Faculty of Electrical Technology and Engineering

DEVELOPMENT OF ELECTRICITY ENERGY MONITORING SYSTEM FOR HOME USAGE BY USING IOT

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Bachelor of Electrical Engineering Technology (Industrial Power) with Honours

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A project report submitted
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DEDICATION

I dedicate this project "Development Of Electricity Energy Monitoring System For Home Usage By Using IoT," to the pursuit of sustainable and responsible energy consumption. This endeavor is fueled by a commitment to creating a more efficient and conscientious approach to electricity usage within our homes.

To my family, whose unwavering support and encouragement have been a constant source of inspiration throughout this journey. Your belief in the importance of environmentally conscious practices has been the driving force behind the development of this electricity energy monitoring system.

I also extend my heartfelt gratitude to the countless individuals who contributed to this project directly or indirectly. Your collaboration, insights, and shared passion for harnessing technology to promote sustainable living have been invaluable.

This dedication is a tribute to the collective effort and dedication of all those who strive for a greener and more energy-efficient future. May this project serve as a stepping stone towards a world where technology and environmental responsibility coexist harmoniously.

ABSTRACT

This work presents the Development of Electricity Energy Monitoring System For Home Usage by using IoT with the objective of tracking and analyzing power consumption. By placing sensors and devices in homes, the system gathers data on electricity flow and wirelessly sends it for analysis. The system aims to provide a low-cost solution for monitoring appliance power consumption while assisting consumers in keeping their electric expenses under control. The project scope includes collecting data and measurements from home appliances through voltage and current sensors wired from the distribution box. Remote data monitoring is achieved using the Node MCU ESP32 microcontroller with Wi-Fi. The method system uses the Blynk app to track and analyze real-time power consumption. It measures energy usage from devices and appliances, providing data on voltage, current, and power through the app. As the number of loads increases in an energy monitoring system, the expected result is that the current measurement will also increase. Each additional load draws a certain amount of current from the electrical system, contributing to the overall current consumption. In conclusion, this electricity energy monitoring system utilizes IoT technology to track and analyze power consumption in real-time. By incorporating voltage and current sensors, the system enables users to gather data on voltage, current, and power usage through the Blynk app. As more loads are added, the expected result is an increase in the measured current, providing valuable insights for optimizing energy usage and managing electricity costs.

ABSTRAK

Kajian ini merangkumi perciptaan sistem pemantauan tenaga elektrik bagi kegunaan di rumah menggunakan IoT dengan objektif mengesan dan menganalisis penggunaan tenaga. Dengan memasang sensor dan peranti di rumah, sistem ini mengumpul data tentang aliran elektrik dan menghantarkannya secara tanpa wayar untuk dianalisis. Sistem ini bertujuan untuk menyediakan penyelesaian kos rendah bagi pemantauan penggunaan tenaga peralatan sambil membantu pengguna mengawal perbelanjaan elektrik mereka. Skop projek ini merangkumi pengumpulan data dan pengukuran daripada peralatan rumah melalui sensor voltan dan arus yang dipasang dari kotak pengagihan. Pemantauan data jarak jauh dicapai dengan menggunakan mikropemproses Node MCU ESP32 dengan kebolehan Wi-Fi. Kaedah ini menggunakan apl Blynk untuk mengesan dan menganalisis penggunaan tenaga secara masa nyata. Ia mengukur penggunaan tenaga daripada peranti dan alat elektrik, menyediakan data tentang voltan, arus, dan kuasa melalui apl tersebut. Apabila bilangan beban meningkat dalam sistem pemantauan tenaga, hasil yang dijangkakan adalah pengukuran arus juga akan meningkat. Setiap penambahan beban menarik jumlah arus tertentu dari sistem elektrik, menyumbang kepada penggunaan arus keseluruhan. Kesimpulannya, sistem pemantauan tenaga elektrik ini menggunakan teknologi IoT untuk mengesan dan menganalisis penggunaan tenaga secara masa nyata. Dengan menggabungkan sensor voltan dan arus, sistem ini membolehkan pengguna mengumpul data tentang voltan, arus, dan penggunaan kuasa melalui apl Blynk. Apabila beban bertambah, hasil yang dijangkakan adalah peningkatan arus yang diukur, memberikan pandangan berharga untuk mengoptimakan penggunaan tenaga dan mengurus kos elektrik.

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I extend my sincere gratitude to my supervisor, Che Wan Mohd Faizal Bin Che Wan Mohd Zalani, for his invaluable guidance, unwavering support, and expert advice throughout the development of this project. His mentorship and insightful feedback have been instrumental in shaping the direction of the research and enhancing the quality of the outcomes.

I would like to express my appreciation to the faculty members of Universiti Teknikal Malaysia Melaka (UTeM) for providing an enriching academic environment. Their commitment to fostering a culture of innovation and research has been a driving force behind the successful completion of this project.

Special thanks to my peers and colleagues for their collaborative spirit and constructive discussions, which have significantly contributed to the refinement of ideas and the overall quality of the project.

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Lastly, my heartfelt thanks go to my family and friends for their unwavering encouragement and understanding during the challenging phases of this undertaking.

This acknowledgment is a testament to the collaborative efforts of all those who played a role, directly or indirectly, in the realization of this project. Your contributions have been invaluable, and I am truly grateful for your support.

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LIST OF SYMBOLS

E	-	Energy
P	-	Power
t	-	Time
lm	-	Rated Lumen

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CHAPTER 1

INTRODUCTION

1.1 Background

The Internet of Things (IoT) is a network of connected devices, sensors, software, and systems that can collect and exchange data with one another. IoT can change the way we conduct our daily lives. These devices include everything from basic home appliances to advanced industrial machinery [1].

The Internet of Things (IoT) concept existed for a long time, but it has acquired major traction in recent years due to the growth of linked gadgets. According to a recent IDC research, there were 41.6 billion internet-connected gadgets in use worldwide in 2020, with that figure predicted to rise to 125 billion before 2026 [2].

Manufacturing, for example, has already felt the effects of IoT technology, which has helped companies become more productive and efficient. IoT devices in the healthcare industry can remotely monitor patient health, lowering the necessity for hospital visits and enhancing patient outcomes. IoT in agriculture can benefit farmers by using linked sensors and analytics to maximize agricultural yields and decrease waste [3].

IoT has a lot of advantages, but it also has a lot of drawbacks, particularly in terms of data security and privacy. The likelihood of data breaches and cyberattacks rises as more gadgets are connected to the internet. To ensure the widespread use of the technology, it is essential to address the important challenge of protecting the privacy and security of IoT data. Although there are obstacles to be addressed, the advantages of IoT are too great to be overlooked [4].

Individuals and governments alike are looking for more sustainable and effective ways to manage energy use as demand for energy rises and concerns about climate change grow. One growing strategy is to monitor and manage household energy consumption using Internet of Things (IoT) technologies. The Electricity Energy Monitoring System For Home Usage using IoT project is a system that intends to assist homeowners in tracking and monitoring their energy usage. This project employs IoT technology, which entails installing sensors and gadgets in the home to monitor the flow of electricity, collect data, and wirelessly communicate it to a central system for analysis. These systems can identify how much energy is used by certain devices and offer suggestions for lowering energy use.

The traditional method of energy monitoring entails manually reading meters and documenting data on energy consumption. This strategy has been around for a long time and remains used today. For a manual meter reading, a meter reader must visit a location and manually enter the energy consumption data into a database after recording it. These methods are time-consuming and frequently provide only a limited understanding of energy usage patterns.

Figure 1.1 Traditional Method Of Energy Monitoring [5]

Furthermore, The Electricity Energy Monitoring System For Home Usage by using IoT project has various advantages over traditional methods of energy monitoring, such as manual meter readings or stand-alone monitoring equipment. It enables homeowners to examine their energy usage in real time, allowing them to understand which appliances and devices are consuming the most electricity and allowing them to make informed choices about their energy consumption. This can assist them in reducing their energy consumption and saving money on their utility bills.

This project has the potential to change the way we manage our home's energy consumption. It can assist homes in saving money on energy costs, lowering their carbon footprint, and contributing to a more sustainable and efficient energy system.

1.2 Problem Statement

As the power demand continues to rise, homeowners are growing more interested in monitoring their home's energy consumption. One of the most significant difficulties that homeowners confront is a lack of information about their energy use patterns. Traditional energy meters only offer a limited amount of data, making it challenging for households to monitor their energy usage. An efficient solution for this issue would be an Internet of Things energy monitoring system. The majority of residences receive either quarterly or monthly energy bills, which offer historical information. Homeowners are unable to control and trace their energy consumption because traditional methods of energy monitoring, such as manual meter readings, are ineffective at providing real-time data on energy usage. As a result, it is difficult for homeowners to determine which appliances and devices consume the most electricity without real-time data. With the help of an Internet of Things energy monitoring system, homeowners can get real-time information on their energy usage and take rapid action to cut expenditures and usage. Furthermore, the implementation of a smart energy monitoring system, on the other hand, is extremely costly. The cost could seem excessively high to some homeowners. Thus, traditional methods of energy monitoring need manual readings, which can be time-consuming and error-prone. This can lead to inaccurate billing and disappointment for energy consumers. Currently, many Internet of Things-based energy monitoring solutions are sophisticated and difficult to operate, makes hard for homeowners to efficiently monitor their energy consumption. A simple energy monitoring device could allow households to quickly monitor and minimize their energy consumption. Moreover, there is a chance of information breaches and cyberattacks because IoT devices are linked to the internet. To guarantee the confidentiality and privacy of user data, an IoT-based energy monitoring system needs to be equipped with strong security mechanisms. Other than that, There are numerous IoT-based energy monitoring devices on the market right now. A lot of these appliances are incompatible with various energy meters, making it challenging for homeowners to select a system that would work in their house. The issue might be resolved by a universal IoT-based energy monitoring system.

1.3 Project Objective

The purpose of the system is to:

a) To design a low-cost home appliance power consumption tracking system

b) To develop a dashboard for a power consumption tracking system using an IoT platform (Blynk app)

c) To analyze energy and load current consumption to assist consumers in controlling their electric bills.

1.4 Scope of Project

The scope of this project is as follows:

a) Single-phase 230V incoming electrical systems would be taken into consideration.

b) Data and measurements (voltage and current sensors) for home appliances will be collected and will be considered being wired from the distribution box.

c) A microcontroller called the Node MCU ESP32 with Wi-Fi functionality will be utilized for remote data monitoring.

d) The Blynk app IoT platform will be used in the development of a dashboard for real-time data on power consumption

e) Display of data on an LCD as a physical power consumption metering.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The project uses the Internet of Things (IoT) to create an electrical energy monitoring system for domestic use. With the help of this system, households will be able to monitor and analyze their electricity usage in real-time and make well-informed decisions about how much energy they use and how much they conserve. Such a monitoring system can be very beneficial in promoting energy efficiency in the modern world when environmental sustainability and energy consumption are major concerns. Homeowners may detect energy wastage, optimize appliance use, and possibly lower their carbon footprint by receiving precise insights into their electricity consumption trends. Overall, this project uses IoT technology to build an effective and user-friendly power energy monitoring system for residential usage, which solves the urgent demand for energy saving and sustainability.

2.2 Smart Energy Monitoring System For Residential In Malaysia

In 2019, Syamsul Syafiq et al. offered a home energy monitoring system that has been developed, featuring a dashboard for visualizing electricity consumption in real time. The system architecture includes the SDM230-Mod, a smart meter device, the Arduino Uno controller, Internet connectivity through the HTTP protocol, a database, and the dashboard interface. There will be an HTTP protocol connection between the dashboard, database, and Arduino Uno. In a study by Syamsul Syafiq et al, the SDM230-Modbus gadget reads the power usage from the user's home. The Arduino Uno controller is an intermediate component that delivers and receives electrical energy usage data from the smart meter to the system database. Six different sorts of data are sent to the Arduino Uno by the smart meter. Four sensors in the smart meter provide data: a heat sensor, a motion sensor, a temperature sensor, and a humidity sensor. Another two pieces of information are the smart meter board's and the LED switch's energy consumption. All data will be interpreted by the Arduino Uno and sent to the database over the HTTP protocol. The system processes data from the database and displays the data on the system dashboard [6].

2.2.1 The System Architecture of Smart Energy Monitoring

Figure 2.1 Processes of System Architecture [6]

Figure 2.1 illustrates the system's overall process flow. The system establishes a connection to the smart meter, ensuring a 5-second delay for reliable connectivity. Once connected, the system records energy consumption data from the smart meter into a database. Subsequently, the system retrieves and reads the data stored in the database. Finally, the system shows energy statistics on the dashboard [6].

2.2.2 The Program Code Segment of Arduino Uno Controller

```
void setup() {
  Serial.begin(9600);
  dht.begin();
  delay(100);
  delay(100);
  NodeMCU.begin(9600);
  pinMode(D7,INPUT);
  pinMode(D8,OUTPUT);
  Serial.println();
  Serial.println();
  Serial.print("Connecting to ");
  Serial.println(ssid);

  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }

  Serial.println("");
  Serial.println("WiFi connected");
  Serial.println("IP address: ");
  Serial.println(WiFi.localIP());
  Serial.print("Netmask: ");
  Serial.println(WiFi.subnetMask());
  Serial.print("Gateway: ");
  Serial.println(WiFi.gatewayIP());
  delay(1000);
}
```

Figure 2.2 Coding From Arduino Uno To Access The Internet [6]

Figure 2.2 depicts The code segment involves establishing an internet connection for Arduino using the HTTP protocol and connecting to the wireless protocol through the ESP8266Wifi.h library. In this code section, the process begins by calling the wifi.begin() function, introducing a 5-second delay to ensure a stable connection is established. The port number for the data to be sent is declared in the other section of the code segment in Figure 2.2.

```
url = "/api/weather/insert.php?temp=" + String(t) + "&hum="+ String(h) + "&energy="
Serial.print("Requesting URL: ");
Serial.println(url);

client.print(String("GET ") + url + " HTTP/1.1\r\n" +
             "Host: " + host + "\r\n" +
             "Connection: close\r\n\r\n");


while(client.available())
{
  String line = client.readStringUntil('\r');
  Serial.print(line);
}

delay (15000);
```

Figure 2.3 Coding That Sends & Receives Data From The Web Server [6]

Figure 2.3 displays the section of code that the Arduino UNO uses to deliver data to the web server. The system will use the header data in the URL code, such as temperature and energy, to produce the energy data visualization.

2.2.3 The Program Code of Dashboard Development

```
Begin
  Get current_time from system
    while current_time is equal to 10 seconds
      Get voltage, humidity, temperature, frequency,
      enery_consumption, LED and current_time from
      SDM630(Smart Meter)

  Save voltage, humidity, temperature, frequency,
  enery_consumption, LED and current_time to database

  Calculate electricity bill
   Electricity Bill = enery_consumption * tariff_rate * current_time

  Read data from database
   Get voltage, humidity, temperature, frequency, energy, LED,
   electricityBill

  Display data to Dashboard
   Get voltage, humidity, temperature, frequency, energy, LED,
   electricityBill
   Generate Bar chart for humidity, energy consumption,
   electricityBill

  Switch control device
    if LED is equal to 1
      Turn on LED
    else if LED is equal to 0
      Turn off LED
    end if
End
```

Figure 2.4 The Dashboard's Pseudocode [6]

A dashboard was created in the system by Syamsul Syafiq et al. to visualize all the information on energy bills and use for residential users. The visualization charts were developed using the PHP language. The dashboard displays residential users' energy usage information residential users' energy usage, including voltage, humidity, temperature, and frequency. An Internet connection was necessary to display the real-time frequency of data. The program pseudocode used to link the system's dashboard and database is displayed in Figure 2.4.

2.2.4 The System Dashboard

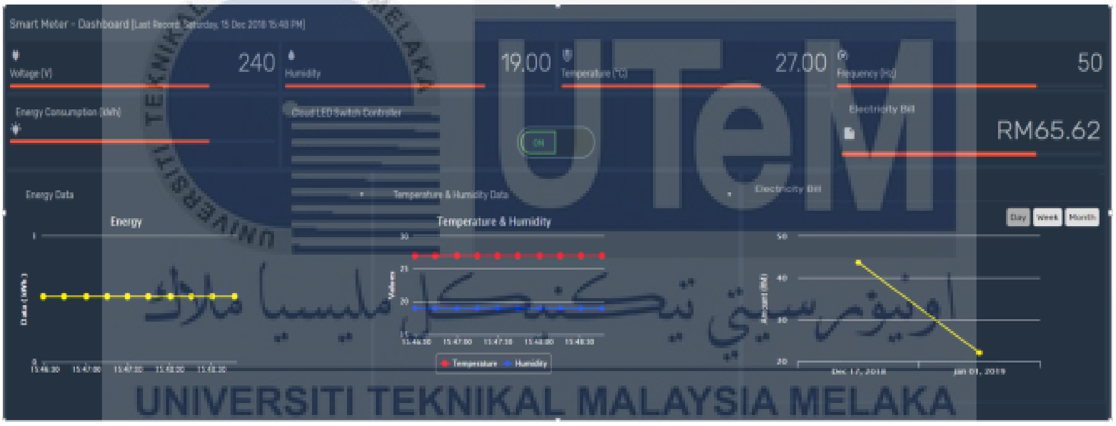

Figure 2.5 The System Dashboard [6]

Figure 2.5 shows the system dashboard, which displays real-time data on electricity usage. Users can easily access information about the current temperature, voltage, frequency, energy usage (in kWh), and power bill through the dashboard. The graphical statistics on energy, temperature, and humidity are also presented, along with detailed breakdowns of electrical costs on a daily, weekly, and monthly basis. The system's dashboard empowers users to manage their energy consumption effectively by providing insights into usage patterns and associated costs over time.

2.3 Energy Consumption Monitoring In Smart Home Systems

R S Hariharan et al. In 2021, an IoT system was developed to monitor household energy consumption, estimating the monthly electricity needs through the utilization of cloud services and a database. The system incorporates a hardware component, like a current sensor, which reports electricity usage data from all appliances to a cloud database. An Android app has been designed to retrieve stored energy usage information for the household from the beginning of the month to the current date. The app performs a test using consumption data to predict the monthly power bill using a machine learning regression model, calculating the anticipated amount due at the end of the month. Additionally, the application provides users with various functionalities, including visualizations that compare daily energy usage through a bar graph and the ability to control devices within a room's proximity, turning them on or off. [7].

2.3.1 Hardware Components

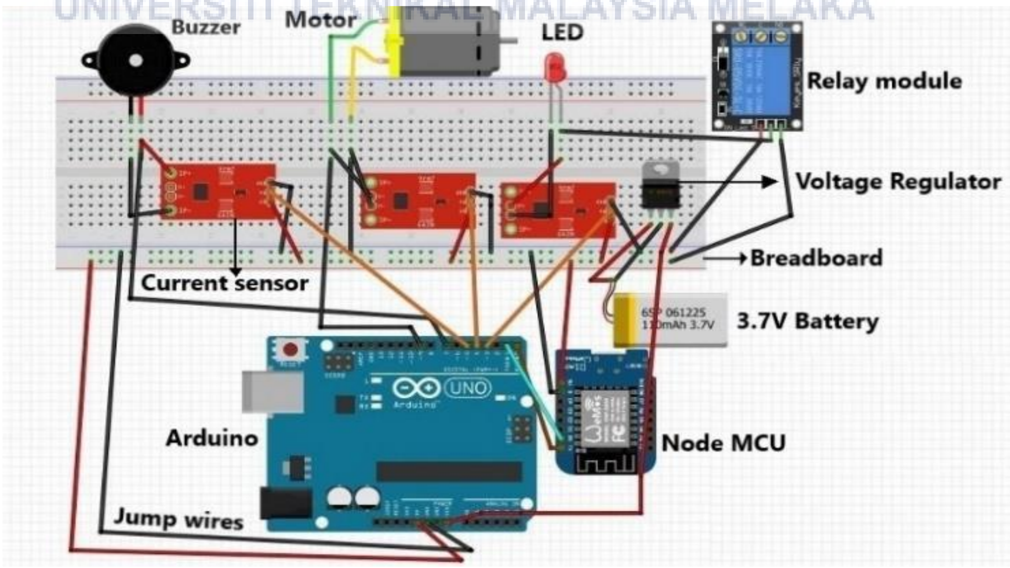

Figure 2.5 Connection of Hardware Circuits [7]

Figure 2.5 shows the hardware model of a straightforward energy monitoring device that performs the same tasks as the suggested smart home system. In the prototype implementation, the hardware components buzzer, motor, and LED serve as the electrical appliances. The Node MCU maintains the link between the cloud and the hardware circuit and connects Arduino to the internet. To make the motor run, the voltage regulator converts 12 DC to 5 DC, and the relay module converts DC to AC [7].

2.3.2 Software Components

Figure 2.6 Dashboard of Android App [7]

Figure 2.6 illustrates the app's bill prediction and appliance control functionalities. The line graph in Figure 2.6 shows an example of how a bill might look on each day of the month depending on how much electricity was used up to that point. The Bill Prediction page collects energy use statistics as well as prior month datasets to simulate the machine learning regression model and estimate the predicted monthly bill more correctly and precisely. The control page provides the user with a Smart Home experience, allowing him to turn on and off the system-connected appliances in his home [7]

2.4 Design of an IoT Energy Monitoring System

Chooruang and Meekul suggested a system in 2018 that consists of energy monitoring nodes that employ the Peacefair PZEM-004T, a cheap energy meter, SD3004 chip, and microcontroller to measure voltage, current, and power and transmit that data as JSON over MQTT protocol. After interpreting this data, the user is presented with an energy consumption pattern [8].

2.4.1 Overview of the System

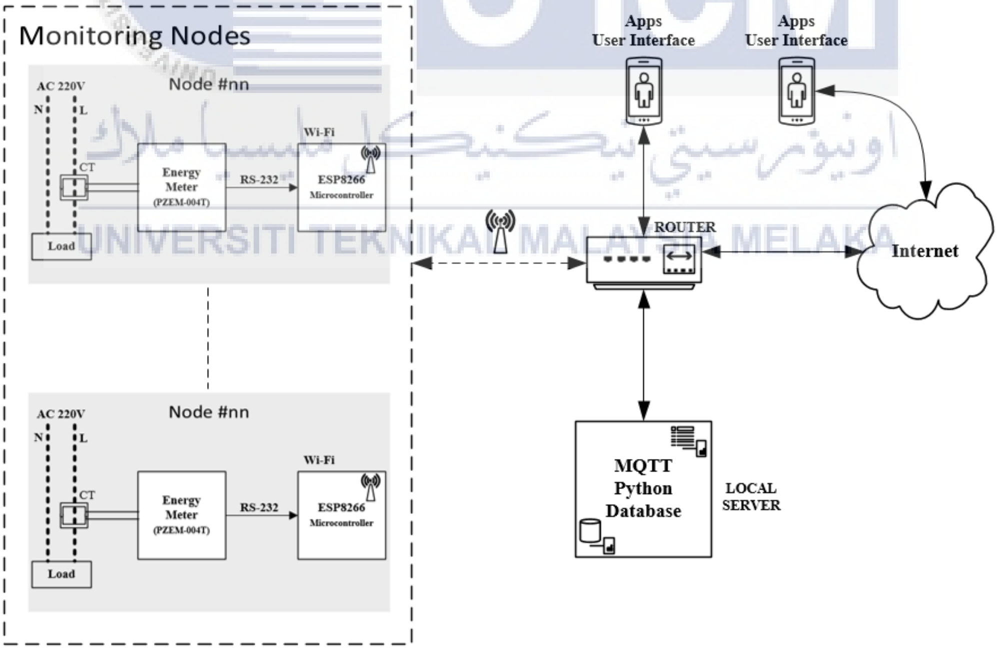

Figure 2.6 System Overview [8]

Figure 2.6 shows the energy monitoring nodes within the system utilize the Peacefair PZEM-004T, an affordable energy meter featuring a noninvasive current transformer sensor, the SD3004 energy measurement chip, and a microcontroller. These components collectively measure voltage, current, active power, and cumulative power consumption. The gathered data is then transmitted to the server in JavaScript Object Notation (JSON) format through MQTT. Opting for a Raspberry Pi 3 model B as the local server enables consumers to access details about their energy consumption through a web application, either locally or over the Internet. [8].

2.4.2 Nodes for Energy Monitoring

Chooruang and Meekul use the Peacefair Electronics PZEM-004T to monitor energy use. Its operation is based on the current transformer idea. As a sensing component, it employs a precise AC transformer coil with a 100A/100mA output. The PZEM-004T measures active power and total energy usage over time or accumulative power consumption and delivers RMS voltage and current. The SD3004 energy-measuring SoC chip from SDIC microelectronics is used in the PZEM-004T. It offers excellent measuring precision [8].

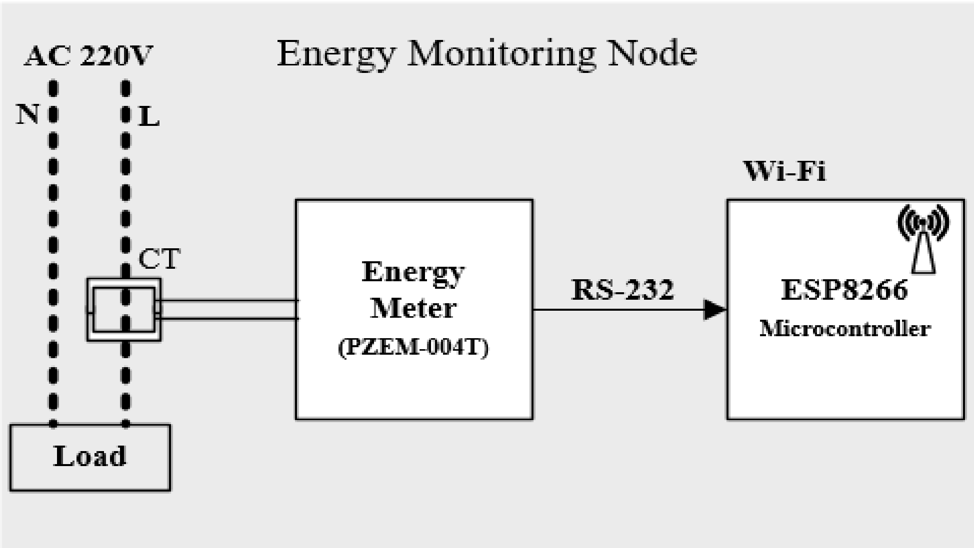

Figure 2.7 IoT electric energy monitoring module diagram [8]

In Figure 2.7, there is a simplified illustration of the constructed IoT energy monitoring node. Chooruang and Meekul employed the ESP8266 Wemos D1 Mini to connect with the PZEM-004T through RS-232, enabling the transfer of measured data from the PZEM-004T onto the network or the internet.

Figure 2.8 Prototype of energy monitoring node [8]

Figure 2.8 displays an energy monitoring node prototype in which the PZEM-004T is linked to the Wemos D1 mini through an RS-232 connector. The Wemos D1 small firmware was created utilizing the Arduino software system. The Wemos D1 mini's main role is to gather energy data via the PZEM-004T and wirelessly communicate it to the server through Wi-Fi. Every 20 seconds, data will be transferred to the server.


```
{
    "id":"emeter-node-01",
    "voltage":224.80,
    "current":2.66,
    "power":394.00,
    "accum":76939.00
}
```


Figure 2.9 Structured data format for JSON [8]

Figure 2.9 shows the JSON data that this system uses. The JSON format is a simple and lightweight data exchange format. As a result, structured data is transmitted via a network connection using MQTT in JSON format.

2.4.3 The Calculation of Energy

The daily energy consumption can be determined by calculating the energy (E) in kilowatt-hours (kWh), which is obtained by multiplying the power (P) in watts (W) by the number of hours of usage per day (t) and then dividing the result by 1000 watts per kilowatt:

$$E_{(kWh/day)} = P_{(W)} \times t_{(h/day)} / \, 1000_{(W/kW)}$$

For example, suppose we use a desktop computer that uses 300 watts of power and is used for 8 hours every day. Following the equation above, the desktop computer will consume 2.4 kWh of electricity every day, or 72 kWh per month. As a result of the calculation, the energy consumptions are automatically recorded and calculated in the server's database [8].

2.4.4 The Local Server, MQTT Communication Protocol, and Software

The Raspberry Pi 3 model B is in charge of running server software packages on the local network; these software packages include Python, an MQTT broker, an InfluxDB database server, and data visualization. A publish/subscribe protocol created for limited devices is called MQTT. It enables a simple connection between several IoT nodes and the server [9].

The sensor nodes are allowed to subscribe to the topic, and the topics are generated automatically by the central server, which is referred to as a broker. Every node that has been subscribed to a specific topic is subsequently given access to the data by the broker. Three different quality of service (QoS) levels are available for publishing. Chooruang and Meekul set up our Raspberry Pi 3 local server, which serves as a broker for the Eclipse Mosquitto software. As a result, Chooruang and Meekul created Python scripts to subscribe to MQTT topics and subsequently store all messages as time series data in the InfluxDB database [10]. The primary reason for this is that it enables the use of Grafana for data analysis. Grafana can be used to create custom dashboards, alerts, and notifications based on data sets. Grafana features an extremely responsive web front [11].

2.4.5 The Dashboard

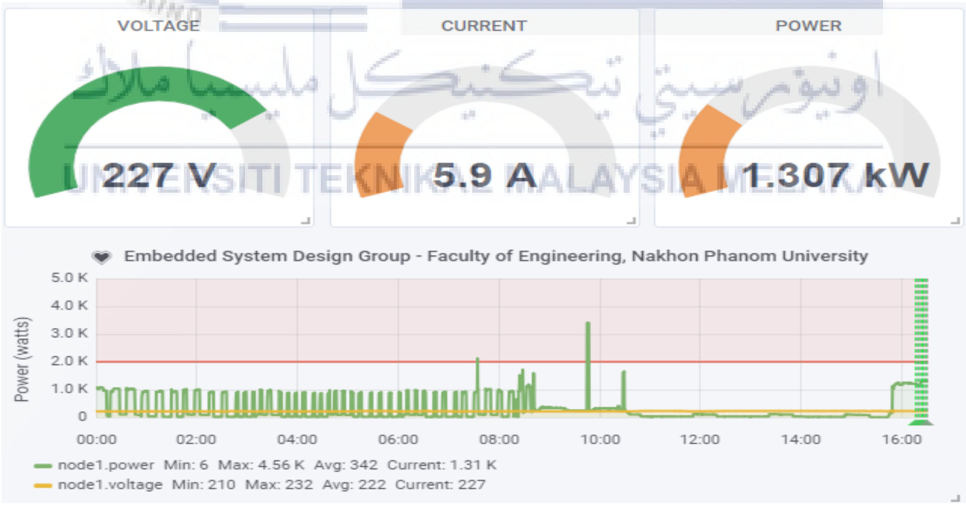

Figure 2.10 The dashboard of the developed energy monitoring system [8]

The user-interface dashboard is shown in Figure 5, with sensor node-1's dashboard used as an illustrative example. Grafana was employed to create these dashboards. The dashboard features gauges that showcase real-time values for active voltage, current, and power. Additionally, graphs on the dashboard illustrate the fluctuations in energy measurements over time. The energy data is collected through the energy sensor node and transmitted to the server. Each sensor is assigned a unique ID and communicates data every 20 seconds throughout the day. This design allows for the deployment of multiple sensor nodes, with their data simultaneously displayed on the dashboard.

2.5 Summary of Previous Literature IoT-Based Energy Meter Monitoring

Maheepala D. C. and colleagues addressed challenges related to energy auditing and proposed a system that monitors real-time energy consumption, analyzes the collected data, detects inefficiencies, and provides technical solutions. Furthermore, the system generates reports and notifies users in case of emergencies [12].

As per the findings of Woong Hee Kim and co-authors, they proposed an energy management system leveraging a ZigBee wireless sensor network and an intelligent home gateway. This system senses, records, and updates electricity data, enabling real-time monitoring of electricity consumption. Information processing, information presentation, and information collecting are the three technical components used in the procedure. The technology offers web and mobile interfaces that let users detect and manage electrical equipment [13].

Devadhanishini A. Y and collaborators proposed a Smart Power monitoring system utilizing Arduino, WIFI, and GSM Short Message Service (SMS). The system incorporates a smart power meter aimed at reducing power consumption for enhanced energy savings. Additionally, a motion sensor is integrated to automatically send signals for halting the electricity supply when no human presence is detected in the area [14].

Rishabh Jain et al. presented an IoT-based energy meter reading system in 2019 that includes defect detection and SMS alerts to the user. The approach employs EEPROM as a flash storage memory and is comprised of an Arduino board, a buzzer, a 16*2 LCD, an ESP 8266 Wi-Fi module, and a power source. By periodically monitoring their vitality, the user may manage their energy use [15].

Ganesh Shirsat K et al. created a low-cost IoT-based energy monitoring system in 2020 using a low-cost PZEM004T, non-invasive CT sensors, SD3004 electric-driven electrical dimension chip, and ESP8266. This system serves as a tool for monitoring and metering electrical usage [16].

2.6 Comparison of previous related electricity energy monitoring system

IoT power energy monitoring systems from the past were made to track and analyze energy consumption in real time, allowing customers to keep an eye on and manage their electricity use. Users might obtain insight into their energy usage habits and use the data to influence decisions that would reduce energy waste by gaining access to it through mobile or online applications. Overall, by giving customers useful data about their electricity consumption, these systems aimed to improve energy efficiency, reduce expenses, and foster sustainability. Table 2.1, on the other hand, highlights and tabulates the important components of previous work that were reviewed in the literature review section.

Table 2.1 Comparison between Previous Electricity Energy Monitoring Systems

Author	Method	Equipment	Objectives	Comment
Syamsul Syafiq et al [6]	Utilizing a dashboard to showcase real-time visualizations of data obtained from smart meters.	1. Node MCU 2. SDM230Modbus 3. ESP8266Wifi	To make it possible for users to monitor and manage their energy consumption	Save cost
R S Hariharan et al [7]	The electricity consumed by every appliance in the home is sent to a cloud database and manages energy usage using an Android app	1. Arduino Uno 2. ESP12/Node MCU 3. ACS712-30Amp Current sensor 4. AC Appliances 5. Jumping Wires 6. Voltage regulator 7. Relay module 8. Battery 9. Breadboard	To help people monitor and keep the number of kilowatts consumed in a month under control	Very efficient

Chooruang K and Meekul K [8]	The system utilizes Wi-Fi, and MQTT protocol to detect voltage, current, active power, and cumulative power consumption.	1. Peacefair PZEM-004T 2. CT sensors 3. SD3004 electric energy measurement chip 4. ESP8266 WemosD1 mini microcontroller 5. Raspberry Pi 3 Model B	To assist customers in understanding their power consumption patterns and then adapting their behavior to minimize their energy profile	Economical
Maheepala D. C. et al [12]	1. Using TCP/IP protocol and MySQL database 2. Providing technical suggestions such as power factor correction and load shifting	1. 3-phase smart energy meter with 0.5 accuracy class 2. RS-232 cable	Developed a system for monitoring and analyzing energy in industrial settings to enhance energy management efficiency.	Suitable for industrial use but complex
Woong Hee K et al [13]	The system communicates via the ZigBee protocol (wireless sensor). It is a wireless communication protocol for home automation.	1. ACS712 current sensor 2. Relay 3. USB cable 4. Microcontroller with ADC	To assist consumers, real-time electricity usage can be controlled remotely via the web and other mobile devices	Simple and efficient

Rishabh Jain et al [15]	Using a Wi-Fi system. Values for voltage and current are constantly saved in the server. A cloud server is used, which is cayenne.com.	1. Arduino ATMEGA328 2. ESP8266 Wi-Fi module 3. 16*2 LCD 4. Buzzer 5. EEPROM 6. Real-time clock 7. Relay Circuit 8. Voltage Sensor 9. Current Sensor	Reduce the power consumption in the house and also reduce manpower and time consumption.	Save cost, suited for homes and businesses in a public electricity supply system.
Ganesh Shirsat K et al [16]	The system utilizes Wi-Fi and MQTT protocol in JSON (JavaScript Object Notation) format.	1. PZEM-004T 2. CT sensors 3. SD3004 chip 4. ESP8266 5. Raspberry Pi 3 version B 6. Sensors 7. Photo resistive Sensor 8. Motion Detective Sensor 9. Air Quality Sensor (MQ135)	To give the consumer a strength tracking and monitoring program	low-price but complex

2.7 Summary

Previous evaluations of the literature on energy monitoring systems emphasized the significance of monitoring and regulating energy consumption for a variety of applications such as residential, commercial, and industrial sectors. These studies looked at the advantages of energy monitoring systems in terms of energy efficiency, cost savings, and environmental sustainability. Several studies have been conducted to examine the various types of energy monitoring technologies available, such as smart meters, wireless sensor networks, and Internet of Things (IoT) devices. The role of data analytics and machine learning approaches in energy monitoring systems has also been highlighted in the literature studies. The reviews also addressed the issues and obstacles associated with energy monitoring systems. These difficulties include concerns about data privacy and security, compatibility of various monitoring devices, and user engagement. Furthermore, the impact of energy monitoring systems on energy consumption behavior has been investigated in the literature reviews. Several studies have found that real-time feedback and visualizations offered by energy monitoring systems can result in significant energy savings and user behavior change. Overall, previous literature reviews on energy monitoring systems have provided a comprehensive overview of the technologies, benefits, challenges, and impacts associated with these systems. The studies established the groundwork for future study and development in the sector, demonstrating the potential of energy monitoring systems in accomplishing energy efficiency and sustainability objectives.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Given the emphasis on affordability, the Electricity Energy Monitoring System's deployment is significant for society. As electricity is the primary energy source, the Electricity Energy Monitoring System is crucial for measuring voltage and current. Evaluating how it's used is essential for ensuring reliability and cost-effectiveness for wider adoption in homes.

3.2 Methodology

The electricity energy monitoring system utilizes the Blynk app to track and analyze energy consumption. By connecting the system to the electrical infrastructure, it measures the energy usage of various devices and appliances in real-time. Users can get specific data about their electricity usage, including voltage, current, and power usage, through the Blynk app. This monitoring system aims to promote awareness of energy consumption patterns, enabling users to make informed decisions about energy efficiency and potentially reduce their electricity costs. Figure 3.1 demonstrates that the AC power through the appliances. The current and voltage sensors are linked to the microcontroller. if the current from the appliances is detected, it will produce power consumption based on the current and voltage values. The value of voltage, current, and power usage will then be displayed. At last, all data will be transmitted to the Blynk app and user.

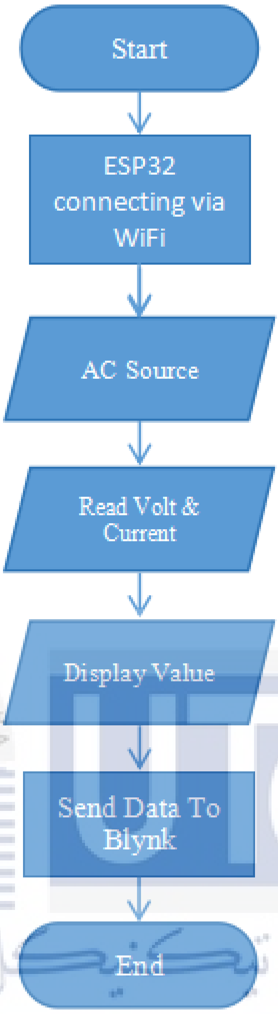

Figure 3.1 Flowchart of Development Electricity Energy Monitoring System

3.2.1 Experimental setup

The Blynk app is used to collect data. It is then presented in the application program so that the data can be recorded from day to day and month to month, as well as to monitor the costs of the energy bill. It will save cost since a function will be built to allow users or homeowners to control their power consumption. As a result, it will be more efficient in terms of electricity usage in homes.

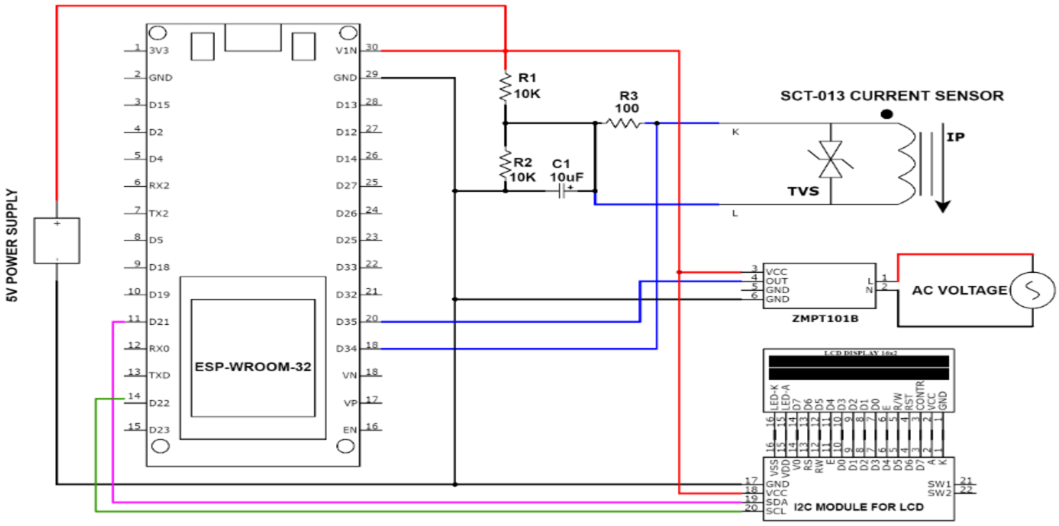

Figure 3.2 Circuit Design of Electricity Energy Monitoring System

Figure 3.2 shows the circuit of the system which is each component connected to the ESP32. The ESP32, SCT-013 current sensor, ZMPT101B AC voltage sensor, and LCD are the primary components in this circuit design.

3.2.2 Parameters

Using the app for energy meters gives customers more insight into their energy consumption and increases their optimism about the supply and demand for power. Users wouldn't be shocked by the amount their electrical bill has increased to at the end of the month. They have a single thing to be concerned about, as they can see from their daily, weekly, and monthly consumption reports. According to earlier studies, the electricity company would be the only one to know how much energy is used at home.

3.2.3 Hardware Component

To make sure that the hardware can do its tasks, a few components are used. There are Node MCU, SCT-013 Current Sensor, ZMPT101B AC Voltage Sensor, and LCD. The entire system's functionality is handled by the ESP32. A microcontroller called the Node MCU can regulate the flow of electricity within a hardware system. The SCT-013 Current Sensor will gauge the current flow. This component is utilized because it is more affordable than other market-available sensors and can handle a wide variety of current supplies. The ZMPT101B AC Voltage Sensor can read voltage values and measure the amount of power consumed.

3.2.3.1 ESP32 Development Board

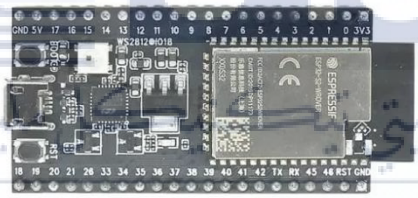

Figure 3.3 ESP32 Development Board [17]

Figure 3.3 shows ESP32, A microcontroller featuring integrated Wi-Fi and Bluetooth capabilities forms the basis of a cost-effective, low-power system. The ESP32, crafted and developed by Espressif Systems, a Shanghai-based Chinese company, is manufactured utilizing TSMC's 40nm chip technology. While the ESP32 NodeMCU presents itself as an alternative, it is essential to note its limitation of only one analog pin. Considering the specific requirements concerning voltage and current measurements, the ESP32, with its abundant analog pins, emerges as the preferred choice over the ESP32 NodeMCU for this project.

3.2.3.2 SCT-013 Current Sensor

Figure 3.4 SCT-013 Current Sensor [18]

Figure 3.5 shows a SCT-013 current sensor, A non-invasive current sensor has been employed to ascertain the precision of current measurements. The SCT-013, a split-core clamp-on current sensor, has been utilized due to its unique feature. The CT is clamped onto the single phase of the wire, allowing for effective monitoring. In the output section, an AC voltage is generated in direct correlation with the fluctuations in AC within the single phase.

3.2.3.3 AC Voltage Sensor ZMPT101B

Figure 3.5 AC Voltage Sensor ZMPT101B [19]

Figure 3.6 shows the ZMPT101B voltage sensor for measuring alternating current voltage. When it comes to voltage and power measurement, it provides great precision and consistency, especially for voltages up to 250V AC. This device is simple to operate and has a multi-turn trim potentiometer for adjusting the ADC (Analog-to-Digital Converter) output to meet unique needs.

3.2.3.4 20x4 LCD Display

Figure 3.6 20x4 LCD [20]

Figure 3.7 shows the LCD 20x4 displays real-time power consumption, allowing users to conveniently track and monitor their energy usage. It provides a clear and easy-to-read interface that shows essential information such as current power consumption, cumulative energy usage, and cost calculations. The LCD screen enhances the user experience by providing visual feedback and promoting energy-conscious behavior.

3.3 Limitation of Proposed Methodology

The Electricity Energy Monitoring system's limited coverage is one of its drawbacks because it can only support households within a certain radius and was not made to be a portable gadget that could be readily moved. Another factor to take into account is the linked cloud system's finite and spatially constrained storage capacity. Older data will eventually be replaced or erased as fresh data is continuously produced. It is crucial to remember that the Electricity Energy Monitoring system's main function is to precisely compute electricity usage and related parameters.

3.4 Premilinary Result

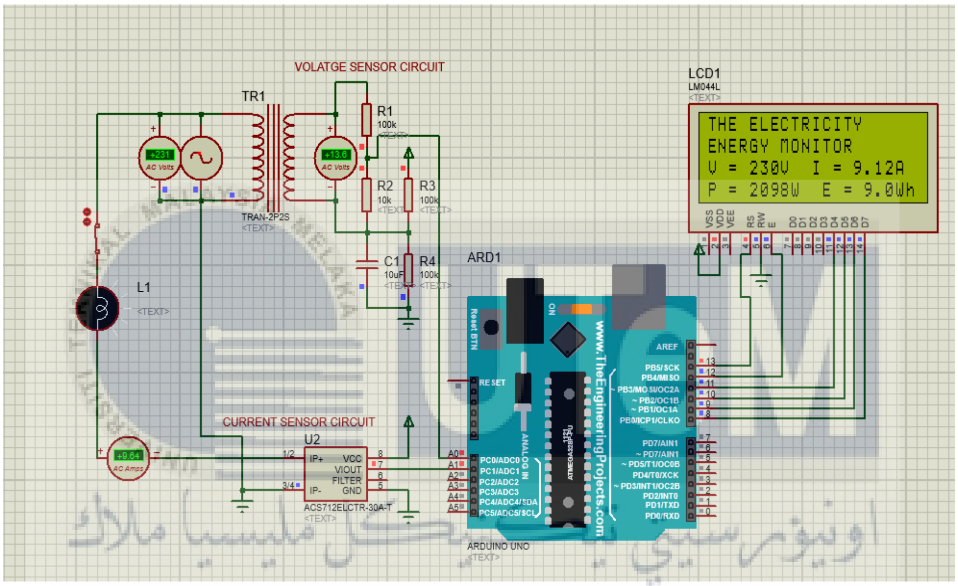

Figure 3.7 Output Display at LCD

Figure 3.8 shows the output display at LCD from the circuit development. The output from an electricity energy monitoring circuit that consists of a voltage sensor and a current sensor provides real-time data regarding the present values of current, voltage, power, and energy consumption within an electrical system. The current sensor measures the electrical current flowing through a circuit. It provides the real-time value of the current in amperes (A). Monitoring the current helps to understand the electrical load and how much power is being drawn by the devices connected to the circuit. The voltage sensor measures the electrical potential difference across a circuit. It provides the real-time value of the voltage in volts (V). Monitoring the voltage allows us to know the supply voltage level and ensure it remains within the expected range. Power is the rate at which electrical energy is consumed or produced. It is calculated by multiplying the voltage and current values. The power output is expressed in watts (W) and represents the instantaneous power consumption of the electrical system. Monitoring the power helps to understand the current power demand and identify energy-efficient devices. Energy is the total amount of electrical power consumed over a specific period. It is calculated by integrating the instantaneous power over time. The energy output is expressed in watt-hours (Wh) and represents the cumulative energy consumption of the electrical system. Monitoring energy usage helps to track overall electricity consumption and identify trends, patterns, and potential areas for energy conservation.

3.5 Summary

The rising power demand has led to increased interest among homeowners in monitoring their home's energy consumption. Traditional energy meters only provide a limited amount of information, making it difficult for homes to accurately monitor their energy usage. An Internet of Things (IoT) energy monitoring system is seen as an efficient solution to this problem, as it can provide real-time information on energy usage and enable homeowners to take immediate action to reduce consumption and costs. The cost of installing a smart energy monitoring system, however, may discourage some homeowners. Additionally, a lot of IoT-based energy monitoring solutions now available are complicated and challenging to use, making it difficult for homeowners to monitor their energy usage effectively. Furthermore, the compatibility of IoT-based energy monitoring devices with various energy meters poses a challenge for homeowners when selecting a suitable system.

The project's objectives are to create a low-cost home appliance power consumption tracking system, create a dashboard for power consumption tracking utilizing an IoT platform (Blynk app), and analyze energy consumption to help consumers manage their electricity costs. The project's scope comprises single-phase 230V electrical systems, sensor-based data collecting from home appliances, remote data monitoring using the Node MCU ESP32 microcontroller, and real-time data display using the Blynk app IoT platform. The project also includes a physical power usage meter that shows data on an LCD.

Previous literature reviews on energy monitoring systems have emphasized the importance of monitoring and regulating energy consumption across various sectors. These reviews have explored the benefits of energy monitoring systems in terms of energy efficiency, cost savings, and environmental sustainability. They have also examined different technologies such as smart meters, wireless sensor networks, and IoT devices, as well as the role of data analytics and machine learning in energy monitoring.

In conclusion, the literature reviews provide a comprehensive understanding of energy monitoring systems, their technologies, benefits, challenges, and impacts. They serve as a foundation for future research and development, highlighting the potential of energy monitoring systems in achieving energy efficiency and sustainability goals. The proposed methodology aims to accurately measure and calculate power supply and demand within households, emphasizing the importance of data accuracy and meeting diverse home needs.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, an in-depth examination and interpretation of data about the "Electricity Energy Monitoring System for Home Usage" project are presented. The project employs the SCT-013 current sensor for single-phase current measurement. These sensors are seamlessly integrated into the ESP32 board. Utilizing the Arduino IDE software, power factor, real power, and apparent power values are calculated based on the measured current, RMS voltage, and phase angle. The Arduino IDE software facilitates the transmission of both measured and calculated values to the ESP32 development board. The communication network is established via TCP/IP protocol, connecting the ESP32, cloud server, and smartphone device through a Wi-Fi access point within the designed CIoT network. This chapter unfolds the intricate workings of the system, shedding light on its key components and the collaborative communication among the devices in the pursuit of efficient electricity energy monitoring for residential use.

4.2 Results and Analysis

In this section, we delve into the outcomes and analysis derived from real-time data monitoring of energy consumption. Voltage measurements are acquired using the AC ZMPT101B voltage sensor, and processed through the ESP32 system. Simultaneously, current readings are obtained from the SCT-013 current sensor clip. The processed data is displayed on an LCD, providing a comprehensive view of both voltage and current values.

This innovative approach enables a detailed examination of energy consumption patterns, facilitating a more nuanced analysis of the system's performance in real-world scenarios. The integration of advanced sensors and processing technologies enhances the precision and reliability of the collected data, contributing to a more insightful interpretation of energy usage dynamics.

Figure 4.1 Final Prototype

Figure 4.1 illustrates the framework of the "Development of Electricity Energy Monitoring System for Home Usage by Using IoT" project. It visually highlights key components like ESP32, SCT-013 current sensor, and ZMPT101B AC voltage sensor, showcasing their interconnected roles in the system. The figure serves to enhance comprehension of the project's architecture for efficient home energy monitoring.

4.2.1 Project demonstration

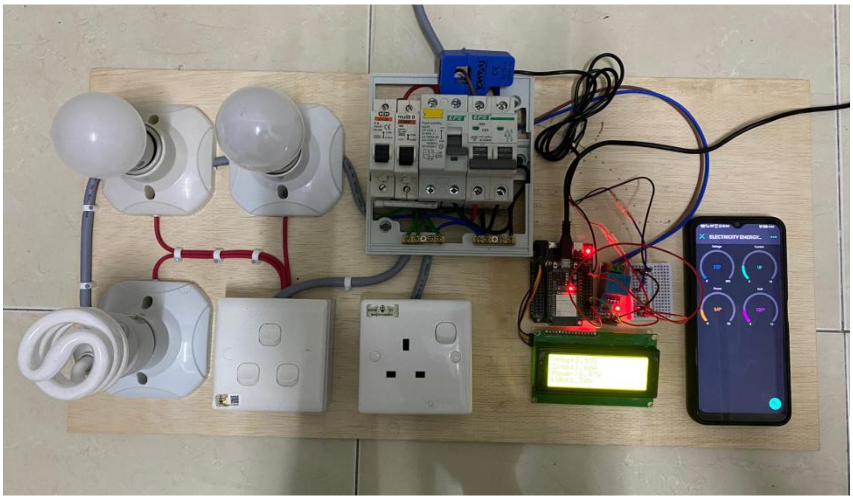

Figure 4.2 Supply ON, Load OFF

Figure 4.2 showcases scenarios where a 230V power supply is active, and all household loads are switched off, the ZMPT101B AC voltage sensor is configured to measure the voltage. The recorded voltage readings are then promptly displayed on the LCD monitor and synchronized with the Blynk monitoring platform. This configuration enables real-time monitoring and visualization of the baseline voltage, providing valuable insights into the electricity supply status when the household is in a standby state with no active loads.

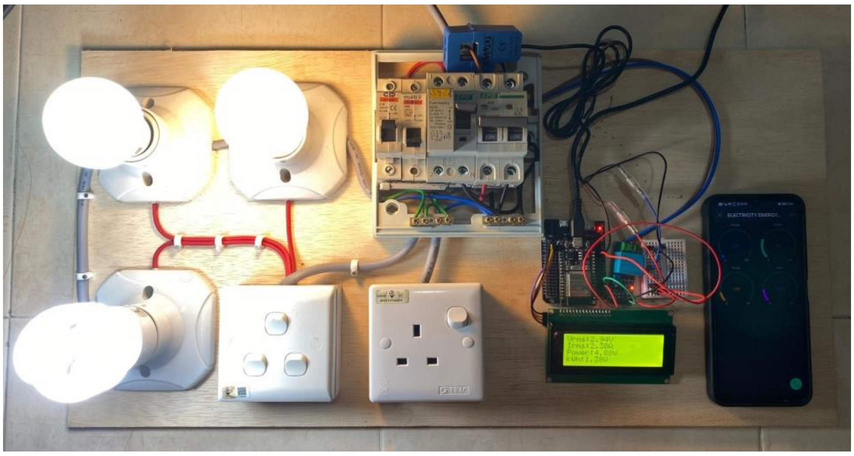

Figure 4.3 Supply ON, Load ON

The figure above shows where electrical loads are actively in use, the system dynamically adapts to the fluctuating conditions. The ZMPT101B AC voltage sensor continuously monitors the real-time voltage under the influence of the applied load. Simultaneously, the SCT-013 current sensor captures the current consumption associated with the operational loads. The SCT-013 has 2000 turns and is clamped around a single conductor carrying the current to be measured, and the goal is to have the output represent the primary current, there is no need to apply a multiplying factor. The combined voltage and current data are promptly processed and displayed on the LCD monitor, offering immediate insights into the electricity consumption patterns during active usage. Additionally, this information is relayed to the Blynk monitoring platform, ensuring a comprehensive and real-time overview of the electricity usage dynamics in the presence of active loads.

4.2.2 Data Acquisition Overview

The summary of data acquisition offers a brief overview of the techniques and procedures employed for collecting information or measurements, represented through tables and graphs. In essence, it delivers a structured understanding of the systematic process involved in gathering data, ensuring the obtained information is clear and consistent for subsequent analysis.

4.2.2.1 Analysis of Lamps

a) Types of Lamps Vs Current

Table 4.1 Data of Type of Lamps Vs Current

Lamp	Incandescent (60W)	Fluorescent (18W)	LED (7W)
Current (A)	0.20	0.05	0.02

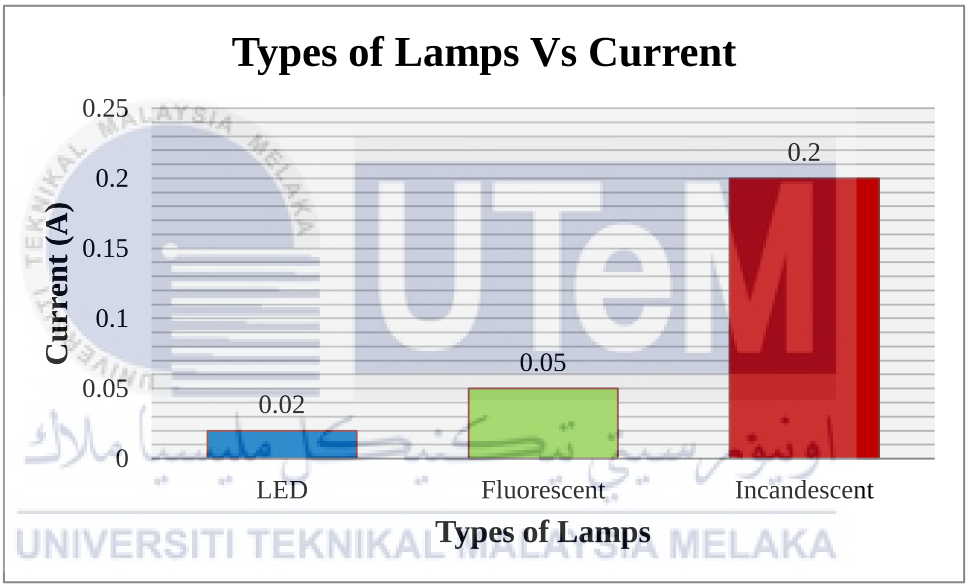

Figure 4.4 Chart of Types of Lamps Vs Current

In Figure 4.4, depicting the relationship between lamp types (Incandescent, Fluorescent, LED) and their corresponding current values (A), clear patterns emerge. The Incandescent lamp has the highest current demand at 0.20 A, followed by the Fluorescent lamp at 0.05 A, and the LED lamp at 0.02 A. This data indicates that the Incandescent lamp places the greatest electrical load, while the LED lamp is more energy-efficient with significantly lower current consumption. The Fluorescent lamp falls in between, presenting a middle-ground current demand in this comparative analysis.

b) Voltage Vs Current

Table 4.2 Data of Voltage Vs Current

Lamp	Incandescent (60W)	Fluorescent (18W)	LED (7W)
Voltage (V)	233	233	233
Current (A)	0.20	0.05	0.02

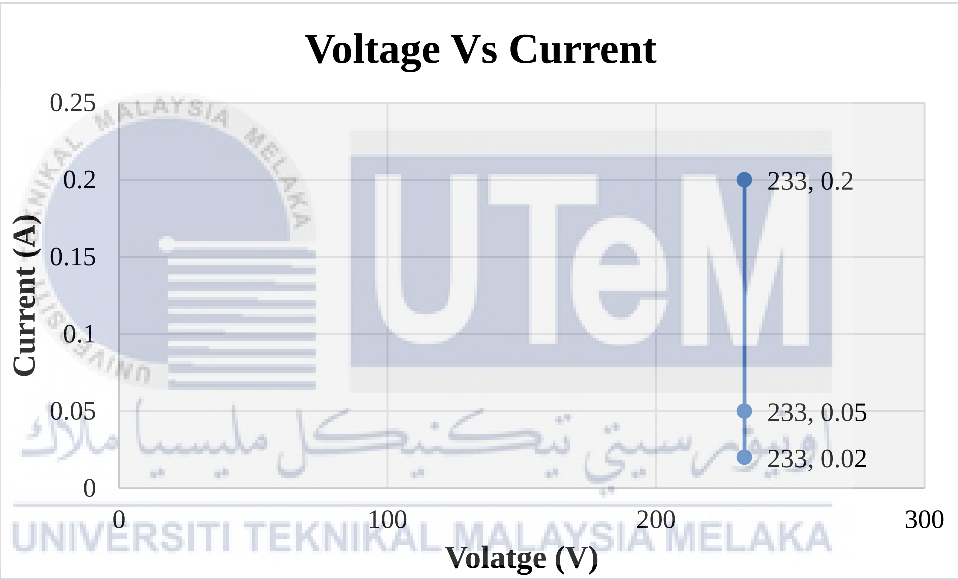

Figure 4.5 Chart of Voltage Vs Current

In Figure 4.5, voltage measures consistently at 233V for Incandescent, Fluorescent, and LED lamps. The Incandescent lamp exhibits the highest current demand at 0.20 A, indicating a significant electrical load. The Fluorescent lamp falls in the middle with a moderate 0.05 A current, while the LED lamp demonstrates energy efficiency, drawing only 0.02 A. This data highlights the efficiency disparity, with Incandescent consuming the most current, Fluorescent in the middle, and LED emerging as the most energy-efficient option.

c) Power Vs Current

Table 4.3 Data of Power Vs Current

Lamp	Incandescent (60W)	Fluorescent (18W)	LED (7W)
Power (W)	46.6	11.7	4.7
Current (A)	0.20	0.05	0.02

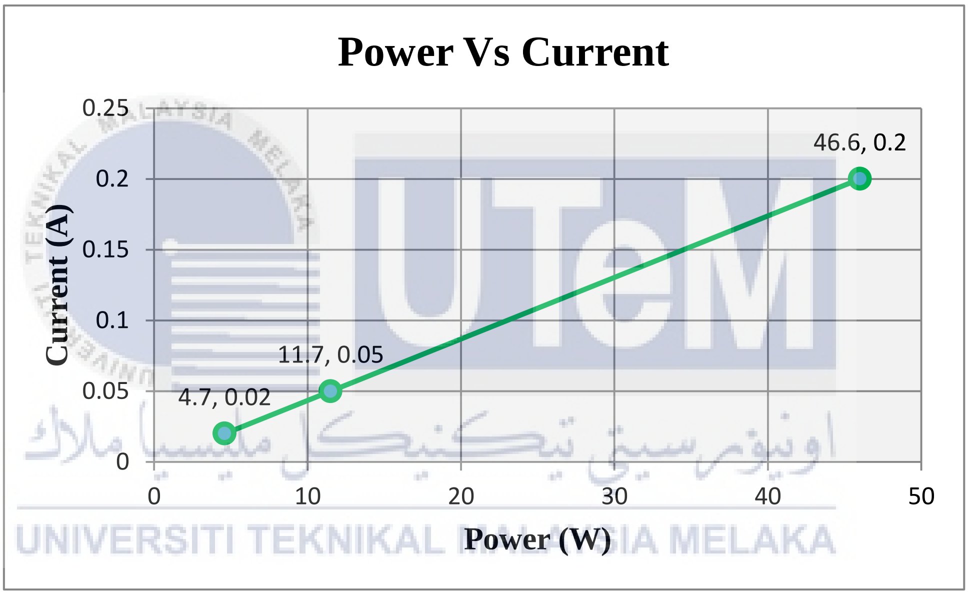

Figure 4.6 Graph of Power Vs Current

In Figure 4.5, the graph depicts a clear correlation between current and power for various lamps. As current increases, power follows suit across the lamp types. The lowest current (0.02 A) corresponds to the lowest power (4.7 W), while the highest current (0.20 A) aligns with the greatest power (46.6 W). This indicates a direct relationship, highlighting how changes in current directly impact the power consumption of the lamps.

d) Power Vs Current Vs Energy Consumption per Hour

Table 4.4 Data of Power Vs Current Vs Energy Consumption per Hour

Lamp	Incandescent (60W)	Fluorescent (18W)	LED (7W)
Power (W)	46.6	11.7	4.7
Current (A)	0.20	0.05	0.02
Energy Consumption per Hour (kWh)	0.047	0.0117	0.0047

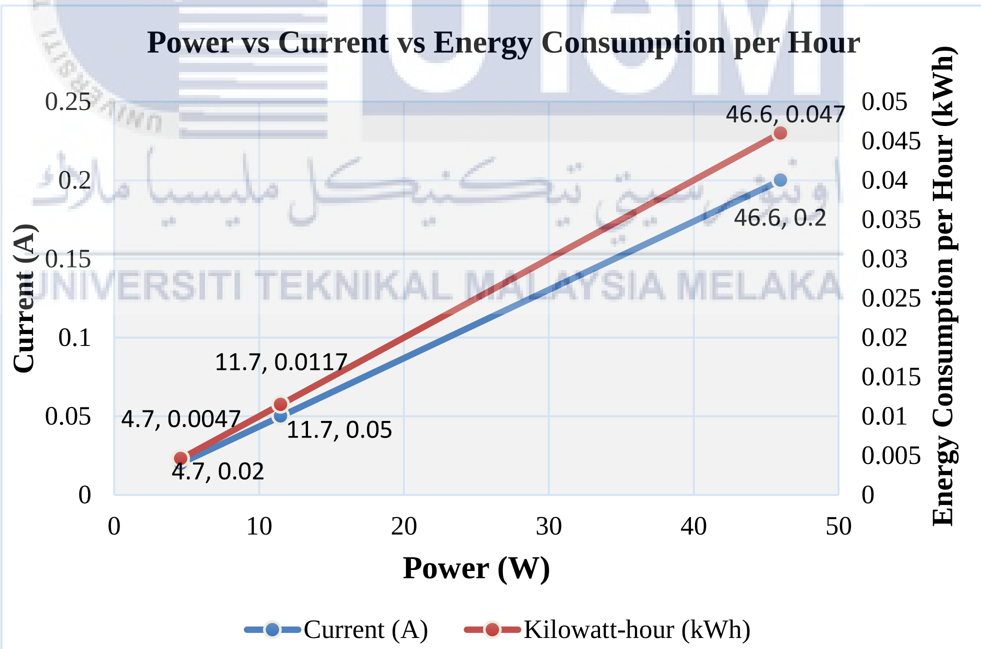

Figure 4.7 Graph of Power Vs Current Vs Energy Consumption per Hour

In Figure 4.6, the graph illustrates the relationships among power, current, and energy consumption for Incandescent, Fluorescent, and LED lamps. The Incandescent lamp, with the highest power and current, exhibits the greatest energy consumption, while the LED lamp, with the lowest power and current, shows the lowest consumption. The Fluorescent lamp falls in between, reflecting moderate values for all three parameters. This data emphasizes the energy efficiency of LED lamps compared to their counterparts per hour.

e) Types of Lamps Vs Rated Lumens

Table 4.5 Data of Types of Lamps Vs Rated Lumens

Lamp	Incandescent (60W)	Fluorescent (18W)	LED (7W)
Rated Lumens (lm)	800	1010	490

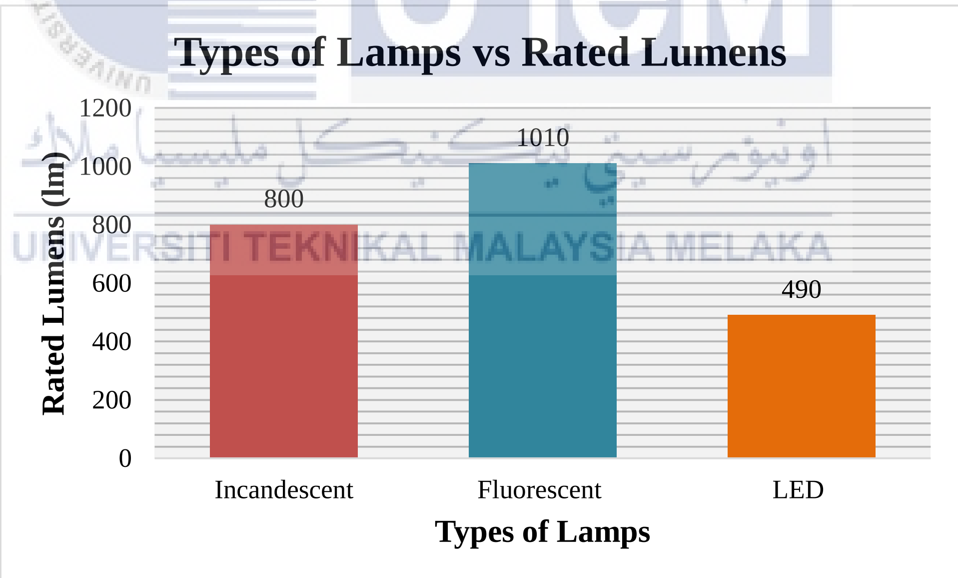

Figure 4.8 Chart of Types of Lamps Vs Rated Lumens

In Figure 4.7, the chart compares Incandescent, Fluorescent, and LED lamps based on their lumen output. Despite the Incandescent lamp's higher wattage (60W), it produces fewer lumens (800lm), indicating lower efficiency. The Fluorescent lamp (18W) shows higher efficiency with 1010lm, while the LED lamp

(7W) excels in luminous efficacy, producing 490lm with the lowest wattage. This emphasizes LED's superior energy efficiency compared to traditional lighting technologies.

f) Rated Lumens Vs Luminous Efficacy

Table 4.6 Data of Lumens Vs Luminous Efficacy

Lamp	Incandescent (60W)	Fluorescent (18W)	LED (7W)
Rated Lumen (lm)	800	1010	490
Luminous Efficacy (lm/W)	17	86	104

$$\text{Luminous Efficacy}\left(\frac{\text{lm}}{\text{W}}\right) = \frac{\text{Rated Lumens (lm)}}{\text{Measured Power (W)}}$$

Table 4.5 shows the data of calculation and estimation of how efficiently the lamp is converting electrical power into visible light based on the rated luminous flux and the measured power consumption.

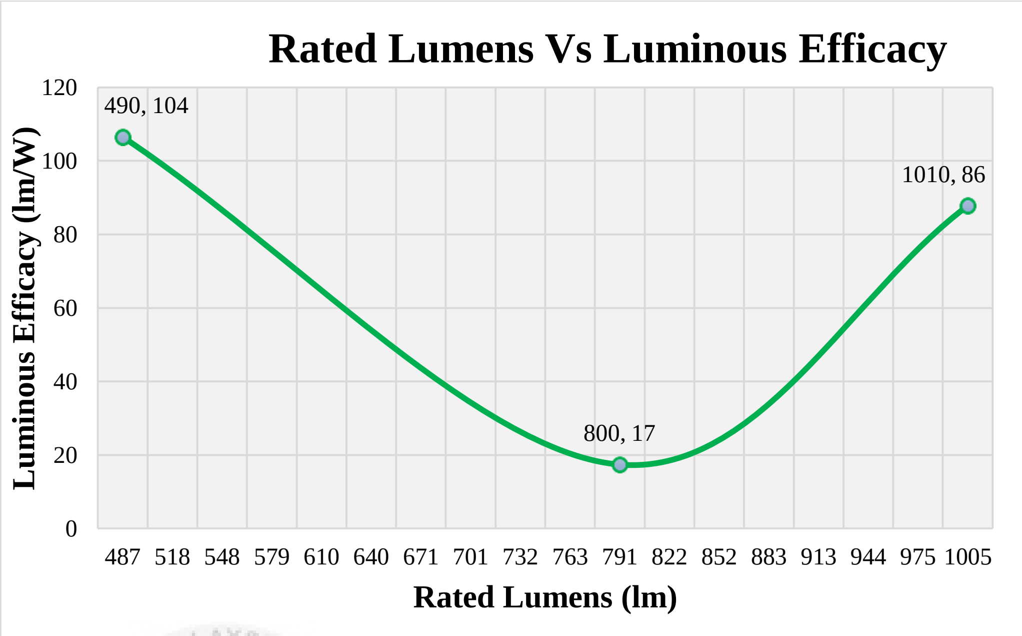

Figure 4.9 Graph of Lumens vs Luminous Efficacy

In Figure 4.8, the comparison of lumens and luminous efficacy among Incandescent, Fluorescent, and LED lamps highlights their efficiency differences. The Incandescent lamp, producing 800 lumens, shows lower efficiency at 17.4 lm/W. The Fluorescent lamp excels with 87.8 lm/W for 1010 lumens, while the LED lamp, with 490 lumens at 7W, demonstrates superior efficiency at 106.5 lm/W. This underscores the distinct energy efficiency of LED lighting compared to traditional options.

4.2.2.2 Analysis of Load At 13A Socket Outlet

a) Types of Load Vs Current

Table 4.7 Data of Types of Load Vs Current

Load	Phone Charger (67W)	Hair Dryer (3000W)	Electric Kettle (1800-2150W)
Current(A)	0.17	5.56	7.8

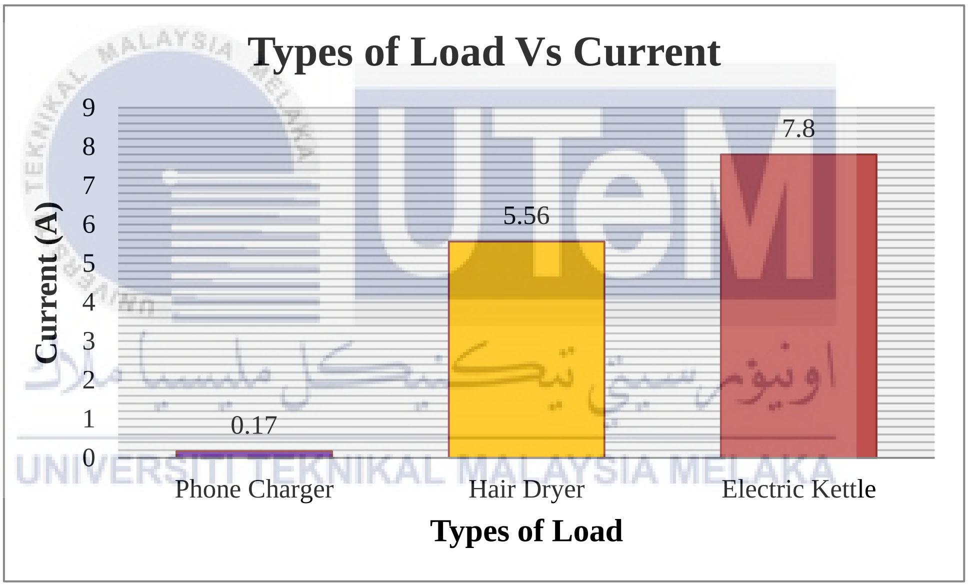

Figure 4.10 Chart of Types of Load Vs Current

In Figure 4.6, the current values for three loads (Phone Charger, Hair Dryer, and Electric Kettle) reveal distinct power requirements. The Phone Charger has the lowest current at 0.17 A, indicating lower power usage. The Hair Dryer draws a substantial 5.56 A, while the Electric Kettle exhibits the highest demand at 7.8 A, reflecting its significant power consumption. Notably, these loads are not used simultaneously, highlighting diverse electrical demands on a 13A socket.

b) Voltage Vs Current

Table 4.8 Data of Voltage Vs Current

Load	Phone Charger (67W)	Hair Dryer (3000W)	Electric Kettle (1800-2150W)
Voltage (V)	235	240	226
Current(A)	0.17	5.56	7.8

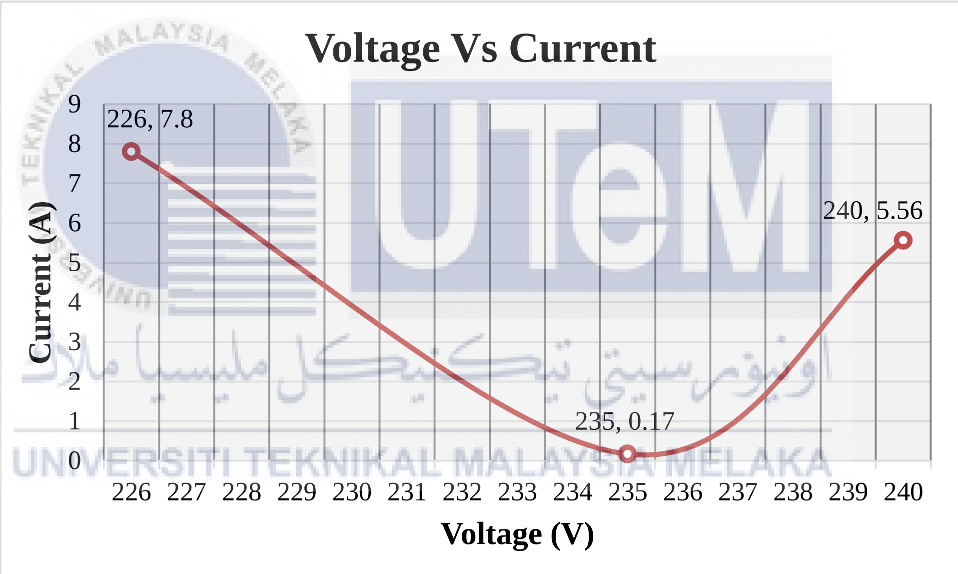

Figure 4.11 Chart of Voltage Vs Current

Figure 4.11 shows measured voltage and current for diverse loads (Phone Charger, Hair Dryer, Electric Kettle), distinct patterns emerge. The Phone Charger operates at 235V with a modest 0.17 A current, signifying low power consumption. In contrast, the Hair Dryer demands a substantial 5.56 A current at 240V, reflecting its high power usage. Notably, the Electric Kettle exhibits the highest power consumption, drawing 7.8 A at 226V. This data emphasizes the varying electrical demands of these loads, with the Phone Charger being energy-efficient, the Hair

Dryer is moderately consuming power, and the Electric Kettle having a significant power demand.

c) Power vs Current

Table 4.9 Data of Power Vs Current (Three Types of Load)

Load	Phone Charger (67W)	Hair Dryer (3000W)	Electric Kettle (1800-2150W)
Power (W)	39.9	1334.4	1762.8
Current (A)	0.17	5.56	7.8

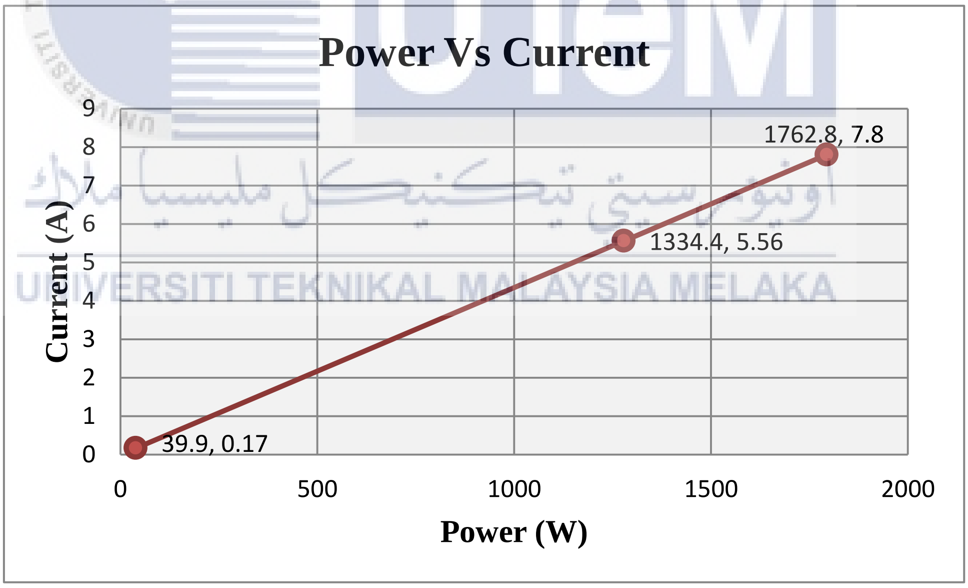

Figure 4.12 Graph of Power Vs Current (Three Types of Load)

In Figure 4.7, the graph illustrates the correlation between power and current for three loads (Phone Charger, Hair Dryer, Electric Kettle). The Phone Charger shows the lowest current (0.17 A) and power (39.9 W), indicating lower power usage. The Hair Dryer, with a current of 5.56 A, exhibits a higher power of

1334.4 W, emphasizing its significant power demand. The Electric Kettle, having the highest current (7.8 A), shows the greatest power at 1762.8 W, highlighting its substantial power consumption. This data underscores the relationship between current and power, offering insights into the energy requirements of different loads.

d) Time Vs Current

Table 4.10 Data of Types of Load Vs Time

Load	Phone Charger (67W)	Hair Dryer (3000W)	Electric Kettle (1800-2150W)
Time (min)	60	15	7
Current (A)	0.17	5.56	7.8

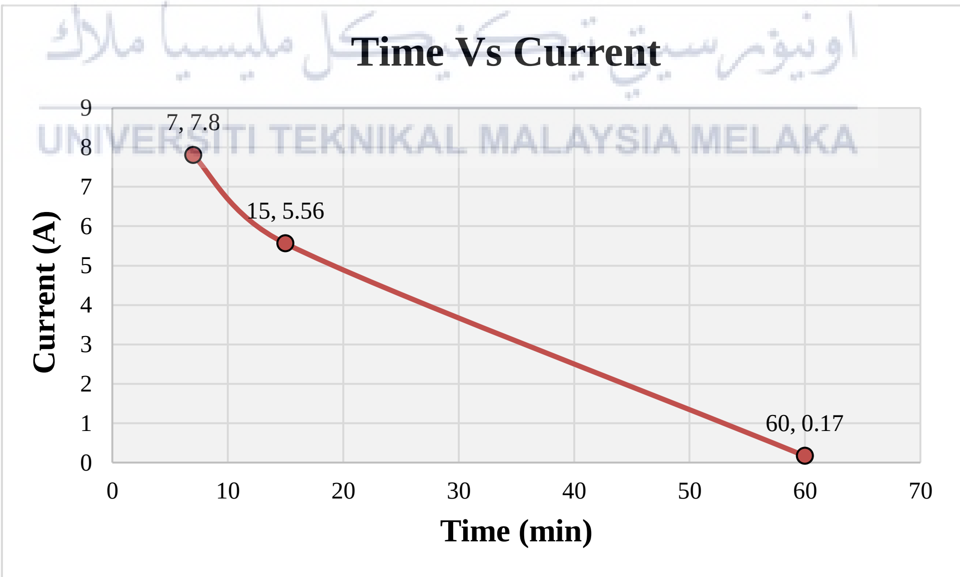

Figure 4.13 Graph of Time Vs Current

In Figure 4.11, the graph illustrates the time-dependent current profiles for three distinct loads connected individually to a 13A socket: Phone Charger, Hair

Dryer, and Electric Kettle. The Phone Charger exhibits a consistent, modest current of 0.17 A over 60 minutes, indicating a steady and low-power charging process. In contrast, the Hair Dryer, used for 15 minutes, shows a noticeable current spike to 5.56 A, reflecting its higher power demand during operation. The Electric Kettle, employed for 7 minutes, displays the highest current at 7.8 A, characteristic of the rapid heating phase. These loads are not used concurrently, and their staggered usage patterns highlight the diverse power requirements of each device.

e) Power Vs Current Vs Energy Consumption per Use

Table 4.11 Data of Power Vs Current Vs Energy Consumption per Use

Load	Phone Charger (67W)	Hair Dryer (3000W)	Electric Kettle (1800-2150W)
Power (W)	39.9	1334.4	1762.8
Current (A)	0.17	5.56	7.8
Energy Consumption per Use (kWh)	0.0399	0.3336	0.2115

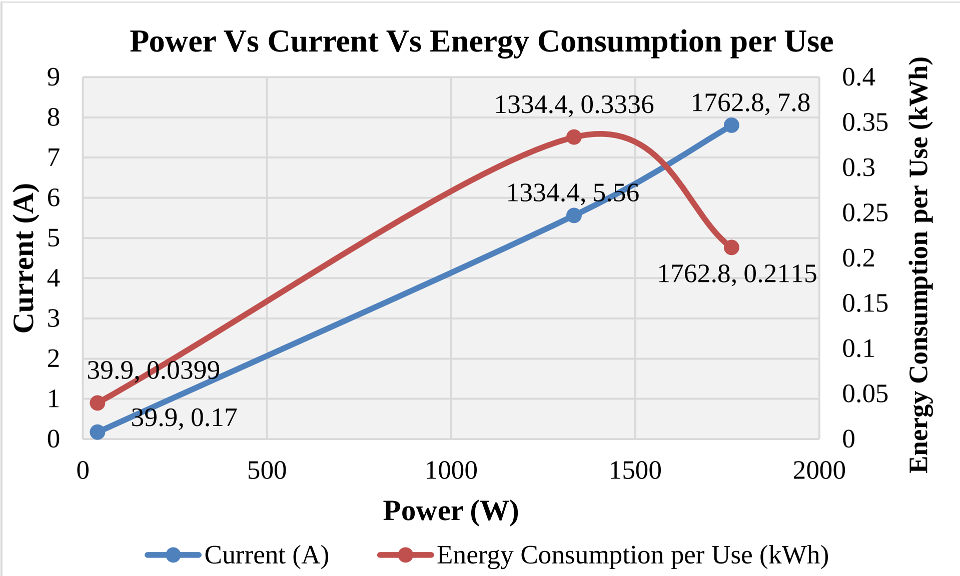

Figure 4.14 Graph of Power Vs Current Vs Energy Consumption per Use

In Figure 4.14, illustrating the relationship between power, current, and energy consumption per use for various loads (Phone Charger, Hair Dryer, Electric Kettle), distinctive characteristics emerge. The Phone Charger, operating at 39.9W with a low current of 0.17 A, reflects its efficiency in power usage, resulting in a minimal energy consumption of 0.0399 kWh per use. Conversely, the Hair Dryer draws a substantial 1334.4W at 5.56 A, leading to a higher energy consumption of 0.3336 kWh per use, indicative of its power-intensive nature. The Electric Kettle stands out with the highest power demand at 1762.8W and 7.8 A, resulting in an energy consumption of 0.2115 kWh per use. This data underscores the varying power efficiency among these loads, with the Phone Charger being the most energy-efficient, the Electric Kettle demonstrating moderate efficiency, and the Hair Dryer having a higher energy demand per use.

4.3 Limitations in The Electricity Energy Monitoring System

a) Power Factor Estimation

While this project successfully addresses the development of an electricity energy monitoring system for home usage using IoT, there are certain limitations to be acknowledged. The accuracy of power measurements may be influenced by variations in the power factor of different household appliances. Additionally, the specific power factor values for individual devices, such as phone chargers, hair dryers, and electric kettles, were not directly measured but rather estimated based on general knowledge.

b) Monitoring Accuracy Limitation

The system's monitoring accuracy may be impacted by factors such as sensor calibration, environmental conditions, and potential signal noise. Calibrating sensors for precise measurements poses a challenge, and environmental variables, like temperature fluctuations, can introduce variations. Additionally, external interference or signal noise might affect the accuracy of the data collected.

c) Connectivity During Blackouts

It is essential to acknowledge that during blackout or power outage scenarios, the electricity energy monitoring system faces a challenge in maintaining connectivity. As the system relies on Wi-Fi for communication and Blynk for monitoring, the absence of power disrupts the ability to establish a connection. This limitation arises due to the dependence on an external power source for the operation of both the IoT-enabled devices and the communication infrastructure. Consequently, the system's real-time monitoring capabilities are temporarily compromised during blackout conditions.

4.4 Summary

In this study, we thoroughly examined an "Electricity Energy Monitoring System for Home Usage," utilizing an SCT-013 current sensor, and an ESP32 board. This system allows for the measurement of single-phase current and the determination of power factor, real power, and apparent power values. The data transmission occurs through a TCP/IP protocol, establishing a connection between the ESP32, cloud server, and smartphone within a CIoT network, facilitating efficient home energy monitoring.

The results and analysis section delves into real-time data monitoring outcomes, highlighting the system's performance in various scenarios. The project framework, as described, emphasizes the interconnected roles of ESP32, SCT-013 current sensor, and ZMPT101B AC voltage sensor. Scenarios with a 230V power supply and active household loads provide insights into electricity supply and consumption dynamics.

Moving on to the analysis of lamps, the data presents current requirements for Incandescent, Fluorescent, and LED lamps, showcasing the energy efficiency of LED lamps. The correlation between power and current for different lamps emphasizes the direct relationship between these variables. The analysis extends to the load at the 13A socket outlet, detailing current, power, and energy consumption for the Phone Charger, Hair Dryer, and Electric Kettle. Non-simultaneous usage patterns and diverse power requirements are underscored.

Limitations are acknowledged, including power factor estimation accuracy, monitoring limitations influenced by sensor calibration and environmental conditions, and connectivity challenges during blackouts. This study provides valuable insights into energy consumption dynamics and system performance for effective residential energy management.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This project, aimed at crafting a cost-effective Electricity Energy Monitoring System for Home Usage utilizing IoT, has successfully materialized a real-time monitoring infrastructure. Employing the ESP32 microcontroller, SCT-013 current sensor, and ZMPT101B AC voltage sensor, the system delivers commendable accuracy in tracking both voltage and current. However, limitations in power factor estimation and dependence on Wi-Fi during blackouts necessitate future refinements.

Prioritizing real-time monitoring over advanced features aligns with the project's objectives, emphasizing its low-cost design. The system's analysis of energy consumption supports consumers in cost-effective bill management. Challenges in monitoring accuracy stemming from calibration and environmental factors present opportunities for enhancement. Addressing these challenges, coupled with the future incorporation of advanced features like load forecasting, ensures the system's evolution toward a more sophisticated and responsive energy management tool.

In conclusion, this project lays a strong foundation for intelligent home energy monitoring, aligning with its initial objectives. The insights gained propel the journey towards sustainable and efficient energy consumption practices. As technology continues to advance, this project paves the way for innovative solutions, ensuring a brighter and more energy-efficient future.

5.2 Potential for Commercialization

The successful development of the Electricity Energy Monitoring System for Home Usage through IoT unveils promising prospects for commercialization. This innovative system, built on a foundation of cost-effectiveness and real-time monitoring capabilities, aligns with the growing demand for intelligent energy solutions in residential settings.

The low-cost design and integration of widely accessible components, such as the ESP32 microcontroller and SCT-013 current sensor, position the system as an attractive option for widespread adoption. Its compatibility with the Blynk app further enhances user accessibility, fostering user-friendly interaction. The system's ability to provide real-time insights into electricity consumption addresses a key need for consumers seeking to manage their energy usage efficiently. This market demand, coupled with the potential for future enhancements, creates a favorable environment for commercialization.

Furthermore, the system's adaptability for integration with other IoT devices and platforms opens avenues for partnerships and collaborative ventures in the rapidly expanding smart home ecosystem. While challenges such as power factor estimation and connectivity during blackouts pose areas for improvement, they also present opportunities for research and development, strengthening the system's competitiveness in the market.

In conclusion, the Electricity Energy Monitoring System holds significant potential for commercialization, offering a scalable and adaptable solution to meet the evolving needs of the residential energy management sector. As the demand for smart and sustainable technologies continues to rise, this project positions itself as a viable and commercially attractive venture in the burgeoning landscape of IoT-based energy solutions.

5.3 Future Works

To address the limitations identified in the project, several avenues for future work can be explored to enhance the system's functionality and performance:

a) Improved Power Factor Estimation

   i. Conduct a comprehensive study on the power factor characteristics of various household appliances to establish a more accurate database for estimation.

   ii. Explore advanced algorithms and machine learning techniques to dynamically adapt power factor calculations based on real-time data, enhancing precision.

b) Enhanced Connectivity During Blackouts

   i. Investigate alternative power sources, such as battery backups or energy storage solutions, to ensure continuous system operation and connectivity during blackouts.

   ii. Explore the integration of a secondary communication channel, such as cellular networks, to maintain connectivity even when Wi-Fi is unavailable.

c) Calibration Refinement for Monitoring Accuracy

   i. Refine sensor calibration processes, incorporating more precise calibration methods and techniques to improve the overall accuracy of current and voltage measurements.

   ii. Investigate the impact of environmental factors on sensor performance and develop strategies to mitigate their influence on monitoring accuracy

d) Market Compatibility and Scalability

   i. Explore opportunities for system integration with other smart home devices and platforms, enhancing its compatibility and scalability within the broader IoT ecosystem.

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APPENDICES

Appendix A Datasheet of ESP32

Product Overview

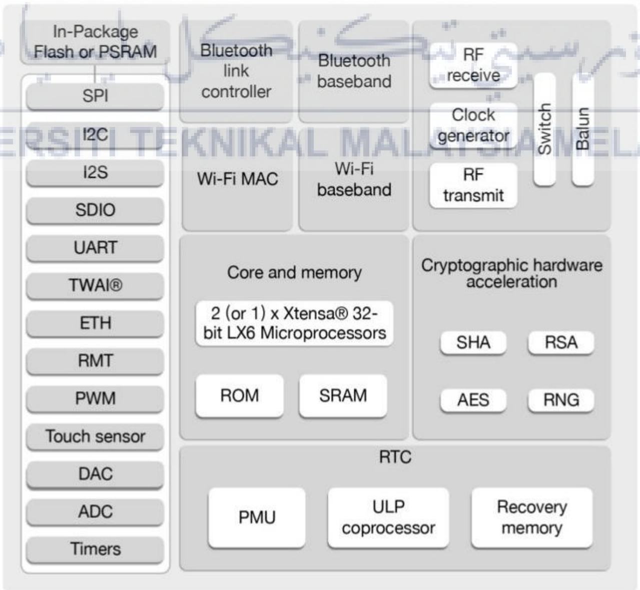
ESP32 is a single 2.4 GHz Wi-Fi-and-Bluetooth combo chip designed with the TSMC low-power 40 nm technology. It is designed to achieve the best power and RF performance, showing robustness, versatility and reliability in a wide variety of applications and power scenarios.

The ESP32 series of chips includes ESP32-D0WD-V3, ESP32-D0WDR2-V3, ESP32-U4WDH, ESP32-S0WD (NRND), ESP32-D0WDQ6-V3 (NRND), ESP32-D0WD (NRND), and ESP32-D0WDQ6 (NRND), among which,

- ESP32-S0WD (NRND), ESP32-D0WD (NRND), and ESP32-D0WDQ6 (NRND) are based on chip revision v1 or chip revision v1.1.
- ESP32-D0WD-V3, ESP32-D0WDR2-V3, ESP32-U4WDH, and ESP32-D0WDQ6-V3 (NRND) are based on chip revision v3.0 or chip revision v3.1.

For details on part numbers and ordering information, please refer to Section 1 ESP32 Series Comparison. For details on chip revisions, please refer to *ESP32 Chip Revision v3.0 User Guide* and *ESP32 Series SoC Errata*.

The functional block diagram of the SoC is shown below.



ESP32 Functional Block Diagram

Features

Wi-Fi

- 802.11b/g/n
- 802.11n (2.4 GHz), up to 150 Mbps
- WMM
- TX/RX A-MPDU, RX A-MSDU
- Immediate Block ACK
- Defragmentation
- Automatic Beacon monitoring (hardware TSF)
- 4 × virtual Wi-Fi interfaces
- Simultaneous support for Infrastructure Station, SoftAP, and Promiscuous modes
  Note that when ESP32 is in Station mode, performing a scan, the SoftAP channel will be changed.
- Antenna diversity

Bluetooth®

- Compliant with Bluetooth v4.2 BR/EDR and Bluetooth LE specifications
- Class-1, class-2 and class-3 transmitter without external power amplifier
- Enhanced Power Control
- +9 dBm transmitting power
- NZIF receiver with –94 dBm Bluetooth LE sensitivity
- Adaptive Frequency Hopping (AFH)
- Standard HCI based on SDIO/SPI/UART
- High-speed UART HCI, up to 4 Mbps
- Bluetooth 4.2 BR/EDR and Bluetooth LE dual mode controller
- Synchronous Connection-Oriented/Extended (SCO/eSCO)
- CVSD and SBC for audio codec
- Bluetooth Piconet and Scatternet
- Multi-connections in Classic Bluetooth and Bluetooth LE
- Simultaneous advertising and scanning

CPU and Memory

- Xtensa® single-/dual-core 32-bit LX6 microprocessor(s)
- CoreMark® score:
  - 1 core at 240 MHz: 504.85 CoreMark; 2.10 CoreMark/MHz

- 2 cores at 240 MHz: 994.26 CoreMark; 4.14 CoreMark/MHz

- 448 KB ROM
- 520 KB SRAM
- 16 KB SRAM in RTC
- QSPI supports multiple flash/SRAM chips

Clocks and Timers

- Internal 8 MHz oscillator with calibration
- Internal RC oscillator with calibration
- External 2 MHz ~ 60 MHz crystal oscillator (40 MHz only for Wi-Fi/Bluetooth functionality)
- External 32 kHz crystal oscillator for RTC with calibration
- Two timer groups, including 2 × 64-bit timers and 1 × main watchdog in each group
- One RTC timer
- RTC watchdog

Advanced Peripheral Interfaces

- 34 × programmable GPIOs
  - 5 strapping GPIOs
  - 6 input-only GPIOs
  - 6 GPIOs needed for in-package flash/PSRAM (ESP32-D0WDR2-V3, ESP32-U4WDH)
- 12-bit SAR ADC up to 18 channels
- 2 × 8-bit DAC
- 10 × touch sensors
- 4 × SPI
- 2 × I2S
- 2 × I2C
- 3 × UART
- 1 host (SD/eMMC/SDIO)
- 1 slave (SDIO/SPI)
- Ethernet MAC interface with dedicated DMA and IEEE 1588 support
- TWAI®, compatible with ISO 11898-1 (CAN Specification 2.0)
- RMT (TX/RX)
- Motor PWM
- LED PWM up to 16 channels

Power Management

- Fine-resolution power control through a selection of clock frequency, duty cycle, Wi-Fi operating modes, and individual power control of internal components
- Five power modes designed for typical scenarios: Active, Modem-sleep, Light-sleep, Deep-sleep, Hibernation
- Power consumption in Deep-sleep mode is 10 μA
- Ultra-Low-Power (ULP) coprocessors
- RTC memory remains powered on in Deep-sleep mode

Security

- Secure boot
- Flash encryption
- 1024-bit OTP, up to 768-bit for customers
- Cryptographic hardware acceleration:
  - AES
  - Hash (SHA-2)
  - RSA
  - ECC
  - Random Number Generator (RNG)

Applications

With low power consumption, ESP32 is an ideal choice for IoT devices in the following areas:

- Smart Home
- Industrial Automation
- Health Care
- Consumer Electronics
- Smart Agriculture
- POS machines
- Service robot
- Audio Devices
- Generic Low-power IoT Sensor Hubs
- Generic Low-power IoT Data Loggers
- Cameras for Video Streaming
- Speech Recognition
- Image Recognition
- SDIO Wi-Fi + Bluetooth Networking Card
- Touch and Proximity Sensing

Appendix B Datasheet of SCT-013-000V

SCT013 YHDC®

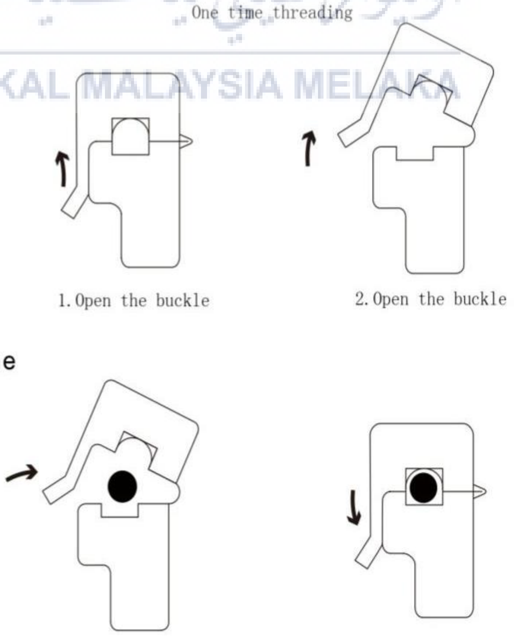
SCT013 Split core current transformer

Product features

- Safety lock buckle，Simple installation
- Audio connector output
- Lead type output，The length can be customized
- Suspended mounting

Installation diagram

One time threading



1.Open the buckle

2.Open the buckle

3.Drop lead

4.Fasten the buckle

Product application

- Portable instrument
- Household metering
- Monitoring the load of the machine

Product advantage

- Small volume，Light weight
- Low cost
- High turns，High precision

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YHDC 1992 ®

Typical technical index:

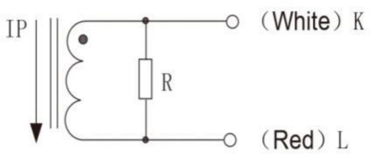
- •Core material——ferrite
- •Working voltage——Phase voltage≤660V
- •Working temperature——-25℃～+60℃
- •Storage temperature——-30℃～+90℃
- •Frequency range——50Hz～1KHz
- •Electrical resistance—— input（Bare conductor）/output AC 800V/1min 5mA 50Hz
  output /Outer shell AC 3.5KV/1min 5mA 50Hz

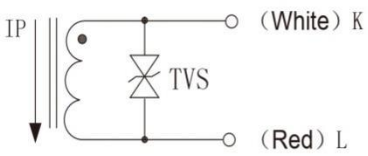
Electrical parameters

Model	Input current	output	Turns	Load resistance	Accuracy	linearity	weight
SCT013-000	100A	50mA	1：2000	10Ω	1%	1%	50g
SCT013-005	5A	1V	-	built-in	1%	1%	50g
SCT013-010	10A	1V	-	built-in	1%	1%	50g
SCT013-015	15A	1V	-	built-in	1%	1%	50g
SCT013-020	20A	1V	-	built-in	1%	1%	50g
SCT013-025	25A	1V	-	built-in	1%	1%	50g
SCT013-030	30A	1V	-	built-in	1%	1%	50g
SCT013-050	50A	1V	-	built-in	1%	1%	50g
SCT013-060	60A	1V	-	built-in	1%	1%	50g
SCT013-000V	100A	1V	-	built-in	1%	1%	50g

Model	Input current	output	Turns	Load resistance	Accuracy	linearity	weight
SCT013	5A	0.333V	-	built-in	1%	1%	50g
SCT013	10A	0.333V	-	built-in	1%	1%	50g
SCT013	15A	0.333V	-	built-in	1%	1%	50g
SCT013	20A	0.333V	-	built-in	1%	1%	50g
SCT013	25A	0.333V	-	built-in	1%	1%	50g
SCT013	30A	0.333V	-	built-in	1%	1%	50g
SCT013	50A	0.333V	-	built-in	1%	1%	50g
SCT013	60A	0.333V	-	built-in	1%	1%	50g
SCT013	100A	0.333V	-	built-in	1%	1%	50g

Wiring schematic diagram:

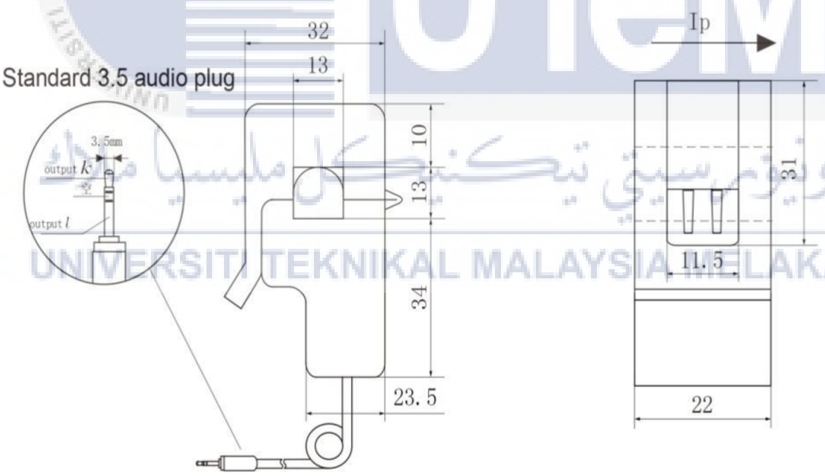




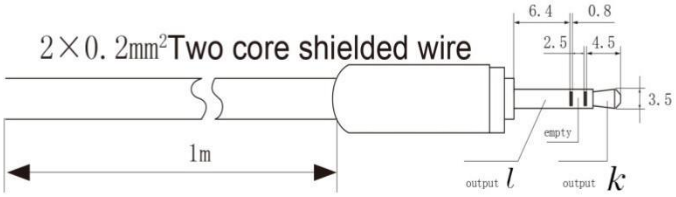
Built-in with sampling resistance
Voltage output type
Secondary are not allowed to short circuit

TVS: Transient voltage suppressor
Current output type
Secondary does not allow open circuit

Dimensions (in mm):



Front view   Side view



Standard three-pin plug diagram