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Real Time Energy Monitoring & Current Spikes Detection System for Enhanced Energy Conservation in Residential Area

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Abstract

As technology advances, the use of electronic devices is growing rapidly. With our increasing dependence on electronic conveniences, there is a rising need for a thorough understanding of energy usage. Thus, this project aims to propose a simple prototype of an energy monitoring system enabling real time monitoring and current spikes detection. The project focuses on building a reliable hardware system using the ESP32, ZMPT101B voltage sensor, and SCT013-030 current sensor. This integrated system is designed with communication facilitated through the cloud via the ThingSpeak platform for IoT. The ESP32 microcontroller functions as the central processing unit. The ZMPT101B operates to measure voltage, and the SCT013-030 monitors current flow. The system sends data to the ThingSpeak platform, and the mobile app reflects the same data. The system can track voltage, current, energy usage, estimate bills, and detect current spikes. It shows acceptable accuracy, with the highest observed error being 12.438%, all achieved through a low-cost approach.

1. Introduction

In Malaysia, there's an ongoing debate about the perceived increase in the cost of living, despite low and steady inflation [1]. People are encouraged to save energy due to rising daily expenses, including high power bills. Inefficient energy use in homes contributes to these high bills [1].

While there are various energy monitoring systems in the market, most are not user-friendly and expensive [2]. Additionally, there's a lack of systems that can promptly detect and diagnose sudden current spikes in home electrical systems, leading to increased energy consumption [2-3]. Many households face challenges in managing monthly energy expenses due to the absence of a complete solution addressing both their consumption patterns and rapid detection of energy spikes [2-3]. Previous investigations have failed to provide a comprehensive and cost-effective approach to energy management [3]. Existing solutions are often too expensive with extended return on investment periods [3]. P. Kumaresan et.al.[4], noted in their research that the system is capable of measuring the electricity supplied to individual home appliances using ZigBee. This allows for the measurement of energy consumed by the appliances, and the collected data is stored in a local server. This stored information is utilized to monitor the proper flow of electricity. Dalvi et al. [5] has conducted a research study examining the awareness of residents regarding energy conservation and activities aimed at reducing energy demand through energy-saving measures.

"IoT" or the "Internet of Things" is a common term used for a platform that many applications use to improve lives [6]. It is a network of connected devices, machines, objects, people, and animals that transfer data over a network without requiring direct human interaction. Each part of the IoT is given a unique identifier (UID) [6].

The primary objective is to develop an economical system that expands the availability of sophisticated energy monitoring and management solutions to a wider range of people. The successful implementation of the prototype has the potential to greatly decrease financial difficulties for residents by providing them with a tool to encourage energy usage and lower monthly costs.

2. Methodology

2.1 System design development

In the initial design phase, the system flow was established, starting with the ESP32 connecting to Wi-Fi. The system splits into four paths, focusing on two sensor types and conditions triggering email alerts. The SCT013 current sensor monitors electrical system current, converting analog to digital signals for ESP32. The ZMPT101B voltage sensor in Arduino code detects root mean square (rms) voltage. Using SCT013 data, ESP32 calculates instantaneous and accumulated kilowatt-hours (kWh), which is used to compute bills based on TNB rates.

The data is then sent to ThingSpeak for comprehensive analysis, combining current and voltage for billing estimates. The system triggers alerts for three consecutive current spikes three times higher than the average, notifying users via email. This feature allows prompt action for energy conservation and potential cost savings. The system also sends email alerts for communication issues, notifying users if ThingSpeak does not receive data for 20 minutes. Daily email reports include average daily kWh consumption and total costs, aiding informed decision-making. Figure 1 shows a flowchart visually depicts the program's structured code, outlining sequential actions and decision-making steps.

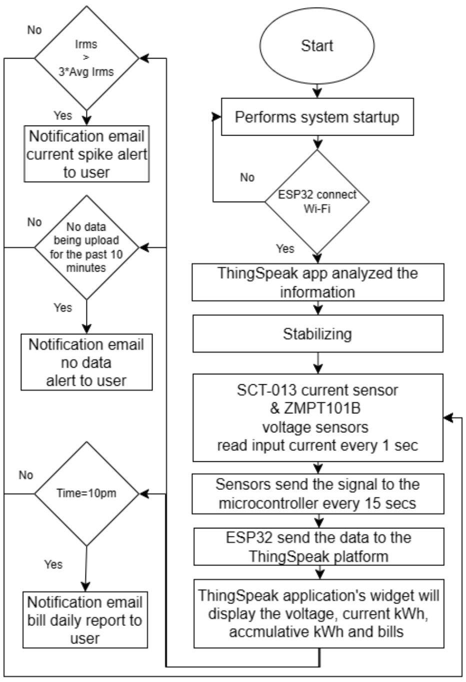


Fig. 1 *Flowchart of structured programme coding of the project*

2.2 Block diagram of the project

The primary block diagram for the project is shown in Figure 2. The system is designed to monitor energy consumption within a residential setting.

Progress in Engineering Application and Technology Vol. 5 No. 1 (2024) p. 79-87

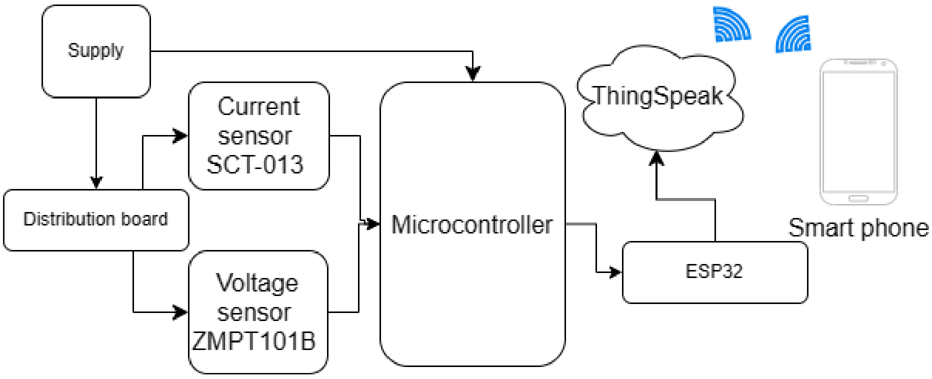


Fig. 2 *The block diagram of the project*

Starting from the power supply side, the system is connected to the power socket supply. The distribution board consist of the main switch, several Miniature Circuit Breakers (MCBs), and Residual Current Circuit Breakers (RCCBs). To accurately measure and monitor energy consumption, the system incorporates a SCT013 current sensor. This sensor is capable of measuring the current flowing through the electrical circuits and provides real time data on energy usage. The output from the current sensor is fed into the microcontroller, which acts as the central processing unit of the system. The microcontroller processes the data received from the current sensor and interfaces with the cloud service, which is represented by the ThingSpeak application.

Through the ThingSpeak platform, users can access a wide range of features and functionalities, including the ability to set energy consumption thresholds, receive notifications on abnormal energy usage, and track historical energy consumption patterns. The final component depicted in the block diagram is the smartphone, which serves as the user interface platform for monitoring energy consumption. Users can conveniently access the ThingSpeak application on their smartphones, allowing them to view real time energy consumption data, receive alerts and notifications. By integrating these hardware and software components, the real time energy monitoring and current spikes detection system enables homeowners to gain valuable insights into their energy consumption patterns, identify potential current spikes and make informed decisions to encourage energy conservation.

2.3 Block diagram of the project

Figure 3 and 4 illustrates the diagram depicting the schematic diagram’s connection and the complete prototype of the main components within this study.

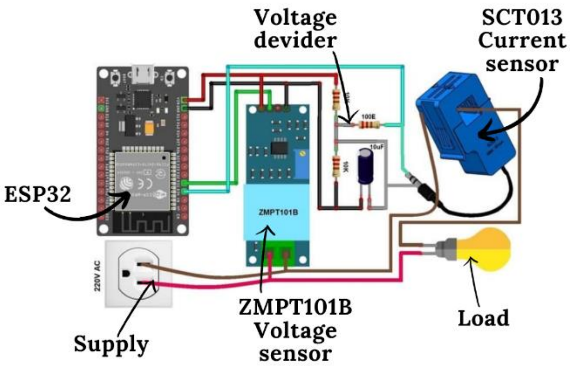


Fig. 3 *Schematic diagram of the main system of the project*

The ESP32's 5V Supply Vin is connected to the sensor's VCC. The ground port (GND) of each module is connected to ESP32's ground. The analog output port of the ZMPT101B Voltage Sensor is connected to ESP32's GPIO35. Comparable to how ESP32's GPIO34 is connected to the analog output pin of the SCT013 Current Sensor. Connect a 10-microfarad capacitor to two 10-kilohm resistors and one 100-ohm resistor. The input AC Terminal of the Voltage Sensor is connected to the AC wires outside the circuit that must be monitored for current and voltage.

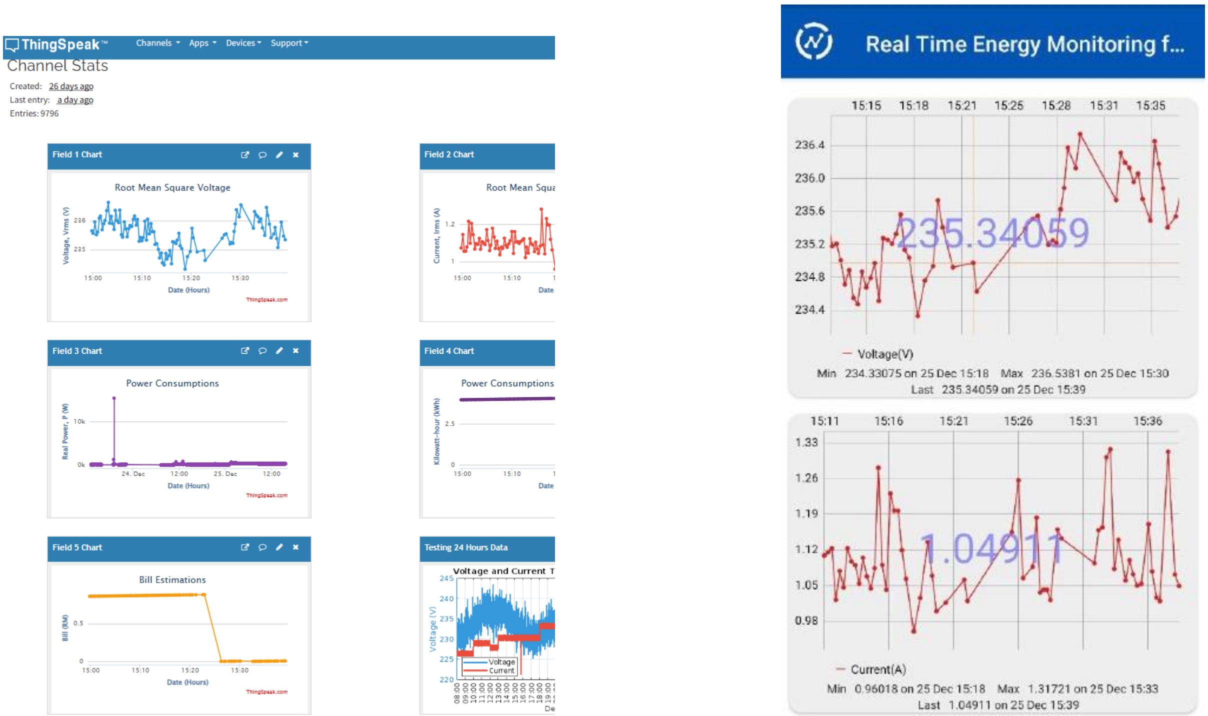
Fig. 4 *Actual prototype of the project*

3. Result and discussion

This chapter centers on the analysis of results and discussion derived from the implemented system. The discourse commences by examining the verification of the percentage error difference in voltage and current in comparison with values obtained from a clamp meter. Additionally, the study includes a 24-hour monitoring of energy consumption in student residential room distribution boxes

3.1 Connection to ThingSpeak through Wi-Fi

Subsequently, the amassed data becomes accessible for monitoring through the interfaces of ThingSpeak web platform and ThingSpeak application, illustrated in Figure 5 (a) and (b). Users are afforded the flexibility to opt for data storage in either a private or public channel, aligning with their individual preferences. Both channel types provide users with customization features, allowing them to tailor the interface according to their preferences. This encompasses options such as selecting color schemes, configuring layout arrangements, and crafting bespoke dashboards.



(a) **(b)**

Fig. 5 *Graphic user interface in (a) ThingSpeak platform*; (b) *ThingSpeak application*

3.2 Voltage and current sensor percentage error comparisons

This section of the comprehensive analysis on voltage and current sensor percentage error comparison. It is necessary to compare the recorded findings of the system with those obtained from a clamp meter, carefully examining the variations in percentage error. This research provides a comprehensive assessment of the accuracy and reliability of the system's measurements, using the clamp meter as a valid benchmark for comparison.

3.2.1 Voltage sensor percentage error and trend analysis

Figure 6, 7 and 8 displays the extracted data from 8:34am-8:44am, 8:44am-8:54am and 8:54am-9:04am respectively. The red values in the dataset signify the percentage lack compared to the clamp meter measurements, while the green values indicate an excess percentage compared to the clamp meter readings.

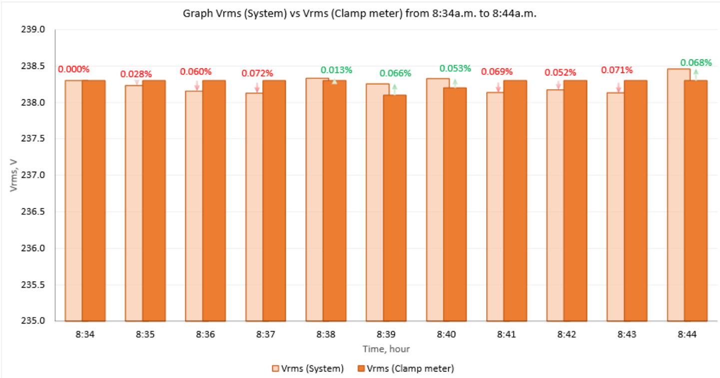


Fig. 6 *Graph Vrms (system) vs Vrms (clamp meter) from 8:34AM to 8:44AM*

The analysis of the data reveals a noteworthy trend, ranging from 0% error immediately after the voltage sensor calibration during the initial setup to a minimal of 0.072% error. The average error difference for the first 10 data points is calculated at 0.048%. These error values consistently fall within the range of 0V error to 0.172V, indicating a generally accurate and stable performance of the voltage sensor across the analyzed dataset.

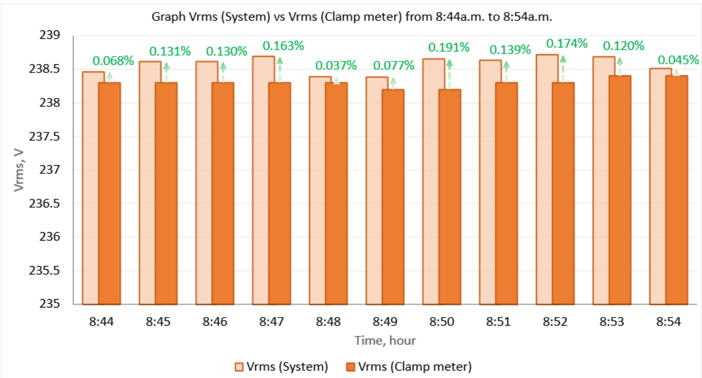


Fig. 7 *Graph Vrms (system) vs Vrms (clamp meter) from 8:44AM to 8:54AM*

Over the subsequent 10 minutes, the percentage error difference between the system and the clamp meter ranges from 0.037% to 0.191%. The average error difference for the 11th to 20th data points is computed at 0.106%. Within this period, the error values span between 0.089V and 0.456V, reflecting consistent performance with slight variations in error.

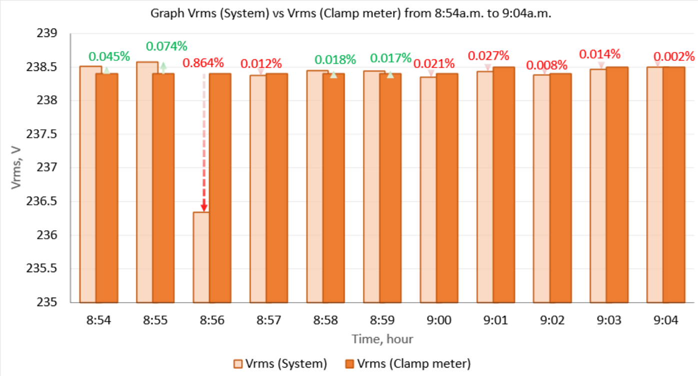


Fig. 8 *Graph Vrms (system) vs Vrms (clamp meter) from 8:54AM to 9:04AM*

In the final 10 minutes, the percentage error difference between the system and the clamp meter varies from 0.002% to 0.864%. The average error difference for this period is 0.106%. The error values range between 0.005V and 2.059V. It's worth noting that the higher voltage difference may be attributed to disturbances during this timeframe.

3.2.2 Current sensor percentage error and trend analysis

Next, the re-plotted data from 8:36am-8:46am, 8:46am-8:56am, and 8:56am-9:06am is shown in Figure 9, 10 and 11 respectively. The equations 4.3 and 4.4 provide the computation for the percentage error value and average percentage error for this testing.

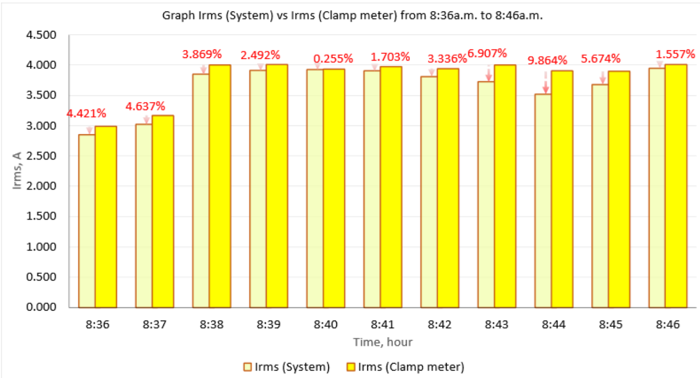


Fig. 9 *Graph Irms (system) vs Irms (clamp meter) from 8:36AM to 8:46AM*

The analysis of the current sensor data reveals a variation in error percentage, ranging from a minimum of 0.255% to a maximum of 9.864%. The average error difference for the first 10 data points is calculated at 4.316%. During this period, the error values span between 0.01A and 0.385A, highlighting a range of discrepancies in the current sensor measurements.

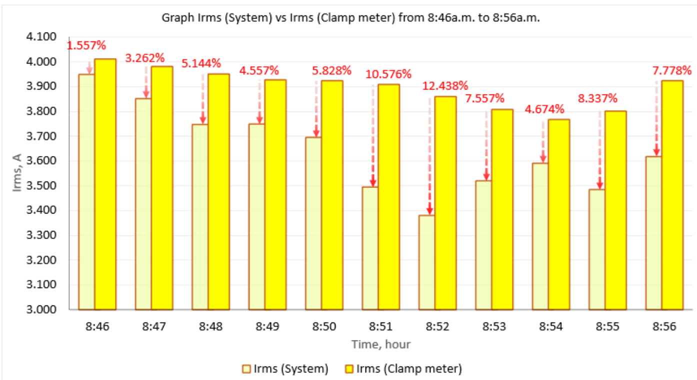


Fig. 10 *Graph Irms (system) vs Irms (clamp meter) from 8:46AM to 8:56AM*

In the following 10 minutes, the percentage error difference varies from 1.557% to a peak of 12.438%. The average error difference for the 11th to 20th data points is calculated at 6.393%. Throughout this duration, the error values range between 0.062A and 0.48A.

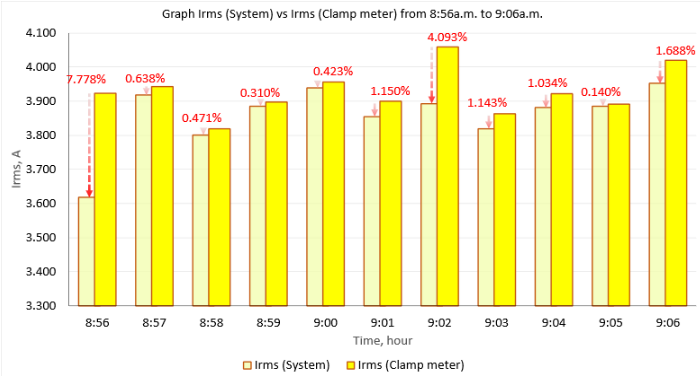


Fig. 11 *Graph Irms (system) vs Irms (clamp meter) from 8:56AM to 9:06AM*

In the last 10 minutes, the percentage error difference fluctuates between 0.140% and 7.778%. The average error difference for this period is recorded at 1.715%. The error values span between 0.005A and 0.305A. It is noteworthy that the higher voltage difference observed during this timeframe may be attributed to disturbances in the system.

3.2.3 Summary voltage and current sensor percentage error comparisons

To summarize, the voltage sensor exhibited consistent performance throughout the 30-minute duration, as the initial calibration yielded accurate readings with minimal error. Subsequent intervals maintained a relatively low average error, showcasing stability despite fluctuations in error values. However, in the final 10 minutes, a slight increase in average error was observed, potentially attributable to system disturbances. Figure 12 and 13 depicts the trend analysis for the whole 30 minutes with 1 minute interval both voltage and current testing respectively.

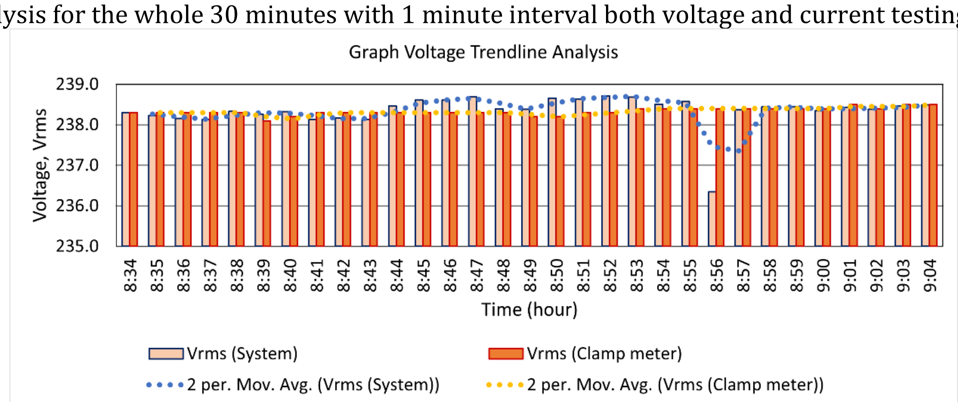


Fig. 12 *Voltage trendline analysis*

In the Figure 12, a notable decrease voltage in other words, increase in percentage error was observed at 8:56 AM, suggesting a potential disturbance or anomaly during that specific timeframe. Further investigation into the system conditions, environmental factors, or any known events during that period may provide insights into the observed spike in error."

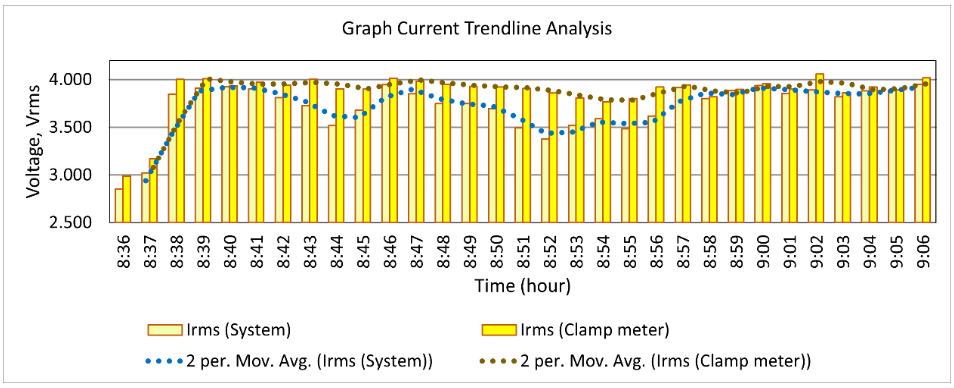


Fig. 13 *Current trendline analysis*

In Figure 13, distinct instances of decreased current, implying an escalation in percentage error, were observed around 8:43 to 8:45 AM and 8:49 to 8:56 AM. These intervals suggest potential disruptions during those specific timeframes, correlating with the previously noted abrupt decrease in voltage. However, upon closer analysis, the system's current, apart from these potentially disturbed periods, appears to closely approximate the clamp meter values. Notably, the trend analysis indicates a systematic lag in the system's current measurements compared to the clamp meter, potentially indicative of the system's response dynamics. Excluding potential disturbance zones, the overall consistency between system current and clamp meter values underscores a reasonable similarity in measurements.

3.3 Power consumption 24 hours trend analysis

This segment constitutes a thorough examination of the monitoring process for power consumption spanning a 24-hour duration, specifically from the 24th to the 25th of December 2023. Figure 14 depicts the output observed on the ThingSpeak platform, while Figure 15 corresponds to the representation within the ThingSpeak application.

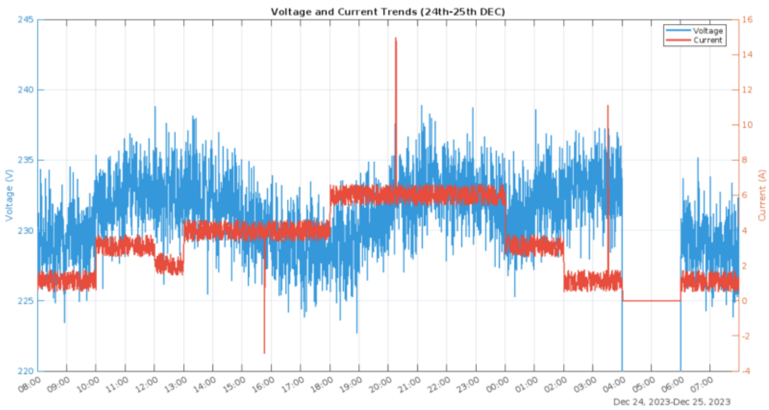


Fig. 14 *Graph voltage and current vs time (platform)*

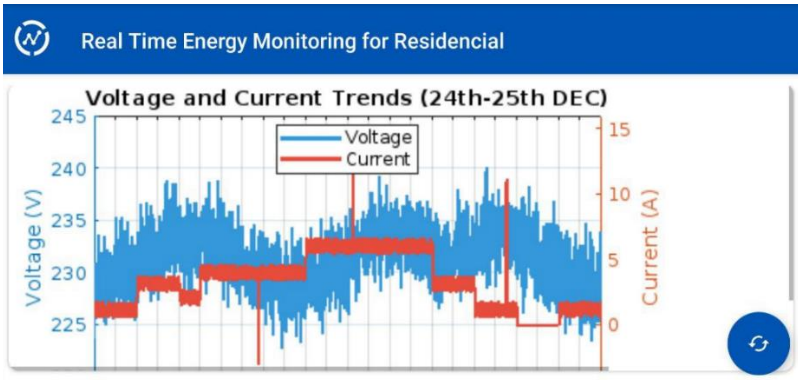


Fig. 15 *Graph voltage and current vs time (application)*

Observing the data, noteworthy instances of sudden current spikes are apparent. There is a discernible surge around 3:30 AM, a sudden decline around 3:45 PM, and another abrupt increase around 8:15 PM. These fluctuations might stem from unforeseen disturbances, as previously identified during data analysis. Additionally, it is conceivable that system-related factors contribute to these occurrences. Importantly, such deviations may not pose a significant concern, given that the monitoring primarily assesses the average current across the collected dataset. However, a notable exception would be the identification of three consecutive instances where the current surpasses three times the average. In such cases, it is deemed noteworthy and warrants notification to the user. In the temporal progression of current monitoring, distinct patterns emerge. Commencing at 8 am, the monitored current consistently maintains a lower level, consistently remaining below 2A. A marginal uptick is discernible at 10 am, followed by a notable decrease between 12 pm and 1 pm, coinciding with a period of reduced occupancy as residents embark on a lunch break.

Lastly, there is a discernible augmentation, with the current peaking at approximately 4A. The most substantial surge in current transpires around 6 pm, correlating with the onset of darkness and the illumination of lights throughout the residence. A subsequent decline transpires in tandem with bedtime, and the current registers near-zero levels from approximately 2 am to 4 am, indicative of minimal electrical appliance utilization during these early morning hours.

4. Conclusion

The primary objectives of this project are the successful development of a real time energy monitoring & current spikes detection system for enhanced energy conservation in residential area. The project's success criteria are threefold. Firstly, the system designed is able to monitor energy consumption in real time and detect sudden current spikes in the system. Second, the project also has developed a low cost yet reliable hardware system that can monitor energy consumption pattern, detect current spikes, and communicate with the mobile application in real time. Finally, the real-time energy monitoring and detection system for current spikes completed a comprehensive validation analysis to evaluate its performance. In nutshell, the accomplishment of the system is marked by its ability to achieve the objective of creating an integrated system for monitoring energy consumption in residential areas and calculating estimation bills. The system demonstrates acceptable accuracy, with the highest observed error difference standing at 12.438%, all achieved through a low-cost implementation. Consequently, the project is deemed successful in meeting its predefined goals and delivering a functional solution for real-time energy monitoring and billing estimation in residential settings.

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