IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

Intelligent Power Factor Correction: Leveraging IoT and AI for Enhanced Energy Efficiency

[1] **Muyombano Happy Axel**, [2] **Kagwesage Anne Marie**, [3] **Keza Chryssa Benie**, [4] **Kaze Smart Arsene**

Africa Center of Excellence in Internet of Things (ACEIoT), College of Science and Technology, University of Rwanda. P.O BOX 4281 Kigali, Rwanda

Abstract : Energy efficiency, shown as a ratio from 0 to 1, is the percentage of electricity used to accomplish productive work. Giving the user this knowledge is crucial for the economical use of electricity since the user will keep an eye on and adjust electrical equipment to conserve energy. The designed power factor meter encapsulates the sonoff pow r2 module for measuring power factor, voltage, current, and power values. The ESP8266 microcontroller processes power calculations, and, through Wi-Fi communication results are displayed on the mobile phone. The existing power factor design is not portable and is bought separately from the energy meter, causing inconvenience to the user and extra cost. The power factor designed in this project fills the user-centricity gap by integrating power factor reading into an energy meter and a user can access this information conveniently in their mobile phone. Contrary to using the original firmware of sonoff devices and eWelink application, this project adopted a method of flashing new firmware onto the sonoff pow r2 which can show power factor values of an AC load, unlike the original firmware.

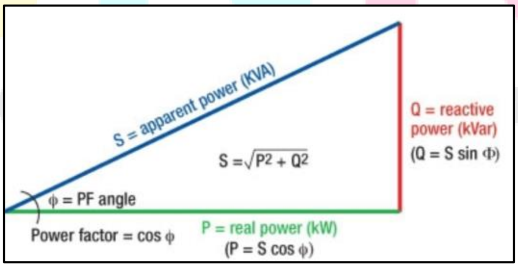
Keywords: Power Factor, Electrical energy optimization, Internet of Things, Automation.

I. Introduction

INTRODUCTION

Introduction of Project

Power factor of an AC electrical load is the ratio between real power (W) and the apparent power (VA) as seen in Figure I-1 . Power factor is a measure of how effective electrical current is converted to useful power and an accurate indicator of the load current effect on the electrical supply system, a low power factor indicates that the load draws high current to meet high reactive power requirements hence greater voltage drops and energy loss (I^2R losses). High current due to low power factor pushes electrical equipment rated based on their current carrying capacity such as generators and transformers (VA) closer to their rated capacities. Additionally, commercial users with low power factor will bear extra cost in form of power factor, high power factor implies efficient energy use and ensures the safe, smooth and efficient operation of electrical utilities [1].



Source (Karthik,2018)

Figure I-1: Power triangle

In this project, the portable power factor designed will show the user power factor, real power, apparent power and reactive power readings and store the total energy readings and at least 1 day previously 'yesterday' energy readings. This is a significant paradigm shift from the conventional energy meter and power factor meter that do not store previous energy readings for the user's reference and monitoring. The aim of this project is to provide users with reliable power factor information in an easy to access way because currently users have to go to a physical electricity meter to keep track of electricity consumption which is time consuming and still users are unable to view power factor information hence this project seeks to provide power factor information at users fingertips. The portable power factor meter will display RMS voltage and current, real power and power factor of the AC load.

The proposed idea of the portable power factor meter Figure I-2 in this project comprises of Sonoff pow r2 module that is connected onto a single phase AC source, and it will measure the voltage and current in rms value. Subsequently Sonoff will wirelessly communicate with mobile phones and display the Vrms, Irms, real power and power factor values.

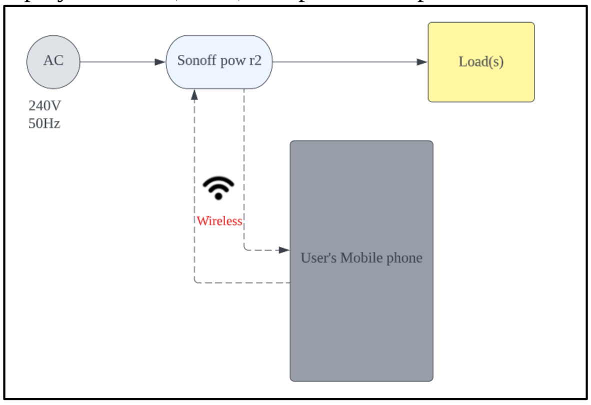


Figure I-2:Illustrates the proposed idea of a portable power factor meter

Single phase electrical outlets are typically rated 230 V or 240 V, In this project the 240 V AC source is connected to the sonoff relay module which is an Arduino compatible module, the sonoff relay module has input circuity comprised of rectifiers to control the input AC supply. The sonoff performs signal conditioning to convert controlled analog signal into digital bits, the sonoff relay module contains ESP8266 microcontroller with Wi-Fi capabilities to wireless communicate with a mobile phone to display, Vrms, Irms, power factor and power values in eWelink mobile application. Essentially sonoff relay used in this project can remotely switch ON and OFF the connected load using the mobile phone.

Power factor ranges from -1 to 1 [2] where negative indicates leading PF and positive indicate lagging PF. Power factor of 0 means that there is no real power consumption whereas power factor value of 1 means that real power produces is effectively used to a degree of 100% without any reactive power. Power factor of 0.9 indicates that 90% of power is used to perform real work whereas 10% is reactive power which does not generate useful work on the load.

In resistive circuits current is in phase with voltage hence all power absorbed from the load is supplied back to the load to perform useful work while in capacitive circuit current leads voltage thus capacitive load in a circuit will result in phase shift between current and voltage waveforms thereby causing leading power factor value from -1 to 0 and in inductive circuits current lags voltage therefore in case there is inductive reactance in a circuit, this will result in lagging power factor value ranging from 0 to 1.

Problem statement

Power factor meters such as electrodynamometers and moving iron-type meters have been increasingly utilized in the industry but with increased inconvenience because these meters are installed separately from electricity meters, one measuring kWh and another measuring power factor. These equipment are not portable and they are separately purchased meaning extra cost and inconvenience to the user. This project seeks to converge both energy meter and power factor meter into one and display results in a mobile phone by adopting an automated and user-centric approach. The approach will wirelessly transmit energy data from the loads to a mobile phone and display power factor, Vrms, Irms, real power per hour, and apparent power in the user's mobile phone.

Specific objectives

(a). To evaluate the viability of remotely controlling a load connected to an AC power supply.
(b). To apply the IoT platform to monitor power factor of AC loads.
(c). To analyze the merits of the portable power factor over the existing power-factor meters.

Hypothesis

Workplace and corporate environments will greatly benefit from the integration of AI and IoT devices into the power factor correction (PFC). In addition to lowering operational costs and increasing energy recovery and minimizing energy losses, this strategy offers real-time monitoring and predictive maintenance capabilities. Smart PFC systems ensure energy economy and regulatory compliance by automatically adapting to changing conditions.

Scope of Project

The scope of this project includes designing a portable power factor monitoring system that is portable and provides accurate energy data through a mobile phone. The reliability of the system is equally important hence reliability and accuracy test will be conducted to compare the designed system against existing energy meters and power factor.

Significance of project

This project is vital for users to check the energy consumption and monitor power factor of loads connected to AC power supply via a mobile phone from a far distance. This will save the user the inconvenience of physically walking to the energy meter to monitor energy consumption and provide accurate power factor information which is linked to overall efficiency and optimization of energy. Besides being a portable device, the designed power factor meter remotely controls appliances connected to the power supply by toggling them at the users convenience (ON/OFF) at a far distance.

Arrangement of project report

This project report consists of five chapters. Chapter 1 is for introduction; Chapter 2 is for literature review , chapter 3 is for methodology, Chapter 4 is for conclusion. Chapter 1 introduces the proposed idea of a portable power factor meter and the requisite components to design it. Chapter 2 delves into power optimization techniques used by other scholars; it also points out the need for power factor information in energy meters as well as electrical components necessary for designing a portable power factor meter. Chapter 3 leverages on the literature review to choose a suitable method and necessary electrical components to design a portable power factor meter which is user centric. Chapter 4 concludes the findings observed in the project implementation phase by linking the findings to technical objectives for this project and recommends improvements required for further optimization of energy. A reference list follows conclusion showing academic research made in this project, finally the appendix that contains project planning and management for this project.

LITERATURE REVIEW

Impact of power factor on electricity bills

The hypothesis that energy costs and consumption patterns are related is not well supported. According to literature [3], which conducted a direct analysis of energy use, air conditioners consume the most energy, consuming 1470 kilowatt-hours per household, or 26.81% of all power used, excluding lighting. Electric stoves and refrigerators come next, using 343.85 kWh (6.27%) and 815.83 kWh (14.88%) of energy, respectively. Based on statistical analysis, there is a correlation between GDP and the installation of electricity, which in turn raises household power usage. outcomes derived from Taiwanese citizens' living circumstances in the utilities industry. According to a study by [4], customers are more likely to refrain from wasting energy when they are aware of the electronic information on electronic products.

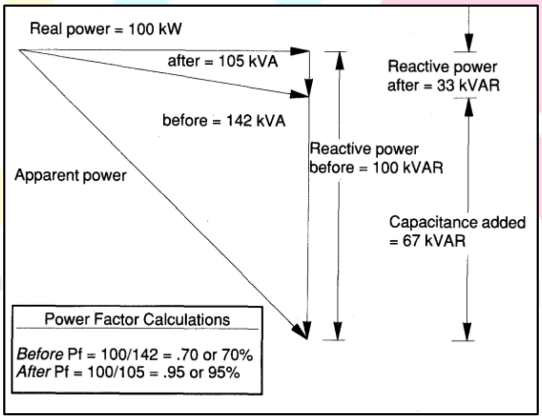
Electric current strength causes the kVA measured by the load to be more than the kW when the power is lower, as mentioned in [5]. Electrical devices typically charge at their maximum kW (actual power) or kVA (apparent power). Equation (1) displays the calculating formula. As a result, enhancing the power supply through power supply adjustments (such as employing a capacitor bank) can lessen the requirement for energy and, consequently, lower the price of electricity. Circuits benefit from high voltage equipment because it lowers electrical losses and enhances load capacity. High energy lowers the carbon footprint, which benefits the environment [6].

$$\mathrm{PF} = \frac{\text{Real power(kW)}}{\text{Apparent power(kVA}} \quad (1)$$

A few consequences of malfunctioning electrical equipment are: higher losses and equipment current, which can lead to capacity constraints and/or increased investment losses, higher labor costs, which can result in shortages of supplies; increased equipment failure because of increased electrical and thermal equipment failure. [7] reports that multinational companies in Nigeria do not pay attention to the power factor of their equipment which results in high maintenance and production cost of over $50,000 annually due to equipment damage as a result of low power factor.

Reduced power factor results in reduced efficiency, and reduced efficiency raises costs. Numerous products penalize consumers with subpar goods. The utility provider must be able to supply the entire kVA even in the event that the consumer does not use it all. Transformers are rated in kVA rather than kW because of this [8]. Customers of certain utilities are billed for the total kVA that is supplied to the facility.

Power loss and voltage drop in the distribution system are the results of poor power quality. Overuse of electricity can lead to overheating and failure of motors and other induction equipment. An inductive load with an operational power of 100 kW and an initial power of 0.70 is depicted in the power triangle in the picture below. The load requires 100 kVAR of reactive power. Installing a 67 kVAR capacitor lowers the needed power from 142 kVA to 105 kVA, which lowers the current by 26% [9]. The power factor reached 0.95.



Source: (Teddy Surya Gunawan, 2020)

Figure 0-1:High vs Low power factor characteristics

Unity power factor which is a power factor of 1 occurs where the apparent power supplied to a facility is only used by electrical equipment on the site to do useful work. A theoretical electrical circuit with only resistive loads, such as ovens and heaters, will have a power factor equal to one [10]. A similar circuit with only inductive or capacitive loads will have a power factor of zero. In reality, an electrical circuit contains a mixture of both of these types of loads. A good power factor is between 1 and 0.95 as seen in Figure 2-

3, between 0.95 and 0.85 is poor, and below 0.85 is bad. [10] predicts that in the future utility companies can charge non-commercial customers when they have poor or low power factor because newer smart meters have capabilities to monitor reactive power.

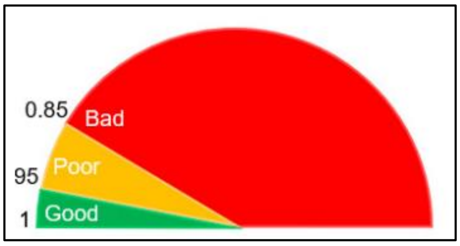
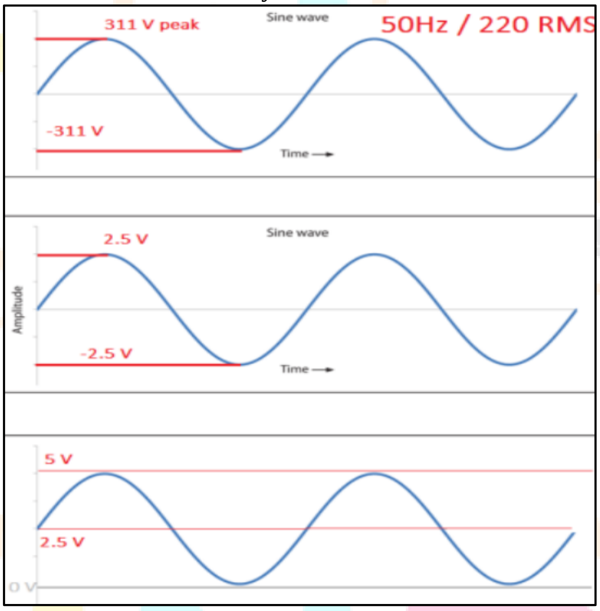


Figure 0-2: Power factor variations Power side(2020)

AC Voltage Measurement

To measure AC voltage, ZMPT101B has been utilized in most literature reviewed, [11], [12], wherein [13] voltage discrepancy reported was under 0.7% due to its high accuracy and good consistency for voltage measurement. ZMPT101B sensor unit is an AC-type voltage sensor based on a built-in voltage transformer. It performs high accuracy, and good reliability for voltage and power measurement, It has a wide range of measurements (0-250 AC voltage) at 50/60Hz. It is very easy to use and build with a multi- trim potentiometer for adjusting the ADC output. The module read the signal that will be measured (220V phase voltage) in current work with a peak value 311 V. The built-in voltage transformer reduces it to 2.5 V (peak). Then a 2.5 V offset has been inserted to shift the signal to a positive level where the microcontroller ADC can be detected. ZMPT101B voltage sensor due to its small size and implementation simplicity on various platforms is a good choice to use as recommended by sufficient literature reviewed.



Source: (Salunkhe, Kanse, & Patil, 2022)

Figure 0-3:Operation of single phase ZMPT101B voltage sensor module

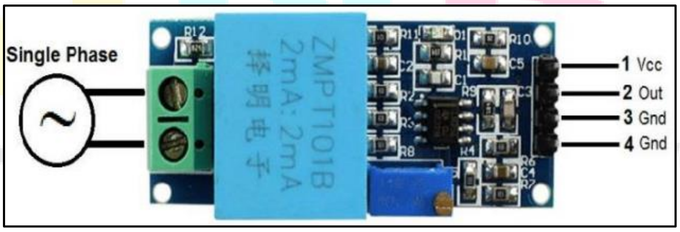
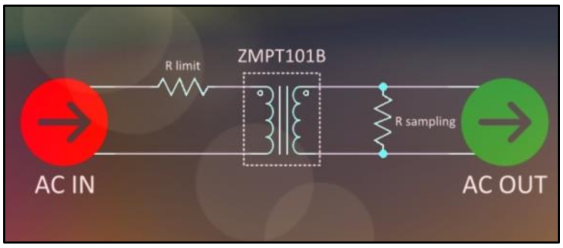


Figure 0-4:ZMPT101B AC voltage sensor module

The ZMPT101B transformer alone has a primary and secondary sides set up with a limiting resistor on the primary side and sampling resistor on the secondary side Its secondary side circuitry is centered on the LM358 dual op amp chip. The recommended operating voltage is 5V DC. For safety purposes a fuse can be installed on the live wire connected to the ZMPT101B module.



Source: (HAREENDRAN, 2022)

Figure 0-5:Set up of ZMPT101B transformer

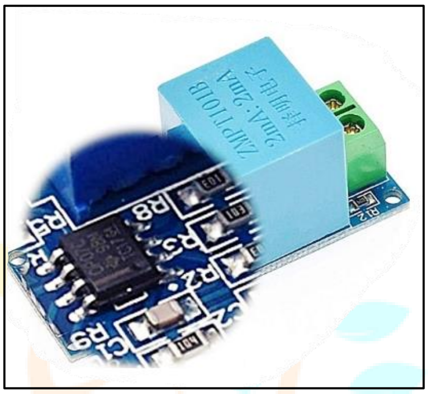
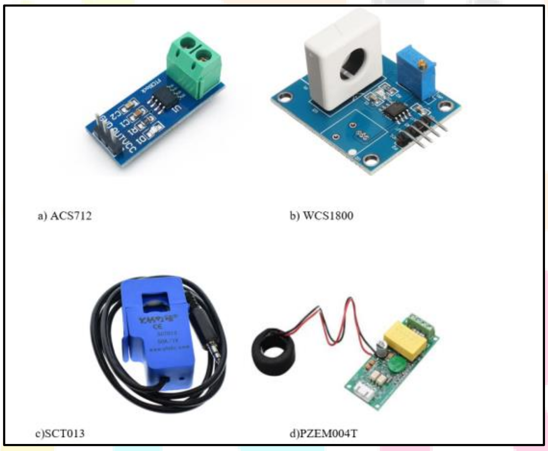


Figure 0-6:LM358 chip on secondary side of ZMPT101B module.

AC Current Measurement

In the article [4] compared AC current measurement accuracy of four low-cost current sensors which exist in the market namely ACS712,WCS1800,SCT013 and PZEM004T. The ESP32wifi microcontroller was used to process the measurements and the test show that PZEM004T gives the best performance however ACS712 is best value current sensor due to its affordable price and performance. In case of designing many units that measure AC current, ACS712 would be adopted to save cost while still having reasonable performance. The ACS712 current sensor is more difficult to install compared to the other current sensors in the market.



Source: Ruengwit Khwanrit(2018)

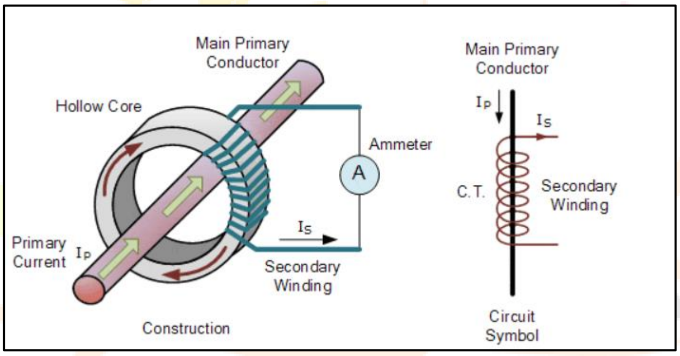
Figure 0-7: Current sensors in reviewed

ACS-712 current sensor operates with 5V, its analog output voltage is proportional to the current measured on the sensing terminals. Microcontroller ADC can be used to read the values . ACS712 sensor mechanism depends on Hall effect principle, according to this mechanism, when the conductor that carries an electrical current placed in magnetic field a voltage will be induced, which called "Hall voltage". The sensor is used to normalize the required voltage level from the current which is further fed to the microcontroller. Then the microcontroller converts the Hall voltage to the RMS actual current using formula given in equation (2). The sensitivity value depends on range (5A,10A,20A &30A) of ACS712 chosen and they include 185mV/A and 100mV/A [12].

$$\text{current(A)} = \frac{(\text{sensor value} - 512) \times \frac{5}{1024}}{\text{sensitivity value} \times \sqrt{2}} \qquad (2)$$

SCT-013 is a non- invasive AC current sensor, it is a split core type clamp meter sensor which can measure AC current of up to 100A.The SCT-013 current sensor can be clipped to the live or neutral wire coming from source without the need for high voltage electrical work [14]. SCT-013 has more merits compared to ACS712, as a high quality AC current sensor with accuracy of ±1% and linearity of ±3% [14]. SCT-013-100A model being a current transformer can step down 100A AC to a maximum of 50mA, this is suitable for measuring electricity consumption [15] and recommends 100-amp service for a modern home of 3,000 square feet without central air-conditioning or electric heat. In terms of pricing, both SCT-013-100A and SCT-013-30A cost in the same budget range.

Figure 0-8:SCT-013-100A current sensor



Source: (Autobotic, 2020)

Figure 0-9:SCT-013 primary and secondary windings

The current sensor is connected to ESP32 microcontroller which has a 12 bit resolution, Analog to Digital conversion will be done to convert analog voltage into digital format for further calculations. The Wi-Fi driver uses the ADC2 peripheral hence ADC2 is usable only when the Wi-Fi is not used [16].

Power factor Measurement

Power factor basic theory

Generally, in electrical systems there are inductive loads that store and supply energy in the circuit, this causes current to lag voltage by the power angle(θ). The cosine of power angle is power factor of the circuit [17]. The power factor is key to determining the average power delivered to the load, consider power delivered to the load as constant, when the power factor is low the current drawn from the load such as fluorescent light, induction motor or transformer will be high which puts a burden on the inverter and reduces the ability to use all available power. This is why it is essential to run electrical loads at a power factor close to 1 (unity).

$$\text{Power factor} = \cos(\theta) \qquad (3)$$

Resistive circuit = current in phase with voltage

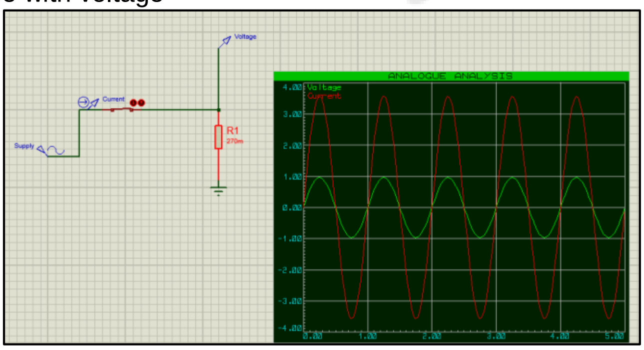


Figure 0-10:Resistive load simulation

Capacitive circuit = current leads voltage

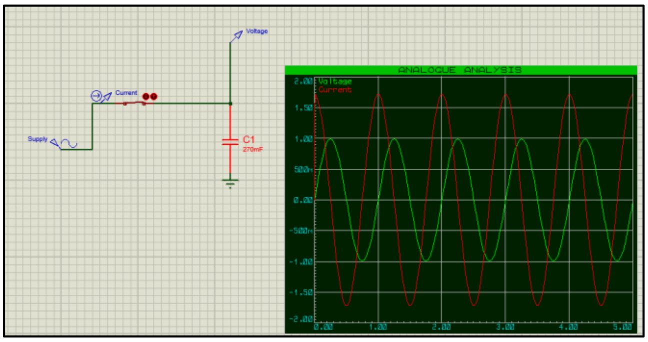


Figure 0-11:Capacitive load simulation

Inductive circuit = current lags voltage

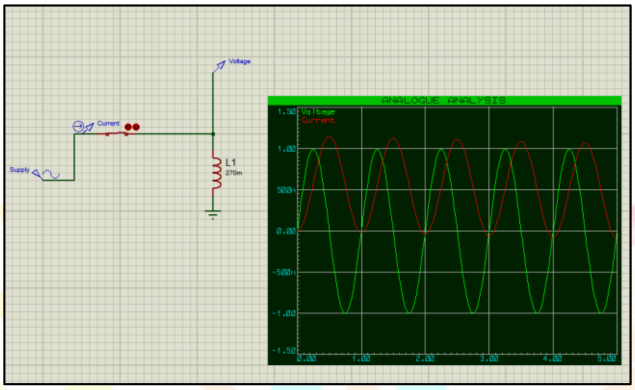
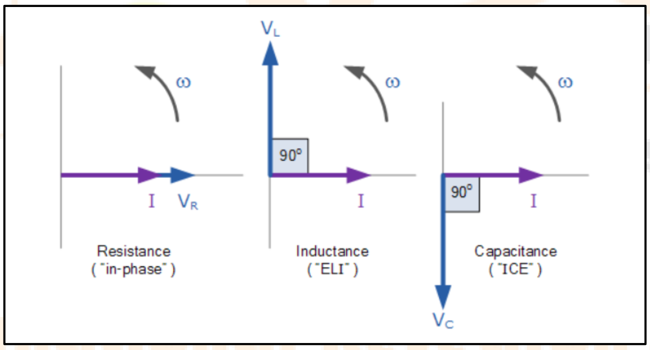


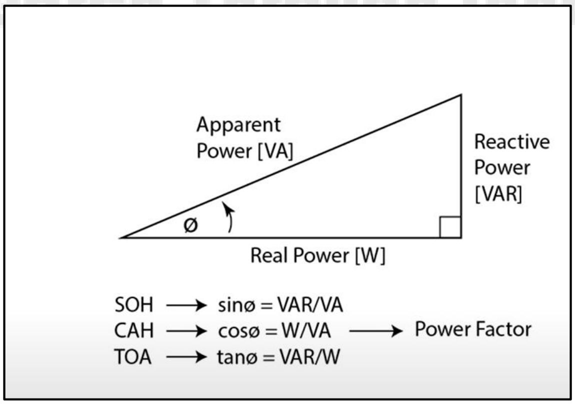
Figure 0-12: Inductive load simulation



Source: (Albeth, 2020)

Figure 0-13: Summary of AC loads phasor diagrams

In a purely resistive load current and voltage are in phase hence the angle θ is zero therefore power factor cos(θ) yields 1 [18]. In both purely inductive and capacitive loads angle θ is 90° hence power factor cos(θ) yields 0. As voltage and current go out phase the power factor gradually becomes worse. The product of current flowing through a resistive part of the load and voltage is active power whereas the product of current flowing through the inductive part and voltage is reactive power. Total voltage in the circuit multiplied by current in the circuit is apparent power.



Source: (Albeth, 2020)

	Citation	Methodology Hardware/software	Findings, recommendations
1	(Maryam Nabihah Zaidi, 2018)	Voltage and current sensing circuits, Zero crossing detectors, PIC microcontroller and capacitor of PF correction	TNB imposes penalty on industrial users with less than 0.85 power factor
2	(A. A. Mukaila, 2018)	Zero Crossing detection is supported by Arduino Nano, 2X16LCD, generic resistor, LM324 operational amplifier, instrument transformers, and generic XOR Gate 7488.	The work amplifier receives the input voltage and current signals from the transformer, uses zero-crossing detection to identify the time difference, and then calculates the power factors and reactive power deficiencies for the microcontroller. After that, it appears on the User Interface.
3	(Anmar Arif, 2013)	Build smart meters based on GSM and ZigBee**.**	The energy meters are made to measure energy and provide data to service providers so they may gather information and notify clients online or by text message.
4	(Niloy Mondal, 2022)	ZMPT101B, ACS712, ESP32 performs calculations and displays V,I and units with corresponding prices on LCD and mobile phone application.	Reduces manpower by employing automation and enhances transparency by reducing flaws caused by human error. The data is stored in the cloud server; hence always more secure.
5	(Mohannad Jabbar Mnati, 2017)	ZMPT101B, ACS712, Arduino nano, Bluetooth HC-05, MIT application invertor 2.	Create and put into use a smartphone application that will allow data from the three-phase measurement system to be monitored, as well as a low-cost, safe three-phase measurement system.
6	(Salunkhe, Kanse, & Patil, 2022)	ESP32, AWS cloud platform, RS485 communication interfaced with smart meter	Design performs calculations of 3 phase voltage, current, active and reactive power with recording at back end. User can monitor data using login panel on daily or weekly basis.
7	(Single Phase Energy Smart Meter System Design and Implementation using RFID and based on IoT, 2020)	ESP32, Raspberry Pi, voltage and current sensor (PZEM-004T), customer unit meter, relay	Design shows user voltage, current, power factor, energy balance in the smart meter. Data transfer between smart meter and control center is done via Wi-Fi. It uses prepaid scheme.

Figure 0-14: Power triangle showing power factor calculation

Therefore, the power triangle shows the relationship between real/active, apparent and reactive power by leveraging on the trigonometry knowledge power factor can be calculated. When the angle (θ) is zero, apparent power will be equal to real/active power hence there will not be any reactive power in the system hence power factor will be unity. Other related research work reviewed

There are numerous methods that have been used by scholars to design power factor meters and energy meters geared towards convenience of the end user, this section reviews and references other scholarly articles, In general literature reviewed acknowledges the need for a paradigm shift from the way users monitor and optimize energy.

Table 0-1: Other literature reviewed

METHODOLOGY.

Unified Modeling Language (UML) class diagram

The proposed idea of the portable power factor meter will be used using the detailed methodology in the UML class diagram below in Figure 3.3.

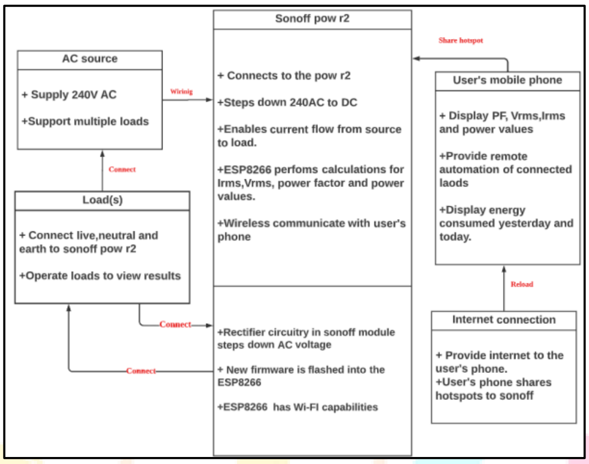


Figure 0-1: UML class diagram of portable power factor meter.

Safety precautions will be taken into consideration when using the above methodology, these include carefully inserting the live and neutral wire from the socket extension carrying 240V AC into the Sonoff module fully to ensure that the user does not get electrical shock from the high voltage, similarly on the load side the live and neutral wires should be sealed fully to avoid danger. Besides the physical safety consideration, in this methodology when the need for additional code into the Sonoff's ESP8266 arises, it can be done However the original software should be saved and reflashed into the ESP8266 for initial intended use. Additional code into the sonoff will remove app support and it also increases the security risk, but this method will enable the objective of this project which is to display power factor for the user to visualize power optimization.

Qualitative analysis

Qualitative research techniques that are suitable for this paper are interviews with industry professionals and executives, to shed light on the problems and pain points of energy efficiency in buildings. On the other hand, multiple methodologies such as detailed questionnaire can be used to collect and analyze large amounts of data on power usage, energy consumption, and other unrelated variables in order to detect trends and make strategic predictions.

Quantitative analysis

Sensors and IoT devices can be installed in pilot sites to monitor power factor, energy consumption and load conditions in real time and continuously and this data deposited into a repository for analysis and baseline comparison. Machine learning algorithms will be applied to optimize power factor correction based on load variations and energy usage patterns and relay statistical analysis to compare performance of traditional and intelligent power factor correction systems in terms of cost rection, energy savings and power factor improvement.

Reliability test

The reliability of this portable power factor meter is as important as its accuracy because for everyday usage of user, energy meters and power factor meters are designed with great emphasis on ability to function without failure under many conditions and long period of time.

For this project, a 10 hour reliability test will be undertaken where the portable power factor meter loads will be connected to it and examined on Mean Time Before Failure (MTBF), Mean Time Before Repair (MTTR) and Availability of the portable power factor meter.

$$\text{MTBF} = \frac{\sum \text{start downtime} - \text{start of uptime}}{\text{number of failures}} \quad (3)$$

$$\text{MTTR} = \frac{\sum \text{start downtime}}{\text{number of failures}} \quad (4)$$

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \times 100\% \quad (5)$$

Flashing tasmota using tasmotizer into sonoff

This section describes the software steps to get the new software working in sonoff module and how to configure internet service for the power results to be accessed through mobile phone by users.

Step 5: Download Tasmota

In GitHub there is tasmota version and is open source hence it can be downloaded.

Figure 0-16: Downloaded tasmotizer

Step 6: Flash the tasmota firmware into sonoff.

It is common practice to save the original sonoff firmware so that it can be flashed if needed, ensure port configured is selected i.e., COM3 in this project, select release and "open" tasmota bin which is usually the first on the list. "Tick" erase before flashing and tasmotize.

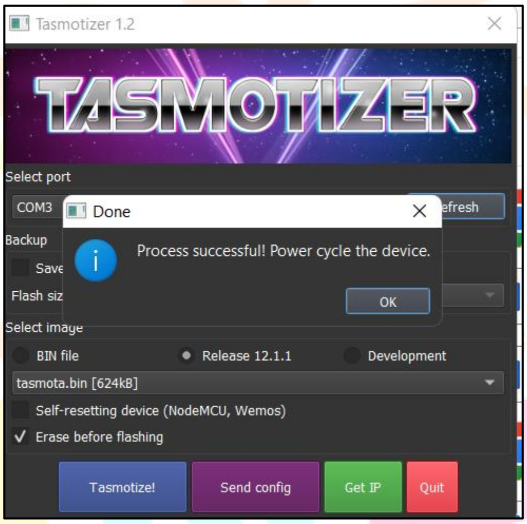
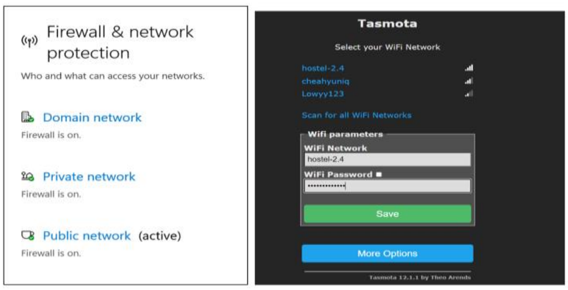


Figure 0-16: Tasmota firmware uploaded on sonoff

Step 7: Connect to tasmota Wi-Fi

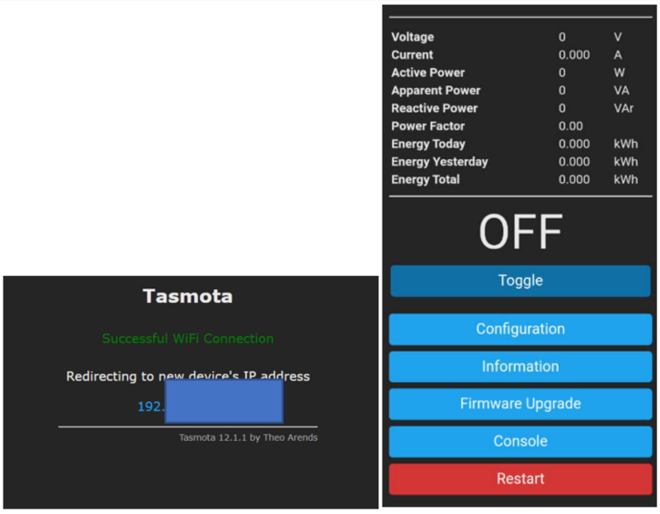
The new sonoff Wi-Fi will be called tasmota, there is a need to modify firewall and security settings to enable visibility of this Wi-Fi network. Turn OFF firewall settings in public or private network whichever is active. If the page labelled b) below does not appear browse "192.168.4.1".



a)Configure firewall settings b) Page will appear after connecting to new Wi-Fi

Figure 0-17: Configure Wi-Fi connections

Step 8: Configure module
After step 7, an IP address will assigned to the sonoff device, use this IP address to access tasmota page to remotely control device and configure the sonoff as long as the sonoff is plugged into AC power and connected to load.



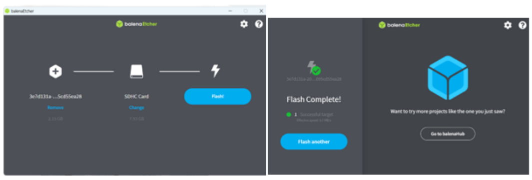
a) IP address assigned b) Configured module to POW R2

Figure 0-18: Configuring module

Raspberry pi and home assistant

The preferred methodology to install home assistant is through flashing the URL image on the SD card and attaching the SD card onto the Raspberry Pi 4 which hosts the home assistant mobile application.

Step 1: Write image to SD card.



a) Flashing URL on SD card b)Flashing completed

Figure 0-19: Image flashing process on SD card

Step 2: Start up raspberry pi
Insert the SD card which has the image into the raspberry pi, attach an ethernet cable and power the raspberry pi.

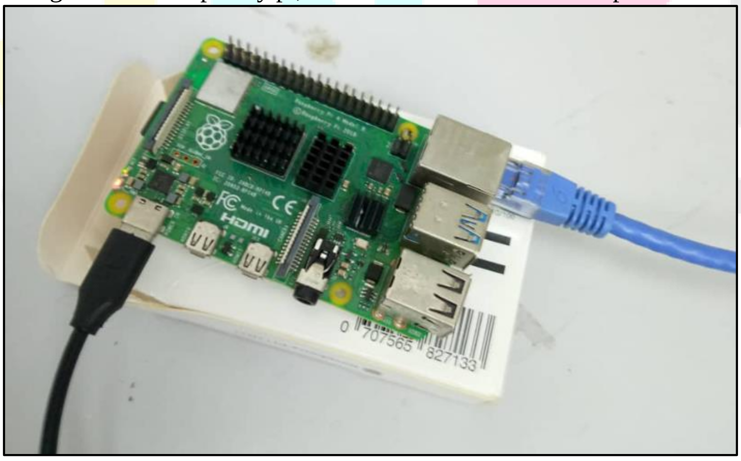
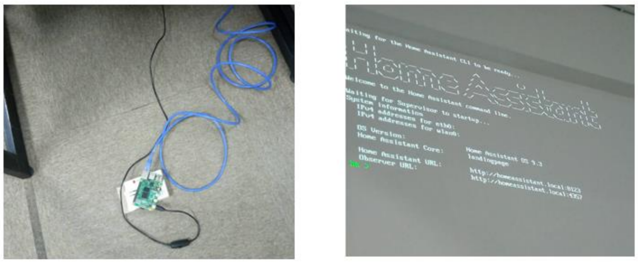


Figure 0-20: Raspberry pi 4 connected.

Step 3: Access home assistant
Home assistant is access through browsing the IP address seen after step 2, to view the IP address a micro HDMI connection is required to a Desktop or TV screen.

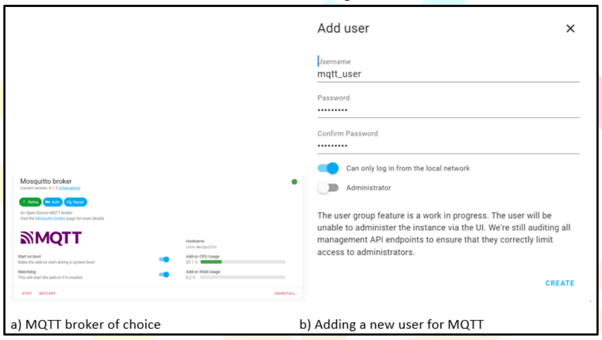
The SD can with home assistant is inserted into home assistant following the steps in Chapter 3 Methodology about home assistant. After raspberry pi 4B is powered up it takes around 2 minutes and then the raspberry pi will broadcast home assistant host IP address. In case no IP address is broadcasted, user can use the command prompt 'cmd' and type 'ipconfig /all' to view the IP address or alternatively use 'http://homeassistant.local:8123/' address to access home assistant.



a) Raspberry pi test   b)Raspberry pi broadcasts IP address

Figure 0-21: Testing Home assistant

In home assistant the remaining part is to configure MQTT and to design the mobile apps by using widgets. The MQTT broker chosen in mosquitto, and a separate user was created to communicate with MQTT as shown below.



a) MQTT broker of choice   b) Adding a new user for MQTT

Figure 0-22: MQTT configuration

Methodology summary

In general, the portable power factor meter comprises of sonoff pow r2 module which is responsible for measuring power values including power factor as described in the code flashed into the module, raspberry pi 4B module which hosts the mobile phone application and load(s) connected on the pow r2. This preferred methodology offers high value compared to any other approach reviewed in literature review because technical objectives of this project are centered around portability and convenience of the user. All power values and remote automations are accessed in the mobile phone of the user.

Figure 0-23: Components of prototype.

RESULTS AND DISCUSSION

Introduction

This chapter will show the experimental results collected for this project. The results are divided into 2 categories, first data collected from the AC loads connected to the AC wattmeter which will be the golden values and used as benchmark for the designed portable power factor meter. Secondly data collected from the AC loads connected to the portable power factor meter designed in this project will be tabulated and analyzed. The result collection process includes 3 AC loads namely desktop PC, air purifier and hair dryer. Irms, Vrms, power factor and real power (W) is collected on each individual AC load. Additionally, power values data is collected when 3 AC loads are connected on the same supply at once as well as when 2 AC loads are connected to the same supply using a multi socket extension to monitor the behavior of the AC loads and determine the robustness of the portable power factor meter. This chapter will be a key determinant to the technical objectives of this project namely especially technical objectives 1 and 3 as seen in chapter 1.

The results collection is meant to reflect real life situations, the AC loads chosen for this study are loads that are usually used in an average household. As discussed in the methodology section, the behavior of AC loads connected is monitored for 30 minutes to gauge the real time power factor of the AC load, power factor results on all the AC loads analyzed keeps on fluctuating however the power factor discrepancy noted is with 5% acceptable range. 5 accuracy experiments are conducted with a laser focus on power factor of individual AC loads and multiple AC loads connected together, in depth analysis of each experiment is detailed to contextualize power factor results collected. A reliability test will be conducted by testing the prototype for 10 hours. Hardware and software testing will be detailed in this section before results are collected and tabulated.

Testing of components

This sub section details testing of hardware and software tools used to construct the portable power factor meter.

Hardware testing

Hardware components of this project are the AC plug extension and the sonoff hardware as well as earth leakage circuit breaker for safety. The AC plug extension tested and used in this project to test the reliability of the overall design based on real life situations, connecting a single load does not full represent real life scenarios where many loads are connected at once.

Figure 0-1:AC extension plug dissection

AC plug extension is dissected to identify live wire, neutral wire and earth wire. These wires are color coded and will be wired to the sonoff hardware. Live wire is colored “brown”, Neutral wire is colored “Blue” and Earth wire is colored “green”. Live and Neutral wires are connected accordingly to the sonoff hardware and caution is considered to seal all live wires from the user.

Figure 0-2:Live and Neutral wire connections.

The sonoff hardware is clearly labelled for the input and output connections, the input has rectifier circuitry which is viewed from the sonoff which is a distinguishing factor between input and output. Input is capable of receiving 240V AC whereas the output cannot receive high voltage, therefore connecting the 240V carrying live wire in the output will result in a short circuit which is dangerous and can damage any electrical appliances connected in series with the AC plug being used by the sonoff hardware.

Figure 0-3: Overall hardware testing

The overall hardware design comprises of AC socket extension cable, sonoff hardware device and earth leakage circuit breaker. A simple test is run to ensure all hardware components are in good working condition, when the sonoff hardware is not paired to the mobile application the AC socket extension cannot be operated.

Figure 0-4:Sonoff POW r2 wiring

The sonoff POW r2 which is used to measure energy consumption unlike the sonoff basic, sonoff pow r2 provides input and out wiring of the 3 extension wires. Live wire (brown) which carries high voltage, neutral wire (blue) which carries current under normal operations and earth wire (green) which carries current under fault condition for safety purposes.

Pairing eWelink and original firmware test

In the methodology section, the preferred methodology for pairing the sonoff hardware with the eWelink mobile application is compatible pairing mode. A test to verify the accuracy and convenience of this hypothesis is conducted in this section.

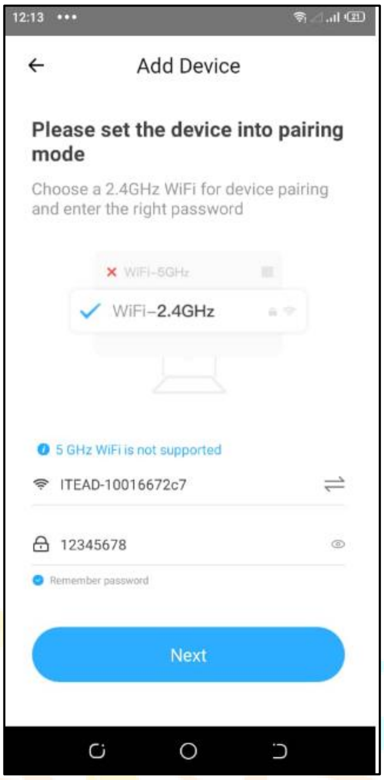
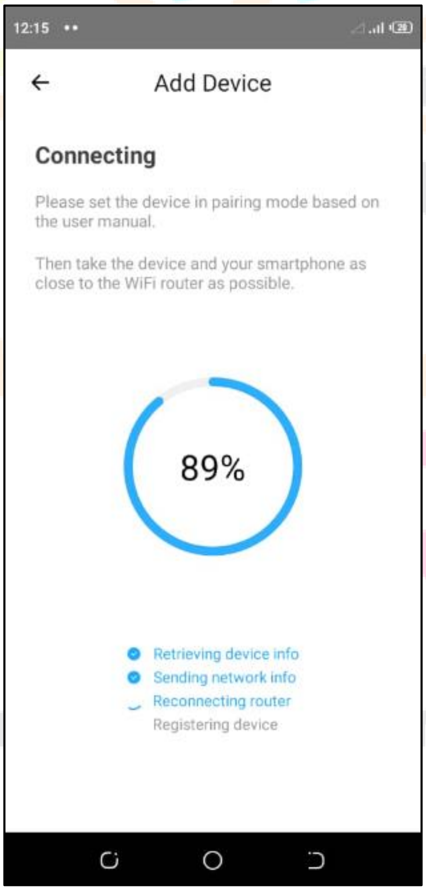


Figure 0-5: Compatible pairing mode test.

Compatible pairing mode enables connection of the sonoff hardware to eWelink mobile application even though they may be connected



in different radio frequency bands namely 2.4GHz and 5GHz by automatically creating AP called "ITEAD-10016672c7" and the password is "12345678".

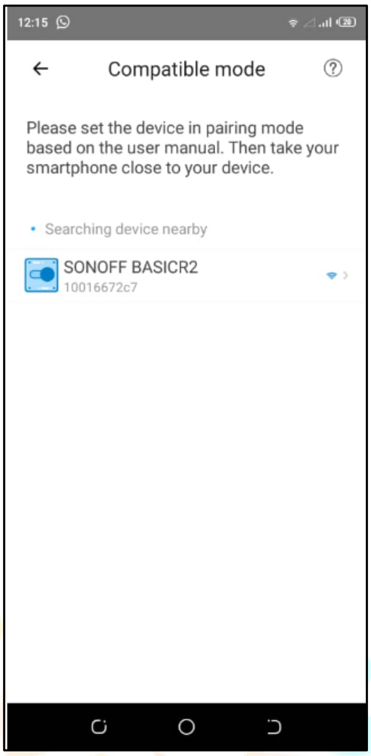
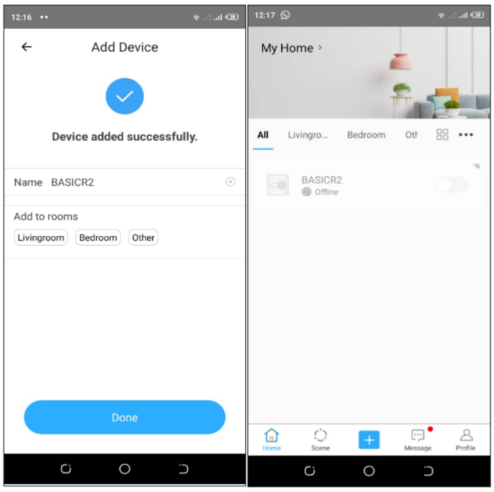


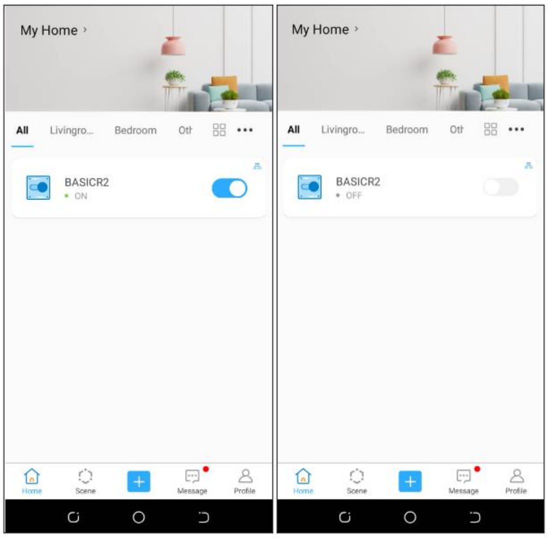
Figure 0-6:Successful pairing of sonoff hardware



a)Sonoff basic successfully added b) Sonoff basic offline

Figure 0-7: Sonoff hardware paired successfully

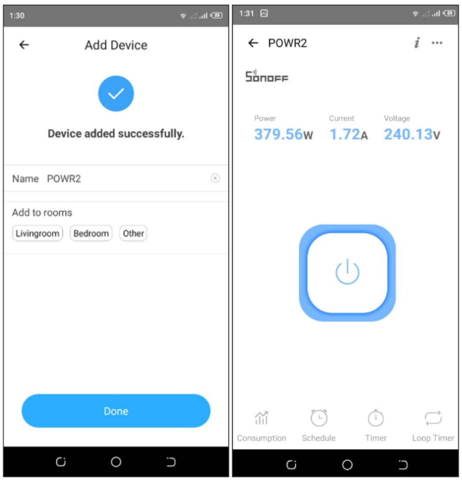
The sonoff hardware is paired to the eWelink mobile application successfully however the sonoff hardware remains offline, this is an issue which was faced during testing phase of software. The root cause of the technical issue is the firewall settings of the Wi-Fi connections that was being used to pair the sonoff hardware with the eWelink mobile application.



a) Sonoff basic ON b) Sonoff basic OFF

Figure 0-8: Sonoff paired and online

The test conducted suggests that firewall settings of the Wi-Fi being used to pair sonoff hardware and eWelink should be modified to accept connections from “ITEAD-10016672c7” .However if they cannot be modified for security reasons the user should use mobile data to perform pairing or change Wi-Fi connection to enable successful pairing and connection of hardware and software. Appliances connected to the hardware are remotely toggled from ON and OFF at the users preferences as seen in Figure 4.8.



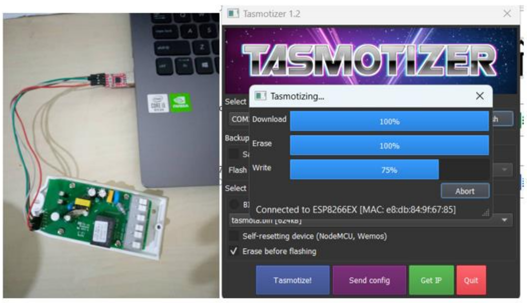
a) Sonoff POW r2 added b) User Interface of POW r2

Figure 0-9: Original firmware operation of Sonoff pow r2

The pairing process is similar to the sonoff basic, the sonoff pow r2 does not show power factor to the user and power factor is a vital piece of information for power optimization and reduces cost as discussed in chapter 2.

Pairing Tasmota and new firmware test

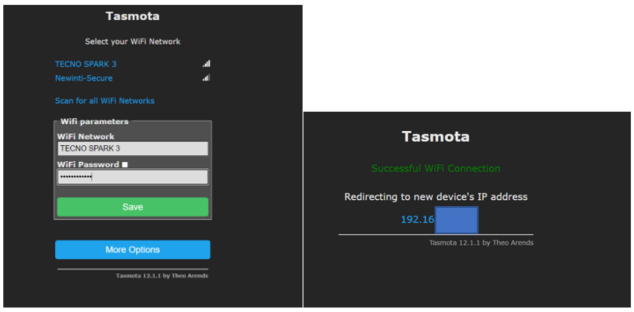
There are numerous ways to flash new firmware onto the sonoff pow r2 however tasmotizer is the methodology chosen for this project. Flashing this new firmware using tasmotizer is straight forward, using CP2102 USB and jumper wires as detailed in the methodology section yields Figure shown below. This firmware unleashed the full potential of sonoff pow r2 as a powerful power monitoring tool unlike the original firmware.



a) Hardware wiring before flashing b) Software flashing firmware

Figure 0-10: Flashing new firmware

Soldering pins in on the sonoff pow r2 is not necessary however to ensure that a new firmware is flashed on the sonoff pow r2 properly, it is recommended to solder the pins and use working jumper wires. Errors generally occur from loose jumper wires and writing the new firmware on ESP8266 may delay as a result.



a) Connecting device to mobile network b) Accessing the IP address of the sonoff pow r2

Figure 0-11:Obtaining IP address of sonoff pow r2

Powering the sonoff with the new firmware will have a different Wi-Fi name and preferably it should be connected to a personal mobile network because public wireless networks have a lot of firewall settings.

Wattmeter results (Bench marking tool)

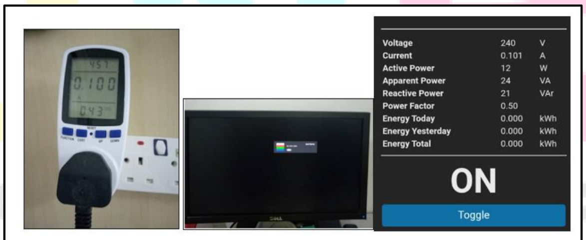
This sub section compares results from the portable power factor meter designed in this project against the AC wattmeter readings. Detailed analysis is provided for all experiments conducted.

Single AC load connected a single supply

1st experiment- Desktop PC

Table 0-1:Desktop (AC Load) power factor testing

Wattmeter readings			
Irms	Vrms	Power factor	Real power
0.123A	244.0V	0.53	12.4W
Designed portable power factor meter			
Irms	Vrms	Power factor	Real power
0.108A	240V	0.51	12W
Power factor deviation			3.92%



a)Wattmeter PF reading b)Desktop AC load c)New firmware result

Figure 0-12:1st experiment

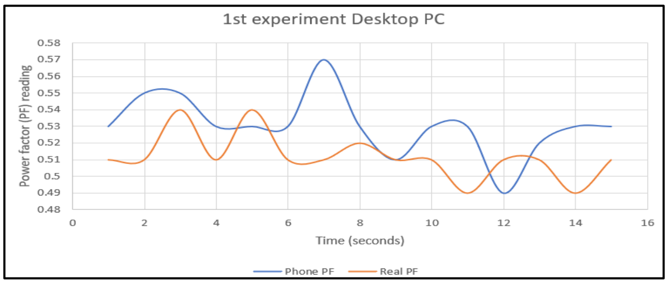


Figure 0-13:Prototype vs market tester Power factor graph

Analysis:
Power factor of the desktop AC load is 0.43 on the wattmeter reading and portable power factor meter reading is 0.5, the discrepancy is 14% however power factor results keep fluctuating in both portable power factor meter and wattmeter which is the benching marking tool. The desktop can be remotely switched ON and OFF by the user when they click the toggle button.

2nd experiment- Air purifier

Table 0-2:Air purifier power factor testing

Wattmeter readings			
Irms	Vrms	Power factor	Real power
0.033A	244.8V	0.49	3.90W
Designed portable power factor meter			
Irms	Vrms	Power factor	Real power
0.054A	240V	0.41	4W
Power factor deviation			19.5%

a)Air purifier AC load b)Portable PF meter results in mobile phone

Figure 0-14: PF monitoring

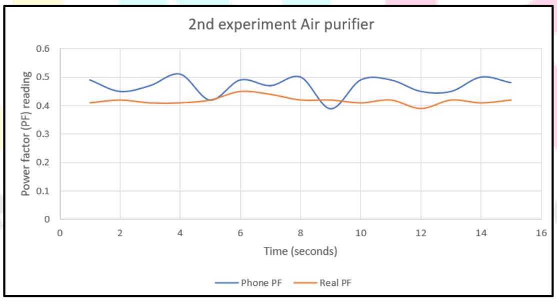


Figure 0-15:Prototype vs market tester Power factor graph

Analysis
After examining the results collected, the designed portable power factor meter will display this low power factor to the user, the user will be informed at should take corrective action. In the eWelink application the user will not be notified about power factor hence the portable power factor meter has added advantage. However, 19.5% deviation on power factor is not withing acceptable range, this purely depends on the load as some loads behavior varies from time to time.

3rd experiment-Hair dryer

Table 0-3: Hair dryer power factor testing

Wattmeter readings			
Irms	Vrms	Power factor	Real power
1.720A	242.0V	0.91	388W
Designed portable power factor meter			
Irms	Vrms	Power factor	Real power
1.704A	239V	0.92	373W
Power factor deviation			1.08%

a) Hair dryer under test b) Results in the mobile phone

Figure 0-16:Power factor monitoring of hair dryer.

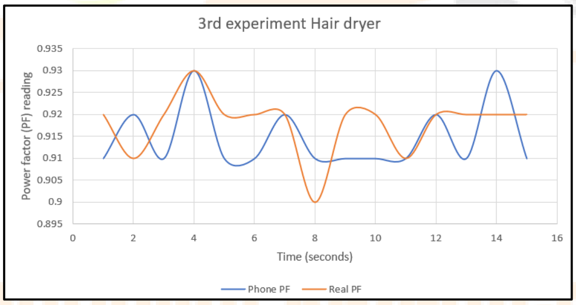


Figure 0-17: Prototype vs market tester Power factor graph

Analysis

Hair dryer has a good power factor both in portable power factor meter and AC wattmeter with a power factor discrepancy of 1.08%. In the designed power factor meter, the user has portability convenience, remote automation and energy consumption monitoring as experienced during testing process

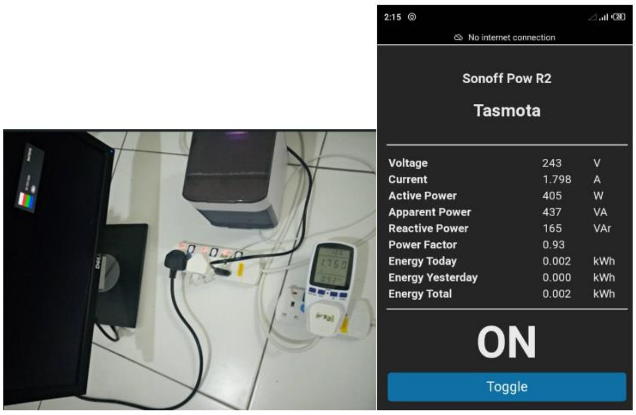
Multiple AC loads on a single supply

This section combines multiple loads together on the same source to depict a real life situation in a normal household for more accurate results and analysis

4th experiment- Hair dryer, desktop PC and air purifier together

Table 0-4:Power factor testing of 3 AC loads

Wattmeter readings			
Irms	Vrms	Power factor	Real power
3.22A	245.2V	0.92	789.5W
Designed portable power factor meter			
Irms	Vrms	Power factor	Real power
1.744A	238V	0.93	384W
Power factor deviation			1.08%



a) 3 AC loads connected on a single supply line b) Power factor in mobile phone

Figure 0-18:Power factor monitoring of 3 AC loads on a single supply line

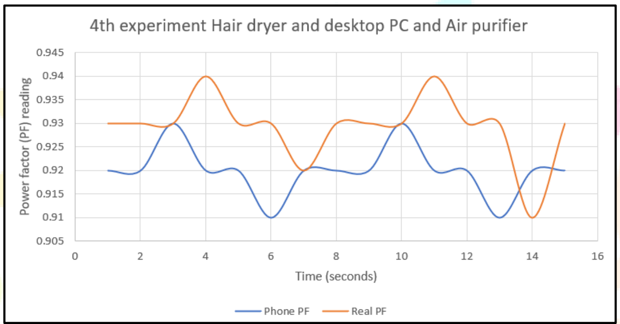


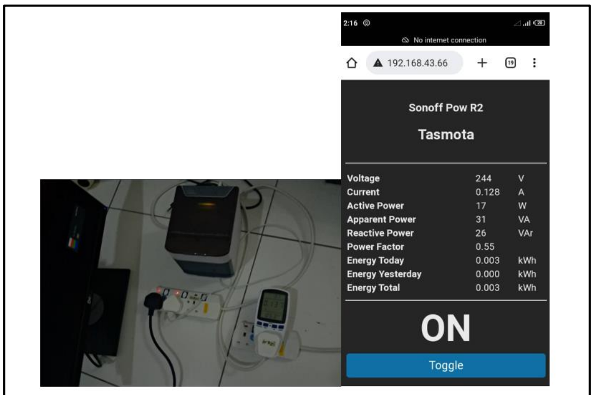
Figure 0-19: Prototype vs market tester Power factor graph

Analysis:
Power factor monitoring in mobile phone is accurate when more AC loads are connected on the single AC supply line because the power factor discrepancy between portable power factor meter designed, and AC wattmeter is 1.08%. This is because the load with high power factor will be the overall power factor of on the AC supply.

5th experiment- Hair dryer and desktop PC

Table 0-5:Power factor testing for 2 AC loads

Wattmeter readings			
Irms	Vrms	Power factor	Real power
0.128A	248.0V	0.52	17.3W
Designed portable power factor meter			
Irms	Vrms	Power factor	Real power
0.108A	239V	0.5	13W
Power factor deviation			4%



a) 2 AC loads connected on a single supply line b) Power factor in mobile phone.

Figure 0-20: Power factor monitoring of 2 AC loads.

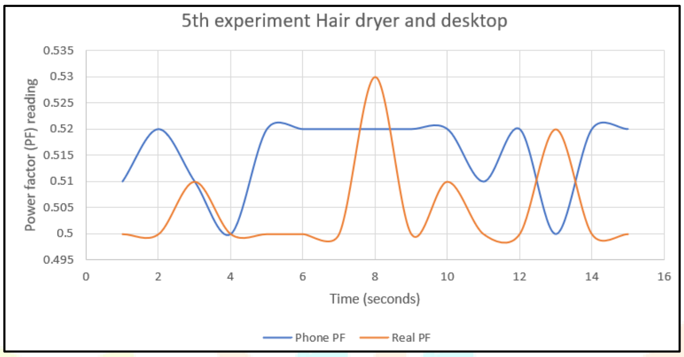


Figure 0-21: Prototype vs market tester Power factor graph.

Analysis

Overall power factor is 0.53 which similar to that Desktop PC, as observed in experiment 5 overall power factor when multiple loads are connected on a single supply is the power factor of the AC load with a power factor closer to unity. This phenomena is reflected in both portable power factor and AC wattmeter where the power factor discrepancy is 4%.

Results in Home assistant

Home assistant was hosted on raspberry pi 4B as detailed in Chapter 3 Methodology, MQTT configuration was done to establish communication between the new firmware in Sonoff pow r2 and the home assistant host.

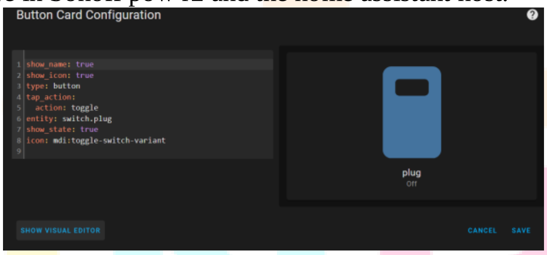


Figure 0-22:Configuring Home assistant UI

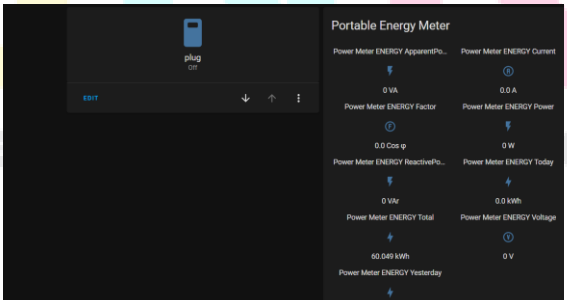


Figure 0-23: Home assistant UI laptop view

After designing the user interface in the laptop view, the mobile application of home assistant was downloaded, and it will automatically scan available home assistant hosts and start displaying selected host user interface.

Reliability test

This section assess the reliability of the portable power factor meter designed in this project, Mean Time Before Failure and Mean Time To Repair will be discussed all geared towards satisfying customer/user requirements with reasonable risks.

A 10 hour experiment was conducted on the prototype to assess its reliability. During the experiment the prototype broke down form roughly 38minutes due to internet malfunction. After the malfunction was fixed the prototype was working as normal.

Mean Time Before failure (MTBF) for prototype

MTBF measures reliability for non-repairable systems, it keeps track of the statistical expected mean time until failure over a long time. Therefore, based on the experiment conducted MTBF calculation is as follows

$$\text{MTBF} = \frac{\sum \text{start downtime} - \text{start of uptime}}{\text{number of failures}}$$

$$\text{MTBF} = \frac{10 - 0.633}{1} = 9.367 \text{ hours}$$

Mean Time to repair (MTTR) for prototype

MTTR measures the maintainability of repairable system, it is the average time to repair components of operation system, in power system MTTR is usually assess for expensive components however for the Sonoff Powr2 hardware component that is used in this project is not a very expensive piece of hardware. Therefore, based on the experiment conducted MTTR calculation is as follows

$$\text{MTTR} = \frac{\sum \text{start downtime}}{\text{number of failures}} = \frac{0.633}{1} = 0.633 \text{ hours}$$

Availability

Availability of the prototype to the user as the name suggests, it is the time the system will be in operation and the formula is given below, for this portable power factor meter based on the 10 hour experiment conducted to collect data the system is available for 93.67% of the time hence it can be concluded that the prototype is reliable.

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \times 100 = \frac{9.367}{10} \times 100 = 93.67\%$$

Table 0-6:Summary of reliability test

MTBF	MTTR	Availability	Reliable?
9.367 hours	38 minutes	93.67%	Yes

CONCLUSION AND RECOMMENDATIONS

This section will outline technical objectives achieved by the designed prototype, it will also discuss problems faced and how they were mitigated. Lastly it will recommend practical improvements to the designed prototype.

Conclusion

The prototype designed in this project is a combination of energy meter and power factor meter accessed through a mobile phone of the user. The prototype not only monitors energy consumption of electrical loads connected to it but also remotely controls appliances for increased user convenience and energy optimizations. Technical objective 1 was achieved because electrical loads can be remotely controlled by the user by pressing the toggle button as seen in Figure 0-12. Technical objective 2 was fulfilled where an IoT open source platform called Home assistant was applied to monitor power factor seen in Figure 0-23, finally technical objective 3 was attained by providing in depth analysis of results collected in the 6 experiments including accuracy and reliability tests in results section, Chapter 4.All the three technical objectives of this project were accomplished and hence it can be concluded that the project was successful.

Problems faced.

Sonoff pow r2 was out of stock in nearly all electronic shops online and disrupted the initial time management scheme additionally there was limited information from sonoff website about the differences in terms of application between the sonoff modules. Live, Neutral and Earth wires connections on the sonoff pow r2 is challenging as naked wires will remain outside which can potentially cause danger. The jumper wires issue during flashing of new firmware caused connection issue and a lot of time was spent in troubleshooting and finding the error, when jumper wires were replaced firmware was able to flash.

Firewall settings on the public networks disable both original sonoff and new firmware connection hence in this project personal network was utilized. To realize the power factor meter in a mobile application a raspberry pi was required to host the open source mobile application "Home assistant" to mitigate cost, the raspberry pi was purchased from a senior student at a subsidies price. However, acquiring the raspberry pi was time consuming.

Recommendations

It is recommended that the system should be able to inform the user how much money they would save on the electricity bill if they were to invest in power factor correction, to encourage users to optimize energy. An alarm system or auto email to the user in case of over usage of energy or low power factor reading because even though readings can easily be accessed through the mobile phone, prompting the user to is highly recommended on this system, similarly automatic shutdown of the meter when not in use as it consumes electricity to operate. Finally, it is also recommended that in case of hazards such as short circuits the system can be improved to be more responsive and protect appliances connected to it by fusing the inrush current.

References

[1] B. H. Y. Y. K. F. Samuel Lotsu, "Effectiveness of a Power Factor Correction Policy in Improving the Energy Efficiency of Large-Scale Electricity Users in Ghana," *Energies,* 2019.

[2] D. loggers, "Is unccorected Power factor costing you money?," 30 November 2017.

[3] Govindarajan et al, "Smart Energy Meter using Android Mobile Application," *International Journal for Research in Engineering Application & Management*, pp. 52-55, 2020.

[4] Chi Zhang et al, "On Electricity consumption and economic growth in China," *Science direct*, pp. 353-368, 2017.

[5] A. P. D. H. J. H. M. M. A. Prof. Dr. Imad hussain AL-Hussaini, "Smart Power Management System Based On," *International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)*, pp. 439-456, 2020.

[6] Yi-Tui Chen, "The Factors Affecting Electricity Consumption and the Consumption characteristics in Residential Sector," *Sustanability* , pp. 2-16, 2017.

[7] H. F. K. K. Ruengwit Khwanrit, "Accuracy Comparison of Present Low-cost Current Sensors for Building Energy Monitoring," *IEEE*, pp. 1-6, 2018.

[8] M. H. A. K. J. Teddy Surya Gunawan, "Design of power factor meter using internet of things for powerfactor improvement, remote monitoring and data logging," *Indonesian Journal of Electrical Engineering and Computer Science*, pp. 700-709, 2020.

[9] L. L. Grigsby, Electric Power Generation, Transmission, and Distribution, Taylor & Francis group, 2016.

[10] N. Edomah, "Economic Implications of Poor Power Quality," *Journal of Energy and Power Engineering* , 2012.

[11] A. S. P.K. Rajan, "Power factor (PF) is defined as the ratio of true power in watts (W) to apparent power volt–amperes (VA).," *Sciencedirect*, 2016.

[12] Bonneville, "Reducing Power Factor Cost," 2018.

[13] Powerside, "The Cost of Power factor," 2020. [Online].

[14] M. A. S. a. F. A. P. N M Yoeseph, "Smart Energy Meter based on Arduino and Internet of Things," *IOP Conference Series: Materials Science and Engineering*, pp. 1-6, 2019.

[15] A. M. T. I. a. O. T. M. Ahmed J Ali1, "Design of a smart control and protection system for three-phase generator using Arduino," *IOP Conference Series: Materials Science and Engineering*, pp. 3-5, 2020.

[16] Y. G. a. T. Adiono, "Design and Implementation IoT SmartPlug for Electricity Usage," *International Symposium on Electronics and Smart Devices*, pp. 1-5, 2019.

[17] Autobotic, "Non-Invasive AC Current Sensor Split Core 100A (SCT-013-100A)," 2020. [Online].

[18] J. Bennett, "How to Calculate Your Home's Electrical Load and What It Means for Your Power Needs," 2022. [Online]. Available: https://www.bhg.com/home-improvement/electrical/how-to-check-your-homes-electrical-capacity/.

[19] R. Teja, "ESP32 ADC Tutorial | How to use ADC in ESP32?," 2021. [Online]. Available: https://www.electronicshub.org/esp32-adc-tutorial/.

[20] A. A. O. J. A. Alaa Kh Abbas, "Comprehensive Modelling of an Optimized Energy Management System for Photovoltaic Stand alone building," *Researchgate*, pp. 1989-1999, 2020.

[21] C. R. Niloy Mondal, "DESIGN OF A SMART ENERGY METER," *ReseachGate*, pp. 316-323, 2022.

[22] Microcontrollerlabs, "ESP32 ADC with Arduino IDE – Measuring voltage example," 2022. [Online]. Available: https://microcontrollerslab.com/adc-esp32-measuring-voltage-example/.

[23] P. F. o. O. Marek Babiuch, "Using the ESP32 Microcontroller for Data Processi," *ResearchGate*, pp. 6-19, 2019.

[24] M. Bajer, "Sonoff based smart home control unit," *IEEE*, pp. 6-12, 2020.

[25] Esspressif, " ESP8266 datasheet," 2016. [Online]. Available: https://espressif.com/sites/default/files/documentation/0a-esp8266ex_datasheet_en.pdf.

[26] Mendez-Monroy, "IoT System for the Continuous Electrical and Environmental," *Google scholar*, pp. 56-57, 2022.

[27] E. tutorial, "Power Triangle and Power Factor," 2017. [Online].

[28] D. M. Dr. Sanjay Warkad, "IOT Based Smart Energy Meter for Domestic Use," *International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET),* pp. 4948-4952, 2021.

[29] P. Seneviratne, "Hands-On Internet of Things with Blynk: Build on the power of Blynk to configure smart devices and build exciting IOT projects," Birmingham & Mumbai, Gebin Georger & Prachi Bisht, 2018, pp. 56-87.

[30] S. P. R. U. Guide, "店长," 2018. [Online].

[31] B. S. S. K. |. M. P. S. Ashwini, "IOT Based home automation system using alexa," *IEEE,* pp. 14-25, 2020.

[32] H. assistant, "Install Home Assistant Operating System," 2020.

[33] S. J. Srijan Saxena, D. Arora and P. Sharma, "Implications of MQTT Connectivity Protocol for IoT based Device Automation using Home Assistant and OpenHAB," *IEEE,* pp. 58-63, 2020.

[34] Peter, "eWelink pairing troubleshooting," 2019. [Online].

[35] S. T. Karthik Suramanian, "Power factor correction using capacitor & filterrs," pp. 8-25, April 2018.

[36] Albeth, "Series RLC Circuit Analysis," 2020. [Online]. Available: https://www.electronics-tutorials.ws/accircuits/series-circuit.html.

[37] A. A. Maryam Nabihah Zaidi, "Power Factor Improvement Using Automatic Power Factor Compensation (APFC) Device for Medical Industries in Malaysia," *MATEC Web of Conferences,* 2018.

[38] I. O. ,. E. S. A. A. Mukaila, "Design and Construction of A Single-Phase Power Factor Meter," *Bilingual publishing.co,* 2018.

[39] M. A.-H. A. A.-A. A.-M. Anmar Arif, "Experimental study and design of smart energy meter for the smart grid," *ResearchGate,* pp. 67-72, 2013.

[40] T. HAREENDRAN, "ZMPT101B AC Voltage Sensor Module Primer," 2022. [Online]. Available: https://www.electroschematics.com/voltage-sensor/.

[41] A. V. d. B. a. R. F. C. 4. Mohannad Jabbar Mnati, "A Smart Voltage and Current Monitoring System for Three phase Inverters using Android Smart phone application," *MDPI,* pp. 2-16, 2017.

[42] A. S. Salunkhe, Y. K. Kanse and S. S. Patil, "Internet of Things based Smart Energy Meter with ESP 32 Real Time Data Monitoring," *IEEE,* pp. 4-7, 2022.

[43] "Single Phase Energy Smart Meter System Design and Implementation using RFID and based on IoT," *IOP publushing,* pp. 23-33, 2020.

[44] D. A. H. A. G. Ismaeel, "Designing ECG Monitoring Healthcare System Based on Internet of Things Blynk application," *Journal of Applied Science and Technology trends,* pp. 1-6, 2020.

[45] Espressif, "ESP8266 Series of Modules features," 2020. [Online]. Available: https://www.espressif.com/en/products/modules/esp8266.