IOT BASED SMART SINGLE WALL OUTLET

Phang Yee Ren

UNIVERSITI TUNKU ABDUL RAHMAN

IOT SMART SINGLE WALL OUTLET

Phang Yee Ren

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Electrical and Electronic Engineering

Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature :

Name : Phang Yee Ren

ID No. : 1702255

Date : 24/4/2022

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"IoT based Smart Single Wall Outlet"** was prepared by **Phang Yee Ren** and has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Electrical and Electronic Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature :

Supervisor : See Yuen Chark

Date : 24 April 2022

Signature :

Co-Supervisor :

Date :

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ABSTRACT

Wall outlets are devices that supply electrical power to appliances and are widely used in the residential, commercial, and industrial sectors. Due to economic growth and population expansion, the demand for electricity in all these sectors surges to a new high every year. Subsequently, the generation of electricity is required to expand at a tremendous rate. To control the demand, Tenaga Nasional Berhad (TNB) introduced the Enhanced Time of Use (ETOU) scheme to offer different tariff rates for commercial and industrial end-users at different times of the day. Fixed electricity tariffs no longer represent actual electricity prices. This report presents an Internet of Things (IoT)-based smart wall outlet system that adapts to the ETOU scheme. With the aid of a central console, this system can link a network of wall outlets together and manage them via the Node-Red or Android application. The network enables this system to measure the real-time electricity bill and current usage of each room in a house, office, or factory. All this information will be visualised in a floorplan layout. Also, the power consumption of appliances connected to a single wall outlet can be predicted based on the user’s usage behaviour. The developed energy consumption predictive model can achieve an accuracy of up to 90% in predicting the wall outlet power consumption.

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LIST OF SYMBOLS / ABBREVIATIONS

AC	Alternating Current
ANN	Artificial Neural Network
API	Application Programming Interface
AWS	Amazon Web Service
CAGR	Compound Annual Growth Rate
DB	Database
ETOU	Enhanced Time Of Use
IFTTT	If This Then That
IoT	Internet of Things
MAE	Mean Absolute Error
MQTT	Messaging Queuing Telemetry Transport
NoSQL	Not Only Structured Query Language
NTP	Network Time Protocol
OTA	Over The Air
PIR	Passive Infrared
SBC	Single Board Computer
SDK	Software Development Kit
SSH	Secure Shell
SVG	Scalable Vector Graphics
SVM	Supervised Machine Learning
TNB	Tenaga Nasional Berhad
RPi	Raspberry Pi
URL	Uniform Resource Locator
UTC	Coordinated Universal Time

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

A wall outlet is a utility to connect electrical appliances to an alternating current (AC) power supply. When electrical appliances are plugged into the wall outlet, current flows through the circuit inside electrical appliances, enabling them to operate. The first two-pin electrical outlet was invented in the 1880s after the emergence of commercial electric power (Fred, 1986). At that time, the wall outlet is mainly used for powering up light bulbs. Until today, wall outlets can be used in many sectors such as residential and industrial. The wall outlet is mainly used for powering up electrical appliances.

Over a century, the technology of wall outlets keeps improving. By using the technology of the Internet of Things (IoT), there are many functions associated with wall outlets nowadays. For instance, If This Then That (IFTTT) support, voice command through Amazon Alexa or Google Assistant, energy monitoring, energy usage reporting, etc.

With IoT, people nowadays can enjoy the convenience of smart homes and their assistive services, such as intelligent voice assistance. The life quality of people enhances by utilizing smart home devices. Smart wall outlets with remote controlling functions are more favoured by consumers when compared to other in-built smart devices such as televisions, air-conditioners, fans, etc (Fortune Business Insights, 2020). This is due to its lower cost and smart features manageable mobile devices. The market of smart wall outlets is expected to expand by 36.2% from 2021 to 2028, according to their compound annual growth rate (CAGR) (Manuel, 2021). Figure 1.1 shows the global CAGR of the smart wall outlet. Figure 1.1 shows the CAGR of the smart wall outlet until 2028.

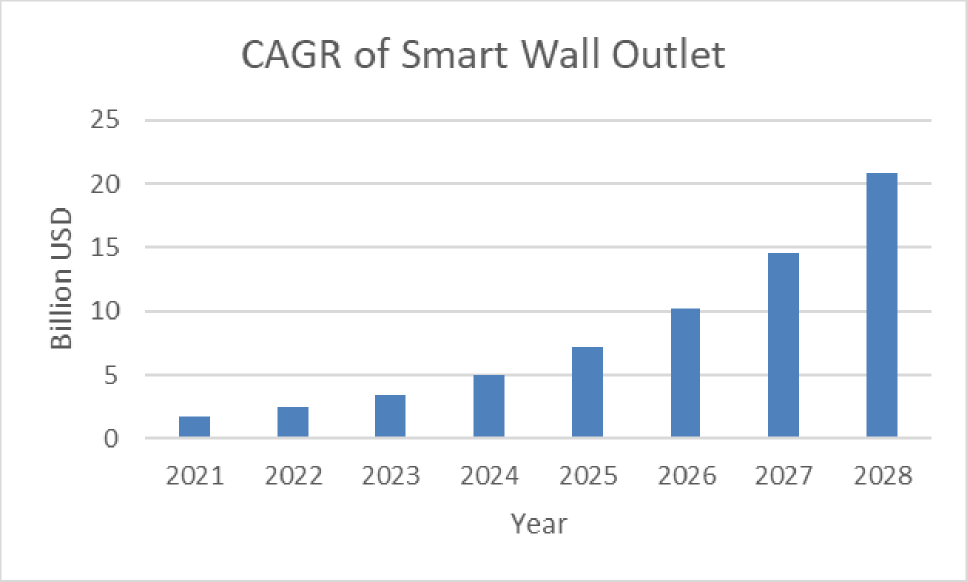


Figure 1.1: Global CAGR of Smart Wall Outlet (Manuel, 2021)

1.2 Problem Statement

In recent years, the worldwide trend in electrical energy consumption has grown due to economic expansion and population increase. The consumption is evident during these two years as most of us work from home due to the COVID-19 pandemic. The housing sector's energy usage has increased by 30% over the previous year (Krarti and Aldubyan, 2021).

Currently, in Malaysia, we are transforming from a second to a first-world country that heavily involves the service-based and manufacturing sectors which consumes a lot of energy. Malaysia's energy consumption has reached 116 million tonnes of oil equivalent in 2020 (Hassan et al., 2014). According to Munir et al., residential consumers consume 24,709 gigawatts of electricity, whereas commercial consumers consume 38,645 gigawatts of electricity (Munir et al., 2020). Due to constraints in electrical energy supply systems, Suruhanjaya Tenaga (ST) or the Energy Commission aims to minimize end-user energy usage through various methods, such as implementing high electricity tariff, tariff based on time period, and demand response programs (Aldhshan et al., 2021). Tenaga Nasional Berhad (TNB) introduced the Enhanced Time of Use (ETOU) scheme to charge different tariff rates for commercial and industrial end-users at different times of the day. Figure 1.2 shows the 24-hour load profile for Malaysia on a working day (Muzmar et al., 2015). Figure 1.3 shows the ETOU time zones. By comparing Figures 1.2 and 1.3, the higher electricity demand period will be labelled as either the mid-peak or peak period. The tariff rate will be charged higher during mid-peak and peak hours. Fixed electricity tariffs no longer represent actual electricity prices. ETOU has become a self-regulating tool for customers to manage their electricity usage and bills. Therefore, end-users must lower their energy usage by modifying their energy use practices and employing energy-efficient equipment and gadgets.

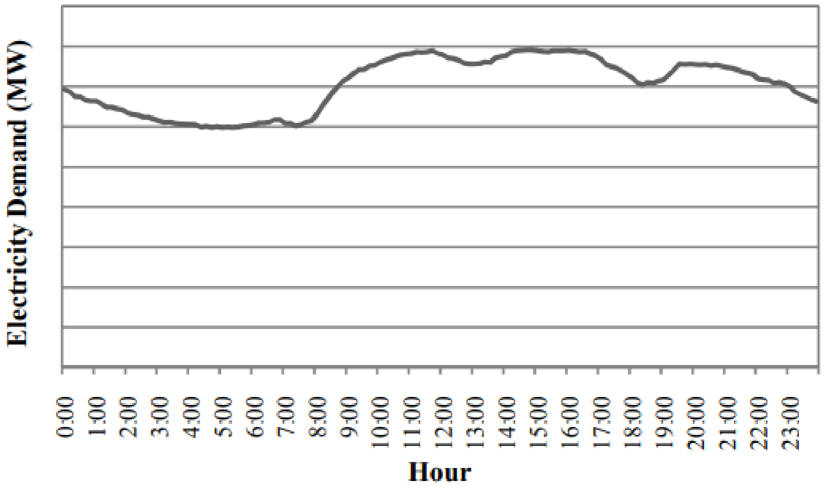


Figure 1.2: 24-hour Load Profile for Malaysia on a Working Day (Muzmar et al., 2015)

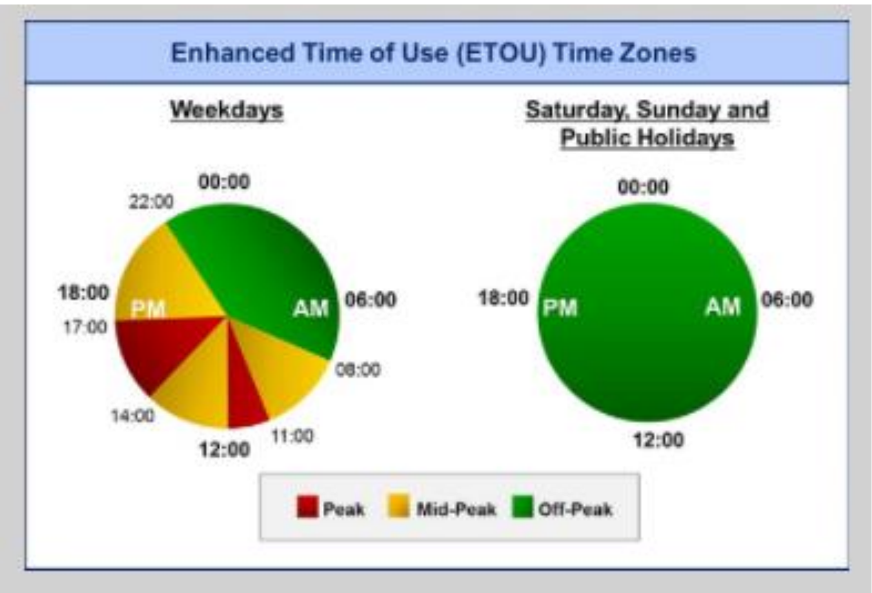


Figure 1.3: ETOU Time Zones

Research shows that regularly supplying data on electricity usage patterns may successfully reduce the habit of user's electricity wastage. According to D.Vine et al. (2013), providing energy use information may change appliance usage patterns and decrease energy consumption by up to 20%. Tenaga Nasional Berhad (TNB) intends to deploy Advanced Metering Infrastructure (AMI), also known as smart meters, in 8.3 million homes in Malaysia by 2022. The meter will compute the energy consumption and provide the pattern of the daily electricity usage. The AMI can use the companion app, the myTNB app, to provide electricity consumption at up to 30-minute intervals (Poovenraj Kanagaraj, 2021). However, the push notification reminding customers of their monthly usage is currently not applicable in the app. Besides that, users cannot identify which terminal is draining electricity, as the smart meters only show the overall usage. As a result, efforts are undertaken in this research to design a smart socket that tackles the problems mentioned above.

1.3 Aim and Objectives

This project's main objective is to build an IoT based smart wall outlet. The breakdowns of the main objective are:

- To design multiple wall outlets that can be remotely controlled and monitored via mobile apps and Node-Red dashboard.
- To integrate the electricity consumption calculation by considering the Enhanced Time of Use (ETOU) scheme for commercial and industrial.
- To develop a power consumption predictive model for appliances connected to a single wall outlet.

1.4 Scope and Limitation of the Study

The scope of this project is to construct a smart wall outlet with remote control and monitoring capability via Node-Red and a custom Android application; linking the smart wall outlet network; integrating the ETOU scheme into the system; and constructing a power consumption predictive model for the wall outlet.

A central console will form a network that links multiple wall outlets together. The data transmitted by each wall outlet will be received and processed by the central console, which will then be stored in the cloud. Meanwhile, the Android application will access the cloud and show the data in the user interface. Message Queuing Telemetry Transport (MQTT) is the communication protocol utilised in this research. This is a low-power, stable, and dependable communication protocol.

The limitation of the study is that the current sensor is a hall effect current sensor, and it is very sensitive to electromagnetic fields. A slight deviation can occur if the surrounding electromagnetic field is very strong.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the literature review will be conducted based on the features of a smart wall outlet, such as power monitoring and remote control. Also, the smart wall outlet that exists in the market will be reviewed. Reviews will focus on the methodology applied. Conference papers and journals are the primary sources to be reviewed.

2.2 Power Monitoring

Musleh et al. proposed a smart plug that performs power monitoring and controlling (Musleh et al., 2017). The system architecture of the smart plug is illustrated in Figure 2.1. The system comprises of one master and several slave sockets. By using Zigbee communication, the commands from the master can be sent to the slave, and the power measurements data from the slave can send back to the master. The slave units consist of current sensors, voltage sensors, microcontroller, and Zigbee connectivity, whereas the master unit consists of Raspberry Pi and Zigbee connectivity.

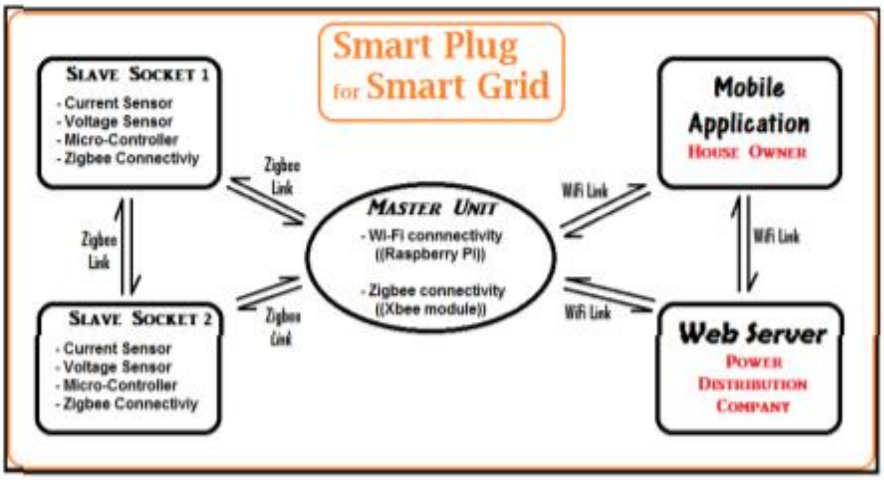


Figure 2.1 System Architecture of the Smart Plug. (Musleh et al., 2017)

Chupong and Plangklang proposed a home energy monitoring system with an electricity bill forecasting application (Chupong and Plangklang, 2017). The energy usage is monitored by using a multi-functional energy meter. Then, a server based on Node JS language is set up and connected to the energy meter. A database based on MongoDB is created so that users can retrieve data from the database and design applications in the form of an Application Programming Interface (API).

Vijeesh et al. proposed a system for household consumers that are connected to the Tamil Nadu Power System to save energy and calculate billing in real-time (Vijeesh et al., 2018). The block diagram of the system is shown in Figure 2.2. By applying a smart meter and controller, a real-time tariff calculator can be implemented and calculate the billing instantly.

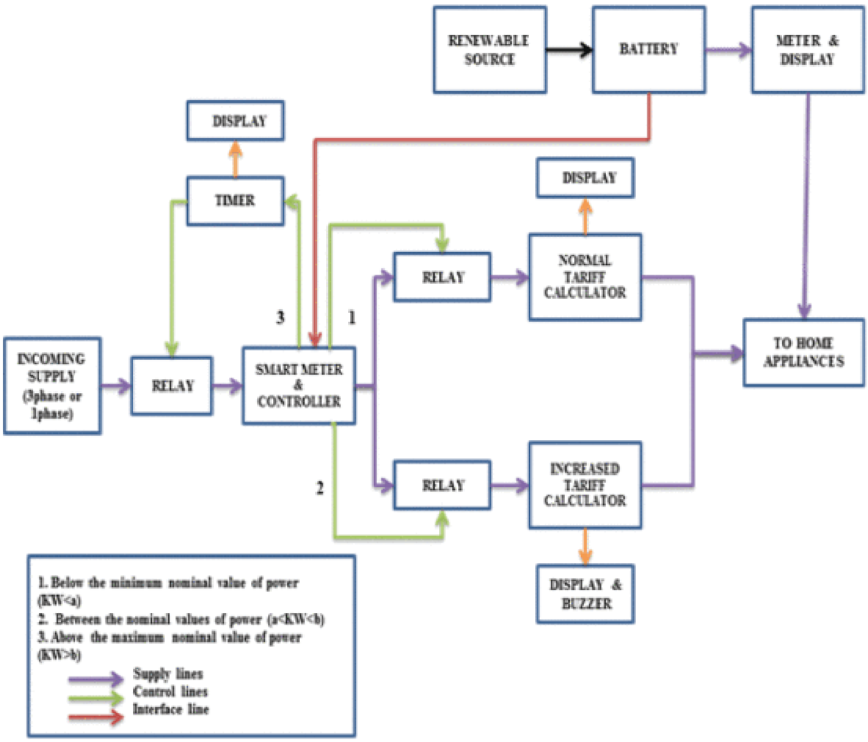
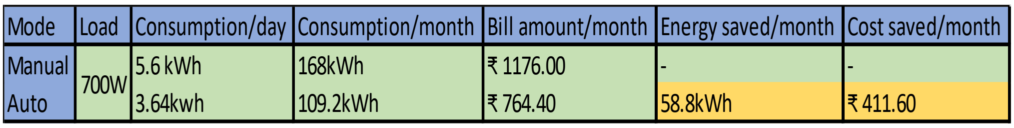


Figure 2.2: Block Diagram of Energy Saving and Smart Billing System

Harsha and GN designed a home automated power-saving system by using a passive infrared (PIR) sensor (Harsha and GN, 2020). The PIR sensor will catch the movement of humans and send a signal to a microcontroller. The presence of a human is identified, and all the appliances connected to the electromechanical relay can be controlled based on the existence of humans.

For instance, the lamp will be turned off automatically when no human is present inside the room. The results showed that the system can save ₹ 411.60 (RM23) every month. Table 2.1 shows the results of the system.



Mode	Load	Consumption/day	Consumption/month	Bill amount/month	Energy saved/month	Cost saved/month
Manual	700W	5.6 kWh	168kWh	₹ 1176.00	-	-
Auto		3.64kwh	109.2kWh	₹ 764.40	58.8kWh	₹ 411.60

Table 2.1: Results of Home Automated Power Saving System (Harsha and GN, 2020)

2.3 Remote Controlling

Tsai et al. designed an energy control system specialize in residence by using a smart energy control scheme (Tsai et al., 2016). The system architecture is shown in Figure 2.3. This research aims to minimize the power consumption of appliances without using sensors. By utilizing an energy controller, users can select their smart sockets to operate under four conditions, which are automatic control, user control, peak-time control, and energy-limit control. ZigBee wireless communication protocols act as a medium between the smart wall outlets and the home server. The results are impressive as there is a 43.4% energy reduction for a water dispenser in a day.

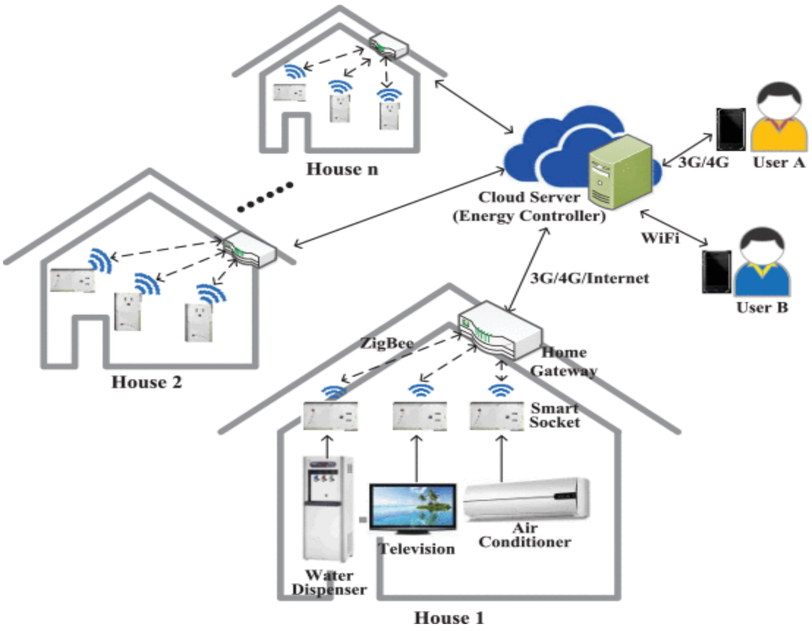


Figure 2.3: System Architecture of the Energy Control System (Tsai et al., 2016)

Yue and Ping have proposed a voice-activated smart home system (Yue and Ping, 2017). This system utilized the Telegram application and voice assistant services from Microsoft and Amazon. The central console to process commands is a Raspberry Pi. Ngrok provided a service to generate Uniform Resource Locator (URL). After receiving the commands, the Raspberry Pi GPIO pins will react with the command and control on and off of appliances. Figure 2.4 illustrates the block diagram of the voice-activated smart home system.

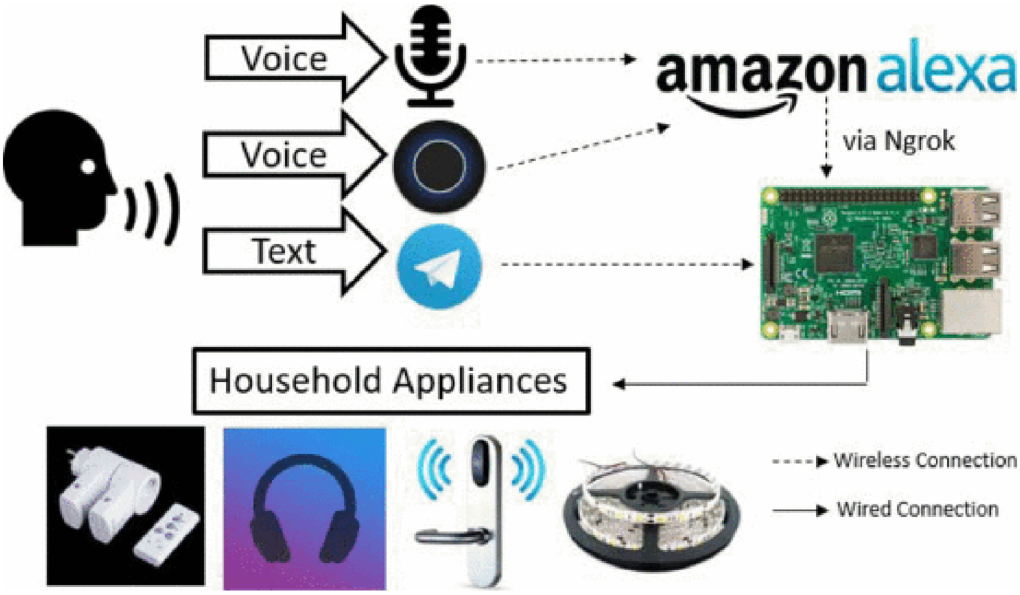


Figure 2.4: Block Diagram of Voice-Activated Smart Home System. (Yue and Ping, 2017)

2.4 Smart Wall Outlet in the Market

Various types of smart wall outlets exist in the market, with prices ranging from RM30 to RM120 per unit. According to Silverio-Fernández et al., the term 'smart' can be defined as context-awareness, humanless control, and device interconnection (Silverio-Fernández et al., 2018). Thus, a smart wall outlet can be understood as data collection capability, lesser human involvement, and connection to other devices such as smartphones.

2.4.1 Amazon Smart Plug

Amazon smart plug is developed by Amazon Company, and it is sold for around RM120 per unit. The attractive point of this smart plug is the combination of Voice Assistant. Users can control the smart plug using the microphone of smartphones through Alexa. This is a huge advantage for people with disabilities. Appliances can be easily controlled at any corner of the house. Furthermore, timers can be set to schedule the on and off time of appliances. With this function, electric energy can be saved as the appliances will be off automatically (Insider, 2020). Figure 2.5 shows the product of the Amazon Smart Plug.

Figure 2.5: Amazon Smart Plug

2.4.2 Meross Smart Plug

Meross Smart Plug is designed by Meross Company, and the price is around RM80 per unit. This smart plug has the same functionality as Amazon smart plug, which includes app control capability, schedule on and off, and voice assistant integration. However, the most significant attractive point of this smart plug is the safety functionality. This smart plug has IP44 waterproof housing, which is suitable for both indoor and outdoor usage. There is an overload protection circuit as well to protect the smart plug from overloading. Last but not least, this smart plug has fire retardant housing to prevent this socket from catching fire. Figure 2.6 shows the safety features of the Meross Smart Plug (Meross, n.d.).

Figure 2.6: Safety Features of Meross Smart Plug

2.4.3 Xiaomi Smart Plug

Xiaomi Smart Plug is invented by Xiaomi Company, and the price is around RM90 per unit. Apart from the same functionality mentioned in Amazon Smart Plug, the biggest advantage of the Xiaomi smart plug is due to the powerful phone application by Xiaomi, which is the Mi app. By using a centralized console or server, the Mi app can integrate the smart plugs with various sensors and let the user define the switching on and off of smart plugs when sensors detect something. This feature is handy at night when users pass by a corridor; the lights can be switched on automatically after sensors detect the movement (Mi, n.d.). Figure 2.7 shows the diagram of the Xiaomi Smart Plug.

Figure 2.7: Xiaomi Smart Plug

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

This chapter will discuss plans to design a smart wall outlet. The system architecture includes both software and hardware implementation.

3.2 System Architecture

The system architecture in the block diagram is shown in Figure 3.1. The system architecture is categorised into four main parts: wall outlets, central console (server), Android smartphone application, and machine learning.

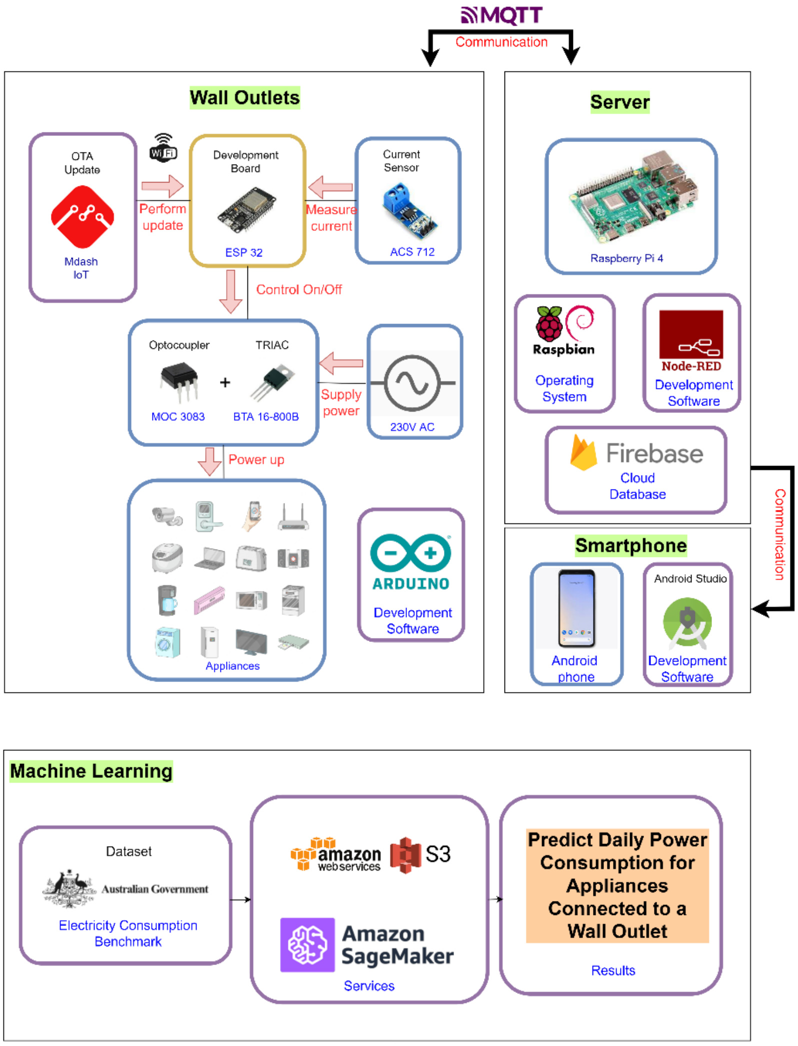


Figure 3.1: System Architecture of Smart Wall Outlet

3.2.1 Wall Outlets

The wall outlets contain three main functions, which are: controlling the state of the wall outlet, monitoring power usage of the appliances that are connected to the wall outlet and communicating with the central console.

The development board used in the wall outlet is ESP 32 DevKit V1. Arduino IDE is the development software selected to write and upload the codes for ESP32. ESP32 will integrate with the ACS 712 current sensor to measure the current consumption of the appliances that are connected to the wall outlet. The optocoupler and the TRIAC are used to control the state of the wall outlet upon receiving the signal from ESP 32. Meanwhile, ESP32 will communicate with the central server to transmit data and receive signals through MQTT.

3.2.2 Central Console (Server)

Raspberry Pi server is used as a central console to communicate with multiple wall outlets. The operating system running on this Raspberry Pi is Raspbian. It is a Debian-based operating system that is specially made for the Raspberry Pi. The Raspberry Pi is controlled by a Windows operating system computer’s Command Prompt. To perform this action, a Secure Shell (SSH) network is required to be established. An SSH network is an encrypted communication protocol that allows users to have an assessment between two computers over an unsecured network.

By implementing a browser-based flow editor called Node-Red, the server can form a network linking multiple wall outlets together. The communication between the wall outlets and central console is called MQTT. MQTT is a lightweight messaging protocol that transfers messages within a network with the least internet bandwidth. In this case, the server will act as an MQTT broker, and the wall outlets act as MQTT clients. Bi-directional communication can be achieved with encrypted messages that level up security.

The server also functions to upload data from the wall outlets to the Firebase so that users can monitor the data remotely through a phone application.

3.2.3 Android Smartphone Application

An Android application is being developed to monitor the wall outlets' condition in real-time. Also, the wall outlets can be remotely controlled using the application. The development software selected is Android Studio. The reason is that Android Studio provides an on-the-go development environment such as a Gradle-based system. It is a system that includes multiple dependencies and toolkits that support various Google services.

The database used for the application is Google Realtime Firebase. Firebase is selected because both Android Studio and Firebase are from Google, and there will be no compatibility issues.

3.2.4 Machine Learning and Electricity Consumption Benchmark Datasets

Machine learning is applied to predict the daily power consumption of appliances that are connected to a single wall outlet.

Electricity consumption benchmark datasets from the Australian Government were selected to do the machine learning. Currently, there is no free daily electricity consumption dataset utilizing the smart meter in Malaysia, thus the dataset from Australia is used. The dataset was obtained from the Department of Industry, Science, Energy, and Resources of the Australian Government (Department of Industry, 2020). The dataset comprises power consumption data for 25 Victorian residences every 30 minutes in Watt-hours from April 1, 2012, to March 31, 2014, after the smart meter was installed. The datasets are stored in the Amazon S3 bucket.

Amazon SageMaker Canvas is selected to perform machine learning. The reason is that Amazon SageMaker Canvas is an industrial standard service that provides business analysts with the ability to generate high-accuracy machine learning predictions.

3.3 Software, Technique Implementation and Services Used

This section discusses the software and services used in this project.

3.3.1 Arduino IDE

Arduino IDE is software for developers to design and upload the firmware to Arduino compatible boards. The language supported includes C and C++. Arduino IDE contains abundant resources created by a worldwide community of makers.

3.3.2 OTA Update

OTA update allows the firmware to be transferred to the microcontroller wirelessly. The traditional way to upload new firmware to the microcontroller is through a data cable connecting to the computer. The traditional way is inconvenient and abundant. OTA updates can replace the traditional method, making the firmware update process effective through Wi-Fi. By implementing OTA updates, the new firmware can be uploaded through Wi-Fi. In the future, if this wall outlet is available in the market, the wall outlet can keep on updating accordingly.

3.3.3 Node-Red

Node-Red is a preinstalled web browser-based flow editor in Raspberry Pi (NodeRed, 2016). It is founded by IBM and become an open-source project in 2016. It provides a wide range of applications to assemble service flows for IoT projects by using Java Script.

3.3.4 Cloud

Cloud is a database (DB) that runs on a server and can be accessed via the internet (Cloudfare, n.d.). The cloud service provider is Firebase. Firebase is a cloud-hosted NoSQL DB using Google infrastructure. Firebase is used to store all the sensor data. Firebase utilizes its Software Development Kit (SDK) to store the data on a local cache when the internet is not available. When the internet is connected back, the local data will be uploaded to the cloud again.

3.3.5 Android Studio

Android Studio is an IDE for Google Android smartphone development. The programming language used is Java, Kotlin or C++. Android Studio is utilized to create an Android smartphone application for this system. The minimum operating system requirement is Android 5.0 as less than 0.1 percent of smartphones used is running on operating system lower than Android 5.0. Apps are the medium of interaction between the users and the smart wall outlet.

3.3.6 Amazon S3 Bucket

Amazon S3 Bucket is an Amazon Web Service (AWS) that provides data storage through a web service interface. Datasets are required to be uploaded to the S3 Bucket before starting the machine learning process in Amazon SageMaker Canvas.

3.3.7 Amazon Sage Maker Canvas

Amazon Sage Maker Canvas is a machine learning instrument that uses a visual point-and-click interface to construct a prediction model. Users may instantly connect and access data from the cloud and on-premises data sources, merge datasets and generate unified datasets for training machine learning models with SageMaker Canvas. SageMaker Canvas finds and corrects data mistakes automatically, as well as analysing data preparation for machine learning.

3.4 Hardware Implementation

This section is about the selection of hardware required for this project. The specification and properties of the hardware will be looked into.

3.4.1 Raspberry Pi 4 Model B

Raspberry Pi 4 (RPi) is a small single-board computer (SBC) that utilizes a Broadcom system on a chip (SoC). RPi operates as a server or central console that communicates with all the subsystems in the smart wall socket outlets. The model used is 2GB RAM and 16GB ROM. Figure 3.2 shows the structure of Raspberry Pi 4 Model B.

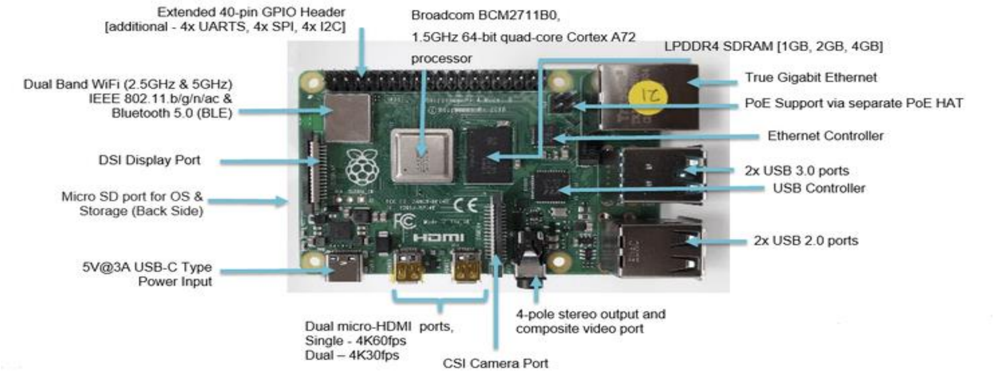


Figure 3.2: Structure of a Raspberry Pi 4 Model B

3.4.2 ESP 32 DevKit V1

ESP 32 DevKit V1 is a low-cost microcontroller under the family of ESP32. ESP 32 is developed by Espressif Systems using a 40 nm process. Figure 3.3 shows the pinout diagram of ESP 32 DevKit V1 and TTGO T-Display respectively. ESP 32 has several features such as:

1. ESP 32 contains a 32 bit-processor with a dual-core CPU that runs at 240 MHz.
2. ESP 32 supports multiple protocols such as inter-integrated circuit, serial peripheral interface, pulse width modulation channel, universal asynchronous receiver-transmitter, an analogue-digital converter, and digital-analogue converter.

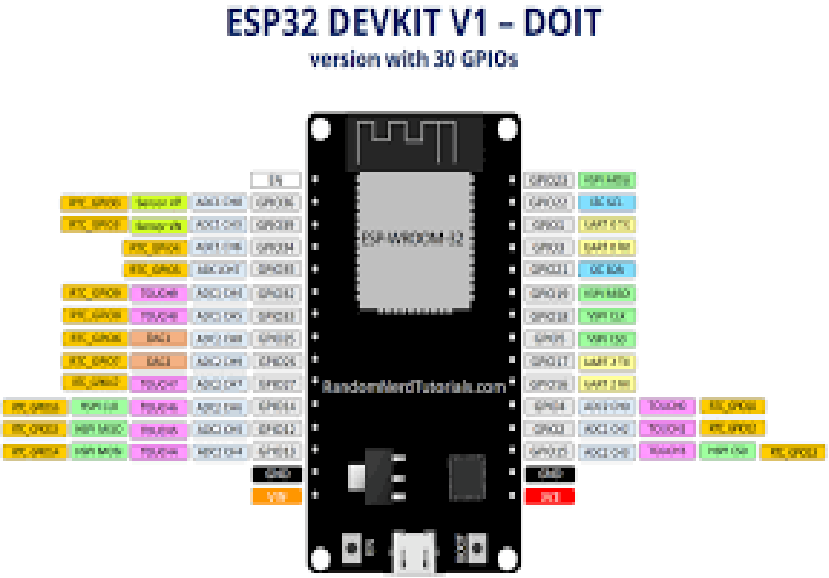


Figure 3.3: Pinout Diagram of ESP 32 DevKit V1

3.4.3 TRIAC

TRIAC is used in AC power control applications to control the switching of high voltages or high currents. In this project, TRIAC is used to switch the on and off of the wall outlet. The model chosen is BTA16-800B. The criteria to be considered for a TRIAC are the repetitive peak off-state voltage, V_{RPM}, and the RMS on-state current, $I_{T(RMS)}$. V_{RPM} is the maximum peak voltage that the TRIAC can withstand, whereas $I_{T(RMS)}$ is the maximum RMS current that can pass through the TRIAC. The voltage rating of a socket outlet in a residential house is 230-240V with a current rating of 13 A. BTA16-800B has a V_{RPM} of 800V and $I_{T(RMS)}$ of 16A. BTA16-800B fulfils all the requirements. The pinout diagram and mechanical drawing of the BTA16-800B are illustrated in Figure 3.4.

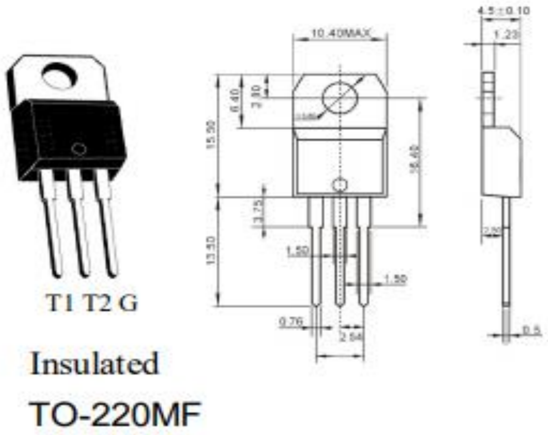


Figure 3.4: Pinout Diagram and Mechanical Drawing of BTA16-800B

3.4.4 Optocoupler

Optocoupler is used to transmit the electrical signal between two isolated circuits using infrared light. The primary function is to isolate the low-voltage devices from the high-voltage circuits. The model chosen is MOC 3083. The criteria considered for an optocoupler are the maximum working insulation voltage, V_{IORM}, and the infrared LED triggering current, I_{FT}. V_{IORM} is the maximum voltage that the optocoupler can isolate between devices, whereas I_{FT} is the minimum current required for the LED to emit the infrared signal. The V_{IORM} of MOC 3083 is 850V, and the I_{FT} is 5mA. Therefore, MOC 3083 is capable of isolating 230-240V residential house voltage.

Assume the output voltage of a microcontroller is 3V; with a resistor of 330Ω, the I_{FT} of 10mA can power up the infrared LED. Figure 3.5 shows the schematic diagram of MOC 3083.

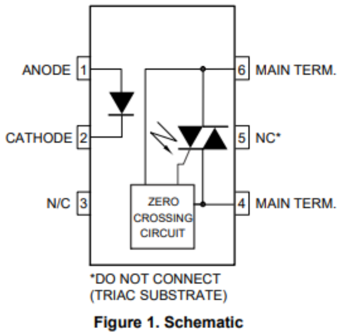


Figure 3.5: Schematic Diagram of MOC 3083

3.4.5 ACS712 Current Sensor Module

ACS712 current sensor is used to measure the current consumed by the appliances connected to the smart wall outlet. The ACS 712 is a linear Hall sensor circuit with low offset voltage. According to Bio-Savart law, a magnetic field will be generated by a constant electric current. The equation can be expressed as $B = \frac{\mu_0 I}{2\pi r}$. From this equation, the magnetic field, B is proportional to the current, I. The integrated Hall IC in ACS 712 utilizes this theory by converting the magnetic field into a proportional voltage. Figure 3.6 shows the typical application of ACS712. The features of ACS 712 include:

1. ACS 712 is integrated with a monolithic hall-effect-based IC, making it reliable and low power loss.
2. ACS 712 has very low magnetic hystereses with 10 mV/A sensing sensitivity.

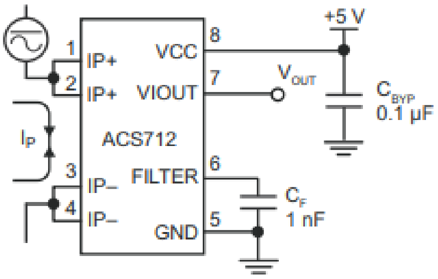


Figure 3.6: Typical application of ACS 712

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter will discuss the results and discussion of the smart wall outlet. Findings and data obtained will be elaborated on this chapter.

4.2 Hardware Prototype

There are two types of hardware prototypes built in this project, which include one central console, and two smart wall outlets.

4.2.1 Central Console

Raspberry Pi 4B acts as the central console. It is covered with a white case to prevent connection to the ground and a short circuit. Figure 4.1 illustrates the picture of the central console.

Figure 4.1: Central Console

4.2.2 Smart Wall Outlet

The prototype of the smart wall outlet is initially built and tested on the breadboard. The prototype is then redesigned onto a 2 layers Printed Circuit Board (PCB) board using Easy EDA software. The dimension of the PCB is designed to be 75mm*70mm so that it can fit into the case of a conventional Malaysia wall outlet.

Figure 4.2 shows the prototype of 2 smart wall outlets built on a breadboard. Figure 4.3 shows the schematic diagram of the smart wall outlet. Figure 4.4 shows the PCB layout of the smart wall outlet. Red colour layout is the first layer, whereas blue colour is the second layer. Figure 4.5 shows the front and back views of the PCB.

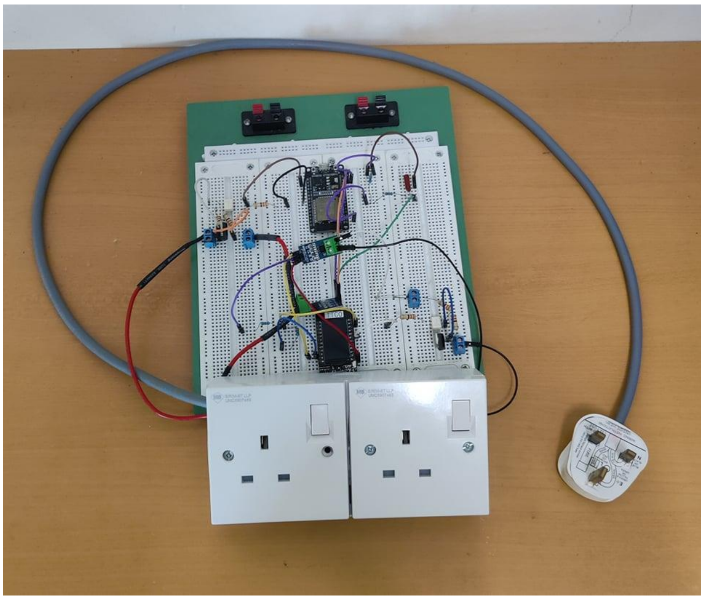


Figure 4.2: Prototype of Smart Wall Outlet Built on a Breadboard

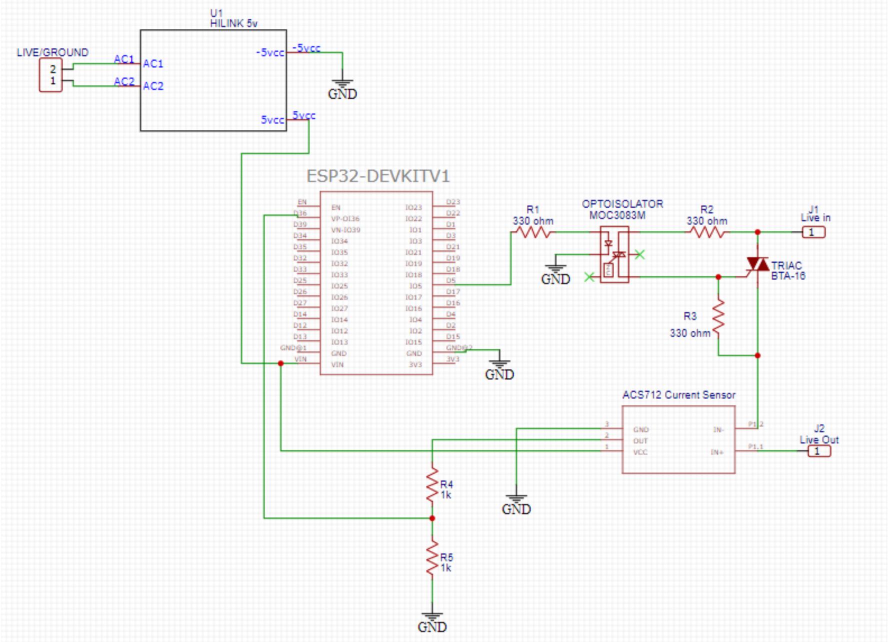


Figure 4.3: Schematic Diagram of Smart Wall Outlet

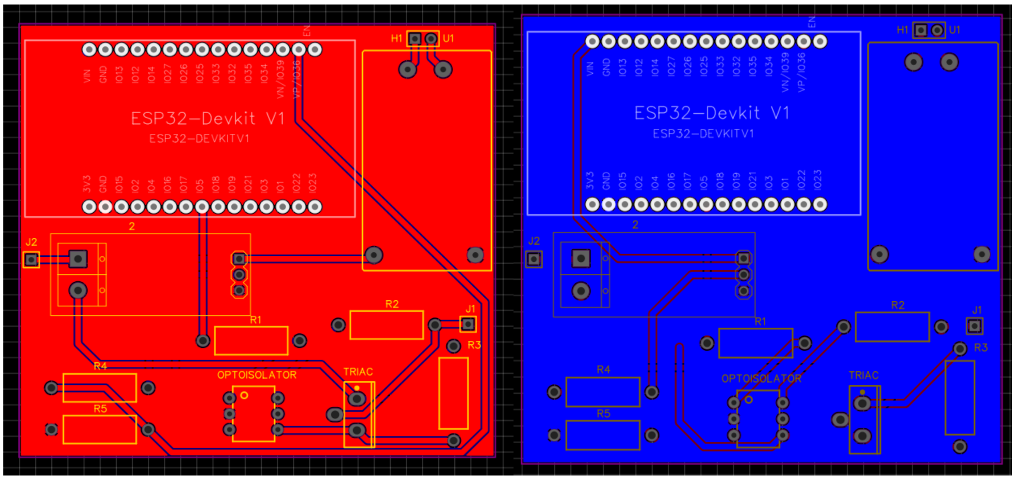


Figure 4.4: Two Layers PCB Layout of Smart Wall Outlet

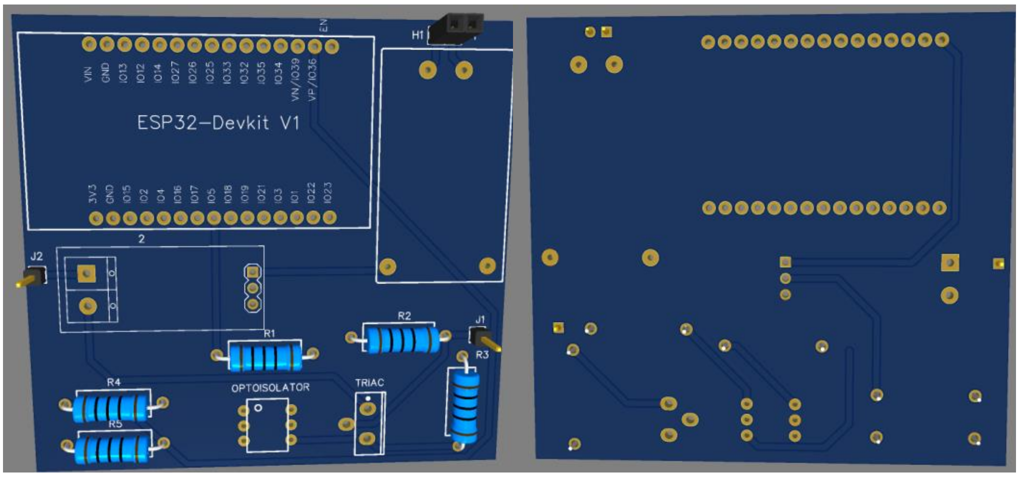


Figure 4.5: Front and Back View of the PCB

4.3 Software and Technique Used for Smart Wall Outlet

There are two ways to control and monitor the smart wall outlets remotely. The first approach is through the Node-Red dashboard. Users can access the dashboard by browsing the IP address of the central console within the local area network. The second approach is through the Android application when outside of the local area network.

4.3.1 Node-Red

The Node-Red script is set up and run on the central console. Users may access the Node-Red dashboard to operate and monitor the wall outlets by browsing the IP address of the central console within the local area network.

The dashboard is divided into three sections, which are the wall outlet section, floorplan section and electricity tariff section.

Figure 4.6 is the script for the central console to receive data from the wall outlets through the MQTT protocol. The messages include current, power consumption, electricity bill and tariff type. Then, the data will be displayed on the dashboard and sent to the Firebase.

Figure 4.7 is the script for the central console to transmit data to the wall outlets. Initially, the state of the wall outlet will be read from Firebase. If the states are changed on the Android application, Firebase will update the state in Node-Red as well. Meanwhile, the on/off state messages will be transmitted to the wall outlet via MQTT protocol. The ‘Floorplan’ node is a widget used to design Scalable Vector Graphics (SVG) in the dashboard. It is utilized to design the Floorplan section.

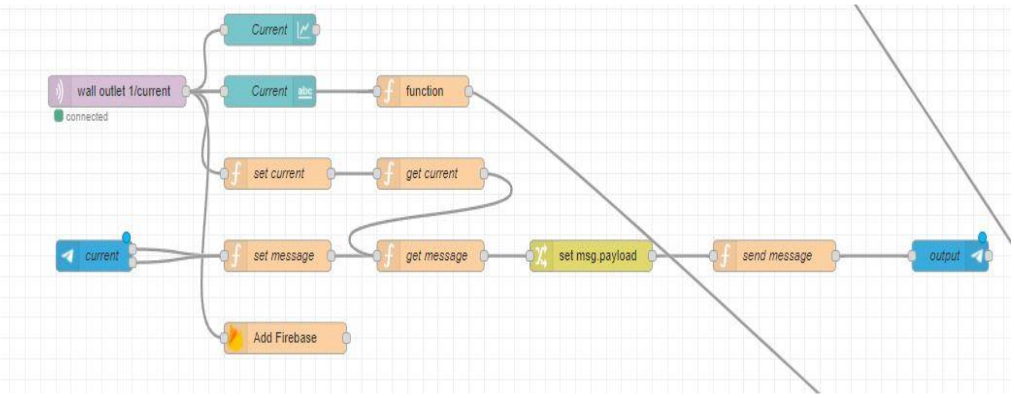


Figure 4.6: Script to Transmit Information from Wall Outlets to Central Console

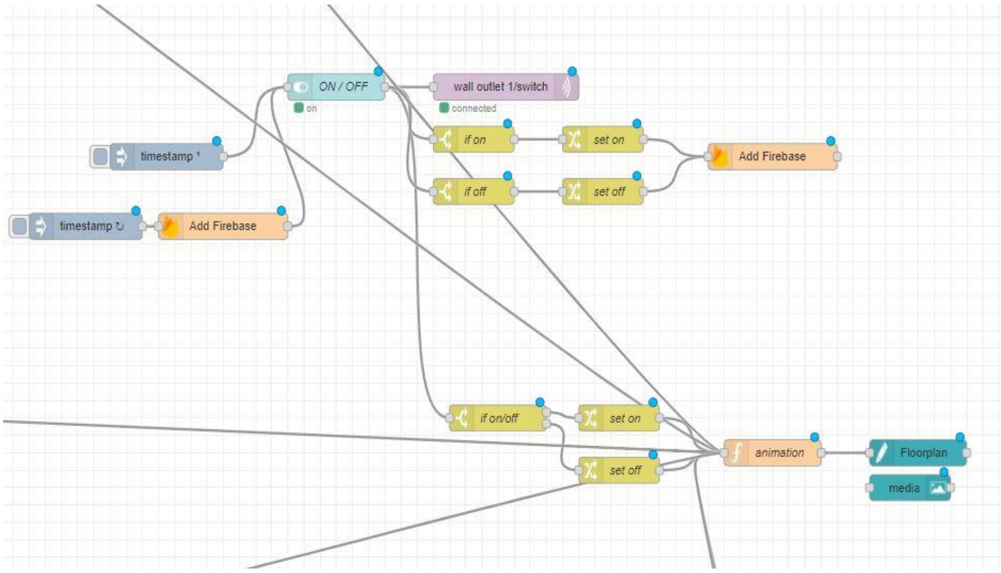


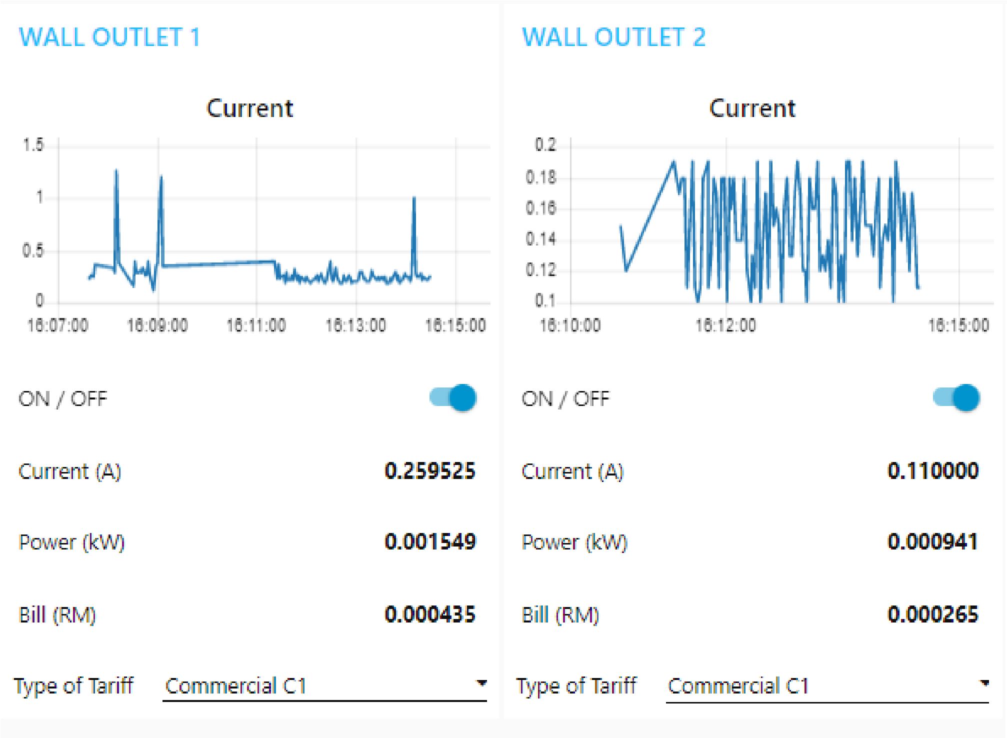
Figure 4.7: Script to Transmit Information from Central Console to Wall Outlets

4.3.1.1 Wall Outlet Section in the Node-Red Dashboard

Figure 4.8 shows the wall outlet section in the Node-Red dashboard. In this section, users can view the status of all wall outlets connected to the central console. For example, there are real-time current consumption, power consumption, and electricity bill. Also, users can control the state of the wall outlet here.

The slicer "Tariff Type" is used to determine the method of calculating electricity bills. The option includes residential, commercial and industrial. For residential, the electricity tariff is fixed according to the time. Meanwhile, commercial and industrial electricity tariff is calculated based on the ETOU scheme. Different tariff is charged at different period.

To implement the ETOU scheme for the wall outlet, a Network Time Protocol (NTP) is required to perform clock synchronisation for ESP32. A time library written by Paul Stoffregen is used (Stoffregen, 2021). By applying this library, ESP 32 can always synchronise to the Coordinated Universal Time (UTC). The time configuration for ESP32 is shown in Figure 4.9. "pool.ntp.org" is selected as the time server. Malaysia's UTC is positive 8 hours, so converted to seconds, it is 28800 seconds. Malaysia does not utilize daylight saving time, so the daylight offset seconds are set to zero.



WALL OUTLET 1

ON / OFF

Current (A) **0.259525**

Power (kW) **0.001549**

Bill (RM) **0.000435**

Type of Tariff Commercial C1

WALL OUTLET 2

ON / OFF

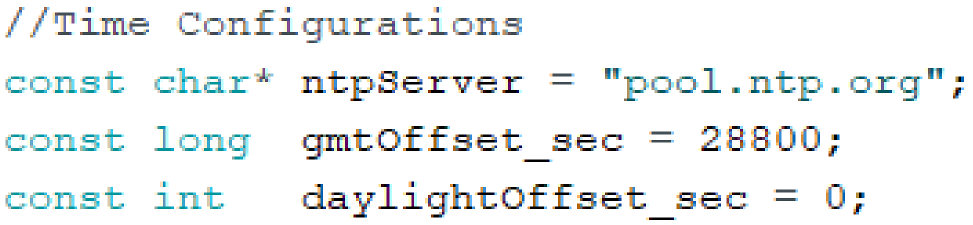
Current (A) **0.110000**

Power (kW) **0.000941**

Bill (RM) **0.000265**

Type of Tariff Commercial C1

Figure 4.8: Wall Outlet Section in the Dashboard

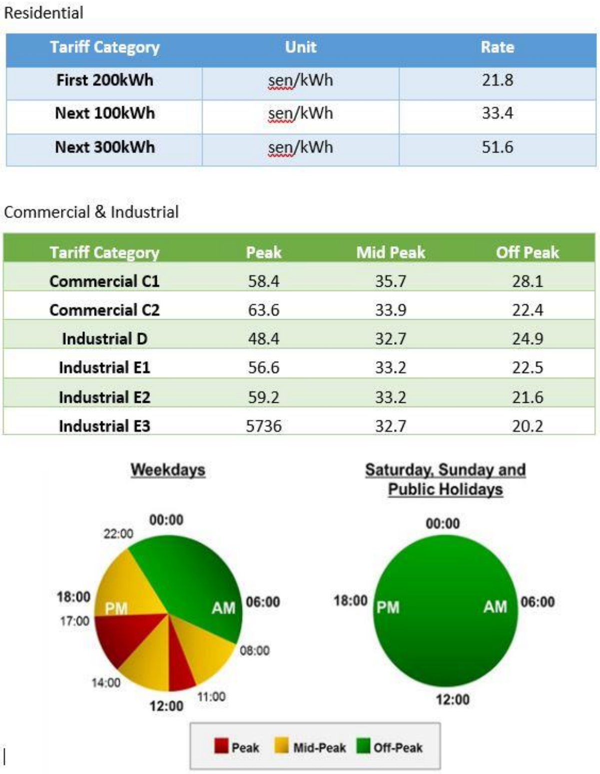


```
//Time Configurations
const char* ntpServer = "pool.ntp.org";
const long  gmtOffset_sec = 28800;
const int   daylightOffset_sec = 0;
```

Figure 4.9: NTP Time Configuration for ESP 32

4.3.1.2 Electricity Tariff Section in the Node-Red Dashboard

Figure 4.10 shows the electricity tariff section in the dashboard. Users can view different kinds of electricity tariffs here. The electricity tariff is calculated based on the ETOU scheme. Peak time costs the highest tariff while off-peak time costs the lowest tariff.



Residential

Tariff Category	Unit	Rate
First 200kWh	sen/kWh	21.8
Next 100kWh	sen/kWh	33.4
Next 300kWh	sen/kWh	51.6

Commercial & Industrial

Tariff Category	Peak	Mid Peak	Off Peak
Commercial C1	58.4	35.7	28.1
Commercial C2	63.6	33.9	22.4
Industrial D	48.4	32.7	24.9
Industrial E1	56.6	33.2	22.5
Industrial E2	59.2	33.2	21.6
Industrial E3	5736	32.7	20.2

Figure 4.10: Electricity Tariff Section in the Dashboard

4.3.1.3 Floorplan Section in the Node-Red Dashboard

This section allows users to quickly learn about the status of wall outlets in each room of the house. The dashboard's floorplan section is shown in Figure 4.11. This is the floorplan layout of a single storey house. There are 6 rooms in this house. The index of wall outlets is labelled near the wall outlet symbol. Through this section, the power usage and electricity bill of each room is clearly shown and the room that consumes the most power can be easily identified.

To make this section more interactive, real-time current usage by the appliances and the electricity bills are presented beside the room. The purpose of this part is to emphasise the unique power usage of each room. Users may notice which room consumes the most energy and take appropriate action if necessary. A hostel, for example, is divided into several rooms. The owner may readily detect the power usage of each room and take appropriate action on tenants by looking at the floorplan section. In industrial settings, machines that abnormally consume more electricity than usual can also be easily detected through this section.

Users can also set a monthly bill threshold for each room. An alert logo will show up when the electricity bill exceeds the threshold, notifying consumers that their electricity use has beyond the threshold. Users can adjust their usage habits accordingly.

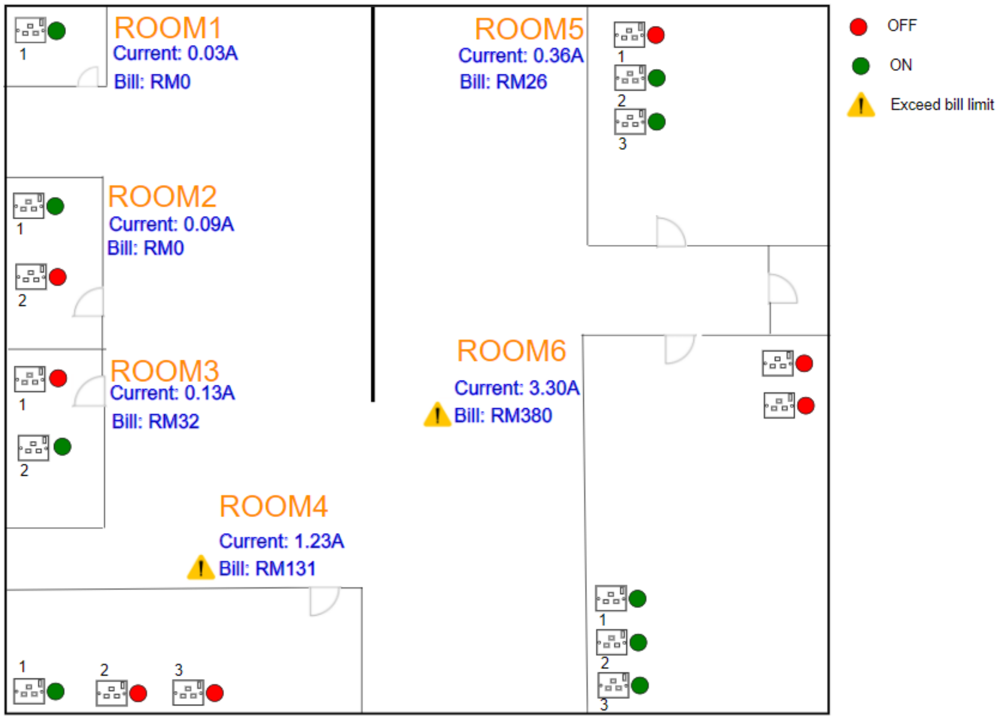
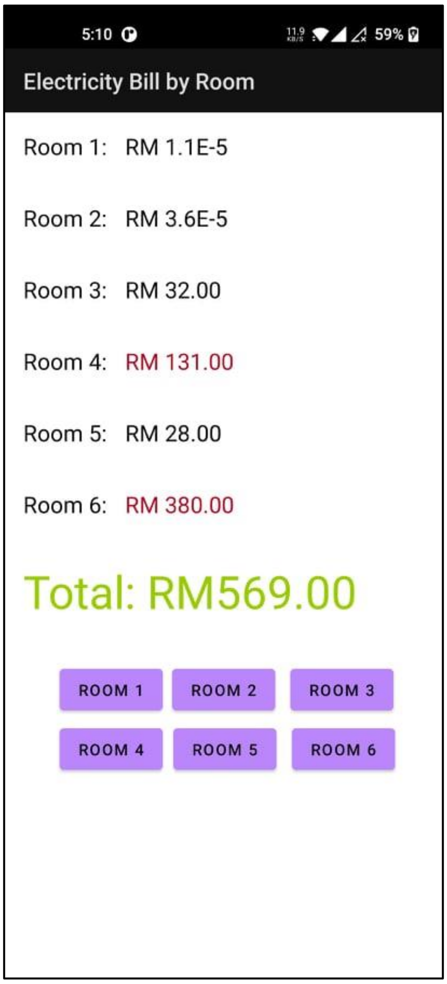


Figure 4.11: Floorplan Section in the Dashboard

4.3.2 Custom Android Application

An Android application named “Smart Wall Outlet” was developed for remote monitoring and controlling. Firebase is utilized as the database for this application. All the smart wall outlet data will be uploaded to the Realtime Database and retrieved by this Android application. This enables the application to control and monitor the smart wall outlet outside of the local area network. Figure 4.12 illustrates the logo of the Android application. Figure 4.13 displays the electricity bill of each room. The concept is similar to the Node-Red floorplan interface, but the floorplan layout is not drawn. The electricity bill of each room is highlighted in red when exceeding the limit threshold. The total electricity bill of the house is displayed in green colour. By clicking the “Room” buttons, the detailed information on individual wall outlets in each room will appear as shown in Figure 4.14. Figure 4.15 displays the page that record the electricity bill by the month. Users can be aware of how much electricity was used in the past and adjust their usage habits accordingly. Figure 4.16 shows the Firebase Realtime Database that is retrieved by this Android application. Figure 4.17 shows a screenshot of Android Studio during the process of developing the Android application.

Figure 4.12: Logo of the Android Application



Electricity Bill by Room

Room 1: RM 1.1E-5

Room 2: RM 3.6E-5

Room 3: RM 32.00

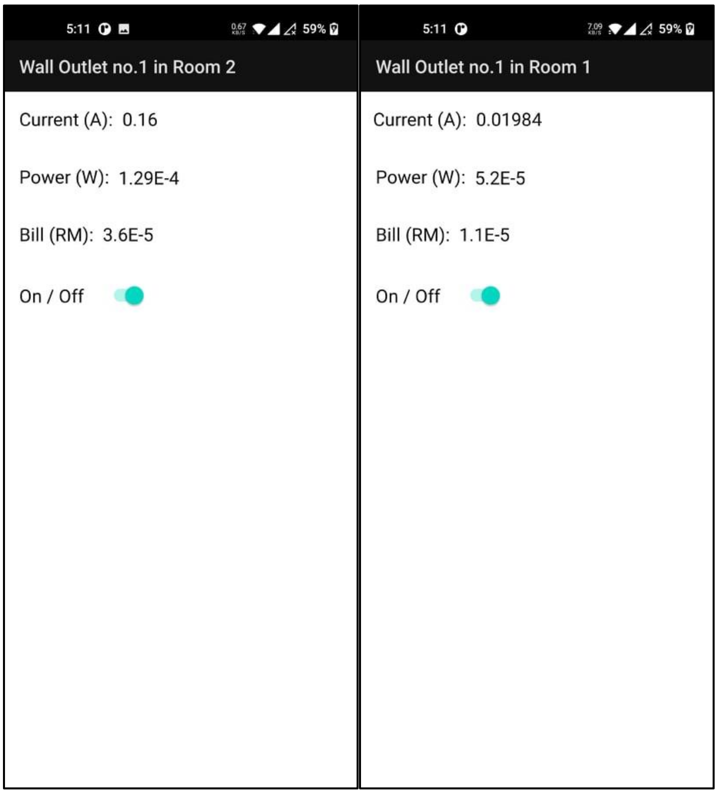
Room 4: RM 131.00

Room 5: RM 28.00

Room 6: RM 380.00

Total: RM569.00

Figure 4.13: Electricity Bill by Room



Wall Outlet no.1 in Room 2

Current (A): 0.16

Power (W): 1.29E-4

Bill (RM): 3.6E-5

On / Off

Wall Outlet no.1 in Room 1

Current (A): 0.01984

Power (W): 5.2E-5

Bill (RM): 1.1E-5

On / Off

Figure 4.14: Individual Wall Outlet Information

Electricity Bill by Month

January: RM9.80

February: RM18.50

March: RM10.30

April: RM15.60

May: -

June: -

July: -

August: -

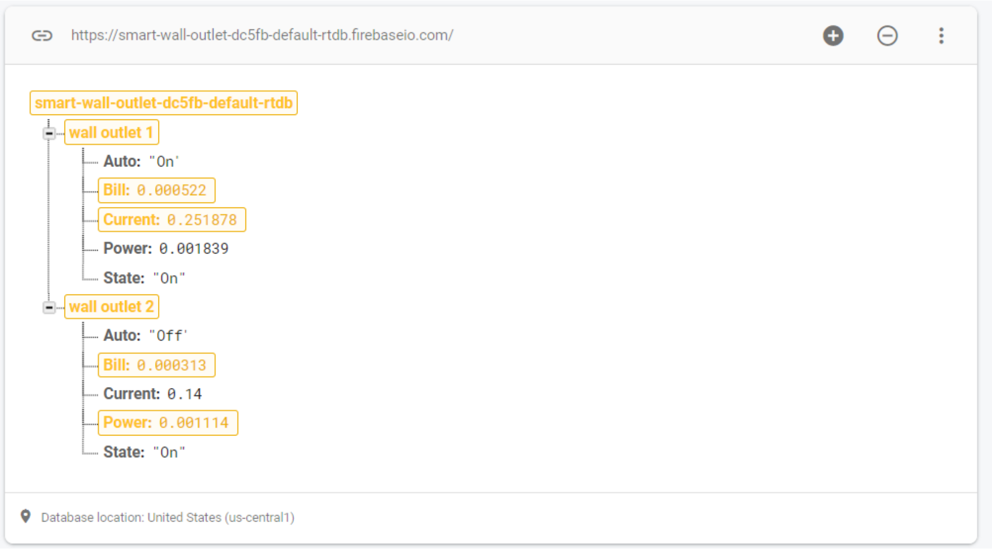
September: -

October: -

November: -

December: -

Figure 4.15: Electricity Bill by Month



https://smart-wall-outlet-dc5fb-default-rtdb.firebaseio.com/

```
smart-wall-outlet-dc5fb-default-rtdb
  wall outlet 1
    Auto: "On'
    Bill: 0.000522
    Current: 0.251878
    Power: 0.001839
    State: "On"
  wall outlet 2
    Auto: "Off'
    Bill: 0.000313
    Current: 0.14
    Power: 0.001114
    State: "On"
```

Database location: United States (us-central1)

Figure 4.16: Firebase Realtime Database

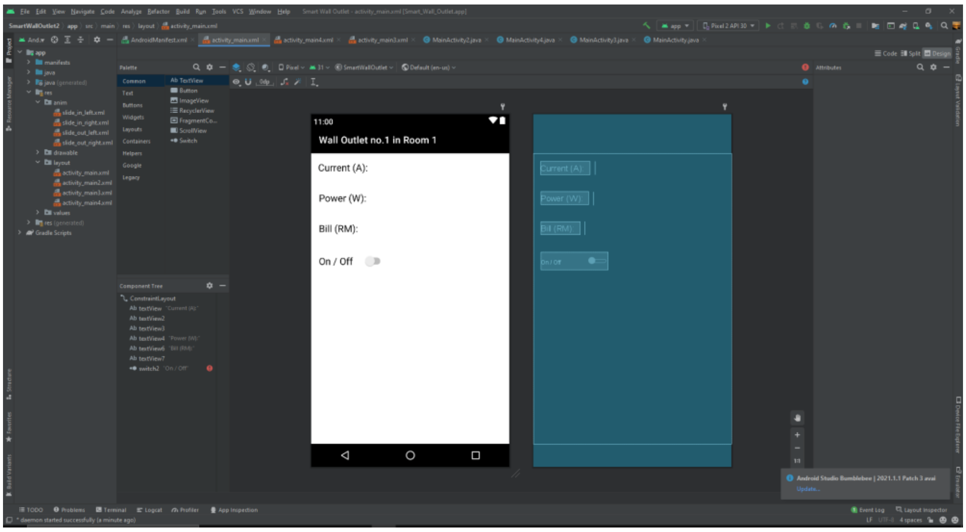


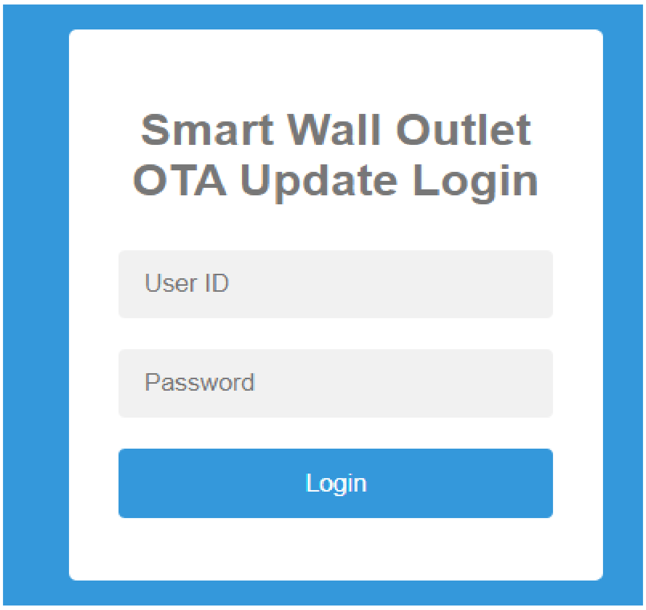
Figure 4.17: App Development in Android Studio

4.3.3 OTA Updates for ESP32

Two techniques for OTA updates have been attempted for ESP32: web server-based and cloud-based. This process is very important if this product is going into mass production. As an example, when a security patch is released, these wall outlets are required to be updated as early as possible, and an OTA update can shorten the processing time.

4.3.3.1 Web Server Based OTA Updates

ESP 32 will act as a web server and users can upload the new firmware through the multicast Domain Name System (mDNS) web page. The webpage can be accessed by browsing the IP address of ESP32. Users are required to convert the firmware into a binary file. Then, the new firmware is ready to be uploaded after the login credentials are inserted and verified by the webserver. Figure 4.18 shows the home page of the web page. After inserting the correct user ID and password, users can perform OTA updates on the spot, as shown in Figure 4.19. Figure 4.20 shows that new firmware is successfully uploaded to the ESP 32.



Smart Wall Outlet
OTA Update Login

Figure 4.18: Home Page

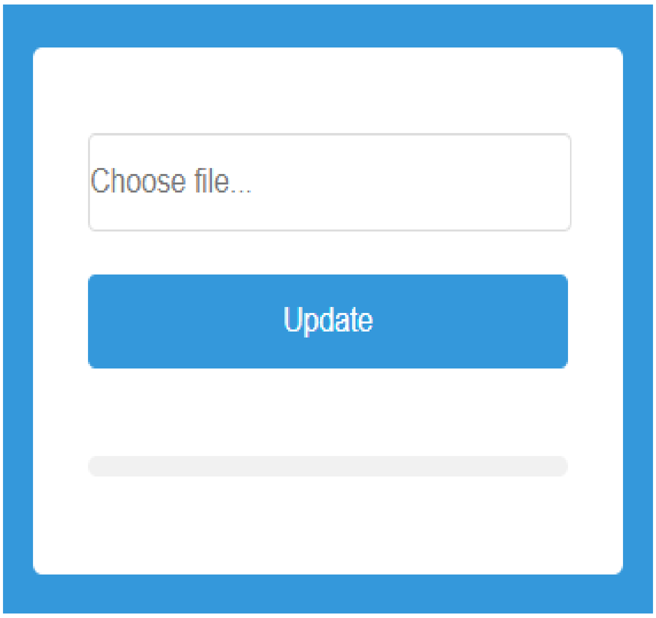
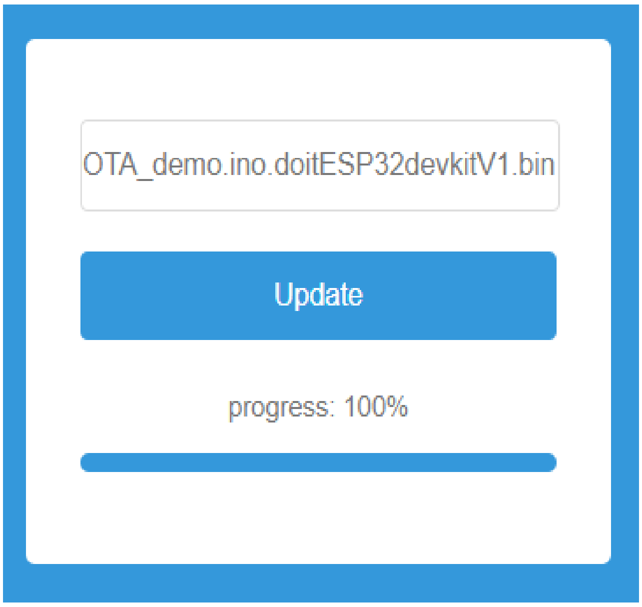


Figure 4.19: OTA Update is Ready

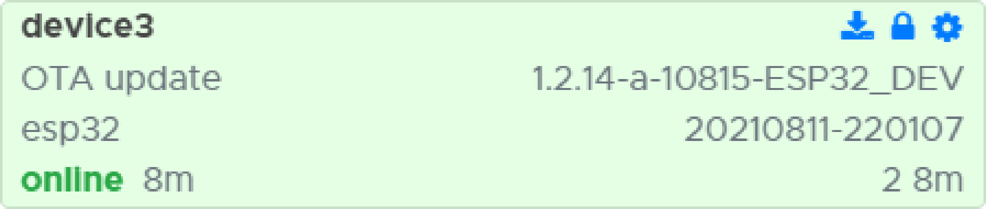


OTA_demo.ino.doitESP32devkitV1.bin

Figure 4.20: OTA Update Successfully

4.3.3.2 Cloud-Based OTA Updates

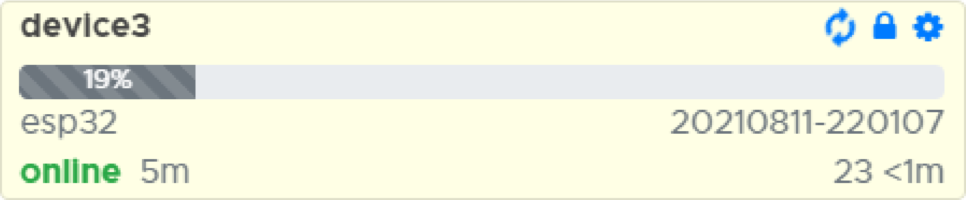
Mdash IoT is the service provider for cloud-based OTA updates. Mdash IoT will generate a password to enable OTA updates on ESP 32. On the firmware side, ESP 32 utilizes the library provided by Mdash IoT. After the corresponding password is added to the firmware, the OTA update function is successfully implemented. The status can be confirmed on the website of Mdash IoT, as shown in Figure 4.21.



device3	
OTA update	1.2.14-a-10815-ESP32_DEV
esp32	20210811-220107
online 8m	2 8m

Figure 4.21: Dashboard Showing that OTA Update is Enabled

New firmware can be uploaded to ESP32 wirelessly in binary format. Mdash IoT website is accessed to upload the new firmware. Figure 4.22 shows the uploading process of new firmware.



device3

19%

esp32

20210811-220107

online 5m

23 <1m

Figure 4.22: Uploading Process of new firmware

4.4 Program Operation

Figure 4.23 shows the operation of the smart wall outlet system in the flow chart. Before going to the main program, initialization of I/O, Wi-Fi, MQTT and NTP time is undergone. After that, the microcontroller on the wall outlets will receive the data from the central console through the MQTT protocol. The TRIAC can be triggered on or off depending on the message received. Meanwhile, the microcontroller will calculate the electricity bill and power consumption. This data will then be transmitted to the central console through the MQTT protocol.

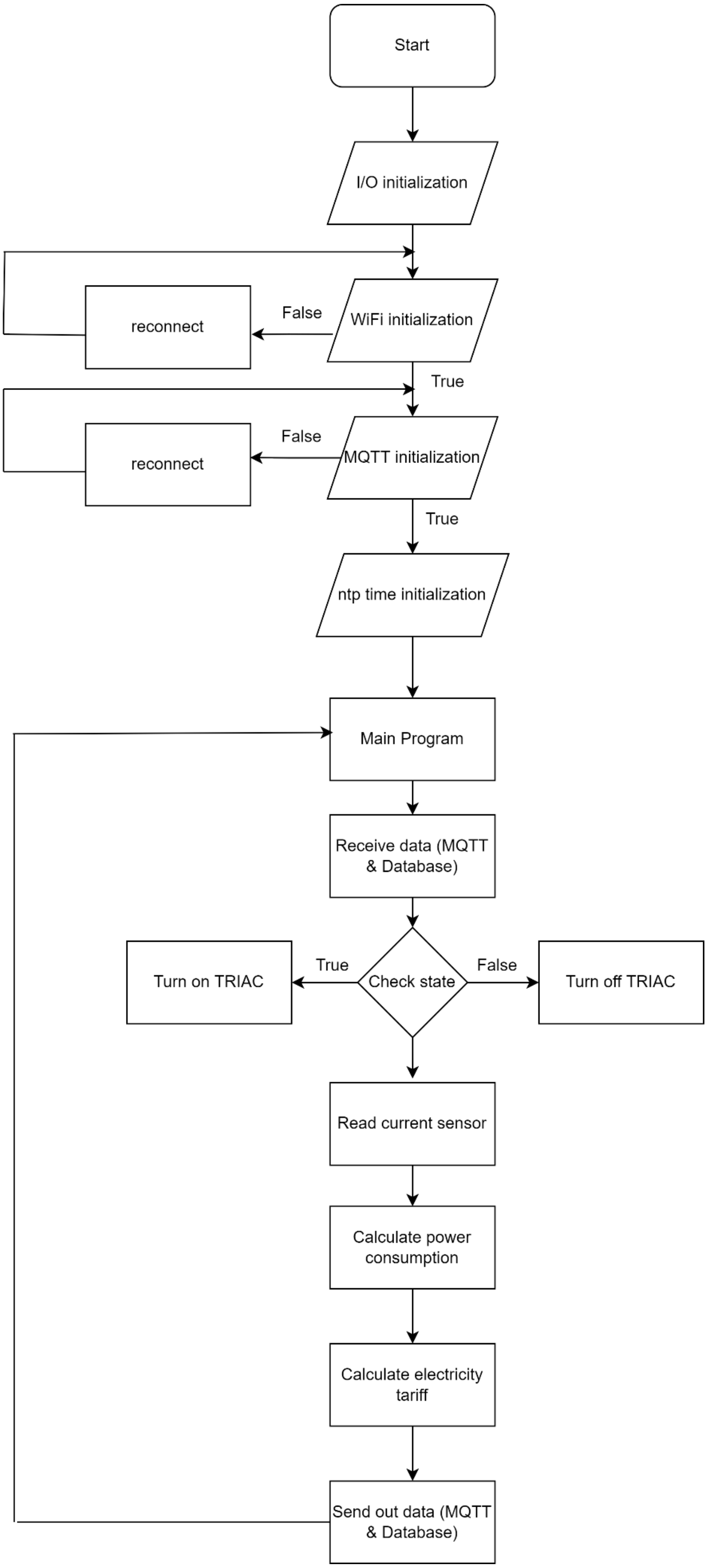


Figure 4.23: Flowchart of the smart wall outlet system

4.5 Power Consumption of the System

In this section, the power consumption of the system is investigated. Two experiments are conducted. One experiment is towards the centre console raspberry Pi and another one is towards the wall outlets. A power meter is used to measure the system power consumption.

The centre console has 3 operating modes: wall outlet not connected mode, 1 wall outlet connected mode and two outlets connected mode. On the other hand, the wall outlet has 3 operating modes: off mode with Wi-Fi disconnected, off mode with Wi-Fi connection, and on mode with Wi-Fi is connected.

The power consumption of these operating modes is taken three times and their average is determined. The measurements are taken at an interval of one hour. The system power consumption is tabulated in Table 4.1.

From this table, when one or two wall outlets are connected to the central console, the power consumption of the central console will increase. This is because the centre console needs to process the data received from the wall outlets and store the data in Firebase.

For the wall outlet, when Wi-Fi is connected, the power consumption will be higher. The reason is that the Wi-Fi module on the ESP32 development board consumes some power when the ESP32 is connected to the Wi-Fi router. When the wall outlets are connected to the Wi-Fi, the on-mode consumes slightly more power than the off-mode because the ESP32 is processing and sending data to the central server broker continuously.

Device	Operating Mode	Power (W)			
		1	2	3	Average
Centre Console/Server (Raspberry Pi)	Wall outlet is not connected	2.40	2.40	2.40	2.40
	1 wall outlet is connected	2.70	2.60	2.70	2.63
	2 wall outlets are connected	2.70	2.70	2.60	2.63
Wall Outlet	Off-mode (Wi-Fi disconnected)	0.35	0.35	0.35	0.35
	Off-mode (Wi-Fi connected)	0.55	0.55	0.54	0.54
	On-mode (Wi-Fi connected)	0.58	0.58	0.58	0.58

Table 4.1: System Power Consumption

4.6 Electricity Cost of the System

The electricity cost of the smart wall outlet system is calculated based on the TNB type A- Domestic Tariff. The rate is assumed to be RM0.218 for the first 200 kWh. The formula to calculate the daily, monthly and yearly electricity cost is shown in Equations 4.1, 4.2 and 4.3. The electricity cost of the system is tabulated in Table 4.2. Two scenarios are assumed, which are on mode and off mode for the wall outlets. Results show that both modes do not have a significant difference. The system costs RM0.02 daily and RM 7.20 if it is implemented continuously for a year. Although this system cost some prices in electricity, however along with all the features provided, users can save more power and at the same time enjoy its functionality.

$$Daily\ cost = Power\ Consumprion\ (kw) * 24 * RM0.218 \quad (4.1)$$

$$Monthly\ cost = Daily\ cost * 30 \quad (4.2)$$

$$Yearly\ cost = Monthly\ cost * 12 \quad (4.3)$$

Scenario	Power Consumption (W)	Cost (RM)		
		Daily	Monthly	Yearly
Central console + 2 wall outlets in off mode	3.786	0.02	0.6	7.2
Central console + 2 wall outlets in on mode	3.854	0.02	0.6	7.2

Table 4.2: Electricity Cost of the System

4.7 Accuracy of ACS712 Current Sensor

The ACS712 current sensor module can measure a maximum of 20A current with a sensitivity of 100mV/A. When compared to the power meter, the result obtained from this current sensor has a high value of percentage error when the current is small due to the Hall Effect Sensor. The live wire will produce some noise and the magnetic field will be affected. The solution to this is to add a filter capacitor to the filter pin of the IC. The greater value of the capacitor, the lower the noise value. The maximum filtering capability will be at 100nF according to the datasheet. However, the noise still can go up to 100mA at the saturation point as shown in Figure 4.24. This explains the high percentage error for low power appliances.

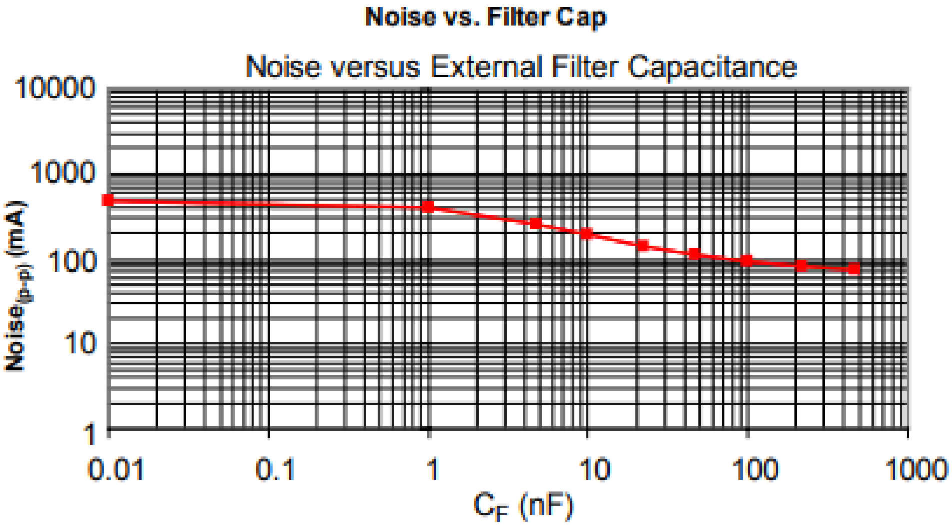


Figure 4.24: Relationship Between Noise and Value of Filter Capacitor

Also, in order to increase the sensor's accuracy, programming methods such as moving average filters and calibration factors were used.

Table 4.4 shows the result of the ACS712 current sensor compared with the power meter. The results are obtained by averaging 3 repeated measurements. The appliances covered a wide range of different power consumption; from 10W to 1600W.

A high percentage error only occurs at low power consumption appliances such as a 10W battery charger. The percentage error can go as high as 51.78%. This shows that the ACS 712 current sensor is not suitable in measuring low current magnitude. The reason behind this is that the current sensor is exposed to the magnetic field and noise. For other appliances with a higher power rating ranging from 35W to 1600W, the percentage error is very low and fluctuates between a maximum of 5.594% and a minimum of 0.23%. This indicates that the ACS 712 current sensor is more suitable for high-power appliances.

Appliances	Through Power Meter	Through Smart Wall Outlet (ACS712 current sensor)	Percentage Error (%)
	Current Measured (A)		
	Average of 3 times	Average of 3 times	
10W Battery Charger	0.048	0.072	51.780
35w Standing Fan	0.117	0.117	0.057
40W Vacuum robot	0.156	0.150	4.051
65W Phone charger	0.286	0.270	5.594
1600W Hair Dryer (Heat Off)	0.470	0.460	2.197
1600W Hair Dryer (Heat On)	2.459	2.465	0.230

Table 4.3: Current Measurement of Different Appliances

4.8 Prediction of Power Consumption for Appliances Connected to Single Wall Outlet

The Australian household electricity consumption dataset is used for training and testing. The details of the dataset are discussed in Section 3.2.4.

The target output to be predicted is the daily total power consumption for appliances that are connected to the wall outlets. The input data is the date and the user’s power usage behaviour every 30 minutes. Due to the budget constraint, the machine learning model was only developed for respondent index 3494. 710 data is used for training, with 10 reserved for prediction.

A numeric prediction model is used to estimate the output. The input data can affect the output data and the affecting factors are expressed in percentages as shown in Figure 4.25. The X-axis represents the percentage of impacting factors while the Y-axis represents the time in 24 hours format. The histogram shows the most impact on the power consumption is from 1700 to 0200 hours, ranging from a maximum of 11.46% at 1830 and a minimum of 0.77% at 2100.

The graph of the actual power consumption versus the predicted power consumption is plotted in Figure 4.26. This is a linear regression technique in which a line is graphed across a group of data points that best suit the general form of the data. The regression line depicts the relationship between a dependent variable (actual power consumption on the y-axis) and an explanatory variable (predicted power consumption on the x-axis). The regression line is obtained using Equation 4.4.

$$y = mx + c \qquad (4.4)$$

where

y = data point y-axis coordinate

m = gradient

x = data point x-axis coordinate

c = y-intercept

The gradient of the regression line, m, can be obtained using Equation 4.5.

$$m = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sum(x-\bar{x})^2} \quad (4.5)$$

where

$\bar{x}$ = mean of x data points coordinate

$\bar{y}$ = mean of y data points coordinate

The best-fit regression line is selected and plotted in purple colour after several iterations. This line has the minimum distance between the actual and predicted value.

The R-squared method is implemented to test the goodness of fit and the performance of the model. Higher R squared is a good sign for a good regression model. The R squared of the model can be obtained using Equation 4.6.

$$R^2 = \frac{\sum(y_p-\bar{y})^2}{\sum(y-\bar{y})^2} \quad (4.6)$$

where

y_p = y coordinate of the predicted data

Figure 4.27 shows the advanced metrics of the model. The R-square of this model is 97%. This indicates that 97% of the data is fit to the regression model. The Mean Absolute Error (MAE) of the model is 1.4585 kWh. This means that the model has an average difference of +/- 1.4585 kWh from the actual power consumption.

Ten sets of data are reserved and used for prediction. The results are tabulated in Table 4.4. The average percentage error between the actual value (daily power consumption data from the original dataset) and the predicted value (daily power consumption predicted by the model) is 9.439%. In short, this model can predict daily power consumption with an average percentage error of 9.439%.

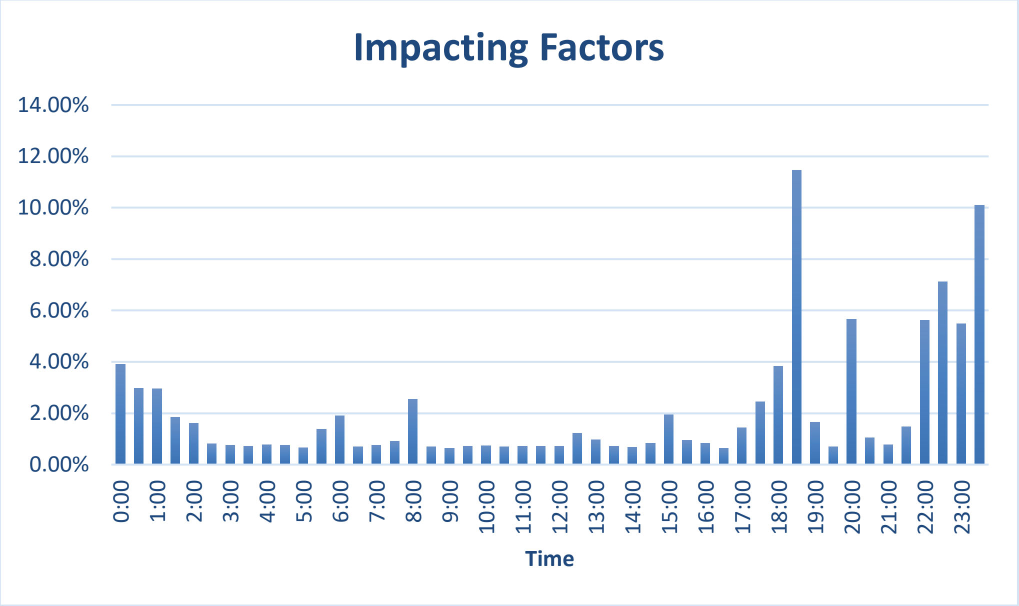


Figure 4.25: Impact on User's Power Usage Behaviour (30 Minutes Interval) Towards Power Consumption

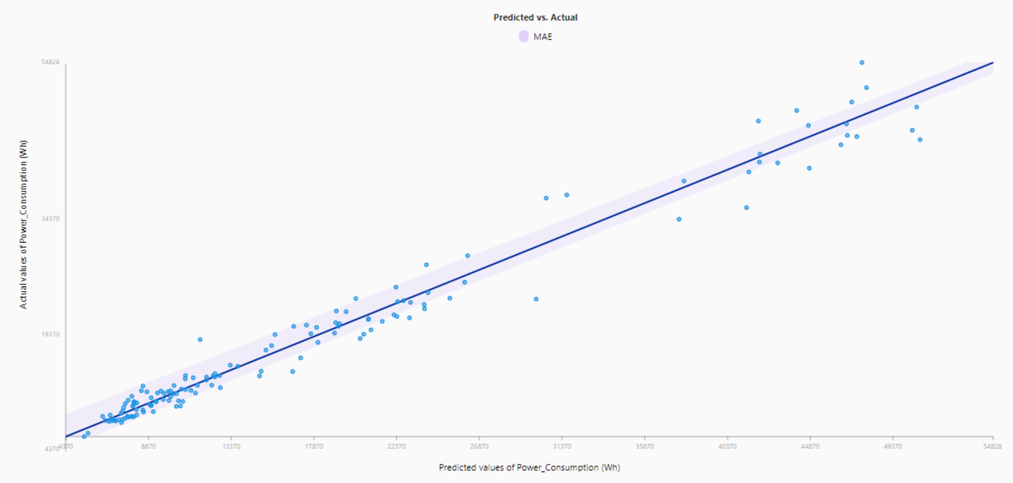
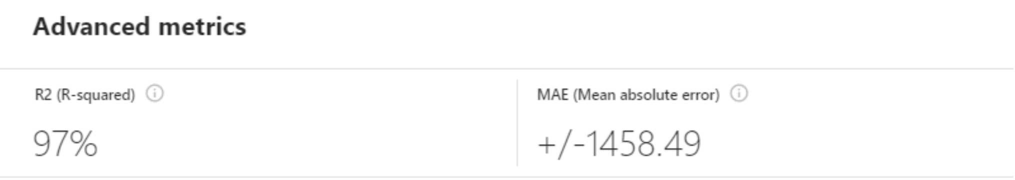
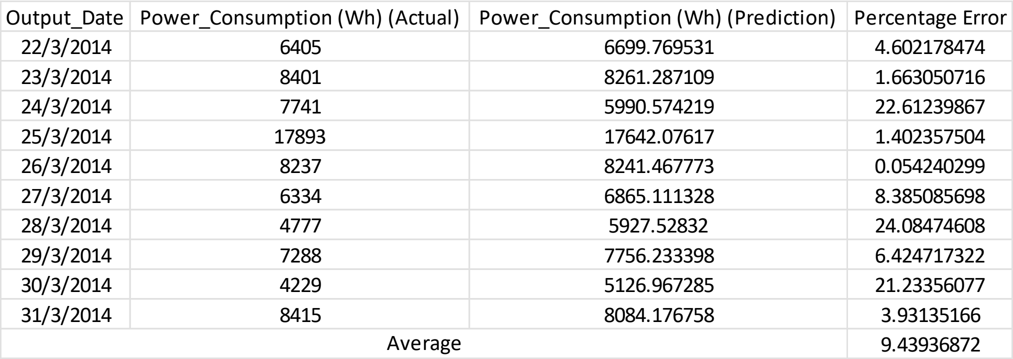


Figure 4.26: Actual Power Consumption Versus Predicted Power Consumption


Advanced metrics

R2 (R-squared)	MAE (Mean absolute error)
97%	+/-1458.49

Figure 4.27: Advanced metrics showing R-squared and MAE of the model



Output_Date	Power_Consumption (Wh) (Actual)	Power_Consumption (Wh) (Prediction)	Percentage Error
22/3/2014	6405	6699.769531	4.602178474
23/3/2014	8401	8261.287109	1.663050716
24/3/2014	7741	5990.574219	22.61239867
25/3/2014	17893	17642.07617	1.402357504
26/3/2014	8237	8241.467773	0.054240299
27/3/2014	6334	6865.111328	8.385085698
28/3/2014	4777	5927.52832	24.08474608
29/3/2014	7288	7756.233398	6.424717322
30/3/2014	4229	5126.967285	21.23356077
31/3/2014	8415	8084.176758	3.93135166
Average			9.43936872

Table 4.4: Percentage Error between Actual and Predicted Power Consumption

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This project introduced an IoT based smart single wall outlet. The proposed system fulfils the requirements of remote control and monitoring away from home. Also, real-time power usage and electricity tariffs can be viewed via the apps and Node-Red dashboard. Multiple wall outlets can form a shared network and are linked by a central server through MQTT. This system suits residential, commercial, and industrial usage in Malaysia and can calculate the electricity bill based on the ETOU scheme. Last but not least, a prediction model that forecasts the daily power consumption of appliances that are connected to a single wall outlet has been developed, and the model can achieve an accuracy of 90%.

5.2 Recommendations for Future Work

The performance of the current sensor is not satisfactory when measuring the current consumption of low-power appliances. A current sensor with higher sensitivity and reliability can be considered in the future. For instance, ADE7757 is a single-phase energy metering IC used in many power meters. It has less than a 0.1% active energy error over a wide dynamic range of 1000:1. Alternatively, a resistor with low tolerance and a differential op-amp can be paired together to measure the current of the appliances.

Also, this system can be integrated with a voltage sensor to measure the power factor of the appliances. Especially for the industry, the power factor is a very important criterion. The power measurement can be more accurate with the aid of a voltage sensor.

Moreover, when this system has been implemented for a long time, data such as power consumption for each wall outlet should be collected. Machine learning can be utilised to predict the power consumption of a network of wall outlets. Based on the datasets collected, the model should be able to predict power consumption for multiple rooms in a house, office, or factory.

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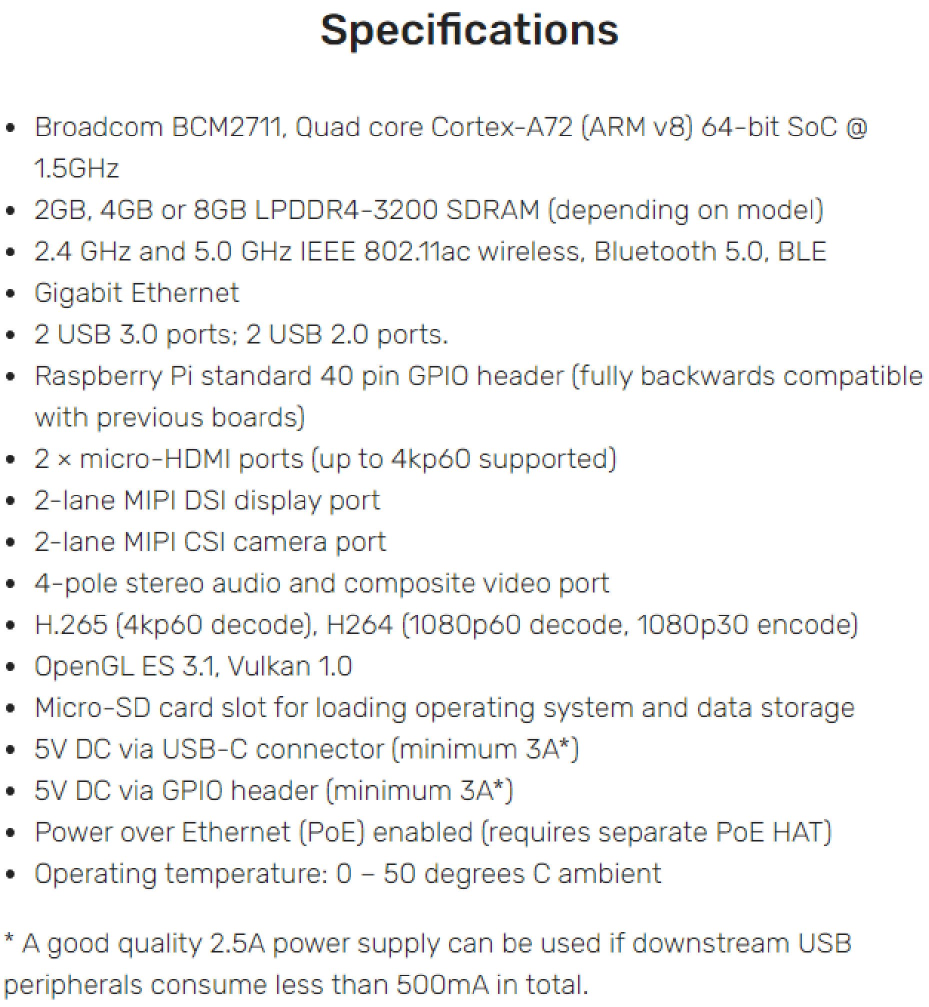
APPENDICES

APPENDIX A: Specification of Raspberry Pi 4 Model B

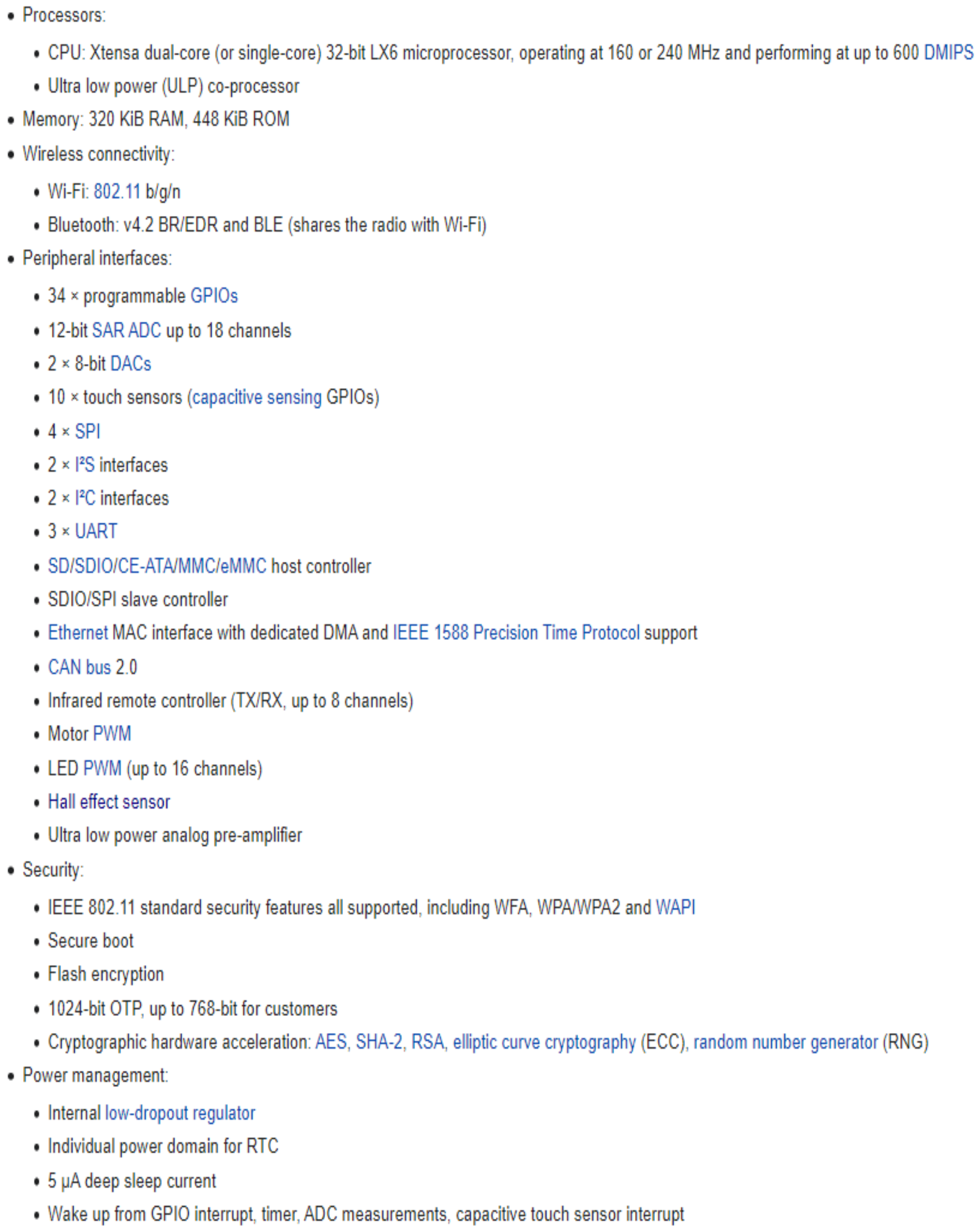


Specifications

- Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz
- 2GB, 4GB or 8GB LPDDR4-3200 SDRAM (depending on model)
- 2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE
- Gigabit Ethernet
- 2 USB 3.0 ports; 2 USB 2.0 ports.
- Raspberry Pi standard 40 pin GPIO header (fully backwards compatible with previous boards)
- 2 × micro-HDMI ports (up to 4kp60 supported)
- 2-lane MIPI DSI display port
- 2-lane MIPI CSI camera port
- 4-pole stereo audio and composite video port
- H.265 (4kp60 decode), H264 (1080p60 decode, 1080p30 encode)
- OpenGL ES 3.1, Vulkan 1.0
- Micro-SD card slot for loading operating system and data storage
- 5V DC via USB-C connector (minimum 3A*)
- 5V DC via GPIO header (minimum 3A*)
- Power over Ethernet (PoE) enabled (requires separate PoE HAT)
- Operating temperature: 0 – 50 degrees C ambient

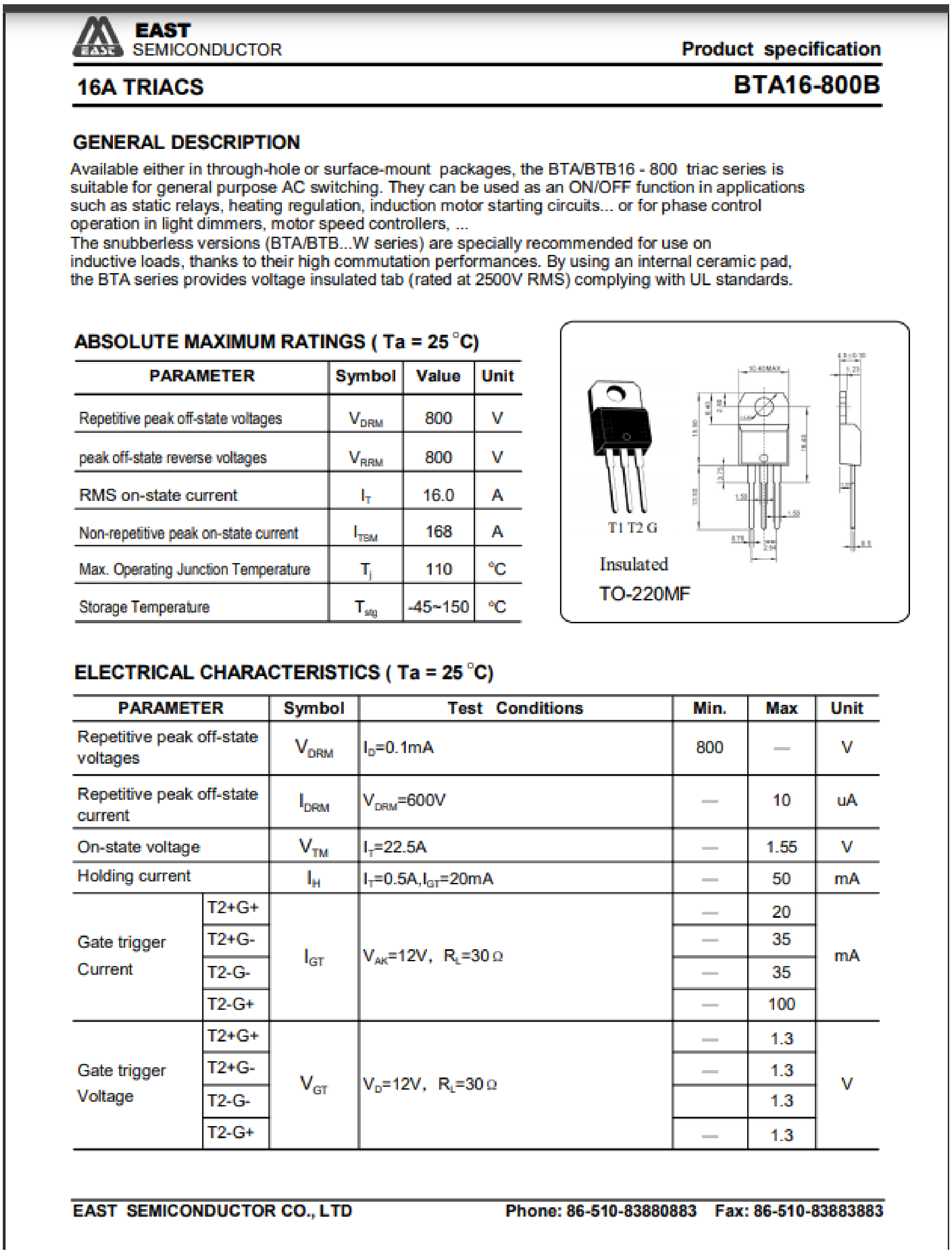
* A good quality 2.5A power supply can be used if downstream USB peripherals consume less than 500mA in total.

APPENDIX B: Specification of ESP 32



- Processors:
  - CPU: Xtensa dual-core (or single-core) 32-bit LX6 microprocessor, operating at 160 or 240 MHz and performing at up to 600 DMIPS
  - Ultra low power (ULP) co-processor
- Memory: 320 KiB RAM, 448 KiB ROM
- Wireless connectivity:
  - Wi-Fi: 802.11 b/g/n
  - Bluetooth: v4.2 BR/EDR and BLE (shares the radio with Wi-Fi)
- Peripheral interfaces:
  - 34 × programmable GPIOs
  - 12-bit SAR ADC up to 18 channels
  - 2 × 8-bit DACs
  - 10 × touch sensors (capacitive sensing GPIOs)
  - 4 × SPI
  - 2 × I^{2}S interfaces
  - 2 × I^{2}C interfaces
  - 3 × UART
  - SD/SDIO/CE-ATA/MMC/eMMC host controller
  - SDIO/SPI slave controller
  - Ethernet MAC interface with dedicated DMA and IEEE 1588 Precision Time Protocol support
  - CAN bus 2.0
  - Infrared remote controller (TX/RX, up to 8 channels)
  - Motor PWM
  - LED PWM (up to 16 channels)
  - Hall effect sensor
  - Ultra low power analog pre-amplifier
- Security:
  - IEEE 802.11 standard security features all supported, including WFA, WPA/WPA2 and WAPI
  - Secure boot
  - Flash encryption
  - 1024-bit OTP, up to 768-bit for customers
  - Cryptographic hardware acceleration: AES, SHA-2, RSA, elliptic curve cryptography (ECC), random number generator (RNG)
- Power management:
  - Internal low-dropout regulator
  - Individual power domain for RTC
  - 5 μA deep sleep current
  - Wake up from GPIO interrupt, timer, ADC measurements, capacitive touch sensor interrupt

APPENDIX C: Datasheet of BTA16-800B



EAST
SEMICONDUCTOR

Product specification

16A TRIACS **BTA16-800B**

GENERAL DESCRIPTION

Available either in through-hole or surface-mount packages, the BTA/BTB16 - 800 triac series is suitable for general purpose AC switching. They can be used as an ON/OFF function in applications such as static relays, heating regulation, induction motor starting circuits... or for phase control operation in light dimmers, motor speed controllers, ...
The snubberless versions (BTA/BTB...W series) are specially recommended for use on inductive loads, thanks to their high commutation performances. By using an internal ceramic pad, the BTA series provides voltage insulated tab (rated at 2500V RMS) complying with UL standards.

ABSOLUTE MAXIMUM RATINGS (Ta = 25 °C)

PARAMETER	Symbol	Value	Unit
Repetitive peak off-state voltages	V_{DRM}	800	V
peak off-state reverse voltages	V_{RRM}	800	V
RMS on-state current	I_T	16.0	A
Non-repetitive peak on-state current	I_{TSM}	168	A
Max. Operating Junction Temperature	T_j	110	°C
Storage Temperature	T_{stg}	-45~150	°C

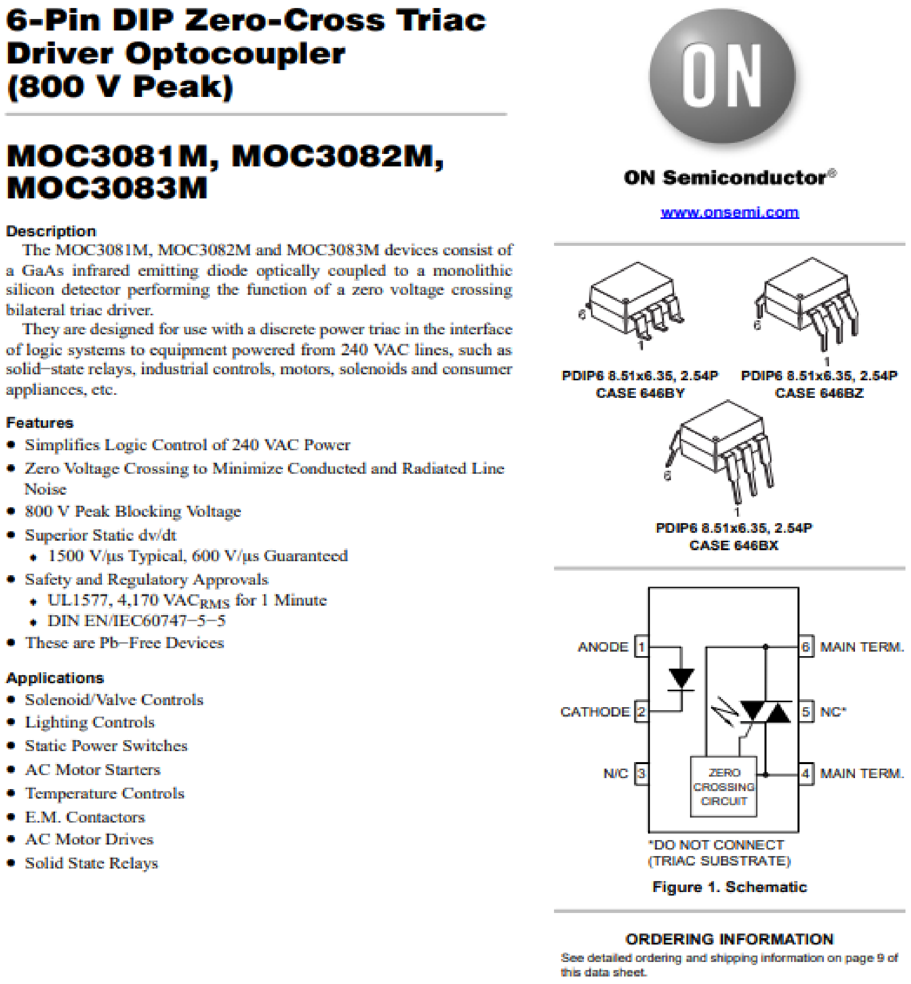
Insulated
TO-220MF

ELECTRICAL CHARACTERISTICS (Ta = 25 °C)

PARAMETER		Symbol	Test Conditions	Min.	Max	Unit
Repetitive peak off-state voltages		V_{DRM}	I_D=0.1mA	800	—	V
Repetitive peak off-state current		I_{DRM}	V_{DRM}=600V	—	10	uA
On-state voltage		V_{TM}	I_T=22.5A	—	1.55	V
Holding current		I_H	I_T=0.5A,I_{GT}=20mA	—	50	mA
Gate trigger Current	T2+G+	I_{GT}	V_{AK}=12V, R_L=30Ω	—	20	mA
	T2+G-			—	35	
	T2-G-			—	35	
	T2-G+			—	100	
Gate trigger Voltage	T2+G+	V_{GT}	V_D=12V, R_L=30Ω	—	1.3	V
	T2+G-			—	1.3	
	T2-G-				1.3	
	T2-G+			—	1.3	

EAST SEMICONDUCTOR CO., LTD **Phone: 86-510-83880883 Fax: 86-510-83883883**

APPENDIX D: Datasheet of MOC 3083



6-Pin DIP Zero-Cross Triac Driver Optocoupler (800 V Peak)

MOC3081M, MOC3082M, MOC3083M

ON Semiconductor®

www.onsemi.com

Description

The MOC3081M, MOC3082M and MOC3083M devices consist of a GaAs infrared emitting diode optically coupled to a monolithic silicon detector performing the function of a zero voltage crossing bilateral triac driver.

They are designed for use with a discrete power triac in the interface of logic systems to equipment powered from 240 VAC lines, such as solid−state relays, industrial controls, motors, solenoids and consumer appliances, etc.

Features

- Simplifies Logic Control of 240 VAC Power
- Zero Voltage Crossing to Minimize Conducted and Radiated Line Noise
- 800 V Peak Blocking Voltage
- Superior Static dv/dt
  - 1500 V/μs Typical, 600 V/μs Guaranteed
- Safety and Regulatory Approvals
  - UL1577, 4,170 VAC_{RMS} for 1 Minute
  - DIN EN/IEC60747−5−5
- These are Pb−Free Devices

Applications

- Solenoid/Valve Controls
- Lighting Controls
- Static Power Switches
- AC Motor Starters
- Temperature Controls
- E.M. Contactors
- AC Motor Drives
- Solid State Relays

PDIP6 8.51x6.35, 2.54P
CASE 646BY

PDIP6 8.51x6.35, 2.54P
CASE 646BZ

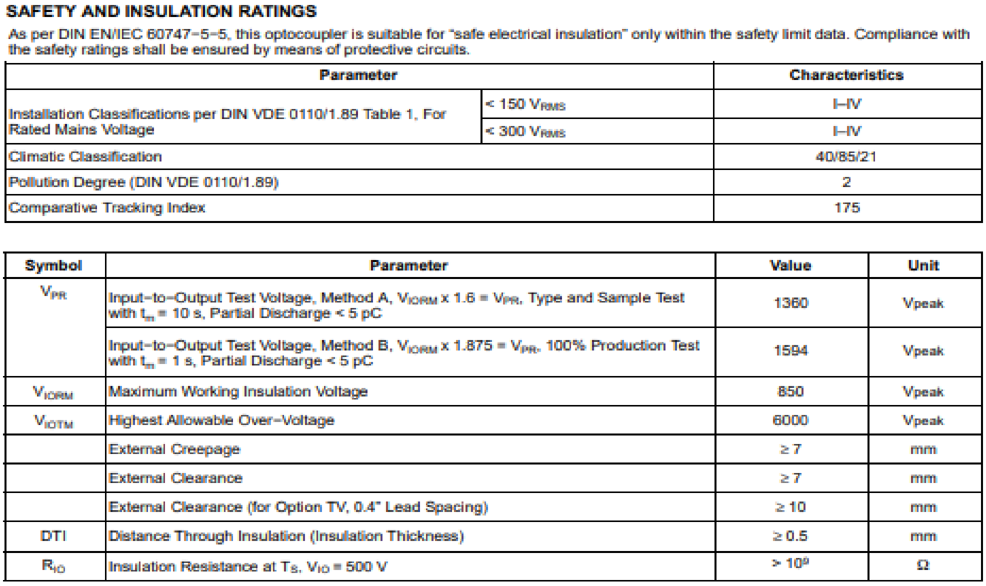
PDIP6 8.51x6.35, 2.54P
CASE 646BX

*DO NOT CONNECT
(TRIAC SUBSTRATE)

Figure 1. Schematic

ORDERING INFORMATION

See detailed ordering and shipping information on page 9 of this data sheet.

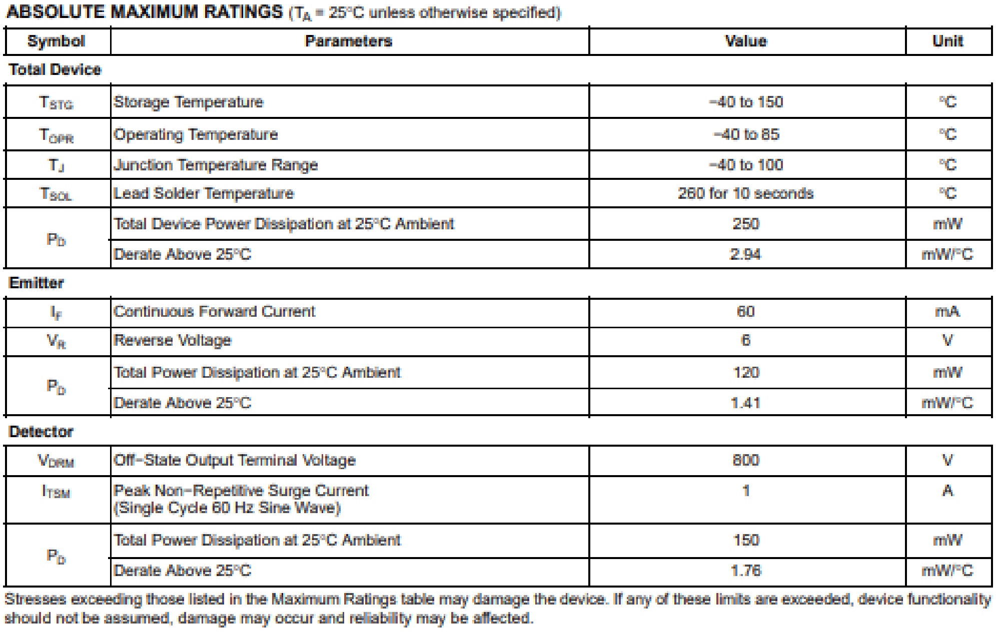


SAFETY AND INSULATION RATINGS

As per DIN EN/IEC 60747−5−5, this optocoupler is suitable for "safe electrical insulation" only within the safety limit data. Compliance with the safety ratings shall be ensured by means of protective circuits.

Parameter		Characteristics
Installation Classifications per DIN VDE 0110/1.89 Table 1, For Rated Mains Voltage	< 150 V_{RMS}	I–IV
	< 300 V_{RMS}	I–IV
Climatic Classification		40/85/21
Pollution Degree (DIN VDE 0110/1.89)		2
Comparative Tracking Index		175

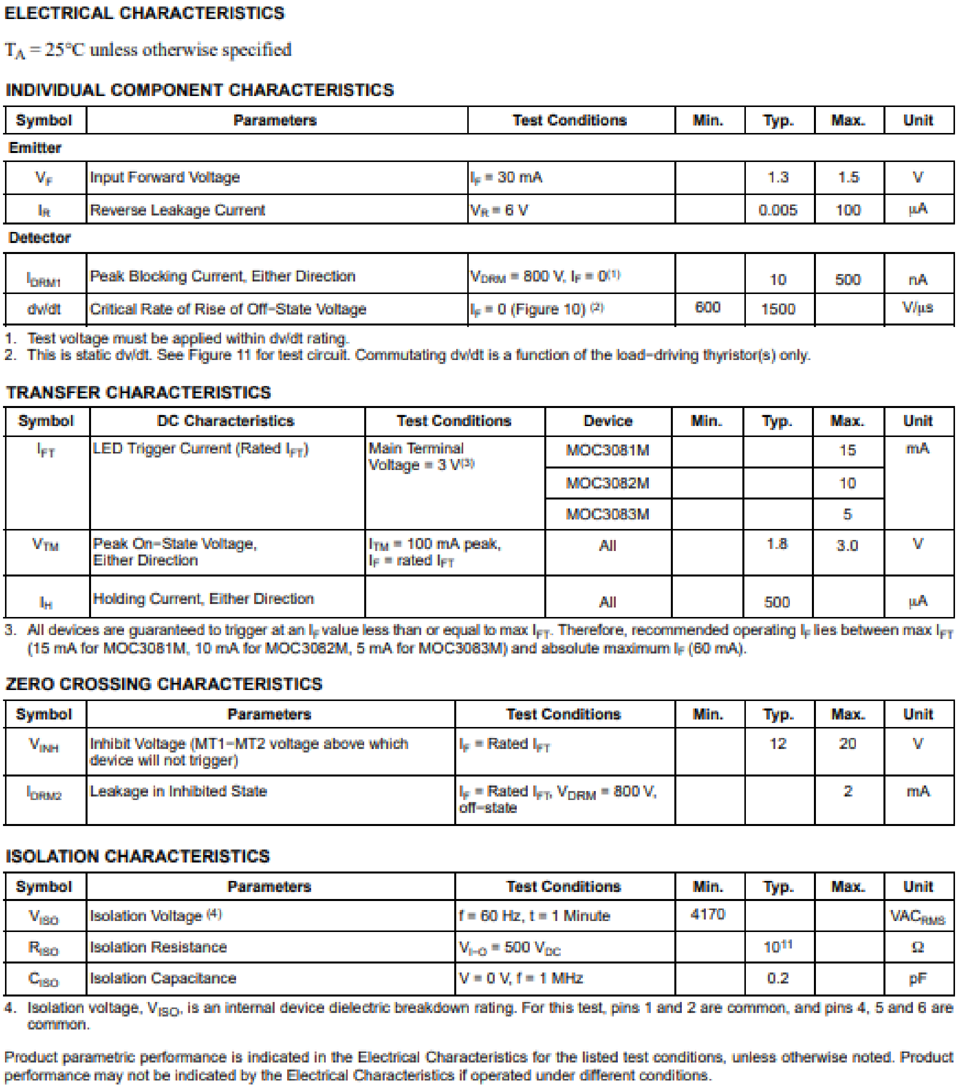
Symbol	Parameter	Value	Unit
V_{PR}	Input−to−Output Test Voltage, Method A, V_{IORM} x 1.6 = V_{PR}, Type and Sample Test with t_m = 10 s, Partial Discharge < 5 pC	1360	Vpeak
	Input−to−Output Test Voltage, Method B, V_{IORM} x 1.875 = V_{PR}, 100% Production Test with t_m = 1 s, Partial Discharge < 5 pC	1594	Vpeak
V_{IORM}	Maximum Working Insulation Voltage	850	Vpeak
V_{IOTM}	Highest Allowable Over−Voltage	6000	Vpeak
	External Creepage	≥ 7	mm
	External Clearance	≥ 7	mm
	External Clearance (for Option TV, 0.4" Lead Spacing)	≥ 10	mm
DTI	Distance Through Insulation (Insulation Thickness)	≥ 0.5	mm
R_{IO}	Insulation Resistance at T_S, V_{IO} = 500 V	> 10^9	Ω



ABSOLUTE MAXIMUM RATINGS (T_A = 25°C unless otherwise specified)

Symbol	Parameters	Value	Unit
Total Device			
T_{STG}	Storage Temperature	−40 to 150	°C
T_{OPR}	Operating Temperature	−40 to 85	°C
T_J	Junction Temperature Range	−40 to 100	°C
T_{SOL}	Lead Solder Temperature	260 for 10 seconds	°C
P_D	Total Device Power Dissipation at 25°C Ambient	250	mW
	Derate Above 25°C	2.94	mW/°C
Emitter			
I_F	Continuous Forward Current	60	mA
V_R	Reverse Voltage	6	V
P_D	Total Power Dissipation at 25°C Ambient	120	mW
	Derate Above 25°C	1.41	mW/°C
Detector			
V_{DRM}	Off−State Output Terminal Voltage	800	V
I_{TSM}	Peak Non−Repetitive Surge Current (Single Cycle 60 Hz Sine Wave)	1	A
P_D	Total Power Dissipation at 25°C Ambient	150	mW
	Derate Above 25°C	1.76	mW/°C

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.



ELECTRICAL CHARACTERISTICS

T_A = 25°C unless otherwise specified

INDIVIDUAL COMPONENT CHARACTERISTICS

Symbol	Parameters	Test Conditions	Min.	Typ.	Max.	Unit
Emitter						
V_F	Input Forward Voltage	I_F = 30 mA		1.3	1.5	V
I_R	Reverse Leakage Current	V_R = 6 V		0.005	100	µA
Detector						
I_{DRM1}	Peak Blocking Current, Either Direction	V_{DRM} = 800 V, I_F = 0(1)		10	500	nA
dv/dt	Critical Rate of Rise of Off−State Voltage	I_F = 0 (Figure 10) (2)	600	1500		V/µs

1. Test voltage must be applied within dv/dt rating.
2. This is static dv/dt. See Figure 11 for test circuit. Commutating dv/dt is a function of the load−driving thyristor(s) only.

TRANSFER CHARACTERISTICS

Symbol	DC Characteristics	Test Conditions	Device	Min.	Typ.	Max.	Unit
I_{FT}	LED Trigger Current (Rated I_{FT})	Main Terminal Voltage = 3 V(3)	MOC3081M			15	mA
			MOC3082M			10	
			MOC3083M			5	
V_{TM}	Peak On−State Voltage, Either Direction	I_{TM} = 100 mA peak, I_F = rated I_{FT}	All		1.8	3.0	V
I_H	Holding Current, Either Direction		All		500		µA

3. All devices are guaranteed to trigger at an I_F value less than or equal to max I_{FT}. Therefore, recommended operating I_F lies between max I_{FT} (15 mA for MOC3081M, 10 mA for MOC3082M, 5 mA for MOC3083M) and absolute maximum I_F (60 mA).

ZERO CROSSING CHARACTERISTICS

Symbol	Parameters	Test Conditions	Min.	Typ.	Max.	Unit
V_{INH}	Inhibit Voltage (MT1−MT2 voltage above which device will not trigger)	I_F = Rated I_{FT}		12	20	V
I_{DRM2}	Leakage in Inhibited State	I_F = Rated I_{FT}, V_{DRM} = 800 V, off−state			2	mA

ISOLATION CHARACTERISTICS

Symbol	Parameters	Test Conditions	Min.	Typ.	Max.	Unit
V_{ISO}	Isolation Voltage (4)	f = 60 Hz, t = 1 Minute	4170			VAC_{RMS}
R_{ISO}	Isolation Resistance	V_{I-O} = 500 V_{DC}		10^{11}		Ω
C_{ISO}	Isolation Capacitance	V = 0 V, f = 1 MHz		0.2		pF

4. Isolation voltage, V_{ISO}, is an internal device dielectric breakdown rating. For this test, pins 1 and 2 are common, and pins 4, 5 and 6 are common.

Product parametric performance is indicated in the Electrical Characteristics for the listed test conditions, unless otherwise noted. Product performance may not be indicated by the Electrical Characteristics if operated under different conditions.

APPENDIX E: Datasheet of ACS 712

Selection Guide

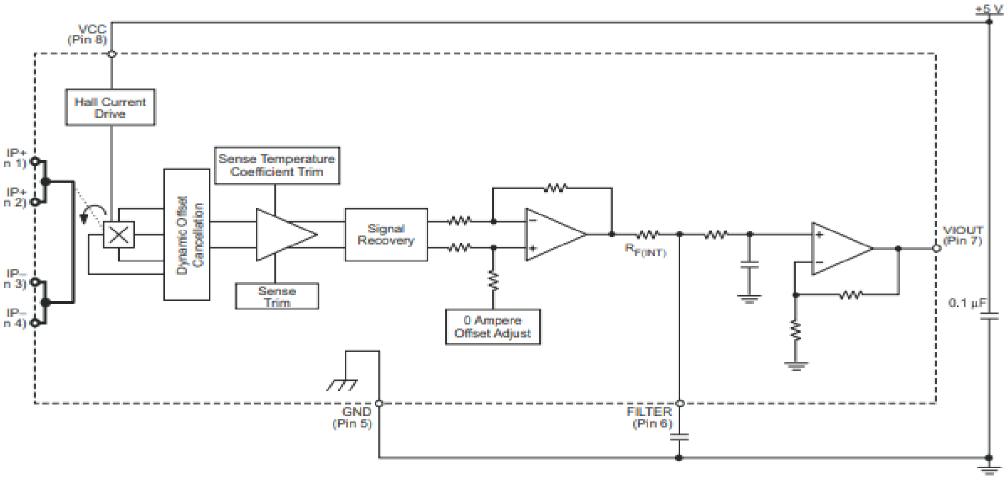
Part Number	Packing*	T_A (°C)	Optimized Range, I_P (A)	Sensitivity, Sens (Typ) (mV/A)
ACS712ELCTR-05B-T	Tape and reel, 3000 pieces/reel	–40 to 85	±5	185
ACS712ELCTR-20A-T	Tape and reel, 3000 pieces/reel	–40 to 85	±20	100
ACS712ELCTR-30A-T	Tape and reel, 3000 pieces/reel	–40 to 85	±30	66

*Contact Allegro for additional packing options.

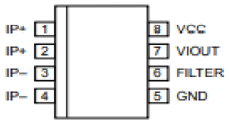
Absolute Maximum Ratings

Characteristic	Symbol	Notes	Rating	Units
Supply Voltage	V_{CC}		8	V
Reverse Supply Voltage	V_{RCC}		–0.1	V
Output Voltage	V_{IOUT}		8	V
Reverse Output Voltage	V_{RIOUT}		–0.1	V
Reinforced Isolation Voltage	V_{ISO}	Pins 1-4 and 5-8; 60 Hz, 1 minute, T_A=25°C	2100	V
		Voltage applied to leadframe (Ip+ pins), based on IEC 60950	184	V_{peak}
Basic Isolation Voltage	$V_{ISO(bsc)}$	Pins 1-4 and 5-8; 60 Hz, 1 minute, T_A=25°C	1500	V
		Voltage applied to leadframe (Ip+ pins), based on IEC 60950	354	V_{peak}
Output Current Source	$I_{IOUT(Source)}$		3	mA
Output Current Sink	$I_{IOUT(Sink)}$		10	mA
Overcurrent Transient Tolerance	I_P	1 pulse, 100 ms	100	A
Nominal Operating Ambient Temperature	T_A	Range E	–40 to 85	°C
Maximum Junction Temperature	T_J(max)		165	°C
Storage Temperature	T_{stg}		–65 to 170	°C

Functional Block Diagram

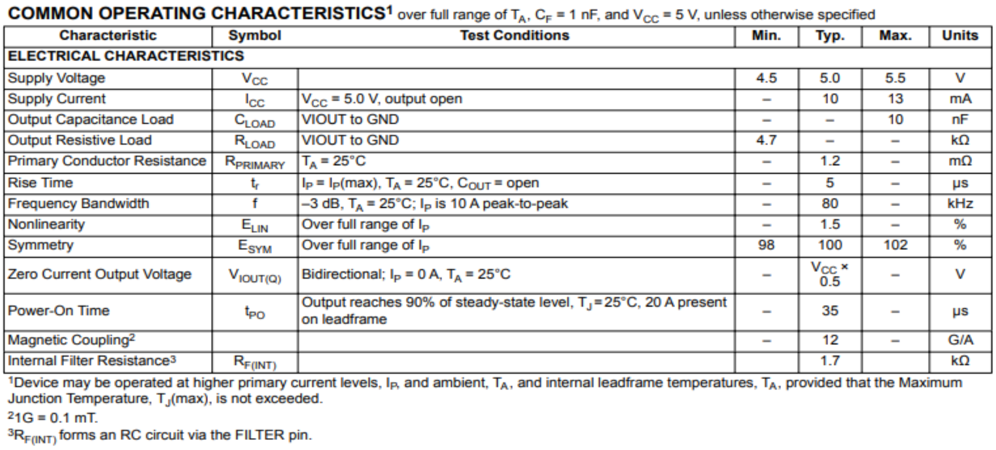


Pin-out Diagram



Terminal List Table

Number	Name	Description
1 and 2	IP+	Terminals for current being sensed; fused internally
3 and 4	IP–	Terminals for current being sensed; fused internally
5	GND	Signal ground terminal
6	FILTER	Terminal for external capacitor that sets bandwidth
7	VIOUT	Analog output signal
8	VCC	Device power supply terminal



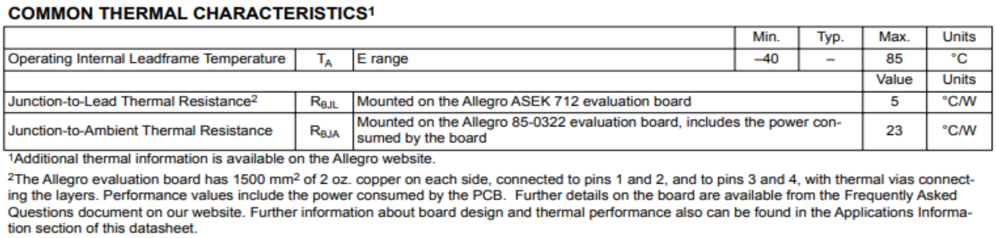
COMMON OPERATING CHARACTERISTICS[1] over full range of T_A, C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
ELECTRICAL CHARACTERISTICS						
Supply Voltage	V_{CC}		4.5	5.0	5.5	V
Supply Current	I_{CC}	V_{CC} = 5.0 V, output open	–	10	13	mA
Output Capacitance Load	C_{LOAD}	VIOUT to GND	–	–	10	nF
Output Resistive Load	R_{LOAD}	VIOUT to GND	4.7	–	–	kΩ
Primary Conductor Resistance	$R_{PRIMARY}$	T_A = 25°C	–	1.2	–	mΩ
Rise Time	t_r	$I_P = I_P(max)$, T_A = 25°C, C_{OUT} = open	–	5	–	μs
Frequency Bandwidth	f	–3 dB, T_A = 25°C; I_P is 10 A peak-to-peak	–	80	–	kHz
Nonlinearity	E_{LIN}	Over full range of I_P	–	1.5	–	%
Symmetry	E_{SYM}	Over full range of I_P	98	100	102	%
Zero Current Output Voltage	$V_{IOUT(Q)}$	Bidirectional; I_P = 0 A, T_A = 25°C	–	V_{CC} × 0.5	–	V
Power-On Time	t_{PO}	Output reaches 90% of steady-state level, T_J = 25°C, 20 A present on leadframe	–	35	–	μs
Magnetic Coupling[2]			–	12	–	G/A
Internal Filter Resistance[3]	$R_{F(INT)}$			1.7		kΩ

[1] Device may be operated at higher primary current levels, I_P, and ambient, T_A, and internal leadframe temperatures, T_A, provided that the Maximum Junction Temperature, $T_J(max)$, is not exceeded.

[2] 1G = 0.1 mT.

[3] $R_{F(INT)}$ forms an RC circuit via the FILTER pin.

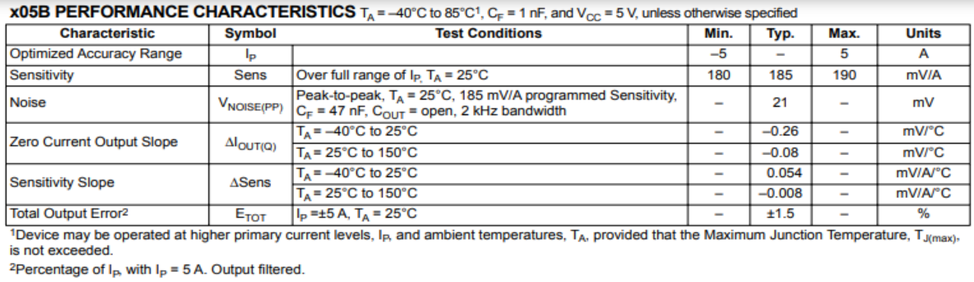


COMMON THERMAL CHARACTERISTICS[1]

			Min.	Typ.	Max.	Units
Operating Internal Leadframe Temperature	T_A	E range	–40	–	85	°C
					Value	Units
Junction-to-Lead Thermal Resistance[2]	$R_{\theta JL}$	Mounted on the Allegro ASEK 712 evaluation board			5	°C/W
Junction-to-Ambient Thermal Resistance	$R_{\theta JA}$	Mounted on the Allegro 85-0322 evaluation board, includes the power consumed by the board			23	°C/W

[1] Additional thermal information is available on the Allegro website.

[2] The Allegro evaluation board has 1500 mm² of 2 oz. copper on each side, connected to pins 1 and 2, and to pins 3 and 4, with thermal vias connecting the layers. Performance values include the power consumed by the PCB. Further details on the board are available from the Frequently Asked Questions document on our website. Further information about board design and thermal performance also can be found in the Applications Information section of this datasheet.

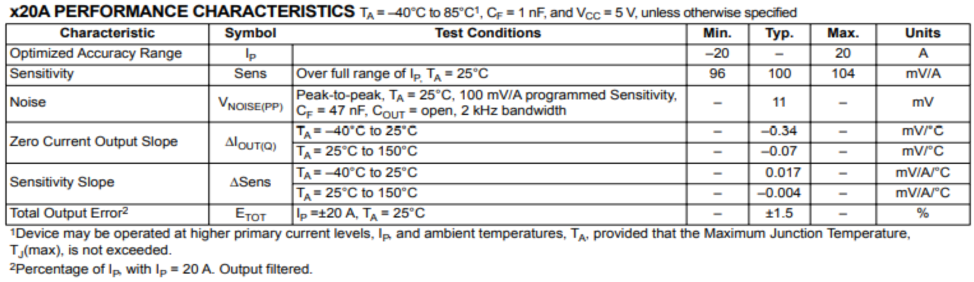


x05B PERFORMANCE CHARACTERISTICS T_A = –40°C to 85°C[1], C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Optimized Accuracy Range	I_P		–5	–	5	A
Sensitivity	Sens	Over full range of I_P, T_A = 25°C	180	185	190	mV/A
Noise	$V_{NOISE(PP)}$	Peak-to-peak, T_A = 25°C, 185 mV/A programmed Sensitivity, C_F = 47 nF, C_{OUT} = open, 2 kHz bandwidth	–	21	–	mV
Zero Current Output Slope	$\Delta I_{OUT(Q)}$	T_A = –40°C to 25°C	–	–0.26	–	mV/°C
		T_A = 25°C to 150°C	–	–0.08	–	mV/°C
Sensitivity Slope	ΔSens	T_A = –40°C to 25°C	–	0.054	–	mV/A/°C
		T_A = 25°C to 150°C	–	–0.008	–	mV/A/°C
Total Output Error[2]	E_{TOT}	I_P = ±5 A, T_A = 25°C	–	±1.5	–	%

[1] Device may be operated at higher primary current levels, I_P, and ambient temperatures, T_A, provided that the Maximum Junction Temperature, $T_{J(max)}$, is not exceeded.

[2] Percentage of I_P, with I_P = 5 A. Output filtered.

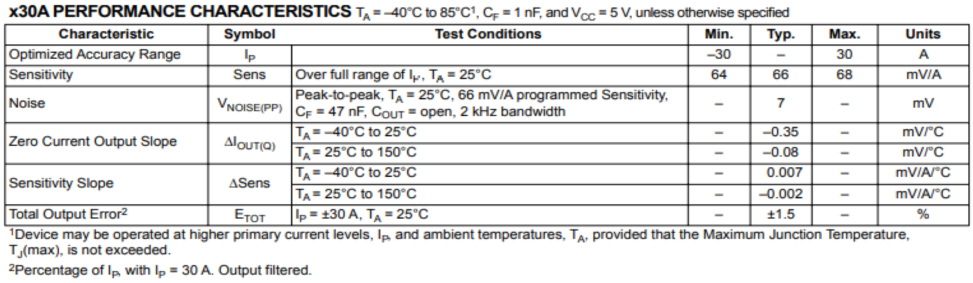


x20A PERFORMANCE CHARACTERISTICS T_A = –40°C to 85°C[1], C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Optimized Accuracy Range	I_P		–20	–	20	A
Sensitivity	Sens	Over full range of I_P, T_A = 25°C	96	100	104	mV/A
Noise	$V_{NOISE(PP)}$	Peak-to-peak, T_A = 25°C, 100 mV/A programmed Sensitivity, C_F = 47 nF, C_{OUT} = open, 2 kHz bandwidth	–	11	–	mV
Zero Current Output Slope	$\Delta I_{OUT(Q)}$	T_A = –40°C to 25°C	–	–0.34	–	mV/°C
		T_A = 25°C to 150°C	–	–0.07	–	mV/°C
Sensitivity Slope	ΔSens	T_A = –40°C to 25°C	–	0.017	–	mV/A/°C
		T_A = 25°C to 150°C	–	–0.004	–	mV/A/°C
Total Output Error[2]	E_{TOT}	I_P = ±20 A, T_A = 25°C	–	±1.5	–	%

[1] Device may be operated at higher primary current levels, I_P, and ambient temperatures, T_A, provided that the Maximum Junction Temperature, $T_J(max)$, is not exceeded.

[2] Percentage of I_P, with I_P = 20 A. Output filtered.



x30A PERFORMANCE CHARACTERISTICS T_A = –40°C to 85°C[1], C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Optimized Accuracy Range	I_P		–30	–	30	A
Sensitivity	Sens	Over full range of I_P, T_A = 25°C	64	66	68	mV/A
Noise	$V_{NOISE(PP)}$	Peak-to-peak, T_A = 25°C, 66 mV/A programmed Sensitivity, C_F = 47 nF, C_{OUT} = open, 2 kHz bandwidth	–	7	–	mV
Zero Current Output Slope	$\Delta I_{OUT(Q)}$	T_A = –40°C to 25°C	–	–0.35	–	mV/°C
		T_A = 25°C to 150°C	–	–0.08	–	mV/°C
Sensitivity Slope	ΔSens	T_A = –40°C to 25°C	–	0.007	–	mV/A/°C
		T_A = 25°C to 150°C	–	–0.002	–	mV/A/°C
Total Output Error[2]	E_{TOT}	I_P = ±30 A, T_A = 25°C	–	±1.5	–	%

[1] Device may be operated at higher primary current levels, I_P, and ambient temperatures, T_A, provided that the Maximum Junction Temperature, $T_J(max)$, is not exceeded.

[2] Percentage of I_P, with I_P = 30 A. Output filtered.