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# A Comprehensive IoT Solution for Electrical Energy Consumption Monitoring: System Development Using NodeMCU ESP32, SCT-013, ZMPT101B, and Blynk Platform

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**Abstract.** This paper presents the design and implementation of an IoT-based electricity consumption monitoring system using the Blynk application. The system employs key electronic components such as NodeMCU ESP32, SCT-013 current sensor, and ZMPT101B voltage sensor to measure and transmit energy consumption data wirelessly. The performance of the monitoring system was evaluated through experiments, which demonstrated its ability to differentiate between unloaded and loaded conditions. The average energy consumption increased by 0.1091 kWh when a soldering iron was connected as a load. However, further calibration and testing are recommended to improve the accuracy and reliability of the system. The proposed IoT-based monitoring system has the potential to enhance energy efficiency and conservation efforts in various settings.

**Keywords:** IoT, Blynk, NodeMCU ESP32, SCT-013, ZMPT101B

# 1. Introduction

Global energy crisis and environmental concerns are increasingly driving organizations and individuals to adopt energy efficiency strategies (Androniceanu et al., 2023; U.S. Department of Energy, 2015). In this context, the electricity consumption sector becomes a primary focus, as electricity is a major energy source in various sectors of modern life (Ahmad & Zhang, 2020; IESR, 2021; Saputri et al., 2023). The electricity consumption sector becomes a primary focus because electricity plays a crucial role as a major energy source in various sectors of modern life, both in Indonesia and around the world. This is due to its versatility, reliability, and widespread usage across residential, commercial, industrial, and institutional settings. Additionally, electricity powers essential functions such as lighting, heating, cooling, communication, transportation, manufacturing, and entertainment, making it indispensable for sustaining modern society and driving economic activities. Efforts to improve energy efficiency in electricity usage require knowledge of consumption patterns and ways to optimize energy use. It is well-known that electricity is still generated from fossil fuel sources, and its usage remains dominant (Handayani et al., 2019; Holechek et al., 2022; Sharvini et al., 2018). The high use of fossil fuels has significant impacts, such as acid rain formation (Hannun & Abdul Razzaq, 2022; Kaushik, 2006), increased ozone levels (Covert et al., 2016), and climate change (Gaulin & Le Billon, 2020). Moreover, the finite nature of fossil energy sources (Gormus et al., 2015; Månberger, 2021; Schiessel, n.d.) necessitates awareness of energy conservation globally (Kreuzer & Wilmsmeier, 2014). Therefore, optimizing electricity consumption is crucial, especially when electricity still relies on fossil fuels.

A system for monitoring electricity consumption becomes a crucial tool in this effort. By integrating sensor technology and real-time data monitoring, this system provides better insights into how energy is used in a specific location or system. Through accurate data analysis, users can identify inefficient energy consumption sources, manage electrical loads more optimally, and implement more effective improvement measures.

Various factors drive the need for the development of electricity consumption monitoring systems (Adebisi & Ndjuluwa, 2024) such as continuously increasing energy prices, prompting the search for new ways to reduce consumption and manage operational costs. Additionally, awareness of the negative environmental impacts of energy consumption encourages individuals to adopt more environmentally friendly practices. The progress in sensor technology and IoT connectivity also opens opportunities to develop more advanced and integrated monitoring systems (Alahi et al., 2023; Arshi & Mondal, 2023). Several studies have been conducted on the design and implementation of electricity consumption monitoring systems, such as the IoT device developed by Korakot and Vijayalakshmi, capable of monitoring daily and weekly electricity consumption in households (Luechaphonthara & Vijayalakshmi, 2019). Himer and colleagues designed a real-time web-based monitoring system to oversee electricity consumption in a specific home. The system can monitor current and energy consumption directly through a computer or smartphone, using a dedicated web server that continuously updates the power consumption profile in a smart home environment. This system is configured with a high level of accuracy, having a deviation of 0.6% (Himer et al., 2023).

Hence, the primary objective of this study is to design and comprehensively analyze the implementation of an electricity consumption monitoring system, with the overarching aim of enhancing energy efficiency and mitigating environmental impacts. Leveraging IoT (Internet of Things) technology, the research endeavors to optimize electricity consumption through the effective deployment of a monitoring system. By amalgamating sensor technology with real-time data monitoring capabilities, the envisioned system is poised to offer invaluable insights into the intricate dynamics of energy utilization within specific locations or systems.

The proposed monitoring system is envisaged to empower users with the ability to scrutinize energy usage patterns with unprecedented granularity. Through meticulous data analysis facilitated by the system, users can discern inefficiencies in energy consumption, pinpointing areas of improvement, and orchestrating more judicious management of electrical loads. This data-driven approach holds immense promise in facilitating informed decision-making, enabling stakeholders to enact targeted measures to curtail energy wastage and optimize resource utilization.

A multitude of factors underpin the imperative for developing robust electricity consumption monitoring systems. Escalating energy prices perpetuate the quest for innovative strategies to rein in consumption and alleviate operational costs, necessitating the deployment of sophisticated monitoring mechanisms. Moreover, burgeoning awareness of the deleterious environmental ramifications of unchecked energy consumption serves as a potent catalyst for communities to embrace sustainable practices. Against this backdrop, the advent of sensor technology and IoT connectivity heralds unprecedented opportunities to engineer advanced, seamlessly integrated monitoring systems capable of meeting the evolving demands of contemporary energy management paradigms.

In essence, this study represents a concerted effort to harness cutting-edge technologies and methodological frameworks to confront the pressing challenges posed by escalating energy consumption and environmental degradation. By conceptualizing and implementing a sophisticated electricity consumption monitoring system, the research endeavors to pave the way for a more sustainable and environmentally conscious approach to energy management in diverse settings.

## 2. Methods

In this study, several main tools and components were utilized, such as microcontrollers, voltage sensors, and current sensors, as well as the Arduino IDE and Blynk applications. The ESP32, chosen as the microcontroller for this study, is a powerful and versatile microcontroller widely employed in Internet of Things (IoT) projects (Hercog et al., 2023). Developed by Espressif Systems, the ESP32 boasts WiFi and Bluetooth capabilities, enabling wireless connectivity to networks or other devices (Espressif Systems, 2023). This wireless technology has a high potential for transmitting both energy and data. (Rinanda Saputri et al., 2023). With strong support for various interfaces and communication protocols, ESP32 is an ideal choice for energy consumption monitoring applications that require reliable internet connection and data communication. The diversity of features and availability of development support make ESP32 the right choice for designing sophisticated and effective energy monitoring solutions. Particularly suitable for IoT applications, including energy consumption monitoring systems, it can seamlessly integrate data directly into cloud platforms or the Blynk application.

The voltage sensor used, ZMPT101B, is commonly employed in electronics projects to measure AC voltage accurately (ETC2, 2021). This sensor can convert AC voltage into a measurable DC signal, often used in electric energy consumption monitoring systems to obtain precise voltage data from the power source. Additionally, the study incorporates the non-invasive current sensor SCT-013, used to measure AC electrical current without the need for power line interruption. Featuring a clamp design for easy installation on the conductor cable, it provides a proportional signal output based on the current flowing through the cable (Miron-Alexe, 2016). SCT-013 is frequently used in energy consumption monitoring applications to measure the current consumed by specific devices or systems without direct intervention in the power line. Its non-invasive design allows for safe and convenient installation, making it particularly suitable for retrofitting existing electrical systems or integrating into IoT-based monitoring solutions. Additionally, SCT-013's high accuracy and reliability ensure precise measurement of current, contributing to more accurate energy consumption data collection and analysis.

The software and applications utilized in this study play integral roles in the development and implementation of the IoT-based electrical energy consumption monitoring system. Among these, the Arduino IDE (Integrated Development Environment) and Blynk stand out as key tools employed throughout the research process. Arduino IDE serves as a fundamental platform for the development and programming of the system, offering a comprehensive suite of tools and functionalities tailored specifically for IoT applications. Its primary objective is to facilitate the creation and customization of software code that governs the behavior and functionality of hardware components within the system. By providing a user-friendly interface and support for easily understandable programming languages, Arduino IDE simplifies the coding and testing processes, thereby expediting the development timeline.

In addition, Arduino IDE fosters an environment conducive to iterative experimentation and refinement, allowing researchers to fine-tune the performance and functionality of the system iteratively. Through its intuitive interface and robust debugging capabilities, Arduino IDE empowers researchers to focus their efforts on enhancing the core functionality of the system, rather than grappling with the intricacies of software development.

Ultimately, the utilization of Arduino IDE underscores a commitment to efficiency and effectiveness in software development, enabling researchers to realize the full potential of the IoT-based electrical energy consumption monitoring system. By leveraging the capabilities of Arduino IDE, researchers can navigate the complexities of software programming with ease, ensuring the seamless integration of software and hardware components to achieve the research objectives.

The Blynk application serves as a pivotal user interface, enabling seamless real-time monitoring and in-depth analysis of energy consumption patterns within the IoT-based electrical energy monitoring system. Functioning as a cloud-based platform, Blynk is specifically engineered to streamline the development and deployment of IoT applications, offering unparalleled convenience and accessibility. Within the scope of this study, Blynk assumes a central role as the primary interface for interacting with the electrical energy consumption monitoring system. Through the intuitive interface provided by Blynk, users gain instant access to comprehensive real-time data on energy consumption, empowering them with valuable insights into their energy usage habits.

Utilizing Blynk, users not only have the capability to monitor energy consumption data as it unfolds but also to exert control over associated devices, thereby facilitating proactive energy management strategies. The versatility of Blynk extends across various devices, including mobile phones and computers, ensuring seamless access to critical energy consumption information anytime, anywhere. This inherent flexibility fosters adaptive monitoring practices, allowing users to respond promptly to evolving energy consumption patterns.

The integration of Blynk with the system underscores a commitment to enhancing user engagement and awareness regarding energy consumption, aligning seamlessly with the overarching research objective of promoting energy efficiency in both residential and office environments. By leveraging the intuitive interface and interactive features offered by Blynk, users are empowered to make informed decisions regarding their energy usage, ultimately contributing to sustainable energy practices and environmental conservation efforts.

The hardware and software components of the system will be intricately interconnected to facilitate seamless data transmission and reception, as illustrated in the block diagram depicted in Figure 1. This system comprises two distinct parts: the transmitter and receiver block diagrams. During the data transmission and reception process, Wi-Fi connectivity is imperative for facilitating communication between devices. Notably, Wi-Fi functionality is inherently integrated into the ESP32 microcontroller, streamlining the wireless connectivity aspect of the system.

Upon processing, the data will be transmitted to the receiver device, which is accessible within the Blynk application via a mobile phone. This integration with the Blynk application enables users to conveniently access and monitor the transmitted data in real-time, enhancing the system's usability and accessibility. Additionally, the block diagram showcases the inclusion of an LCD, which serves as a display interface for presenting data. Unlike the wireless transmission facilitated by Wi-Fi, the LCD is directly connected using a cable, providing an alternative method for data visualization that does not rely on wireless connectivity. This dual approach ensures robust data presentation capabilities, catering to diverse user preferences and scenarios.

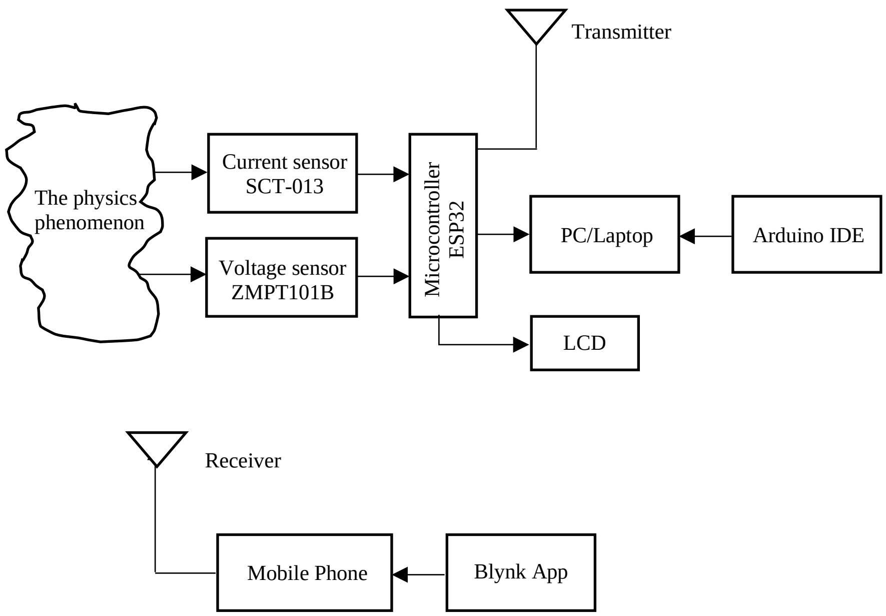



Fig. 1: Block diagram of electricity monitong system

Calibration within this system is conducted by cross-referencing the output values of the voltage and current sensors with measurements obtained from a multimeter. The multimeter utilized possesses the capability to measure both voltage and current accurately. Data acquired from the sensors are stored in the Blynk cloud, leveraging the cloud-based infrastructure of the Blynk application. This approach ensures the reliability and accessibility of the collected data for subsequent analysis and monitoring.

Moreover, the system is meticulously designed with scalability in mind, allowing for seamless adjustments and capacity enhancements as necessitated by evolving requirements. This inherent scalability empowers the system to effortlessly accommodate additional sensors or connected devices while efficiently managing larger volumes of data without compromising performance. Such flexibility ensures the adaptability and longevity of the system, enabling it to evolve and meet the dynamic needs of various applications effectively.

## 3. Results and Discussion

In this section, we delve into a comprehensive analysis of the results obtained from the research, coupled with an extensive discussion elucidating the implications and significance of these findings. Through a meticulous examination of figures and graphs, we aim to elucidate the intricate nuances of the data, rendering it accessible and comprehensible to the reader. The discussion unfolds across several sub-sections, each dedicated to exploring distinct facets of the research outcomes, thereby providing a holistic understanding of the implications and potential avenues for further investigation.

### 3.1. The circuit diagram of the monitoring system

The circuit diagram, depicted in Figure 2, illustrates the configuration of an electricity consumption monitoring system incorporating ZMPT and SCT sensors, resistors, capacitors, a NodeMCU ESP32 microcontroller, and an LCD screen. This detailed schematic outlines the connections and interactions between these components to facilitate accurate energy monitoring.

The ZMPT101B voltage sensor is integral to the system, designed to measure the electrical voltage from the AC power source. It connects to the AC mains and outputs a proportional analog signal that represents the voltage level. This sensor ensures precise voltage readings, which are crucial for calculating power consumption.

The SCT-013 current sensor functions as a split-core current transformer, allowing it to measure the electric current flowing through a conductor without requiring a direct electrical connection. It clips around the conductor, producing an analog signal proportional to the current. This method provides a safe and non-intrusive way to measure current, protecting both the user and the system from potential electrical hazards.

Resistors in the circuit serve multiple purposes. They are used for signal conditioning, ensuring that the signals from the sensors are within the acceptable range for the analog-to-digital converter (ADC) of the NodeMCU ESP32. Resistors also provide current limitation, preventing excessive current flow that could damage the components or cause inaccuracies in readings.

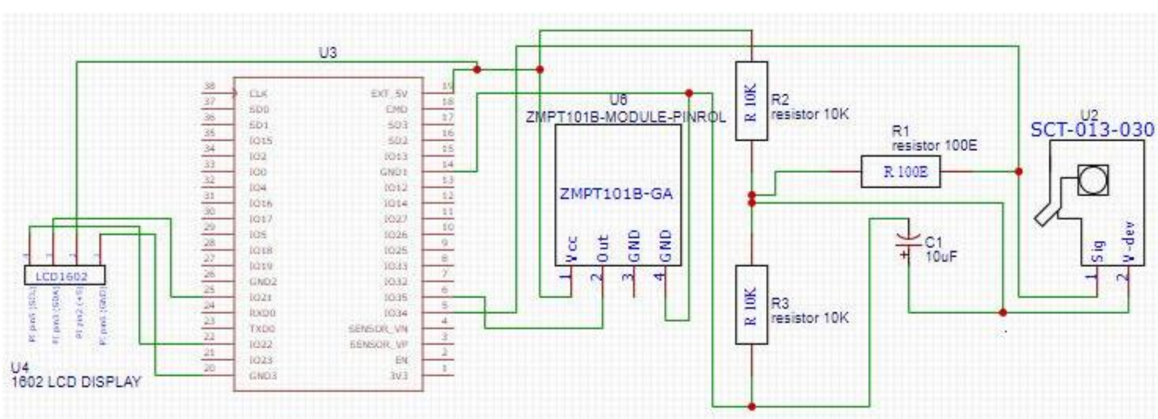



Fig. 2: Circuit diagram of an electricity consumption monitoring system

Capacitors play a critical role in signal filtering and voltage stabilization. They are strategically placed to filter out noise from the sensor signals, ensuring a clean and stable input to the microcontroller. This filtering is essential for accurate and reliable data acquisition. Additionally, capacitors stabilize the voltage at critical points in the circuit, maintaining consistent performance and preventing fluctuations that could affect the system's accuracy.

The NodeMCU ESP32 microcontroller acts as the central processing unit of the system, receiving analog signals from the ZMPT and SCT sensors. It processes these signals using its built-in ADC, calculates power consumption based on voltage and current data, and converts the analog signals into digital values while applying necessary corrections and calibrations to compute real-time power usage. The microcontroller's built-in Wi-Fi capabilities also enable it to transmit this data for further analysis.

An LCD screen is connected to the NodeMCU ESP32, providing a user-friendly interface to display the monitored voltage, current, and power consumption data. This screen updates in real-time, allowing users to instantly observe and track their energy usage. The use of the NodeMCU ESP32 not only processes and displays data on the LCD screen but also provides flexibility in programming specific functions and adding additional monitoring capabilities to the system.

Beyond the LCD screen, the research also incorporates the Blynk application, which allows for wireless display of electricity consumption monitoring results on smartphones and PCs. This integration enhances user accessibility and convenience, enabling users to monitor the electrical condition of the system in real-time from anywhere.

By combining the functionalities of the NodeMCU ESP32, ZMPT and SCT sensors, LCD screen, and Blynk application, the system ensures comprehensive and efficient real-time monitoring of electricity consumption. This setup provides users with easy access to detailed energy usage data, promoting more informed and efficient energy management practices.

### 3.2. Data output from the energy consumption monitoring system

The system consists of several electronic devices, including sensors designed to measure current and voltage. These sensors are critical in the construction of this system as they detect the physical phenomena of current and voltage. Based on their readings, the system can calculate power and energy values. Power is obtained through a mathematical calculation where power is the product of current and voltage. Similarly, energy is calculated by multiplying power by time. Consequently, the results can be visualized in a pattern similar to the graph shown in Figure 3, where data for voltage, current, power, and energy are depicted.

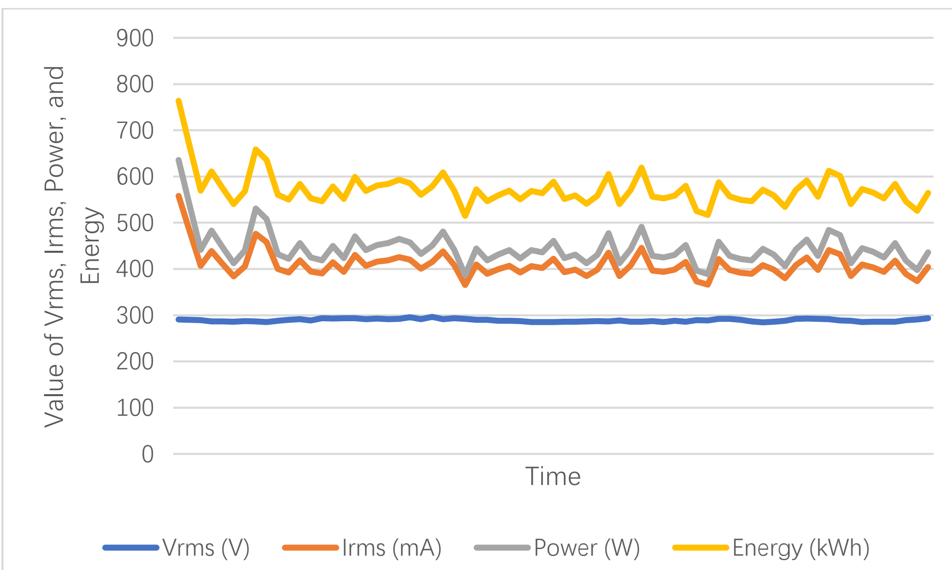



Fig. 3: The output results of the sensor system are in the form of Vrms, Irms, Power, and Energy

Vrms (Root Mean Square Voltage) represents the effective voltage value of an alternating current (AC) signal or waveform. Vrms is calculated by taking the square root of the average of the squares of all instantaneous voltage values over one complete cycle of the AC waveform. It is a measure of the equivalent continuous DC voltage that would produce the same amount of power dissipation in a resistive load as the AC waveform.

Irms (Root Mean Square Current) represents the effective current value of an AC signal or waveform. It is calculated by taking the square root of the average of the squares of all instantaneous current values over one complete cycle of the AC waveform. Irms indicates the equivalent continuous DC current that would produce the same amount of power dissipation in a resistive load as the AC waveform.

Power refers to the rate at which energy is transferred, converted, or consumed. It is typically measured in watts (W) and represents the amount of energy used or generated per unit of time. In an electrical system, power is calculated as the product of voltage and current in watts in a direct current (DC) circuit, or as the product of voltage, current, and the power factor in watts in an alternating current (AC) circuit. Power can be further categorized into active power (real power), reactive power, and apparent power, each serving different purposes in electrical systems.

Energy refers to the capacity of a system to perform work and is typically measured in watt-hours (Wh) or kilowatt-hours (kWh). It represents the total amount of power consumed or generated over a specific period. Energy is the integral of power over time, meaning it is the product of power and time. For example, if a device consumes 100 watts of power for one hour, it consumes 100 watt-hours of energy. In electrical billing and utility contexts, energy usage is often measured and billed in kilowatt-hours (kWh), where 1 kWh is equal to 1000 watt-hours.

Upon closer examination of the graphs, it is evident that the patterns for current, power, and energy closely resemble each other. This similarity indicates a strong mathematical relationship among these parameters. Specifically, since power is directly derived from the product of current and voltage, any change in current or voltage will proportionately affect the power. Likewise, since energy is a product of power over time, its pattern mirrors that of power, reaffirming the interconnectedness of these measurements.

Meanwhile, Figure 4 also displays a graph similar to Figure 3 but under different conditions. In Figure 4, the system is subjected to a load by connecting it to an electrical device, specifically a soldering iron. The average energy consumption in the no-load condition, as shown in Figure 3, is 128.0971 kWh. In contrast, when the system is connected to a soldering iron, as depicted in Figure 4, the average energy consumption increases to 128.2063 kWh. This higher value under load conditions demonstrates that the sensor system effectively detects and responds to changes in electrical consumption.

These observations underscore the system's responsiveness and accuracy in measuring electrical parameters. However, for future research, attention should be given to the baseline measurement when no load is applied. Ideally, the energy consumption value should start at 0 kWh in the no-load state and increase proportionately as a load is introduced. This initial discrepancy suggests the need for further calibration to ensure more precise measurements.

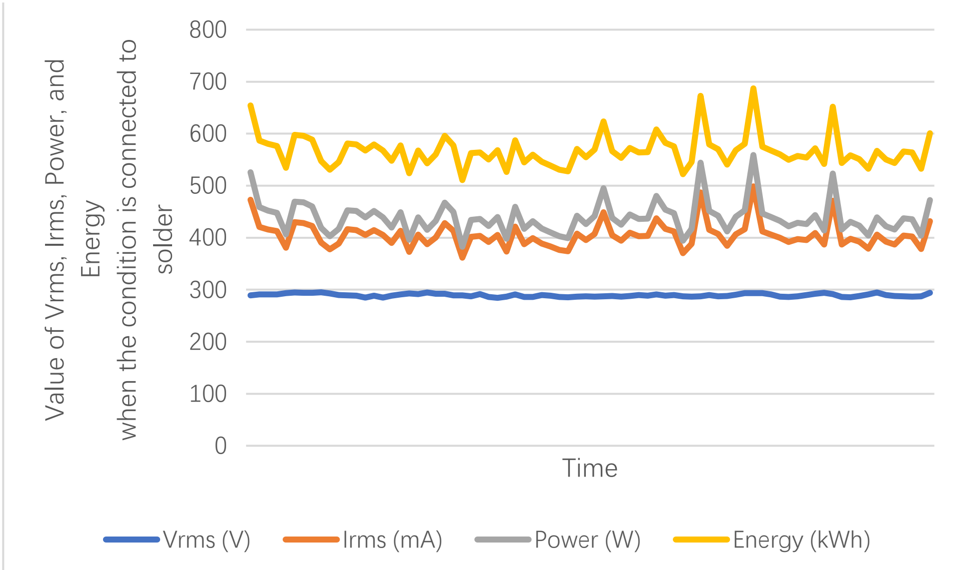


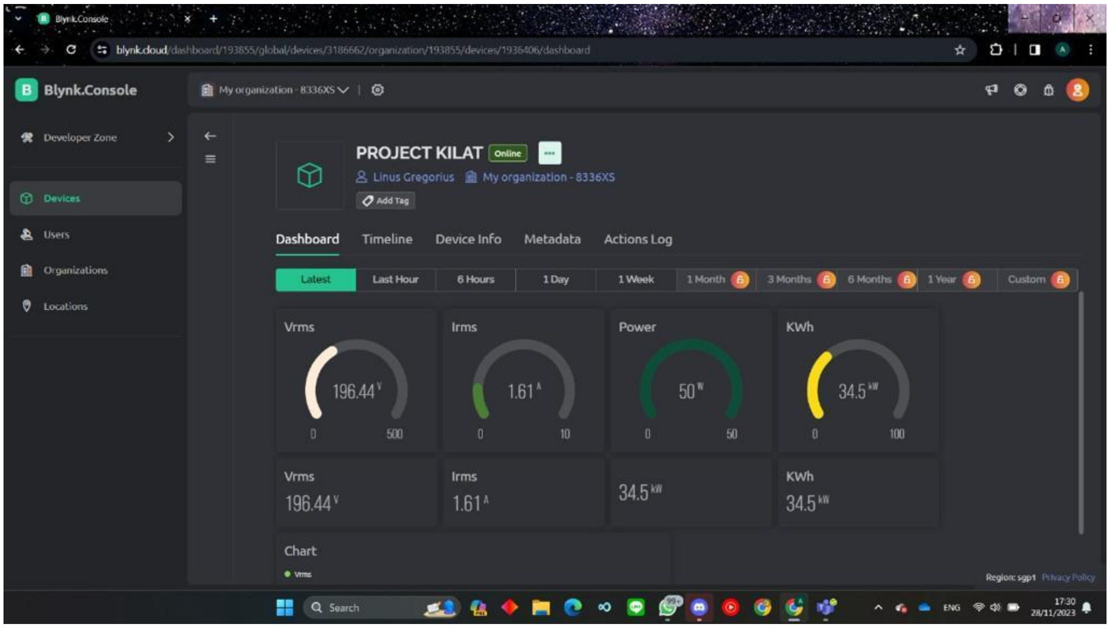

Fig. 4: The output results of the sensor system when connected to an electrical device such as a soldering iron are Vrms, Irms, Power, and Energy

Calibrating the sensors accurately will be crucial for improving the system's reliability and ensuring that the initial energy value is correctly set to zero. This adjustment will enhance the system's ability to accurately reflect the actual energy consumption once a load is applied. Future research should focus on refining this calibration process and conducting extensive testing with various loads to validate the system's accuracy and consistency.

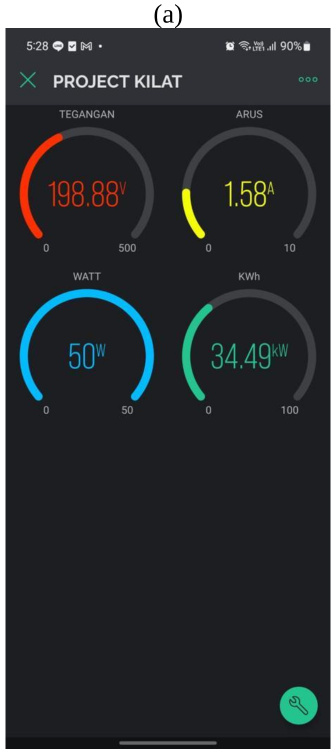
In summary, the detailed analysis of Figures 3 and 4 highlights the effective performance of the current and voltage sensors in measuring and calculating power and energy. The system's ability to reflect increased energy consumption under load conditions indicates its practical applicability. However, further calibration is essential to perfect the system's accuracy, ensuring it meets the high standards required for precise energy monitoring and management.

## 3.3. Display data

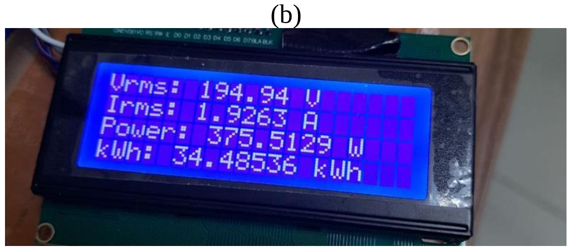
In the circuit design, we have incorporated an LCD screen to effectively present monitored data, providing detailed insights into voltage, current, and power consumption. This feature enables users to conveniently monitor the real-time electrical condition of the system, facilitating prompt decision-making and adjustments as needed. Additionally, our research integrates the use of the Blynk application, offering a wireless platform for presenting electricity consumption monitoring outcomes. This integration allows users to access monitoring data from smartphones and PCs, providing flexibility and accessibility. Figure 5 exemplifies the interface of our research, showcasing the accessibility of data through Blynk on both PC (Figure 5a) and smartphone (Figure 5b), as well as directly displayed on the LCD screen (Figure 5c). The displayed data includes crucial parameters such as voltage, current, power, and energy in kWh, offering comprehensive insights into the system's performance and enabling informed decision-making.




(a)




(b)




(c)

Fig. 5: Display data through (a) Blynk on PC (b) Blynk on smartphone, and (c) LCD

However, despite the robust functionality of our system, it is important to acknowledge its weakness in lacking accuracy values. This deficiency hampers the ability to assess the reliability and precision of the system's measurements accurately. To address this limitation, future research efforts should prioritize presenting accurate measurement values, allowing for a thorough evaluation of the system's performance. By establishing the reliability and accuracy of measurements, confidence in the system's capabilities can be strengthened, enhancing its suitability for various applications.

Furthermore, while our study has primarily focused on the experimental phase involving a soldering load, there is significant potential for broader applications in real-world scenarios. For instance, the proposed system could be utilized for energy optimization in households or industrial settings, contributing to enhanced efficiency and sustainability. Although this exploration has not been conducted in the present study, future research endeavors could delve into scenarios involving diverse household appliances, expanding the applicability and relevance of the system in practical settings. Through such endeavors, the potential benefits of the proposed system can be fully realized, driving advancements in energy monitoring and management practices.

## 4. Conclusion and Recommendation

In conclusion, this study showcases the successful design and implementation of an IoT-based electricity consumption monitoring system utilizing the Blynk application. Through the integration of NodeMCU ESP32, SCT-013 current sensor, and ZMPT101B voltage sensor, the system effectively discerns between unloaded and loaded conditions, exhibiting an average energy consumption increase of 0.1091 kWh when subjected to a soldering iron load. However, it is imperative to acknowledge the necessity for further calibration and testing to enhance the system's accuracy and reliability. Future endeavors should prioritize refining the calibration process and conducting more extensive experiments encompassing diverse loads to validate the system's performance comprehensively.

Moreover, exploring the integration of advanced data analytics techniques, particularly machine learning algorithms, holds significant promise in augmenting the system's functionality. By leveraging artificial intelligence, the system can glean insights from complex energy consumption patterns, facilitating more precise recommendations for optimizing energy usage and detecting anomalies indicative of underlying electrical system issues. This strategic approach has the potential to significantly enhance the system's effectiveness in achieving higher energy efficiency and sustainability objectives.

Furthermore, it is recommended that future research ventures delve into the integration of machine learning algorithms for energy consumption prediction and anomaly detection. These advancements will not only bolster the system's capabilities but also pave the way for more intelligent and adaptive energy management strategies. Additionally, efforts should be directed towards expanding the applicability of the proposed IoT-based monitoring system across diverse settings, ranging from households to industrial facilities.

By offering real-time access to energy consumption data through user-friendly interfaces like the Blynk application, the proposed system empowers users to make informed decisions and embrace sustainable energy practices. Despite its current limitations, the system harbors significant potential to contribute to energy efficiency and conservation initiatives, thereby fostering a greener and more sustainable future. Through continuous refinement and integration of cutting-edge technologies, the envisioned IoT-based monitoring system can play a pivotal role in driving positive environmental impact and promoting energy sustainability on a global scale.

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