

IoT -Based Electrical Distribution Box Power Monitoring System Using Raspberry PI

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Abstract

The "IOT - Based Residential Electrical Distribution Box Power Monitoring and Notification System using Raspberry PI" is a sophisticated solution designed to empower homeowners with the ability to monitor and manage power consumption at the circuit level within their residential electrical distribution box. The system is built around the Raspberry Pi 3 Model B and utilizes two key sensors: the ZMPT101B for voltage measurement and the SCT-013 for current measurement. This project addresses the pressing need for homeowners to optimize energy efficiency, enhance electrical safety, and reduce utility expenses. The core functionalities of this system include real-time power monitoring, data logging, abnormality detection, and instant notifications to homeowners in case of power anomalies, such as surges, overloads, or short circuits. The intuitive web interface and mobile application grant users' remote access to the system, allowing them to visualize real-time power data, control individual circuits, and receive timely notifications. The integrated user authentication ensures security and control. The ZMPT101B and SCT-013 sensors are accurately interfaced with the Raspberry Pi 3, and their output is processed to provide precise measurements of voltage and current on individual circuits. The system takes advantage of the Raspberry Pi's processing power and GPIO capabilities to create a robust solution that is both reliable and efficient. In summary, this project offers homeowners a comprehensive solution to enhance energy efficiency, electrical safety, and cost management. Through meticulous sensor integration, data analysis, and user-friendly interfaces, this project aims to transform the way homeowners interact with and monitor their electrical systems.

1. Project Introduction

This section fully describes the project aims and problem statement for this project. The project scope, problem statement, and objective.

1.1 Introduction

Electricity is fundamental to modern life, playing a vital role in powering homes, industries, and transportation systems. It also supports various household functions like heating, cooling, and operating electronic devices (Niu et al., 2020) [1]. According to Niu et al. (2020), the effective management of electricity within a building is crucial

for ensuring both efficiency and safety. This is achieved through systems like the distribution box, which manages and distributes electrical power, ensuring a safe and reliable electricity supply (Rangwala, 2020) [2]. Maintaining the distribution box involves monitoring components such as circuit breakers, wiring, and connectors to ensure their proper functioning (Gani et al., 2020) [3]. With the increasing complexity of household electrical systems, traditional manual methods for monitoring and managing power usage are becoming inadequate. An IoT-based power monitoring and notification system can address these issues by providing real-time data on power usage and system health (Yin et al., 2021) [4]. This approach leverages technologies like the Raspberry Pi to offer a cost-effective, user-friendly solution for improving power management and safety in residential settings.

1.2 Project Scope, Objective, and Problem Statement

The typical domestic protection system is manually controlled, requiring significant time and effort to restore the power supply if a short circuit occurs when no one is home. Such an event could affect the entire household's electrical appliances if it happens at the distribution box. This problem mainly arises when residents stress the Miniature Circuit Breaker (MCB) by using too many electrical appliances that consume excessive electricity, particularly motorized appliances that impact the load. Monitoring the system by checking and measuring current and voltage is essential for maintaining optimal performance (BYJUS, 2023) [13].

The objectives of this project are to design a distribution box power monitoring system with notification capabilities for residential electrical systems. Specifically, the project aims to investigate residential power monitoring systems with voltage, current, and power consumption monitoring capabilities, design and construct a portable housing monitoring system using a Raspberry Pi, and validate the designed system to ensure its functionality in providing real-time power monitoring to homeowners (Gani et al., 2020) [3]; (Yin et al., 2021) [4].

The project scope includes using a Raspberry Pi 3 control module as the hardware interface, powered by a standard micro-USB cable (5V). The user interface platform will be based on the Raspberry Pi OS, which will monitor data acquired by the split-core current transformer (SCT-013) and the voltage sensor (ZMPT101B) through the internet. The constructed system will be implemented on the household distribution box for power monitoring. The application will use Flask to display the data to users via their phones or computers (InnovatorsGuru, 2019) [18]; (MikroElectron, 2023) [19]; (PowerUC, 2018) [11].

2 Project Methodology

This section fully describes the resources and method used in this project. The project methodology includes all aspects of the work procedure for each stage, such as a block diagram, the hardware and software used, and an overview of the system flowchart.

2.1 Overview of System

Figure 1 depicts the architecture of the project's block diagram. The system is organized into four sections: input, microcontroller as the brain, output, and the IoT platform. The Raspberry pi microcontroller was chosen for this system because it has an operating system that has its own interface, and it can produce graph like result in flask. The current transformer (SCT-013) sensor and AC voltage sensor module ZMPT101B were used as an input device in this project. They are all powered by a 12V adapter and will send a signal to the Raspberry pi when the sensor detects current flow from the MCB. Monitor is an output that can shows the voltage, current and power usage

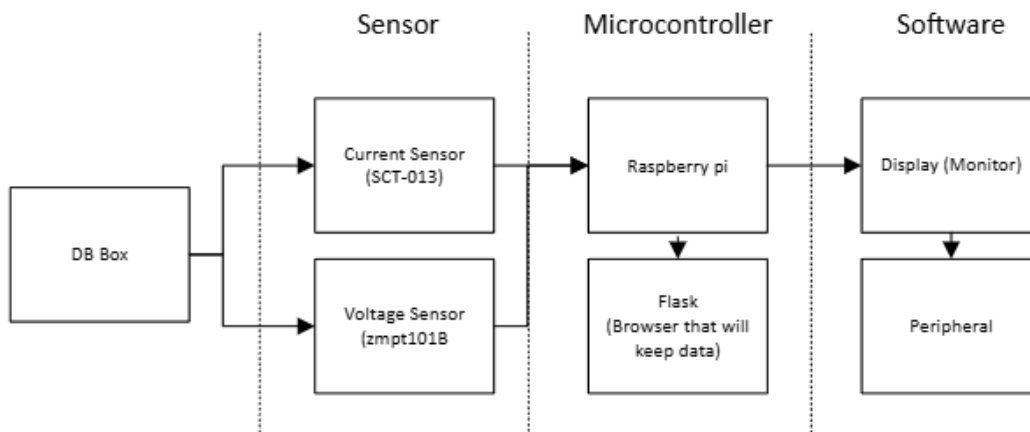


Fig. 1 Block diagram of IOT - Based Residential Electrical Distribution Box Power Monitoring and Notification System using Raspberry PI

2.2 Flowchart of System

Figure 2 depicts the monitoring system flowchart for the whole system. The initial phase of the system will begin when the Raspberry Pi is powered on and will connect to Wi-Fi automatically. This will enable Raspberry Pi to Internet access so that it may store data in cloud. It also can be stored physically in micro-SD card. The current transformer (SCT-103) and AC voltage sensor module ZMPT101B were installed in the system to maintain the operation. This sensor's purpose is to monitor the electrical load of the MCB's power and lighting. When the sensor detects current and voltage, it generates an analogue signal that is transmitted to the Raspberry Pi. The data from the sensor will be received and processed by the Raspberry Pi. The data processed by the Raspberry Pi will be shown on the monitor, allowing the user to monitor the power use without using the internet. Following that, the Raspberry Pi will send the data to the application. The data will then be visualized in the flask, allowing the user to monitor their power usage in a waveform.

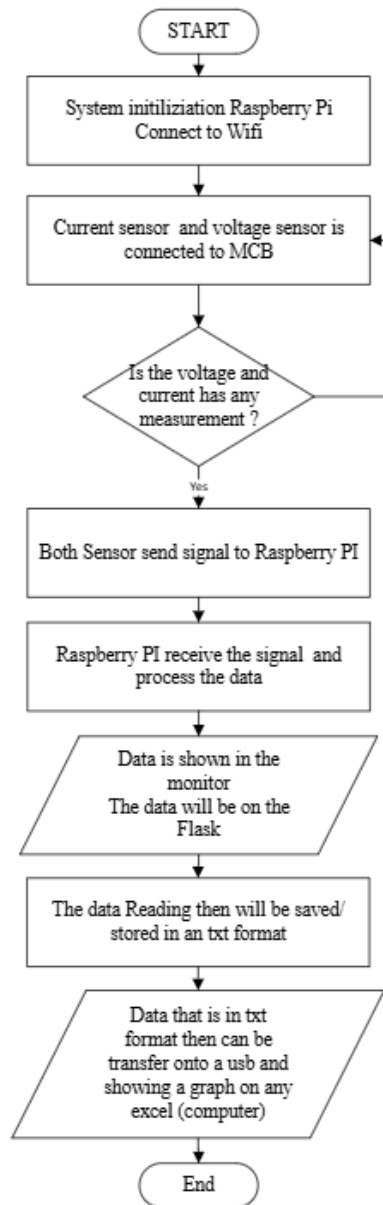


Fig. 2 Flowchart of IOT – Based Residential Electrical Distribution Box Power Monitoring and Notification System using Raspberry PI

2.3 Measuring Component

This section will shows the component used in the project that is used to measured the current and voltage.

2.3.1 Raspberry Pi

The Raspberry Pi is widely used for monitoring due to its affordability, versatility, and ease of use. Its low cost makes it an economical choice for creating monitoring systems, especially when multiple units are needed. Its compact size allows it to be easily integrated into various environments, including remote or space-constrained locations. The Raspberry Pi supports various interfaces such as GPIO, USB, HDMI, Ethernet, Wi-Fi, and Bluetooth, making it adaptable for connecting to sensors, cameras, and other monitoring equipment. Running on various Linux-based operating systems, it supports a wide range of monitoring software and tools, including custom scripts and applications. Its energy-efficient design is ideal for continuous monitoring tasks without requiring significant power resources. Additionally, a large, active community provides extensive resources, tutorials, and support, making it easier to set up and troubleshoot monitoring systems. Despite its small size, the Raspberry Pi has sufficient processing power to handle data collection, analysis, and even real-time monitoring tasks.



Fig. 3 *Raspberry Pi Board*

2.3.2 Voltage Sensor (Zmpt101b)

The ZMPT101B voltage sensor module is highly regarded for its precision and compact design, making it an excellent choice for measuring AC voltages in various applications. It is particularly useful for power monitoring, home automation projects, and electrical measurement tasks. The module's small size allows for easy integration into diverse setups, even in space-constrained environments. It offers the added benefit of electrical isolation between the high voltage AC input and the low voltage output, ensuring safety during operation. The ZMPT101B provides an analog output that reflects the AC voltage, which can be interfaced with microcontrollers or ADCs for further analysis. Additionally, it features an adjustable gain setting, allowing for precise calibration and measurement tailored to specific application needs.

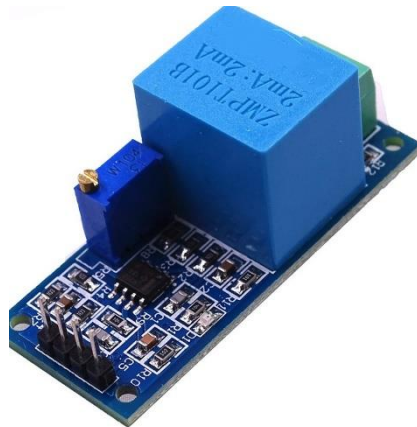


Fig. 4 *Voltage Sensor Zmpt101B*

2.3.3 Current Sensor

The SCT-013 current sensor is a popular and reliable tool used for measuring alternating current (AC) in various electrical applications. This sensor is well-regarded for its ease of use and effectiveness in both residential and industrial settings. The SCT-013 operates based on the principles of the Hall effect, which allows it to measure AC current without requiring direct electrical contact with the circuit being monitored. The sensor consists of a current transformer with a toroidal core, which surrounds the conductor carrying the current. As the current flows through the conductor, it generates a proportional magnetic field that is detected by the sensor. The SCT-013 then converts this magnetic field into a corresponding AC voltage signal, which can be easily read by a microcontroller, data acquisition system, or measurement device. Its non-invasive design ensures both safety and convenience when integrating the sensor into existing systems. Additionally, the SCT-013 is known for its high accuracy and reliability, making it a preferred choice for applications such as energy monitoring, load measurement, and electrical fault detection.



Fig. 5 Current Sensor Sct-013

2.3.4 Analog to Digital Converter

This ADC is designed to accurately convert analog signals into digital data, making it ideal for a variety of applications including sensor interfacing, data acquisition, and signal processing. The ADS1115 offers a 16-bit resolution that provides detailed digital representations of analog signals, which is crucial for applications requiring high measurement accuracy. It supports up to four single-ended or two differential input channels, allowing users to measure multiple signals simultaneously with a single device. A notable feature of the ADS1115 is its programmable gain amplifier (PGA), which enables users to adjust the gain settings to accommodate a wide range of input signal amplitudes, enhancing measurement flexibility. Additionally, the ADS1115 includes a built-in comparator for real-time monitoring and event triggering based on specific voltage thresholds. The ADC communicates via the I2C protocol, facilitating easy integration with various microcontrollers and processors, and supports multiple devices on the same bus for more complex system designs. Its programmable sampling rates allow users to choose between faster or slower conversion speeds based on application needs.



Fig. 6 Analog to Digital Converter (ADS1115)

2.4 Hardware Development

The purpose of the prototype project is to ensure the correct connection and optimal performance of electronic devices, specifically the SCT-013 current transformer and the AC voltage sensor. To activate the prototype, a 3-pin, 13 Ampere plug top is connected to the main switch, allowing 240V AC voltage to flow into the circuit and power the prototype.

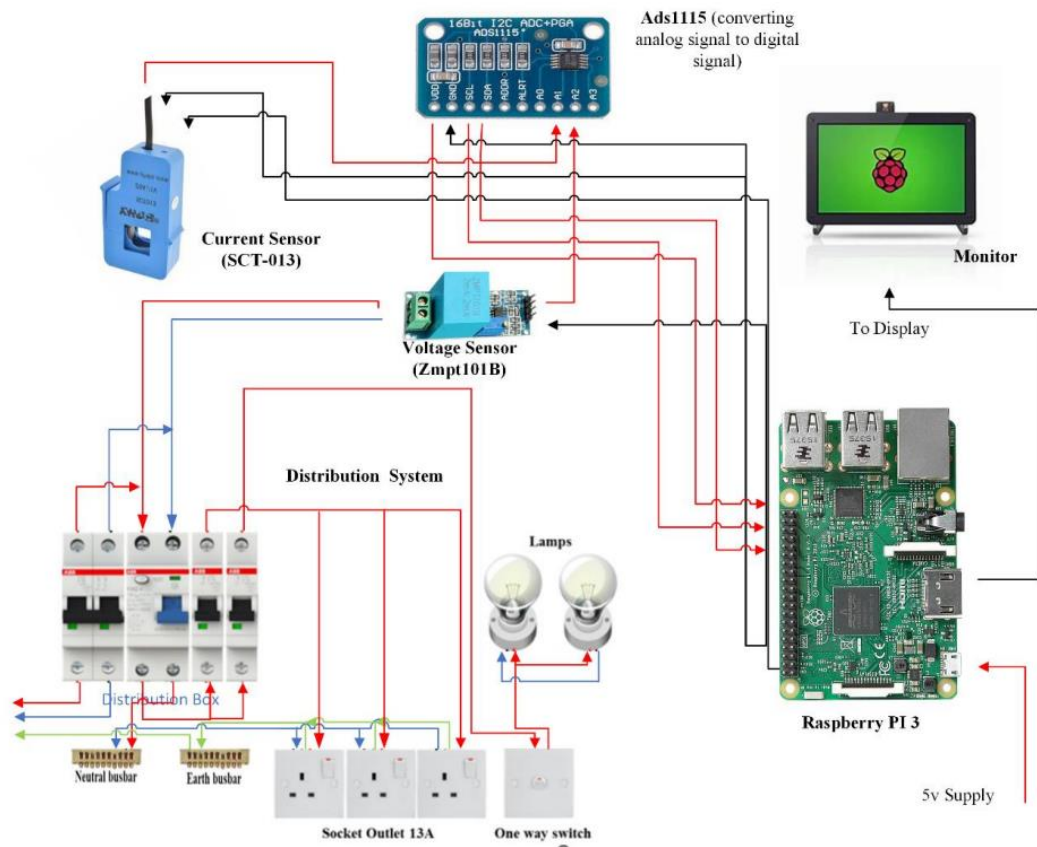


Fig. 7 Schematic diagram of IoT – Based Residential Electrical Distribution Box Power Monitoring and Notification System using Raspberry Pi

The purpose of the prototype project is to ensure the correct connection and optimal performance of electronic devices, specifically the SCT-013 current transformer and the AC voltage sensor. To activate the prototype, a 3-pin, 13 Ampere plug top is connected to the main switch, allowing 240V AC voltage to flow into the circuit and power the prototype. Additionally, the grounding cable from the plug top is connected to the earth busbar to ensure safety in case of any leakage current. The prototype includes a 40 Ampere main switch, a 40 Ampere Residual Current Circuit Breaker (RCCB) with 0.1mA sensitivity, and two Miniature Circuit Breakers (MCBs) - one rated at 6 Ampere for lighting circuits, and another rated at 16 Ampere for power circuits. The socket outlet is rated at 13 Ampere. Regarding the prototype's connection, the outgoing side of the main switch is connected to the incoming side of the RCCB. The live conductor from the outgoing side of the RCCB is connected to both the MCBs - one for lighting and one for power. The neutral conductor from the RCCB is connected to the neutral busbar to complete the circuit. For the 6A MCB, the live conductor is directly connected to the common terminal of a one-way switch, while the L terminal is connected to the load. In the case of the 13A socket outlet, the live conductor is directly connected to the 16A MCB, while the neutral and earth conductors are connected to their respective busbars. The raspberry pi is powered by 5v power supply with the connection of micro usb. This also connected with almost all component (SCT-013 current transformers, the ZMPT101b AC voltage sensor, and monitor display) The Raspberry Pi does not have an analog pin which it needed a converter that can convert digital signal from analog to digital which in this case mcp3008 is used to convert the signal and sends to the Raspberry Pi. Then the text will be displayed onto a virtual terminal which is connected directly to the Raspberry Pi.

3 Result and Discussion

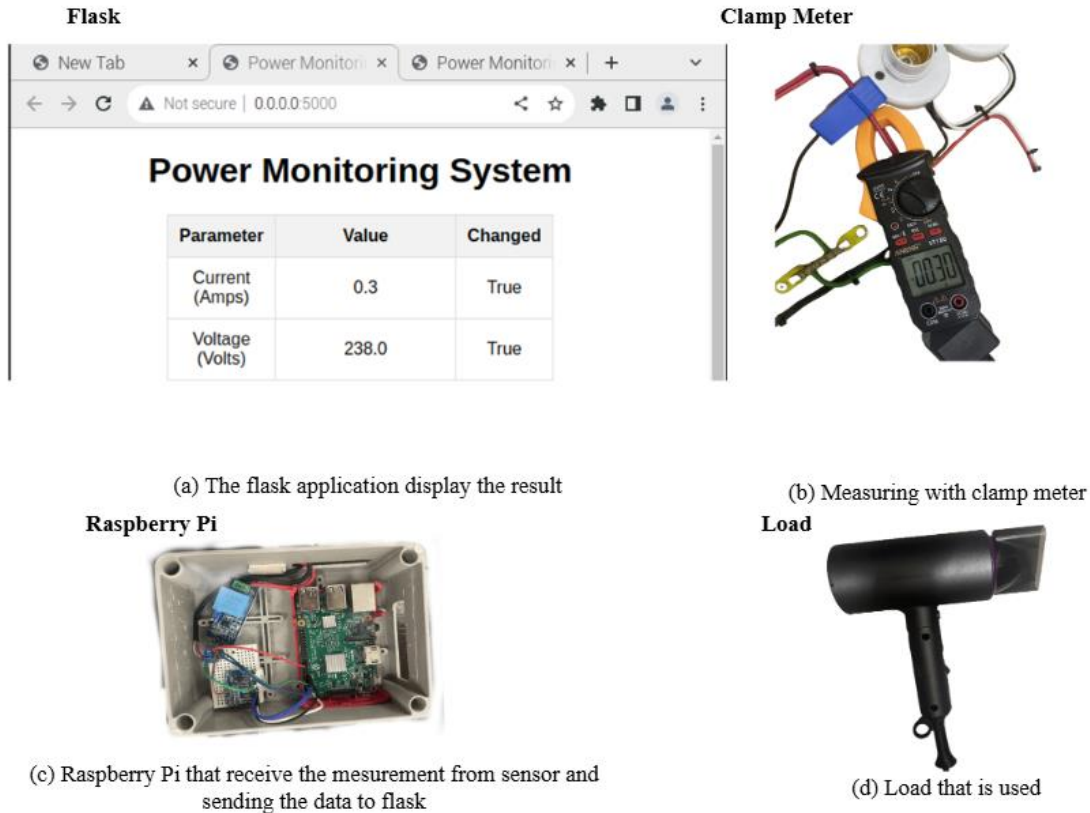
The performance of the project monitoring system was examined and deliberated upon by comparing experimental data. For ease of viewing, the results are summarized in several tables, graphs, and figures. By comparing the results, the performance is investigated and discussed. The results are presented in various types of charts to make it easier for the readers to understand.

3.1 Raspberry Pi Testing

This section the Raspberry Pi is tested to prove the microcontroller to be functional as power monitoring.

3.1.1 SCT-013 Testing (current sensor)

The process of setting up a current sensor to detect current load in the MCB Circuit. Python language is used to code the current sensor and connect the ads1115 to the Raspberry PI. Figure 4.1 below shows the result when there is a load on the MCB which is as in Figure 3 the load that is used is a hair dryer. The consumed load was around 0.3 and when it is measured it aligns with the flask and clamp meter that is clamp on Mcb 1.



(a) The flask application display the result

(b) Measuring with clamp meter

Raspberry Pi

Load

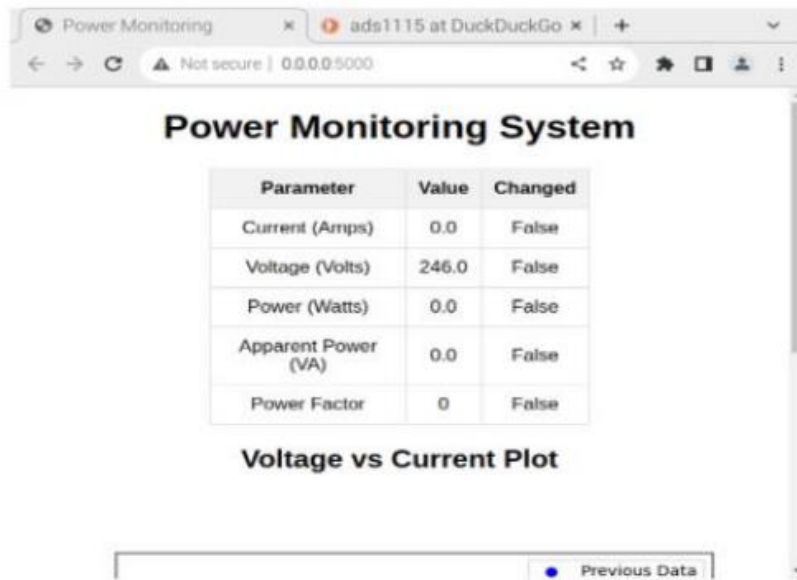
(c) Raspberry Pi that receive the mesurement from sensor and sending the data to flask

(d) Load that is used

Fig. 8 Raspberry Pi current testing to to display result which is 0.3A

3.1.2 Flask Application Result

The Raspberry Pi offers a diverse range of peripherals, including monitoring GPIObased components for electronic projects. This board has the USB connection which allow vast use in sensor, mouse and keyboard. Figure 4.2 below shows the connection that can be used in the Raspberry Pi. The Flask application will display the data on the webserver which will use the raspberry pi ip address that can be display on other devices which is in this project is (<https://127.0.1.1:5000/>) the measurement can only be detect with device under the same Wifi connection. All of the consist of voltage, current, power, apparent power and power factor. The data throughout the measurement period then will be saved in txt file format named as "Sensor data .txt" based on figure 4.5 the data can be transferred to removable disk and can be display via USB to other devices such as PC, mobile phone or any other device that can read the file format.



(a) All of the reading from flask will be recorded

sensor_data	25/5/2024 7:30 AM	Microsoft Excel C...	3 KB
sensor_data	1/6/2024 9:02 AM	Text Document	297 KB

(b) The reading that is converted into tx file and can be converted into excel file

Fig. 9 Flask application display the measurement from the sensor

3.1.3 AC Voltage measurement

The AC voltage for this circuit varied from 230v to 245v, this standard for the residential voltage. Then in real application it should be that the result around 240v as the figure the measured is around 238.9v which is accurate to the exact measurement.

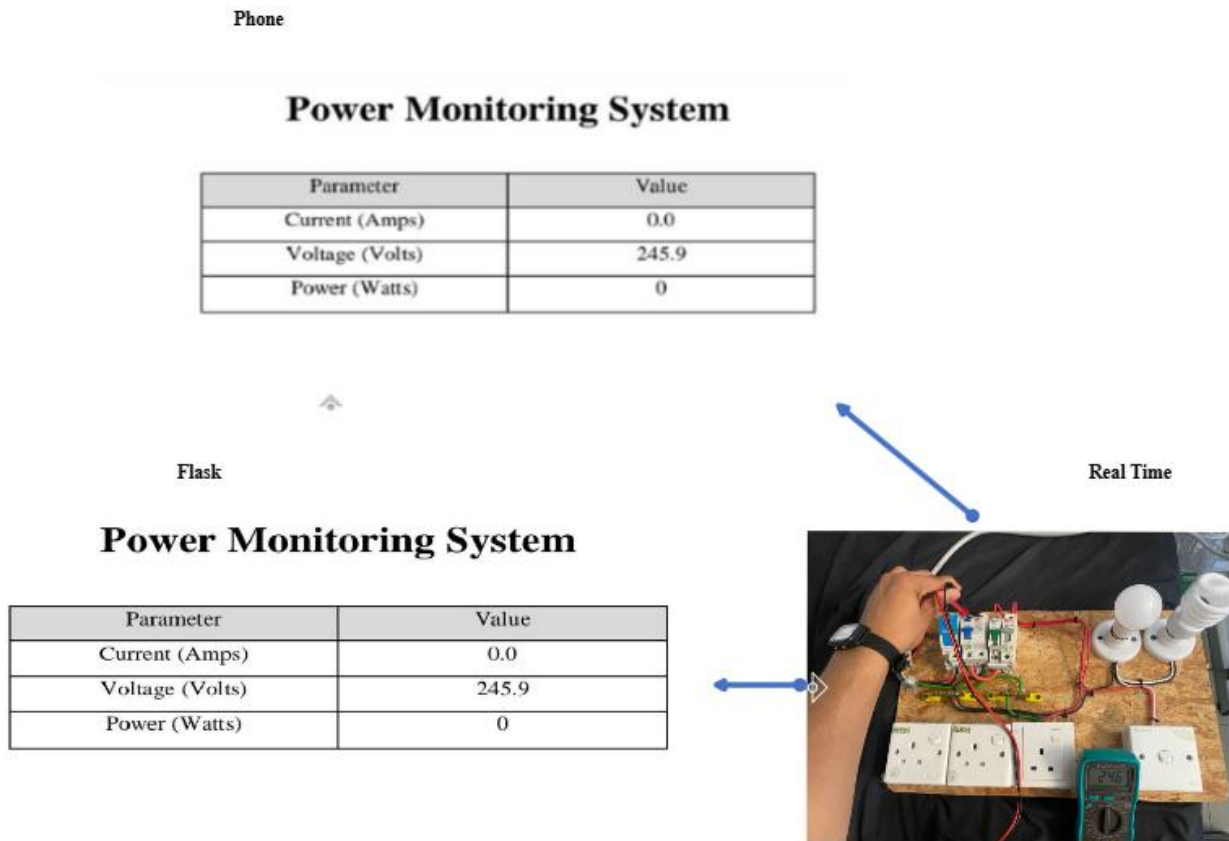


Fig. 10 Voltage is accurate and series to both real-time and on software

3.2 Load Result

Several electrical appliances have been used to test the load on the MCB and it is shown that different appliances has different loads. Hairdryer load is higher compared to fan as in Table 1 and 2 shows that both of result running in separate time.

Table 1 Result for current measurement of the hairdryer for 30 minutes

Time of running (hour)	0:00	0:05	0:10	0:15	0:20	0:25	0:30
Current (Amps)	2.67	2.85	2.51	2.73	2.63	2.79	2.61
Voltage (Volts)	225	228	231	227	232	226	230
Power Watts	600	650	580	620	610	630	

Table 2 Result for current measurement of the 120w fan for 3 hours

Time of running (hour)	0:30	1:00	1:30	2:00	2:30	3:00
Current (Amps)	0.52	0.50	0.55	0.48	0.57	0.51
Voltage (Volts)	225	229	227	230	240	238
Power Watts	120	115	125	119	130	118

The current and voltage fluctuations for both the hair dryer and the fan are measured over different time frames. The hair dryer's current and voltage vary over a 30-minute period, with measurements taken every 5 minutes, reflecting short-term fluctuations in electrical supply. In contrast, the fan's fluctuations are observed over a 3-hour period, with measurements taken every 30 minutes, indicating longer-term variations in electrical load. These fluctuations can arise from changes in the electrical grid or variations in the load on the system, impacting the devices' power consumption and performance.

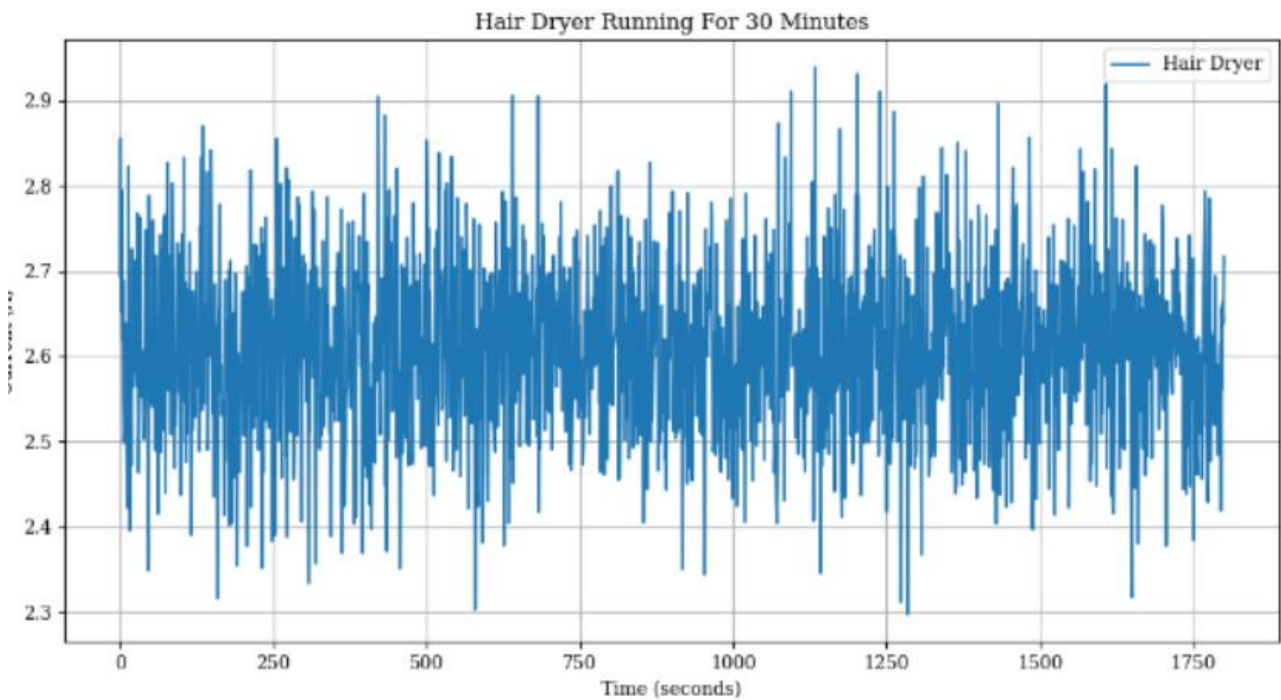


Fig. 11 The result of the current for the hairdryer running for 30 minutes

Fig. 6 is hair dryer running for 30 minutes and measured for every 1 second. The current load is fluctuating around the 2.4 A and 2.9 A, the average current load is at 2.6A.

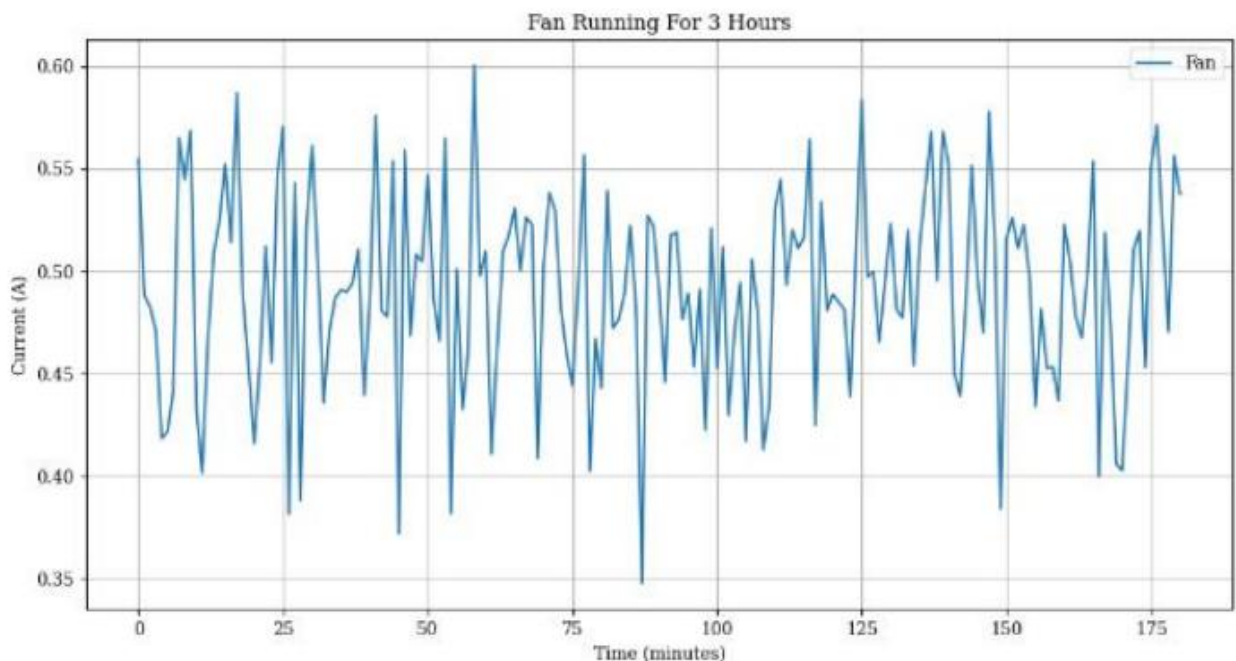


Fig. 12 The result of the current for the fan for 3 hours

Fig. 7 is fan running for 3 hour and measured every minute the current load is fluctuates around the 0.35 to 0.6 , the average current load is at 0.477A.

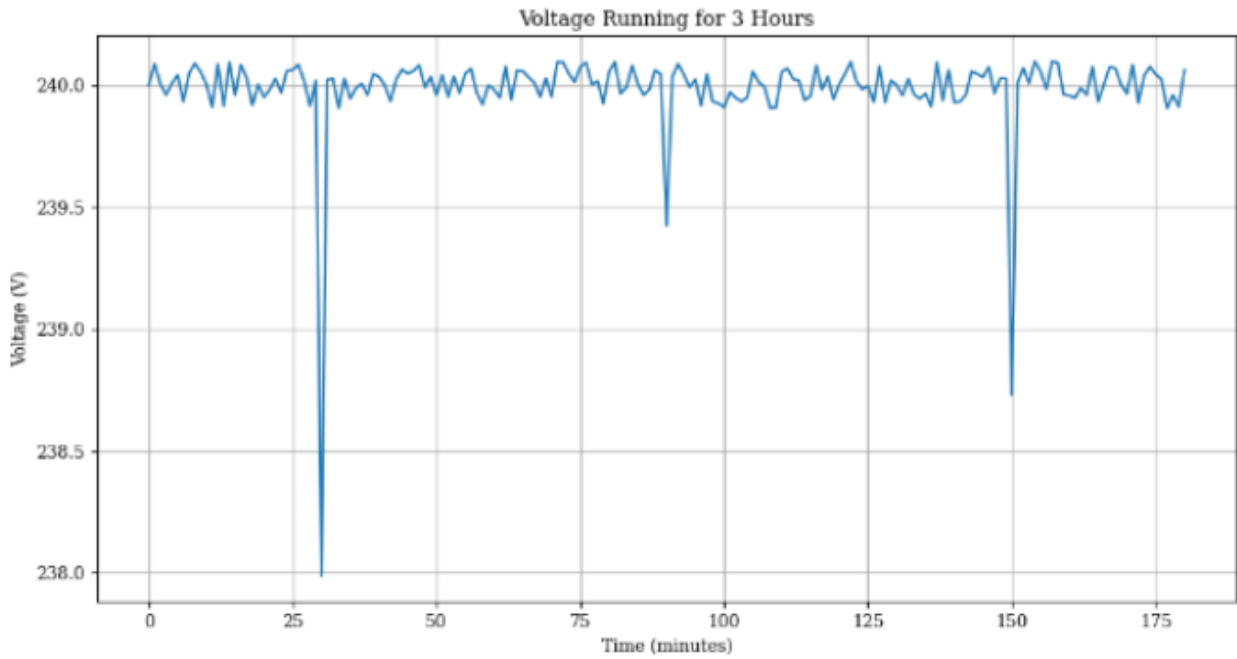


Fig. 13 The result of the voltage running for 3 hours

As per fig. 8 below shows that the system running for 3 hour and this is the system running with only fan for straight 3 hour and hairdryer will be turn on for every 30 minute. The voltage drop occur for around -1 to -2 and it stays fluctuate around 240v.

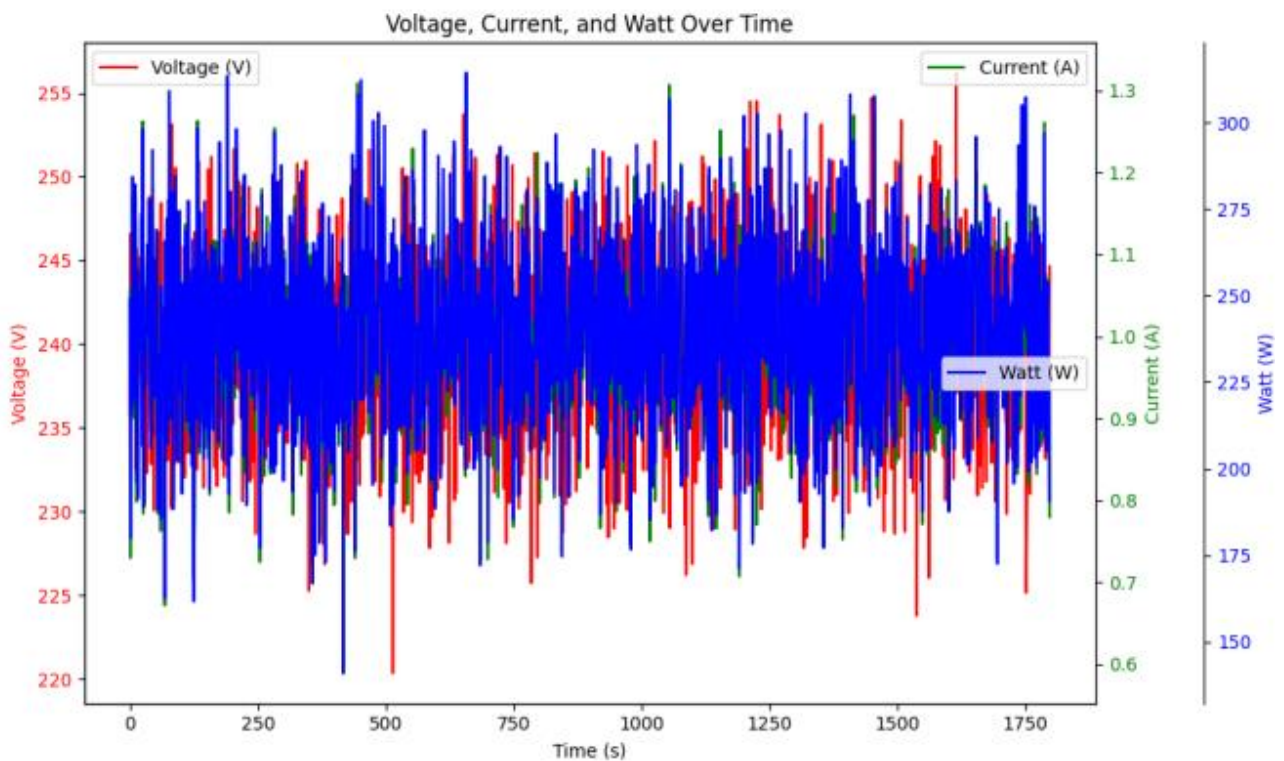


Fig. 14 The result of the voltage, current and watt for 3 hour

Fig. 9 shows that running the load 120W fan for an hour and it shows that the voltage will drop for certain of time as fans, is a motors, draw a higher current when they start up compared to when they are running steadily. This

rush of current can cause a temporary voltage drop until the fan reaches its operating speed. The speed of fan is also variable as the and when the speed changes it could contribute to voltage drop.

4. Conclusion

In conclusion, the project was initiated to ensure that there will be a device that could monitor electric use of residential. The result and the power use is portray in monitor that is connected to raspberry pi that is also connected to current sensor and voltage sensor also will be installed on load. The program for the whole system successfully develops for the micro controller using the software, Raspberry Pi OS. However, there are some limitations of the prototype. The system itself is still imperfect with certain shortcomings. Possible future works will be discussed later in this chapter. Overall, the system can be implemented, and the objective almost achieved as the system need more improvement in term of result.

Looking to the future, there are several suggestions that can further improve the project in term of the input and output wise. A new source of power also could be added to the Raspberry Pi to power as the project intends to be moveable and mobility wise. This also imply that to greatly improve the project by combining another microcontroller with this Raspberry Pi as this is a microprocessor.

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References

- [1] A. Ameer and G. George, "Smart Plug and Smart Distribution Board," **International Research Journal of Engineering and Technology (IRJET)**, vol. 08, no. 07, 2021. [Online]. Available: <https://www.irjet.net/archives/V8/i7/IRJET-V8I7730.pdf>. [Accessed 23 May 2023].
- [2] Z. L. Zahari and N. S. Shariffuddin, "An experimental of distribution board monitoring using GSM application," **ResearchGate**, 2016. [Online]. Available: https://www.researchgate.net/publication/298714719_An_experimental_of_distribution_board_monitoring_using_GSM_application. [Accessed 23 May 2023].
- [3] T. Selvaraj and M. Zulkifli, "IoT Based Power Monitoring Device (Distribution Box)," **Progress in Engineering Application and Technology**, vol. 2, no. 1, pp. 635–641, 2021. [Online]. Available: <https://publisher.uthm.edu.my/periodicals/index.php/peat/article/view/901>. [Accessed 23 May 2023].
- [4] W. Hlaing, S. Thepphaeng, V. Nontaboot, N. Tangsunantham, T. Sangsuwan, and C. Pira, "Implementation of WiFi-based single phase smart meter for Internet of Things (IoT)," in **2017 International Electrical Engineering Congress (IEECON)**, 2017, pp. 1-4. doi: 10.1109/IEECON.2017.8075793.
- [5] L. Angrisan, P. Arpaia, F. Bonavolontà, A. Liccardo, and R. S. L. Moriello, "First step towards a cost-effective IoT platform for customers power consumption awareness," in **2017 IEEE International Workshop on Measurement and Networking (M&N)**, 2017, pp. 1-5. doi: 10.1109/IWMN.2017.8078388.
- [6] A. Y. Mohammed and R. M. Hagem, "Design and Implementation of Monitoring System for Power Station base on IoT," **International Journal of Advance in Computer and Electronic Engineering**, vol. 5, no. 8, pp. 1-8, Aug. 2020.
- [7] S. Thakare, A. Shriyan, V. Thale, P. Yasarp, and K. Unni, "Implementation of an energy monitoring and control device based on IoT," in **2016 IEEE Annual India Conference (INDICON)**, 2016. doi: 10.1109/INDICON.2016.7839066.
- [8] Benne, "Character I2C LCD With Arduino Tutorial (8 Examples)," **Makerguides.com**, 3 Feb. 2019. [Online]. Available: <https://www.makerguides.com/character-i2c-lcd-arduino-tutorial>. [Accessed 23 May 2023].

- [9] "Getting Started with ESP8266 and Arduino: ESP8266 Arduino Interface," *Electronics Hub*, 13 Dec. 2017. [Online]. Available: <https://www.electronicshub.org/esp8266-arduino-interface>. [Accessed 23 May 2023].
- [10] P. Pieter, "A Beginner's Guide to the ESP8266," *A Beginner's Guide to the ESP8266*. [Online]. Available: <https://tttpa.github.io/ESP8266/Chap04%20-%20Microcontroller.html>. [Accessed 4 Jan. 2023].
- [11] "Non-Invasive Sensor: YHDC SCT013-000 CT Used With Arduino," *PowerUC*, 28 June 2018. [Online]. Available: <https://www.poweruc.pl/blogs/news/non-invasive-sensor-yhdc-sct013-000-ct-used-with-arduino-sct-013>. [Accessed 8 Jan. 2023].
- [12] E. Media, S., & M. Rif'an, "Internet of Things (IoT): BLYNK Framework for Smart Home," *KnE Social Sciences*, vol. 3, no. 12, pp. 579–586, 2019. doi: 10.18502/kss.v3i12.4128.
- [13] "Miniature Circuit Breaker (MCB) - Definition, Types and Working Principle of MCB," *BYJUS*. [Online]. Available: <https://byjus.com/physics/miniature-circuit-breaker>. [Accessed 20 Dec. 2023].
- [14] "Getting Started with the ESP32 Development Board," *Random Nerd Tutorials*, 2 Nov. 2022. [Online]. Available: <https://randomnerdtutorials.com/getting-started-with-esp32>. [Accessed 20 Dec. 2023].
- [15] "NodeMCU ESP32," *Joy-IT*. [Online]. Available: <https://joy-it.net/en/products/SBC-NodeMCU-ESP32>. [Accessed 8 Jan. 2023].
- [16] "ESP32 Pinout Reference: Which GPIO pins should you use?," *Random Nerd Tutorials*, 2 Oct. 2019. [Online]. Available: <https://randomnerdtutorials.com/esp32-pinout-reference-gpios>. [Accessed 20 Dec. 2023].
- [17] J. L. A. (CNXSoft), "ESP8266 and ESP32 Differences in One Single Table," *CNX Software - Embedded Systems News*, 25 Mar. 2016. [Online]. Available: <https://www.cnx-software.com/2016/03/25/esp8266-and-esp32-differences-in-one-single-table>. [Accessed 8 Jan. 2023].
- [18] "SCT-013-000 Split Core Current Transformer, 100A, 50A, 30A," *InnovatorsGuru*, 31 July 2019. [Online]. Available: <https://innovatorsguru.com/sct-013-000>. [Accessed 8 Jan. 2023].
- [19] "ZMPT101B Single Phase AC Voltage Sensor Module," *MikroElectron*. [Online]. Available: <https://mikroelectron.com>. [Accessed 8 Jan. 2023].
- [20] F. Nawazi, "ZMPT101B AC Single Phase Voltage Sensor Module," *Circuits DIY*, 12 Dec. 2022. [Online]. Available: <https://www.circuits-diy.com/zmpt101b-ac-single-phase-voltage-sensor-module>. [Accessed 8 Jan. 2023].
- [21] R. K. Kodali and K. S. Mahesh, "A low-cost implementation of MQTT using ESP8266," in *2016 2nd International Conference on Contemporary Computing and Informatics (IC3I)*, pp. 404-408.
- [22] R. M. Snyder, "Power Monitoring Using the Raspberry Pi," *Association Supporting Computer Users in Education (ASCUE) (47th, Myrtle Beach, SC, Jun, 8-12, 2014)*.