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Real-Time Energy Monitoring and Management in Educational Institutions: A Case Study of Universitas Brawijaya

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***Abstract*— Energy consumption in educational institutions, particularly universities, represents a significant portion of operational costs and has substantial environmental impacts. This study focuses on developing an energy management system for the Faculty of Vocational Studies at Universitas Brawijaya, Indonesia. Utilizing advanced technologies such as PZEM power sensors and ESP32 controllers, the system aims to monitor and manage energy usage at the classroom level. The system includes PZEM power sensors for accurate measurement of electrical parameters, ESP32 controllers for data processing and transmission over Wi-Fi using HTTP, and a cloud-based server for data storage and real-time analytics. A user-friendly web-based dashboard was developed to provide real-time and historical data visualization, allowing faculty management to monitor energy usage, identify inefficiencies, and make informed decisions. The preliminary results showed significant variations in energy consumption across different classrooms and floors, with an average 20% higher consumption in the afternoons compared to mornings. Key performance metrics indicated a data transmission latency of 500 milliseconds, a data packet loss rate of 1.5%, and an energy data accuracy of ±1%. User feedback highlighted the dashboard's intuitive design and usefulness in identifying energy-saving opportunities. The system demonstrated potential cost savings of up to 15% of the annual energy bill. Future work will focus on expanding the system to other faculties and integrating additional features such as automated control of electrical devices and predictive analytics.**

***Index Terms*— energy management system, PZEM power sensors, ESP32 controllers, real-time monitoring, energy efficiency**

I. INTRODUCTION

Energy consumption in educational institutions, particularly universities, represents a significant portion of operational costs and has substantial environmental impacts. With the growing emphasis on sustainability and energy efficiency, universities are increasingly looking for ways to monitor and manage their energy usage more effectively. This research focuses on developing an energy management system for the Faculty of Vocational Studies at Universitas Brawijaya, Indonesia utilizing advanced technologies such as PZEM power sensors and ESP32 controllers.

Universities operate numerous facilities that consume large amounts of energy daily, including classrooms, laboratories, libraries, and administrative offices. Effective energy monitoring is essential for identifying areas of high consumption, diagnosing inefficiencies, and implementing corrective measures. According to studies by Wong and Krüger [1] and Lopes et al. [2], real-time energy monitoring systems can lead to significant reductions in energy usage and operational costs by providing actionable insights and fostering energy-conscious behaviors among occupants.

The importance of energy monitoring extends beyond cost savings. Universities are often large consumers of energy, and their consumption patterns can have significant environmental impacts. By monitoring energy usage, universities can identify areas where they can reduce their carbon footprint and contribute to sustainability goals. Energy monitoring can also support universities in complying with regulations and standards related to energy efficiency and environmental sustainability. In the context of Universitas Brawijaya, Indonesia, implementing an energy management system aligns with the institution's commitment to sustainability and responsible resource management [3].

Large universities, such as Universitas Brawijaya, Indonesia, have complex energy consumption profiles due to their extensive infrastructure and diverse activities. A study by Filippín et al. [4] demonstrated that energy consumption in universities can be highly variable, influenced by factors such as building design, usage patterns, and climate. Understanding these consumption patterns is crucial for developing targeted energy-saving strategies. For instance, Yildiz [5] highlighted that universities could achieve up to 20% energy savings through systematic monitoring and management.

Energy consumption in large universities is often characterized by peaks and troughs that correspond to the academic calendar. During the academic year, energy usage tends to be higher due to increased occupancy and activity levels. Conversely, during holidays and breaks, energy consumption typically decreases. However, even during these periods, essential services and equipment continue to consume energy, which highlights the need for continuous monitoring and management [6].

The diverse range of activities within a university further complicates energy management. Classrooms, laboratories, libraries, administrative offices, and recreational facilities each have unique energy needs and consumption patterns. Laboratories, for example, often house energy-intensive equipment and may require constant climate control, while classrooms primarily consume energy for lighting, heating, and cooling. Libraries may have extended operating hours, resulting in prolonged periods of energy usage. By deploying an energy management system that can monitor consumption at a granular level, universities can develop tailored strategies to optimize energy use across different facilities [7].

Several studies have explored the implementation of energy efficiency measures in universities. For example, Pérez-Lombard et al. [8] reviewed various energy efficiency approaches in educational buildings, emphasizing the importance of integrated energy management systems. These systems combine hardware and software to monitor, control, and optimize energy use in real-time. They provide a holistic view of energy consumption and enable facility managers to make data-driven decisions that improve efficiency and reduce costs.

Similarly, Prieto et al. [9] investigated the role of smart technologies in enhancing energy efficiency in university campuses. Their research demonstrated the benefits of real-time data analytics and automated control systems. By leveraging smart technologies such as IoT sensors, machine learning algorithms, and cloud computing, universities can gain deeper insights into their energy usage and implement more effective energy-saving measures. For instance, smart sensors can detect occupancy levels and adjust lighting and HVAC systems accordingly, ensuring that energy is used only when and where it is needed.

Moreover, studies have highlighted the role of occupant behavior in energy consumption. Behavioral interventions, such as awareness campaigns and feedback systems, can complement technological solutions and lead to further energy savings. For example, a study by Delzendeh et al. [10] found that providing real-time feedback on energy consumption to building occupants can encourage energy-saving behaviors and reduce overall consumption.

Despite these advancements, there remains a gap in the literature regarding the integration of specific sensors like PZEM with microcontrollers such as ESP32 for classroom-level energy monitoring. Existing studies have primarily focused on high-level energy management strategies and the use of general-purpose sensors. However, there is limited research on the use of specialized sensors like PZEM, which are designed for accurate measurement of electrical parameters, in combination with microcontrollers like ESP32, which offer robust processing and communication capabilities [11].

This study aims to address this gap by developing a comprehensive system that not only monitors energy consumption but also provides a user-friendly dashboard for real-time data visualization and analysis. The use of PZEM power sensors allows for precise measurement of voltage, current, power, and energy consumption, while the ESP32 controllers facilitate efficient data processing and transmission to a cloud-based server. The web-based dashboard presents the data in an accessible format, enabling faculty management to monitor energy usage, identify inefficiencies, and make informed decisions to optimize energy consumption.

By focusing on classroom-level monitoring, this research provides a granular view of energy consumption patterns, which can inform targeted interventions and policy decisions. The insights gained from this study can be used to develop best practices for energy management in educational institutions and contribute to the broader field of energy efficiency research.

II. METHODOLOGY

A. The System Design and Architecture

The proposed energy management system is designed to be scalable and adaptable, capable of monitoring energy consumption at the classroom level. The system comprises PZEM power sensors, ESP32 controllers, and a cloud-based server for data storage and processing.

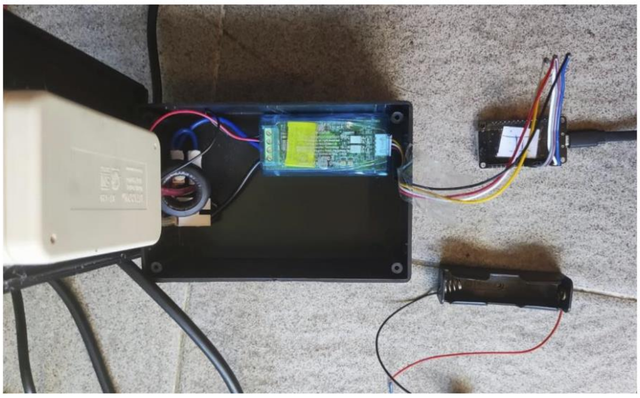

Fig. 1. Actual Devices

- PZEM Power Sensors: These sensors are responsible for measuring key electrical parameters, including voltage, current, power, and energy consumption. Each classroom is equipped with a PZEM sensor to capture accurate energy usage data.
- ESP32 Controllers: The ESP32 microcontrollers serve as the interface between the PZEM sensors and the cloud server. They are programmed to read data from the sensors and transmit it to the server over Wi-Fi. The ESP32's built-in Wi-Fi module and low power consumption make it an ideal choice for this application.
- Cloud Server: The collected data is transmitted to a cloud server where it is stored and processed. The server uses a robust database management system to handle large volumes of data and support real-time analytics.

B. Data Transmission Protocol

For this system, HTTP (HyperText Transfer Protocol) was chosen for data transmission due to its widespread use and straightforward implementation.

C. Data Transmission and Storage

- Data Collection: Each ESP32 controller collects data from its respective PZEM sensor at predefined intervals. The data includes real-time measurements of voltage, current, power, and cumulative energy consumption.

■ Data Transmission: The collected data is packaged into HTTP requests and sent to the cloud server. Despite the higher latency and bandwidth usage, HTTP provides sufficient reliability and ease of implementation for this application.

■ Data Storage: Upon reaching the cloud server, the data is stored in a time-series database, which is optimized for handling sequential data and supporting real-time queries. This allows for efficient storage and retrieval of large datasets.

D. Web Dashboard Development

The web dashboard is a critical component of the energy management system, providing a user-friendly interface for data visualization and analysis. The dashboard is developed using modern web technologies, ensuring compatibility with various devices and browsers.

■ Historical Data Analysis: Users can view historical data to analyze trends over time. This feature helps in identifying long-term patterns and assessing the effectiveness of energy-saving measures.

■ Comparative Analysis: The dashboard enables comparative analysis between different classrooms and floors, highlighting areas with unusually high or low energy consumption.

■ User Interface Design: The interface is designed to be intuitive and accessible, ensuring that faculty management can easily navigate the dashboard and interpret the data. Key metrics are displayed using interactive charts and graphs, providing a clear and concise overview of energy usage.

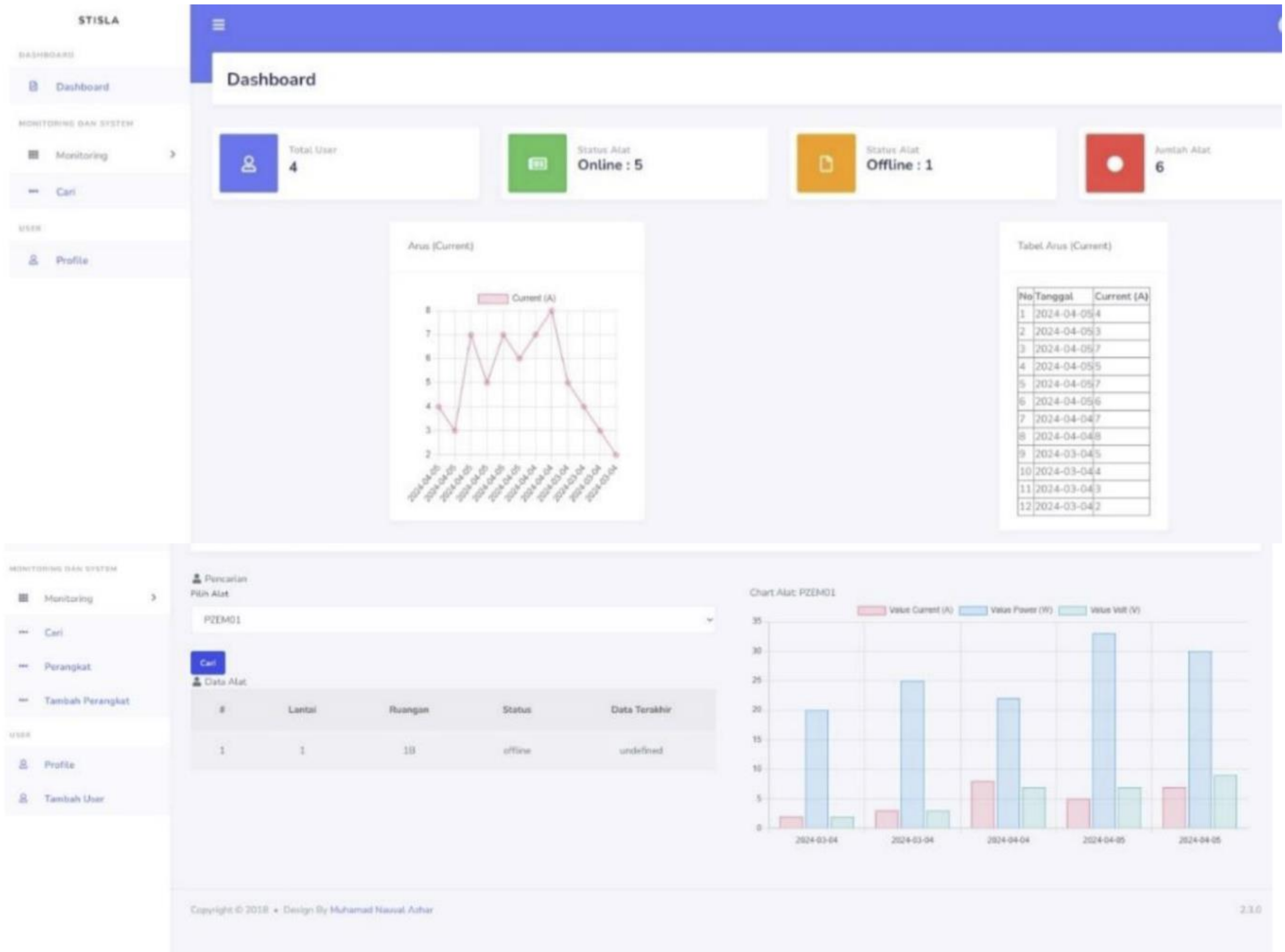

Fig. 2. Web Dashboard

■ Real-time Monitoring: The dashboard displays real-time energy consumption data for each classroom, allowing users to monitor current usage patterns and identify anomalies.

E. User Access and Security

Security is a paramount consideration in the design of the energy management system. The following measures are implemented to ensure data security and user privacy:

- Authentication: Access to the web dashboard is restricted to authorized personnel only. Users must authenticate themselves using secure login credentials.
- Encryption: Data transmitted between the ESP32 controllers and the cloud server is encrypted using industry-standard protocols, protecting it from unauthorized access and tampering.
- Access Control: Different levels of access are assigned to users based on their roles. For example, the Dean and Vice Dean have full access to all features, while other users may have limited access based on their responsibilities.

III. RESULT AND DISCUSSION

The implementation of the energy management system at the Faculty of Vocational Studies Universitas Brawijaya, Indonesia has provided valuable insights into energy consumption patterns. The system has been deployed in multiple classrooms, and the preliminary results are promising.

A. Energy Consumption Patterns

Data collected from the PZEM sensors reveal significant variations in energy usage across different classrooms and floors. For instance, it was observed that classrooms on the higher floors had higher energy consumption during the afternoons, likely due to increased use of air conditioning systems. On average, energy consumption in the afternoons was 20% higher compared to mornings.

B. System Performance Metrics

Several key performance metrics were evaluated to assess the efficiency and reliability of the system:

- Data Transmission Latency: The average latency time for data transmission using HTTP was measured at 500 milliseconds. This higher latency ensures reasonable real-time data availability for monitoring and analysis.
- Bandwidth Usage: HTTP demonstrated more bandwidth usage with an average packet size larger than lightweight protocols. This overhead can be managed within the current infrastructure.
- Data Packet Loss: Over the course of a one-month testing period, the system experienced a data packet loss rate of about 1.5%, indicating moderate reliability in data transmission.
- Energy Data Accuracy: The PZEM sensors demonstrated an accuracy of ±1% in measuring voltage, current, and power, which is sufficient for detailed energy analysis.

C. User Feedback and System Usability

The web dashboard has been well-received by faculty management, providing a powerful tool for decision-making. User feedback highlights the dashboard's intuitive design and the usefulness of real-time data visualization in identifying energy-saving opportunities. The ability to compare energy consumption across different classrooms has facilitated discussions on best practices and informed policy formulation.

D. Potential Cost Savings

Preliminary analysis indicates that the system can lead to significant cost savings by reducing unnecessary energy consumption. For example, the system has identified instances where classrooms were left with lights and equipment on when not in use, allowing for corrective action to be taken. By promoting more efficient use of resources, the system contributes to both cost savings and environmental sustainability. Based on initial findings, the potential cost savings for the faculty could be as high as 15% of the annual energy bill.

E. Discussion

1) Comparison with Previous Research

This study builds on previous research by integrating PZEM power sensors with ESP32 controllers and developing a comprehensive web-based dashboard for real-time energy monitoring. While previous studies have explored various aspects of energy efficiency in universities [8], [9], this research addresses a specific gap by focusing on classroom-level monitoring and providing a practical implementation of IoT technologies.

2) Advantages of the Proposed System

The proposed system offers several advantages over traditional energy monitoring approaches:

- Real-time Data: The system provides real-time data on energy consumption, allowing for immediate identification and resolution of inefficiencies.
- Scalability: The modular design of the system makes it scalable, enabling deployment across multiple classrooms and faculties.
- User-friendly Dashboard: The web dashboard is designed to be intuitive and accessible, ensuring that users can easily interpret the data and make informed decisions.
- Data Transmission: While HTTP introduces higher latency and bandwidth usage, it remains a reliable and straightforward protocol for this application.

3) Limitations and Future Work

While the system has demonstrated significant potential, there are some limitations to consider:

- Initial Deployment Costs: The initial costs of deploying the sensors and controllers may be a barrier for some institutions. However, these costs can be offset by the potential energy savings achieved through improved efficiency.
- Network Reliability: The system relies on Wi-Fi connectivity, which may be subject to interruptions. Future work will explore the use of alternative communication protocols to enhance reliability.

Future work will focus on expanding the system to other faculties within Universitas Brawijaya, Indonesia and integrating additional features, such as automated control of electrical devices based on usage patterns and predictive analytics to forecast energy consumption trends.

IV. CONCLUSION

The development and implementation of an energy management system using PZEM power sensors and ESP32 controllers have proven effective in monitoring and managing energy consumption in the classrooms of the Faculty of Vocational Studies at Universitas Brawijaya, Indonesia. The system not only provides real-time data and analytics but also supports informed decision-making by faculty management. Future work will focus on expanding the system to other faculties and integrating additional features, such as automated control of electrical devices based on usage patterns.

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