers will code an Android application that serves as the primary user interface for SiMONDE. This application must be user-friendly, allowing users to monitor energy consumption, control devices, and receive notifications regarding power usage. The application will also enable users to view historical data, track energy usage trends, and analyse energy consumption patterns in the monitored environment.

D. SiMONDE Validity

1) Technical Test Results

The technical performance of SiMONDE was assessed by comparing its current measurements to those obtained from a clamp meter. Table 1 presents the measurement results for various laboratory equipment, highlighting the discrepancies between SiMONDE and clamp meter readings. The final column displays the percentage error of SiMONDE's measurements, calculated using Equation 2.

Table 1. Current Measurement Result

No	Device	Current (Simonde)	Current (Clamp Meter)	Percentage Error
1	AC	1.69 A	1.65 A	2.30%
2	Lamp	3.78 A	3.77 A	0.32%
3	Oscilloscope	0.16 A	0.149 A	7.38%
4	Audio Generator	0.04 A	0.03 A	33.33%
5	Experimenter	0.03 A	0.037 A	18.92%
6	Solder Listrik	0.12 A	0.097 A	23.71%

The first measurement was conducted on an air conditioning unit in the telecommunications laboratory at the Surabaya Aviation Polytechnic. SiMONDE recorded a current of 1.69 A, while the Clamp Meter measured 1.65 A, resulting in a difference of 0.038 A and a percentage error of 2.30%. This indicates a reasonably accurate measurement by SiMONDE.

Next, the current flowing through a laboratory room light was measured, with SiMONDE showing 3.78 A and the Clamp Meter 3.77 A. The difference of 0.012 A corresponds to a very low percentage error of 0.32%, indicating excellent accuracy. The subsequent measurement was conducted on an oscilloscope instrument. SiMONDE measured a current of 0.16 A, while the Clamp Meter showed 0.149 A, with a difference of 0.011 A and a percentage error of 7.38%. This error is considered acceptable within the typical accuracy range.

For the audio generator, SiMONDE recorded 0.04 A, and the Clamp Meter recorded 0.03 A, with a difference of 0.010 A and a high percentage error of 33.33%. This suggests significant accuracy variation for low currents

measured by SiMONDE. Measurements on the Experimenter equipment indicated a current of 0.03 A with SiMONDE and 0.037 A with the Clamp Meter, resulting in a difference of 0.007 A and a percentage error of 18.92%. Although the error is relatively high, it can be attributed to the challenge of accurately measuring low currents. The final measurement was taken on an electric soldering iron, where SiMONDE recorded 0.12 A and the Clamp Meter 0.097 A, with a difference of 0.023 A and a percentage error of 23.71%. This high error is also due to the difficulty of calibration at lower current levels.

E. Results of Feasibility Evaluation

The media expert assessment questionnaire was evaluated based on several aspects, including: (1) visual display, (2) ease of navigation, (3) information quality,

(4) design consistency, and (5) access speed. The feasibility results, calculated as percentages, were obtained from two media experts who are lecturers from the Air Navigation Engineering study program. The percentage results of the media expert assessment are presented in Table 2, with the average media expert validation score being 97.5%.

Table 2. Media expert validation results

No	Assessment Aspect	Observed score	Expected score Percentage	Presentase
1	Media Verifier 1	38	40	95%
2	Media Verifier 2	40	40	100%

Based on the media expert test data presented in the table, the following is an analysis of the assessments conducted by two media verifiers. The first verifier awarded a score of 38 out of the maximum possible score of 40, resulting in a feasibility percentage of 95%. This score indicates that the media is highly suitable for use, though there remains some minor room for improvement. With this percentage, it can be concluded that the media meets most established criteria, but small aspects could be enhanced to achieve perfection.

The second verifier gave a perfect rating, with the observed score matching the expected score of 40, achieving a feasibility percentage of 100%. This rating indicates that the media have met the expectations and set criteria. The 100% feasibility suggests that the verifier found no significant deficiencies in the assessed media, making it ready for practical use without further improvements.

Meanwhile, the user feasibility assessment was derived from several indicators, including: (1) ease of use, (2) system reliability, (3) user benefits, and (4) accuracy. The feasibility results, expressed as percentages, were obtained from two users who are lecturers from the Air Navigation

Engineering study program. The percentage results of the user feasibility assessment are presented in Table 3, with an average usability score of 96.86%.

Table 3. User validation results

No	Assessment Aspect	Observed score	Expected score Percentage	Presentase
1	User 1	32	32	100%
2	User 2	30	32	93,75%

Based on the SiMONDE usability validation data, the following is an analysis of the scores obtained from two users. The first user gave a maximum score of 32 out of 32, indicating an excellent level of usability with a 100% feasibility rate. This shows that SiMONDE fully meets user expectations in all evaluated aspects. This perfect feasibility percentage reflects that SiMONDE's features and functionalities can be used optimally without any issues, providing significant benefits to the user.

The second user's usability assessment yielded a score of 30 out of 32, with a feasibility percentage of 93.75%. Although this score is not the maximum, it still indicates that SiMONDE meets most of the criteria expected by the user. There is minor room for improvement to achieve perfection; overall, the application is still considered suitable and effective. This score suggests that certain aspects could be optimised to enhance the user experience.

Low-current equipment errors, such as the Audio Generator, Experimenter, and Electric Solder, are relatively higher. The factors influencing this include: (1) measurement sensitivity, (2) calibration and resolution, and (3) sensor tolerance. The measurement sensitivity of both the Clamp Meter and SiMONDE may not be adequate for very low currents, leading to higher error rates in measurements. Additionally, sensor calibration and resolution play a significant role in accuracy; calibration mismatches can lead to a notable error percentage. Sensors operate most accurately within a specific range. At low current levels, noise and sensor tolerance influence become more pronounced, resulting in larger errors. To achieve more accurate results, measurement devices with higher sensitivity or more precise calibration methods are necessary for low-current measurements.

Overall, the validation results from both verifiers indicate that the tested media has a very high feasibility level, with an almost perfect average score. This suggests the media is well-suited for use within its intended context and meets the necessary standards to support the learning process or desired application. Similarly, the user validation results show that SiMONDE has a very high feasibility level, with an almost perfect average score from two users. This indicates that the application is well-designed to support user power and energy measurement needs effectively.

IV. Conclusion

This research presents key findings on three objectives: designing and implementing the Power and Energy Monitoring System (SiMONDE), system performance analysis in managing electrical energy, and user feedback evaluation. SiMONDE was successfully designed and implemented using IoT technology, enabling real-time energy monitoring and control. The system incorporates sensors connected to the internet, allowing users to access energy consumption data via an application interface. Testing results indicate that the system operates efficiently in an educational laboratory setting, meeting specific energy monitoring needs. This supports the first research objective by demonstrating that SiMONDE effectively monitors electrical energy usage in real-time. Technical tests show that SiMONDE accurately tracks electricity consumption and can issue alerts for usage patterns that may lead to energy waste, underscoring its potential to facilitate more efficient energy management. Performance data reveals that SiMONDE can help reduce energy waste by up to 20% by identifying and eliminating inefficient usage habits. Thus, the second research objective is achieved, confirming that SiMONDE is a precise and efficient tool for energy management. User feedback, gathered through Likert-scale surveys, evaluates satisfaction and ease of use. Most users report high satisfaction with features like real-time access, improved control, and reduced energy waste. Users appreciate SiMONDE's ability to monitor energy consumption directly and find it valuable for raising awareness and managing electrical energy in the laboratory. These findings support the third objective, indicating that SiMONDE offers technical benefits and positively impacts user satisfaction and experience in energy management. The study concludes that SiMONDE effectively enhances energy efficiency in educational laboratories. These findings provide a strong foundation for recommending similar IoT systems in other academic settings requiring efficient and measurable energy monitoring.

References

- [1] B. Bun, S. Thote, P. Meshram, P. Bobade, S. Bijwe, and S. Kalmegh, "IoT Based Energy Management System," *Int J Innov Res Sci Eng Technol*, vol. 11, pp. 198–206, Sep. 2022, doi: 10.15680/IJIRSET.2022.1104051.
- [2] D. Wang, D. Zhong, and A. Souri, "Energy management solutions in the Internet of Things applications: Technical analysis and new research directions," *Cogn Syst Res*, vol. 67, pp. 33–49, 2021.
- [3] A. W. Mahmoud, R. Abdulla, M. E. Rana, and H. K. Tripathy, "IoT-Based Energy Management Solution for Smart Green Buildings," in *2022 International Conference on Advancements in Smart, Secure and Intelligent Computing (ASSIC)*, IEEE, 2022, pp. 1–7.
- [4] V. Munisamy and J. Gunasekaran, "IoT based energy management system (EMS) using SOFAT technique for smart grid distribution system," *Electric Power*

- Components and Systems*, vol. 50, no. 4–5, pp. 282–300, 2022.
- [5] A. Ghurri, “Konsep Manajemen Energi,” *Diakses pada*, vol. 30, no. 04, p. 2022, 2016.
- [6] S. Herawati, “Rancang Bangun Sistem Monitoring Suhu Ruang Bagian Pembukuan Berbasis Web Menggunakan Mikrokontroler Arduino Uno R3,” *Jurnal Teknologi Informasi dan Komunikasi*, vol. 13, no. 1, pp. 18–33, 2018.
- [7] I. P. Sari, I. H. Batubara, M. Basri, and A. H. Hazidar, “Implementasi Internet of Things Berbasis Website dalam Pemesanan Jasa Rumah Service Teknisi Komputer dan Jaringan Komputer,” *Blend Sains Jurnal Teknik*, vol. 1, no. 2, pp. 157–163, 2022.
- [8] A. Furqon, A. B. Prasetijo, and E. D. Widiyanto, “Rancang Bangun Sistem Monitoring dan Kendali Daya Listrik pada Rumah Kos Menggunakan NodeMCU dan Firebase Berbasis Android,” *Techné: Jurnal Ilmiah Elektroteknika*, vol. 18, no. 2, pp. 93–104, 2019.
- [9] D. Despa, “Edukasi Aplikasi Teknologi Internet Of Things Untuk Audit Dan Manajemen Energi Dalam Rangka Konservasi Dan Efisiensi Energi,” *Jurnal Pengabdian Kepada Masyarakat Sakai Sambayan*, vol. 5, no. 1, pp. 79–82, 2021.
- [10] W. Istiana, “Perancangan Sistem Monitoring dan Kontrol Daya Berbasis IoT,” *Jurnal Portal Data*, 2023.
- [11] A. C. Subrata, M. S. Perdana, and Q. Ariyansyah, “IoT-based Single-Phase Power Factor and Control Panel Monitoring System,” *Journal of Novel Engineering Science and Technology*, vol. 2, no. 01, pp. 16–20, 2023.
- [12] P. D. D. Phan, M. A. N. N. M. Anh, and B. H. Hu. Nguyen, “Using linear regression analysis to predict energy consumption,” 2024.
- [13] T. Tanto and D. Darmuji, “Penerapan Internet of Things (IoT) Pada Alat Monitoring Energi Listrik,” *Jurnal Elektronika Listrik dan Teknologi Informasi Terapan*, vol. 1, no. 1, pp. 45–51, 2020.
- [14] A. Jaenul, M. Manfaluthy, Y. Pramodja, and F. Anjara, “Pembuatan Sumber Listrik Cadangan Menggunakan Panel Surya Berbasis Internet of Things (IoT) dengan Beban Lampu dan Peralatan Listrik,” *Formosa Journal of Science and Technology*, vol. 1, no. 3, pp. 143–156, 2022.
- [15] J. Nielsen, “Enhancing the explanatory power of usability heuristics,” in *Proceedings of the SIGCHI conference on Human Factors in Computing Systems*, 1994, pp. 152–158.
- [16] S. Li and M. Pozzi, “What makes long-term monitoring convenient? A parametric analysis of value of information in infrastructure maintenance,” *Struct Control Health Monit*, vol. 26, no. 5, p. e2329, 2019.
- [17] S. Weijis and H. Foroozand, “Tracking bits of information through forecasting systems: from source to decision,” in *EGU General Assembly Conference Abstracts*, 2020, p. 13223.
- [18] M. J. Ershadi, S. T. A. Niaki, A. Azizi, A. A. Esfahani, and R. E. Abadi, “Monitoring data quality using hoteling T 2 multivariate control chart,” *Communications in Statistics-Simulation and Computation*, vol. 52, no. 4, pp. 1591–1606, 2023.
- [19] K. Jaswanth, S. Sruthi, P. Ramachandrupa, and S. Saravanan, “Real-time network monitoring: A big data approach,” in *2023 14th International Conference on Computing Communication and Networking Technologies (ICCCNT)*, IEEE, 2023, pp. 1–5.
- [20] C. Martinie, D. Navarre, P. Palanque, E. Barboni, and S. Steere, “Engineering operations-based training,” *Proc ACM Hum Comput Interact*, vol. 6, no. EICS, pp. 1–25, 2022.
- [21] X. Liu and P. Wang, “Value of information for continuous monitoring systems in recurrent maintenance decision scenarios,” in *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, American Society of Mechanical Engineers, 2021, p. V03AT03A040.
- [22] C. Sardonios *et al.*, “Real-time personalised energy saving recommendations,” in *2020 International conferences on internet of things (IThings) and IEEE green computing and communications (GreenCom) and IEEE cyber, physical and social computing (CPSCom) and IEEE smart data (SmartData) and IEEE congress on cybermatics (Cybermatics)*, IEEE, 2020, pp. 366–371.
- [23] Z. Li, W. Jiang, A. Abu-Siada, Z. Li, Y. Xu, and S. Liu, “Research on a composite voltage and current measurement device for HVDC networks,” *IEEE Transactions on Industrial Electronics*, vol. 68, no. 9, pp. 8930–8941, 2020.