

Portable Residential Power Monitoring Distribution Box

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Abstract

The increasing adoption of renewable energy and rising electricity costs have heightened the need for affordable, user-friendly power monitoring solutions for residential consumers. Conventional power monitoring systems are often large, expensive, and devoid of remote accessibility and real-time data logging. The Internet of Things (IoT) is used in this project to provide a portable residential power monitoring distribution box with notification capability that fills these gaps by accurately monitoring power use. A NodeMCU ESP32 microcontroller, SCT-013 current transformers, and a ZMPT101B AC voltage sensor are all integrated into the suggested system to measure electrical parameters in real time. A DS1307 data-logger shield is also included in the system to timestamp and locally record power data. Users may monitor their household's power use, trends in energy usage, and receive alerts of unusual usage on their smartphones thanks to these readings, which are instantly relayed over Wi-Fi to the Blynk application and shown on an LCD screen for instant feedback. The device's ability to measure current and voltage correctly within reasonable tolerances was shown during testing under various load circumstances. The system's dependability was confirmed by the small discrepancy between measured data and multimeter readings. Additionally, data was successfully sent and shown on the Blynk dashboard for both historical and real-time analysis. To sum up, home users may monitor power consumption, effectively regulate energy usage, and promote energy conservation with this portable monitoring box. This system may be expanded to monitor three-phase electricity in the future, and machine learning can be used to add predictive features for better energy management.

1. Introduction

Everyday living depends heavily on lighting and electrical equipment, thus residential customers need a steady and uninterrupted supply of power. The majority of homes, however, lack useful methods for tracking their energy consumption in real time, which frequently leads to waste that goes unrecognised and needlessly expensive electricity bills [1]. For meter readings, Tenaga Nasional Berhad (TNB) workers still have to physically visit customers' locations, which takes time and increases the possibility of estimated billing mistakes [2]. Furthermore, gadgets such as security cameras, freezers, and CCTV cameras need a constant power source, and if an unexpected power outage or malfunction goes unnoticed, it might result in damage or security threats. The majority of home monitoring systems on the market today are permanently fixed, immobile, and do not offer automated alerts for unusual use or real-time data logging. The integration of non-invasive sensors like the

ZMPT101B voltage sensor and SCT-013 current transformer into a monitoring setup can effectively track household energy usage and send notifications to the user interface, according to recent research on IoT-based energy monitoring systems, such as that conducted by Amirul Akmal and Hassan (2024) [3]. Motivated by these results, the project centres on a portable monitoring box based on the ESP32 microcontroller that links to the Blynk mobile platform for automatic alarms, wireless data access, and historical usage reporting. A DS1307 real-time clock is also included in the design to locally timestamp the data. Most households are unable to promptly detect any electrical problems or proactively regulate their energy consumption without these characteristics. Therefore, the goal of this project is to provide a useful, affordable, and easy-to-use power monitoring tool that will enable homes to maximise their energy use, improve safety, and lower their electricity costs.

1.1 Objective and Project Scope

The primary objective of this project is to design and build a portable power monitoring distribution box with Internet of Things (IoT) features for data logging, automated notifications, and real-time energy use monitoring. With the use of an ESP32 microcontroller, SCT-013 current transformers, and a ZMPT101B voltage sensor, the system continuously detects the current, voltage, and power consumption of every MCB in a residential distribution box. In addition to a DS1307 real-time clock to timestamp recorded data, it integrates a Blynk-based mobile interface that enables wireless access to measurements, historical energy consumption, and threshold-based notifications [4].

The scope of this project is limited to single-phase household electrical networks, and its primary objectives are cost, portability, and ease of installation so that homeowners may monitor their energy consumption without professional assistance. Unlike commercial smart meters that require permanent installation, our technology may be swiftly and non-invasively deployed in existing distribution boxes [5]. Prior research indicates that similar IoT-enabled monitors have successfully employed WiFi-enabled microcontrollers and mobile platforms for effective residential energy monitoring [6], and helpful online tutorials highlight that the ESP32 and Blynk architecture is a dependable and reasonably priced choice for this use case [7].

1.2 Literature Review

A recent study on home energy monitoring indicates that there is increasing interest in low-cost, microcontroller-based systems that offer real-time tracking of power use. Early systems relied on utility-installed meters that provided only cumulative consumption figures and required human readings without any data-logging or remote access capabilities [8]. More recently, inexpensive and non-intrusive systems that employ sensors like the ZMPT101B voltage module and SCT-013 current transformer to continually collect precise consumption data have been made possible by the use of microcontrollers like the ESP32 [9]. Li et al. claim that ESP32-based devices can efficiently record voltage and current data at home, which can then be wirelessly shared and shown locally for further examination [10].

Time-stamped data logging is another crucial component of home energy monitoring that has been studied. Sharma et al. state that offline data-logging is made possible by the addition of a real-time clock, namely the DS1307 module, which preserves and retrieves historical consumption patterns even in the case of Wi-Fi outages [11]. This allows the device to keep an accurate use record over time without relying just on network connectivity. Additionally, wireless connections with user-friendly interfaces are a crucial part of modern monitoring systems. Kaur and Singh proposed using the Blynk application to provide a remote dashboard and alerts for any anomalous power consumption detected by the sensors [12]. Furthermore, non-invasive current sensors for domestic power monitoring are feasible and safe to use, which makes installation easier and encourages household users to utilise them without technical expertise [13].

Despite these improvements, most business energy meters still need permanent installation and lack portable, real-time warning features. In order to ensure that residential users can easily track their energy consumption and receive real-time updates to maximise usage and boost energy savings, the project aims to integrate these tried-and-true methods — ESP32 microcontroller, SCT-013, ZMPT101B sensors, DS1307 for data-logging, and Blynk interface — into a single portable solution.

2. Methodology

This chapter outlines the general methodology used in the development, deployment, and assessment of the Portable Residential Power Monitoring Distribution Box. It describes the steps used to accomplish the project's goals in terms of process flow, hardware configuration, software integration, and testing.

2.1 System Flowchart

Figure 1 shows the portable power monitoring system's general process flow. From initialising the ESP32 and its peripherals to sensor calibration, data acquisition, processing, and timestamping with the DS1307 RTC, data display on the LCD, data logging onto the SD card, and real-time data transmission to the Blynk mobile application, the flowchart describes the order of operations. In order to deliver messages, the system also determines if power values surpass predetermined levels. After then, the gadget goes back to its monitoring loop to read, analyse, log, and show data continually.

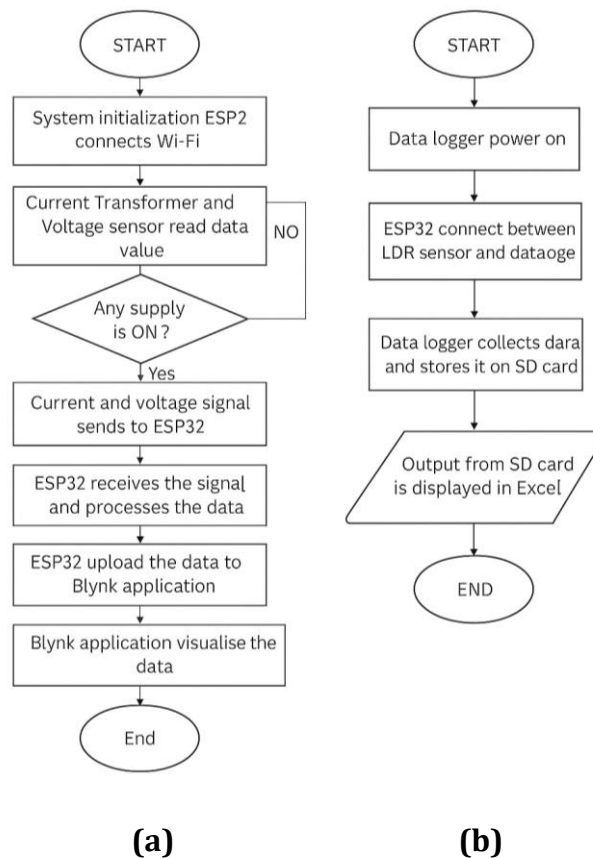


Fig. 1 System Flowchart of (a) Monitoring system and (b) Data logger

2.2 System Block Diagram

The portable power monitoring system's general block diagram, which shows how its several essential parts cooperate to track household energy usage, is shown in Figure 2.2. The distribution box, where each Miniature Circuit Breaker (MCB) is outfitted with non-intrusive current and voltage sensors, receives the residential AC power at the start of the system. The ESP32 microcontroller receives scaled analogue data for processing from the ZMPT101B voltage sensor and SCT-013 current transformer, which continually detect the supply voltage and load current. These measurements are used by the ESP32, the central control unit, to determine the current, voltage, power, and energy usage in real time. A DS1307 real-time clock (RTC) module is attached to the ESP32 and supplies date and time information for every reading in order to guarantee precise timestamping of the observed data. To make it simple for customers to see the power parameters on-site, the data is shown locally on a 16x2 LCD screen. Using the Blynk app, the ESP32 simultaneously sends the measured data to a smartphone over Wi-Fi, enabling homeowners to remotely monitor their energy use and get alerts in the event that a power

trip or exceeding certain thresholds happens. The system furthermore has an SD card module for local data logging, guaranteeing that previous consumption data is safely saved for later use even in the event that the Wi-Fi network is momentarily unavailable.

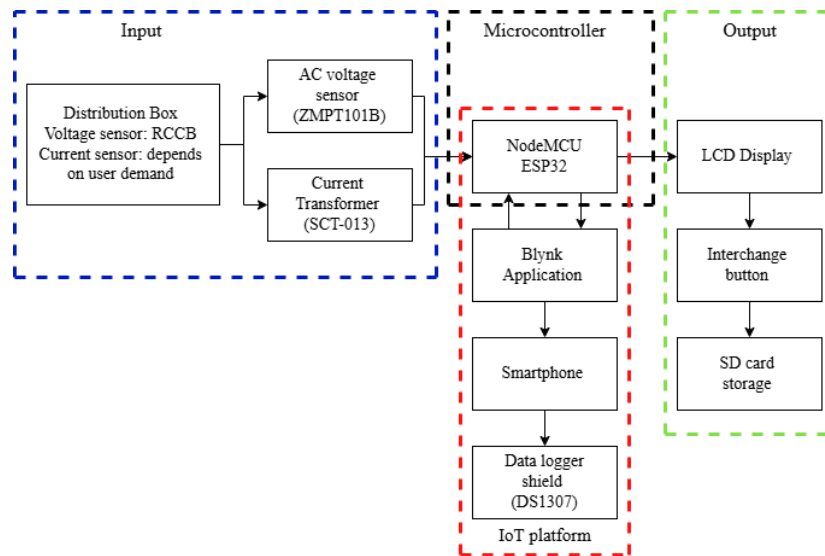


Fig. 2 System Block Diagram of Portable Residential Power Monitoring Distribution Box

2.3 Monitoring System Component

The power monitoring system is composed of numerous important components, each chosen to suit the functional requirements of precise sensing, processing, display, data storage, and communication. The ESP32 microcontroller, which is at the heart of the system, was selected due to its many ADC channels, integrated Wi-Fi, and low power consumption, which make it perfect for remote monitoring and real-time data processing. Because of its clip-on design, which enables safe and simple installation around existing wires without cutting the power supply, the SCT-013 current transformer is used to monitor the current consumption of each circuit non-invasively. The ESP32 can calculate power and energy usage by combining current measurements with the ZMPT101B voltage sensor, which delivers a scaled-down analogue output that represents the mains voltage. In order to preserve precise time and date information for every data point and guarantee correct timestamping even in the event of network outages, a DS1307 real-time clock (RTC) is incorporated into the architecture. In the event that internet connectivity is not available, the SD card module allows the system to locally log consumption data, facilitating the recovery of past data. The Blynk mobile application allows wireless data transfer and visualisation on the user's smartphone, enabling remote monitoring, historical analysis, and real-time notifications when power consumption exceeds predefined limits. Lastly, a 16×4 LCD is mounted on the front panel to provide immediate feedback of measured parameters.

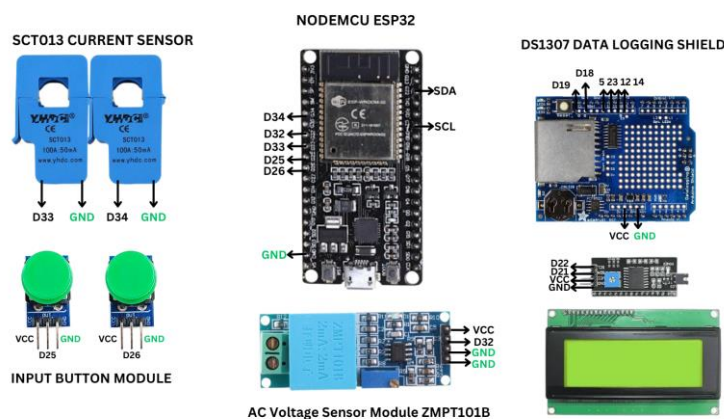


Fig. 3 Monitoring system component of Portable Residential Power Monitoring Distribution Box

2.4 Hardware Development

The portable power monitoring box, which is powered by a typical 3-pin 13A plug top that gives the system a secure and reliable 240 V AC input, was assembled first in the hardware development process. To guarantee safety and dependability, protection components were fitted, such as a 40A main switch and a 40A RCCB (0.1 mA sensitivity) to guard against leakage currents. Two Miniature Circuit Breakers (MCBs) distribute electricity to their respective loads from the RCCB output: a 16A MCB for power outlet circuits and a 6A MCB for lighting loads. The neutral and earth conductors are connected to a common neutral busbar and earth busbar for appropriate grounding, while the live conductors from the RCCB travel through each MCB before arriving at the output. A ZMPT101B voltage sensor is attached across the incoming live and neutral lines to measure mains voltage, and SCT-013 current transformers are clamped onto each MCB's output to detect current non-invasively for energy monitoring. The ESP32 microcontroller receives these sensor signals through its analogue inputs, interprets the data, and calculates the power and energy usage in real time. Supporting modules like as a 16×2 LCD for local data display, an SD card module for offline data logging, and a DS1307 real-time clock for precise timestamps are installed with the ESP32. Wi-Fi connectivity completes the system, enabling the ESP32 to communicate with the Blynk app to provide status alerts and measured data straight to a smartphone. To create a small, robust, and secure portable monitoring device, wire management, insulation, and grounding were carefully considered throughout the construction process.

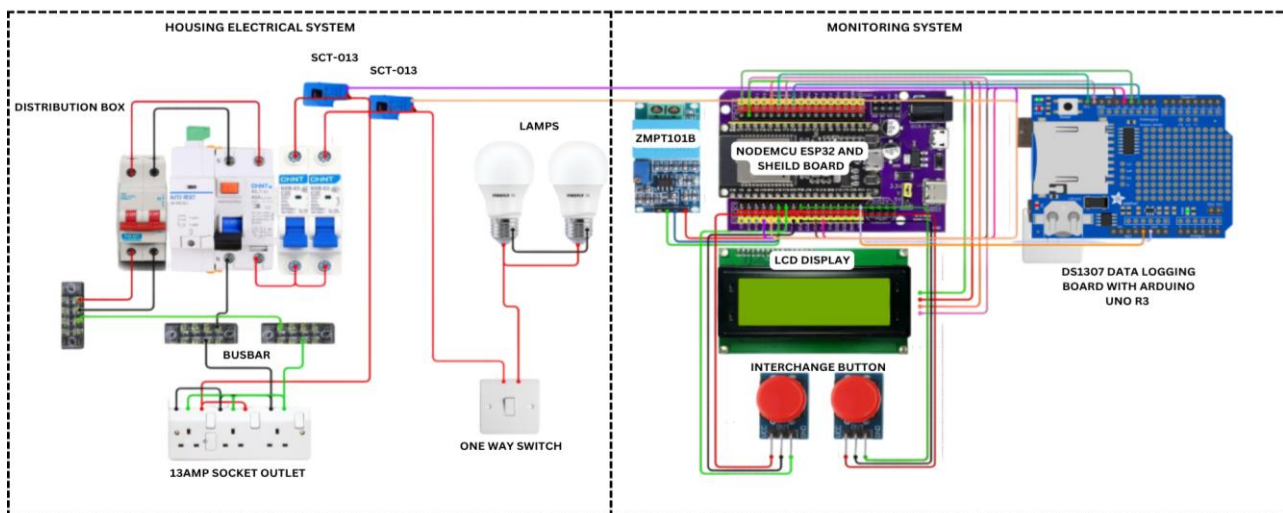


Fig. 4 Hardware development of Portable Residential Power Monitoring Distribution Box

3. Results and Discussion

This chapter describes how to design, build, and test the portable power monitoring system step-by-step. The process starts with the overall setup's conceptualisation, then moves on to hardware design, component selection, and system assembly. Following the integration of the hardware components into the distribution box, software development is necessary to ensure correct current, voltage, and power measurements. This includes sensor calibration, data processing, and ESP32 microcontroller programming. The system's accuracy, data-logging capabilities, and ability to react to unusual consumption patterns are then confirmed by testing under a variety of home load scenarios. Every significant element and how it is implemented are covered in detail in this chapter, beginning with the sensors that are the foundation of the energy measuring procedure.

The finalised product, which includes the ESP32 microcontroller, sensors, SD card module, DS1307 RTC, and LCD, is contained in a small and sturdy shell. The front panel has input and output ports that are clearly identified and a 16x4 LCD for real-time data display. In order to avoid loose connections or short circuits, every internal wiring is carefully organised and fastened using cable ties. Additionally, ventilation apertures are included for heat dissipation during prolonged operation. Figure 5 displays the product's final configuration, which is a reliable and easy-to-use setup that can be quickly installed, maintained, and moved as needed.

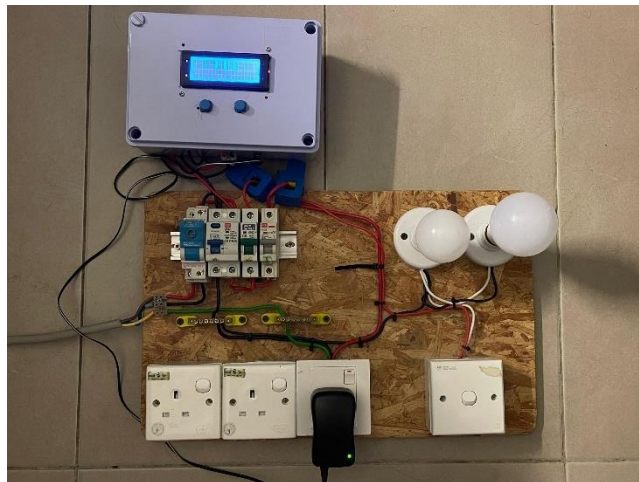


Fig. 5 Final Arrangement for The Project Product

The main objective of the monitoring box is to make placement at a home distribution board simple and secure. In order to clip directly onto the live wires within the existing distribution box without interfering with existing connections, sensor clamps, like the SCT-013 current transformers, pass through special apertures at the top of the box. To make it easier for the user to set up the device, the enclosure is made of heat-resistant material and has a clearly designated faceplate with all interface points (power input, MCB output connections, and LCD readout). Figure 6 shows the whole configuration of the monitoring box, giving a good picture of its design and usefulness in a normal home installation.

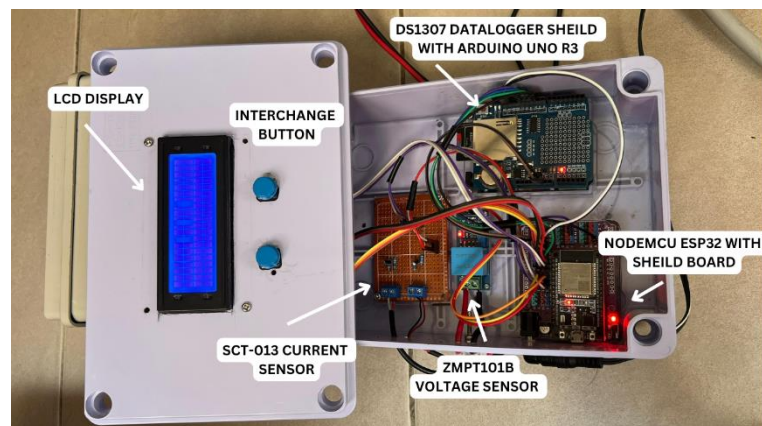


Fig. 6 Monitoring Box

3.1 Component Part Functionality Testing

Each part was tested separately to ensure appropriate operation before the entire system was put together. The SCT-013 current sensor, ZMPT101B voltage sensor, DS1307 RTC, SD card, LCD, and the Blynk connection were among the sensors, modules, and peripherals that were examined one at a time. This guaranteed precise readings and proper communication between all parts and the ESP32. At this point, any necessary modifications or calibrations were done to ensure the system would function properly when it was fully constructed.

3.1.1 Current Transformer SCT-013 Sensor Testing

A non-invasive split-core sensor called the SCT-013 current transformer is made to precisely detect the amount of alternating current (AC) passing through a conductor without causing damage to the wire. The sensor was only fastened around each MCB's live wire during testing. The magnetic field produced by the AC current is transformed by the SCT-013 into an output signal that the ESP32 analogue input can read. The measured current was found to have a variance of less than $\pm 2\%$ when the readings were calibrated against a multimeter as a reference, demonstrating its dependability for real-time monitoring of electrical circuits in homes.



Fig. 7 Current Transformer SCT-013 Sensor Testing

3.1.2 AC Voltage Sensor ZMPT101B Testing

Comparably, the ZMPT101B voltage sensor is a small module that offers a secure, separate method of determining the voltage of the AC mains. Its adjustable potentiometer enables fine-tuning to increase measurement accuracy, and its integrated potential divider reduces the mains voltage to a safe analogue level for the ESP32's ADC input. The output signal closely mirrored the genuine mains voltage with little variance when tested against a conventional multimeter, demonstrating that the sensor delivers reliable and accurate readings under various loads. The fundamental component of the energy monitoring system, these two sensors let the gadget to accurately calculate the power usage in real time for each monitored MCB.

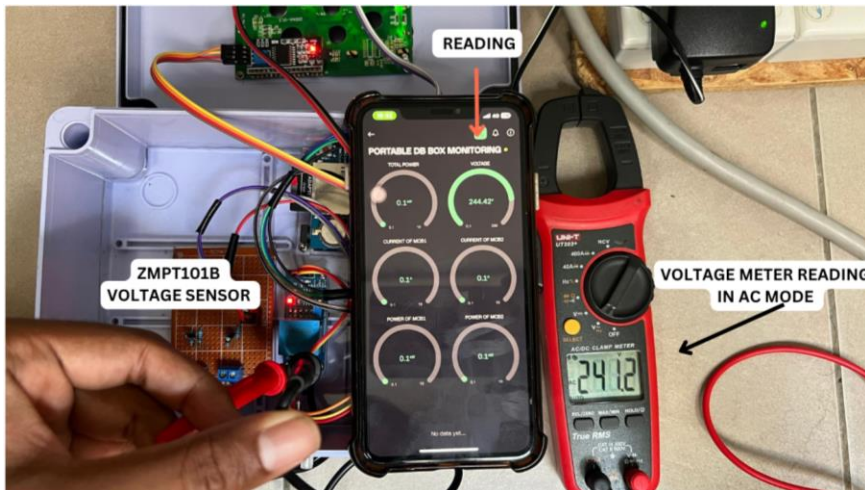


Fig. 7 AC Voltage Sensor ZMPT101B Testing

3.1.3 DS1307 Datalogger Testing

The DS1307 real-time clock (RTC) is incorporated into the system as a timestamp source to facilitate data-logging and historical analysis. Even in the event that the primary power source or internet connection is lost, the DS1307 can maintain a correct date and time thanks to its backup coin-cell battery. Before putting the data on the SD card, it adds precise timestamps to each power reading after interacting with the ESP32 over the I2C interface. This makes it possible to continuously monitor and save data offline, allowing for the chronological evaluation of previous energy use at any point in time.

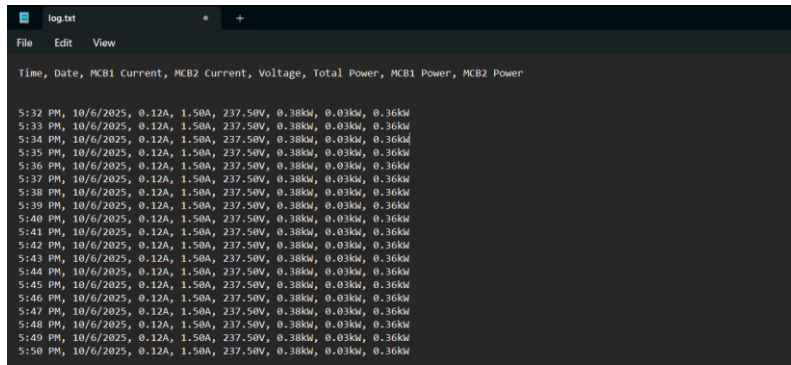


Fig. 8 DS1307 Datalogger Testing

3.2 Load Results

The graph of current consumption under low-load conditions using a laptop and phone charger is shown in Figure 9. The current progressively increases to 0.23 A, demonstrating the sensitivity of the SCT-013 sensor to tiny currents.

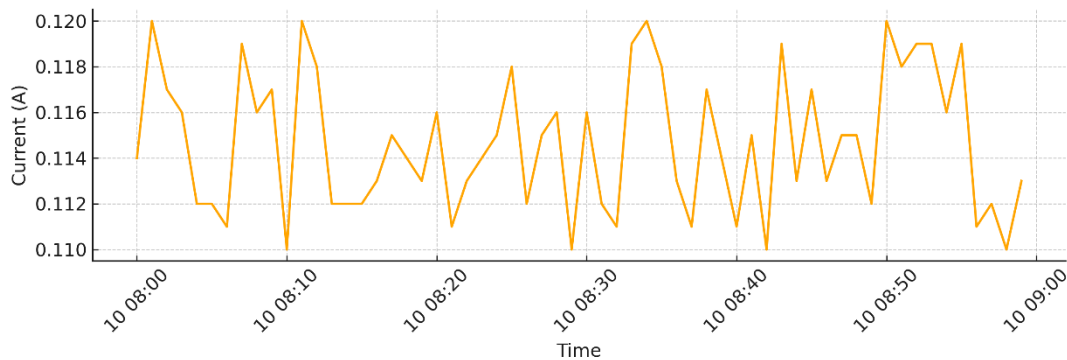


Fig. 9 Graph of Current Over Time For Low Load

The medium load graph is displayed in Figure 10. A hair dryer was utilised for the medium load tests. Current values stayed close to 0.02 A while the gadget was not in use. The current rose to around 1.1 A to 1.30 A when the dryer was switched on at level 1 heat and speed. The value increased to about 2.20 A 2.68 A as it escalated to level 2 heat. The current peaked at 5.3 A 5.68 A at maximum power (level 2 heat and speed). This amply illustrates how the system may adapt to changes in real time according to the device's operating level.

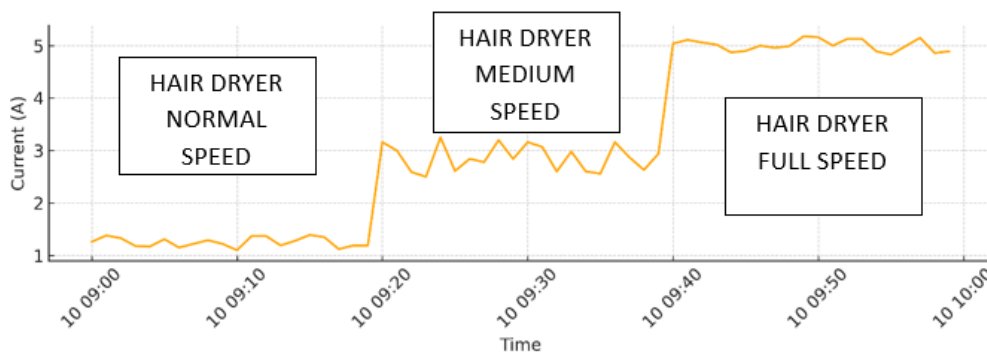


Fig. 10 Graph of Current Over Time For Medium Load

Figure 11 shows how an electric kettle was used to simulate a high-load scenario. Before turning the switch to the ON position, the current values were up to 0.02 A. The current values quickly increased to 14.98 A when they were turned on, suggesting that the kettle had a significant initial power consumption. The current gradually decreased to the preset 0.02 A when the water boiled and the automated cutoff activated,

demonstrating the high load profile and the effectiveness of the monitoring system in documenting the device cycles.

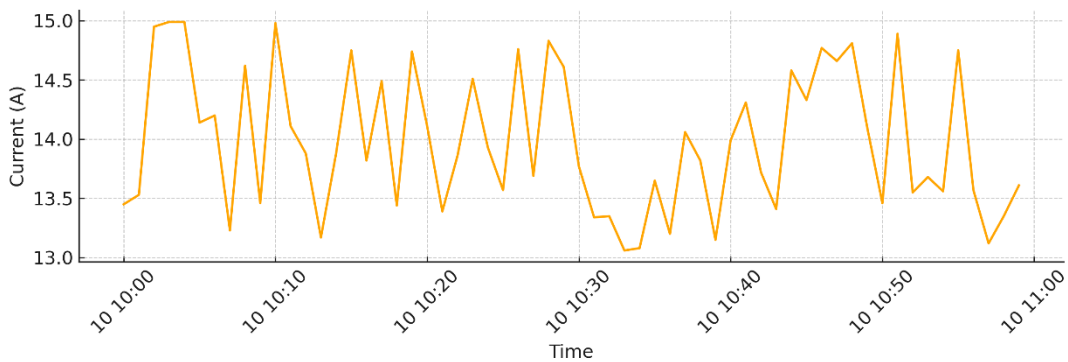


Fig. 11 Graph of Current Over Time For High Load

The power consumption curve under low-load situations, where tiny devices like laptop adapters and phone chargers use only a few watts, is shown in Figure 12. The system's ability to identify slight differences in power demand is confirmed by the power data's gentle fluctuation in response to device activity. This confirms that even at low consumption levels, the ESP32's computations based on current and voltage readings are accurate.

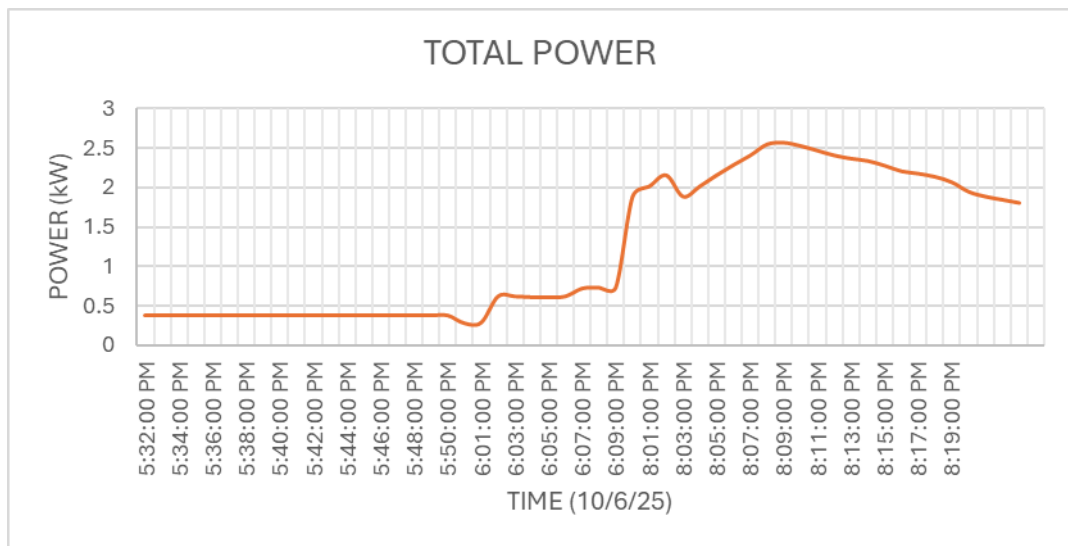


Fig. 12 Graph of Total Power Over Time

A graph of the hair dryer's power usage at various heat settings is shown in Figure 13. It is evident from the graph that power increases gradually when the heating level is raised, peaking at about 1,200 W. These findings show how well the monitoring system can detect significant changes in power use when appliance demand fluctuates.

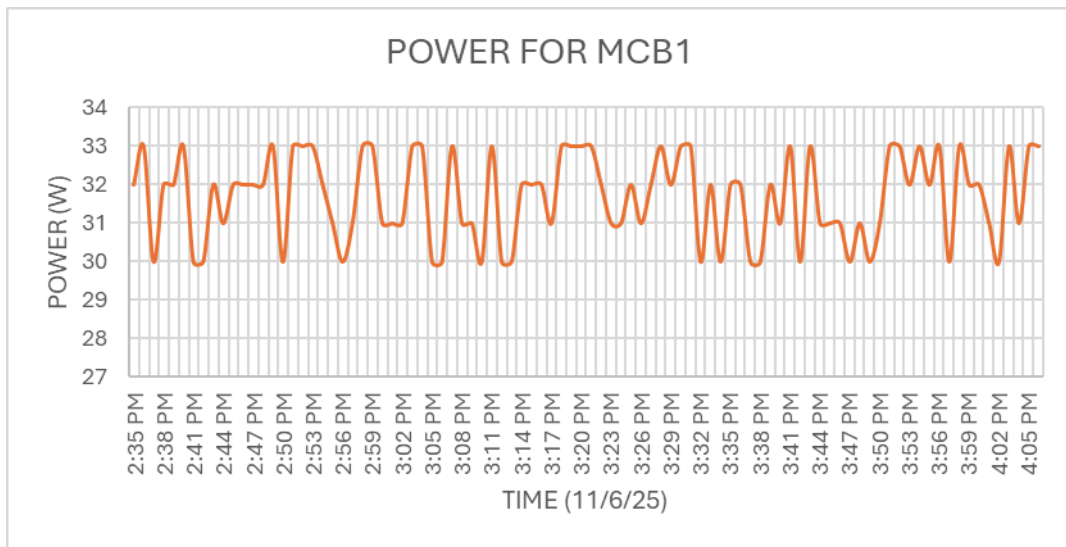


Fig. 13 Graph of Power for Mcb1 Over Time

The power consumption curve for an electric kettle under heavy load conditions is shown in Figure 14. As soon as the kettle is turned on, the graph shows a sudden rise to around 3,500 W, which is followed by a quick decline to zero as the water boils and the cycle is over. This demonstrates that the system can properly record fast, high-power transitions and promptly notify of significant changes in consumption.

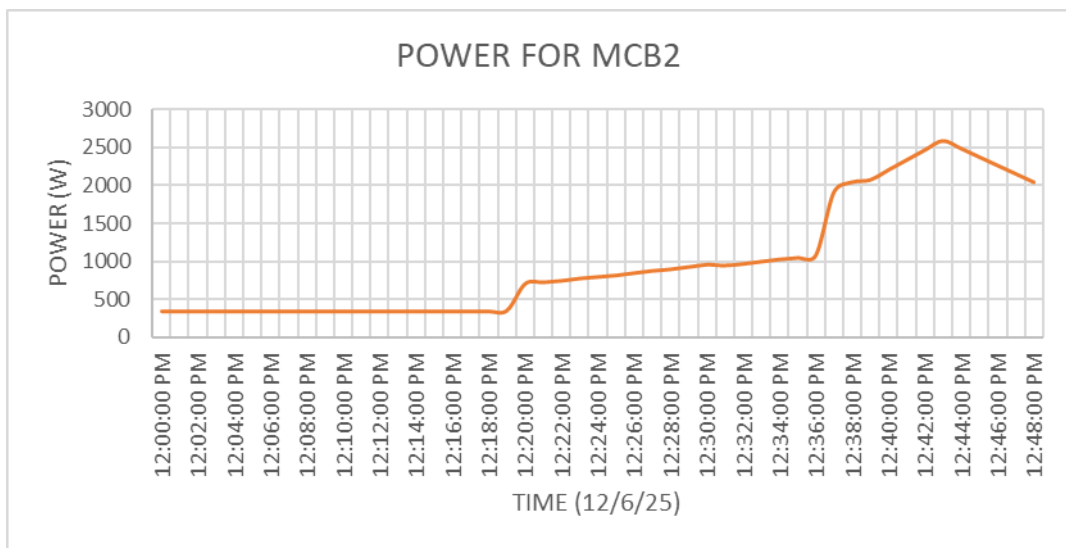


Fig. 14 Graph of Power for Mcb2 Over Time

Figure 15 displays the mains voltage readings over the entire testing period. The graph indicates a stable supply close to 240 V with only minor fluctuations at different times of the day. This stable voltage profile validates the consistency and accuracy of the ZMPT101B sensor in monitoring the mains supply and reinforces the overall reliability of the monitoring system under different load conditions.

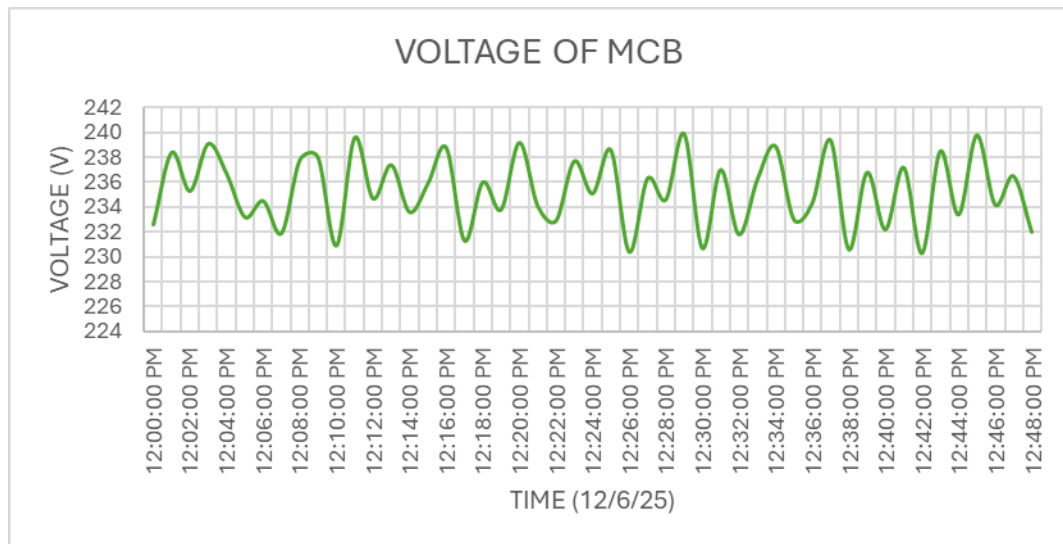


Fig. 15 Graph of Voltage of Both Mcb Over Time

4. Conclusion

A portable home power monitoring distribution box with real-time measurement, data-logging, and automatic alerting functions was successfully designed and produced as part of this project. The selection of suitable hardware and software components that satisfy the project's requirements was carefully considered throughout the development process. These components included the ESP32 microcontroller, SCT-013 current sensors, ZMPT101B voltage sensor, DS1307 real-time clock, SD card module, LCD display, and Blynk application. Because the integrated system was put together in a sturdy, readily navigable enclosure with unambiguous interface labelling, it was simple to install into an existing home distribution box without the need for specialist assistance.

The sensors' ability to provide precise current and voltage measurements and the system's ability to calculate real-time power usage with little error were both verified by testing and calibration against a standard multimeter. Both high-current appliances like kettles and low-current ones like phone chargers were picked up by the gadget, which also demonstrated stability and responsiveness under a range of household loads. The LCD panel showed real-time data, which was wirelessly sent to the Blynk program for remote monitoring and recorded on the SD card with exact timestamps from the DS1307. The system's practical value in enhancing energy awareness and safety was demonstrated by the instant warnings that were given to the user whenever power usage exceeded certain criteria or power outages occurred.

Overall, the project's goals were met, and the outcomes show that a portable, reasonably priced energy monitoring system for homes is both feasible and useful. Future research may look into improvements including switching to higher-precision sensors for even more precise readings, modifying the system to work with three-phase electrical networks, and adding automated control or predictive analytics to aid maximise energy use. This would enable the system to continue supporting safety, sustainability, and proactive energy management while scaling to bigger residential and commercial spaces.

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