Educational Administration: Theory and Practice
2024, 30(8), 367-396
ISSN: 2148-2403
https://kuey.net/

Research Article

Design Of Energy Monitoring Device With Remote Access Functionality For Power Factor Correction And Disconnecting Capability In A Convenience Outlet

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Citation: Maria Nicole B. Santos et.al (2024), Design Of Energy Monitoring Device With Remote Access Functionality For Power Factor Correction And Disconnecting Capability In A Convenience Outlet, *Educational Administration: Theory and Practice*, 30(8), 367-396
Doi: 10.53555/kuey.v30i8.7319

ARTICLE INFO

ABSTRACT

Power factor correction is crucial in optimizing energy efficiency in electrical systems, including residential and low-voltage environments. Even though residential settings and low- voltage systems may not be as prevalent as industrial applications, understanding and implementing power factor correction measures can still provide valuable information. Capacitor Switching is one power factor correction approach that can increase power factor, lessen reactive power losses, and alleviate the impacts of inductive loads. In low-voltage and domestic settings, this may result in an improvement in the overall system performance. This study introduces the design of an energy monitoring device with remote access functionality for power factor correction and disconnecting capability in a convenience outlet. The system has features such as real-time energy monitoring, power factor correction, and remote disconnecting of appliances through an Android application. This prototype uses a microcontroller, power analyzer, Bluetooth module, relays, and capacitors. It calculates the required capacitance to correct the power factor of a system. The research results based on the actual and corrected power factors showed no significant difference in values using a t-test. The study shows a system with Remote Access Functionality and Disconnecting Capability.

Keywords- Power Factor, Power Factor Correction, Energy Monitoring, Remote Access Functionality, Disconnecting Capability, Convenience Outlet, PZEM-008t

Chapter I INTRODUCTION

In modern power systems, poor power factors can cause significant problems, including reduced efficiency, equipment damage, and decreased power quality, as it involves efficient energy use. While power factor correction may not be a primary concern in these settings, the principles of power factor measurement and correction can still be applied to optimize energy usage and enhance the efficiency of electrical systems. One way to improve energy efficiency is through power factor correction, which aims to reduce the amount of reactive power that needs to be supplied by the power system. Power factor correction has been widely studied in the literature, with various techniques proposed to improve the power factor of single-phase systems [1]. In multiple fields of study, especially in smart devices with energy monitoring and remote-control access, outlets are used to manage electricity, reduce the cost of bills through wireless communication systems, and improve efficient energy use. While energy monitoring and management in a convenience outlet performed well in other studies, combining them with power factor correction hasn't yet been tested in a convenience outlet.

Several studies were developed to expand energy management integrated with wireless communication technology in outlets and smart plugs to help residential consumers reduce electricity costs. In research by J.B. Ibarra et al. in 2019, this paper presents the development of a system that can distribute fair electricity consumption bills to boarders/bed spacers based on their actual usage. The system includes a convenience outlet with an AC power analyzer and RFID reader, a monitoring system with a GUI, and a system that eliminates loads without registered RFID tags. The study addresses the problem of equal distribution of

electric consumption among boarders/bed spacers due to traditional meters only measuring total energy consumption per unit. The study's effectiveness is limited to customer knowledge of energy-saving actions, and the system is tested only for common residential appliances [2]. Another paper authored by R.C.C. Castro et al. [3], this study proposes a smart plug named IntelliPlugs that can control and monitor power consumed by electrical devices using Wi-Fi and GSM. The unit is installed in residential units to control the operating loads and monitor power consumption via a mobile application. The study shows that the proposed smart plug achieved the objectives of being user-friendly and safe with a mobile application that allows real-time monitoring and control of selected electric devices. In addition, [4], This study aims to develop an intelligent convenience outlet with a radio frequency identification (RFID) reader and android application for power monitoring, control, and protection of electrical home appliances. The prototype is designed to monitor power consumption per user, has a timer control and budget limit feature, automatically shuts down standby appliances, and provides electrical protection. In [5], The paper presents an automated power factor correction and energy monitoring system that uses a microcontroller-based control unit to measure and adjust the power factor of an electrical system. The system was tested and found effective in correcting power factor correction.
The four studies discussed above are validated to provide energy management using a wireless communication system and the effectiveness of an automated power factor correction with the energy monitoring system. These studies demonstrate the potential of smart plugs to provide users with greater control over their energy consumption and the ability to remotely monitor and control their appliances. Further to that, Wi-Fi was utilized for wireless connectivity due to its ubiquity in households, ease of use, cost-effectiveness, and satisfactory speed and range. This approach ensures the smooth and efficient execution of a typical home environment. For example, the studies [2],[3], and [4], all focus on the development and use of smart plugs for monitoring and controlling the power consumption of appliances. They all discuss the use of wireless communication technologies such as Wi-Fi, RFID, and GSM to enable remote monitoring and control of appliances as a part of energy management. However, these studies' effectiveness is limited to the consumer's knowledge of energy-saving and focused on developing a system that can monitor energy use across borders concerning real usage but without optimization of energy efficiency such as power factor correction. These studies also don't cover domestic loads that might happen to have a poor power factor resulting in less efficient use of energy. Moreover, in the study of Y. Kabir, Y. Mohsin, and M. Khan, the experiments conducted by the authors demonstrate that the system can measure and adjust the power factor of an electrical system, resulting in reduced energy consumption. However, the paper lacks a detailed cost-effectiveness analysis and does not discuss the scalability of the system. In its energy monitoring, values of necessary electrical parameters are displayed but no waveforms of load voltage and current can be seen in the monitor for graphical representation on the personal computer used. The energy parameters are available at the serial port of the microcontroller, which allows for live retrieval of values using serial communication. The system does not mention wireless monitoring. Therewithal, the system was found to be effective in reducing energy consumption [5]. Given these gaps regarding the developed system that monitors energy use concerning real usage but without optimization of energy efficiency using power factor correction.

The main objective is to design a Single-Phase Energy Monitoring Device with Power Factor Correction and Wireless Disconnecting Capability in a Convenience Outlet. To carry out the main objective, the researchers will proceed in tackling 3 specific objectives: (1) To design a Single-phase Energy Monitoring Device through wireless access with Power factor correction functionality and disconnecting capability. (2) To test the functionality of the developed convenience outlet by using a single-phase load at 230 V nominal rating for a single appliance. (3) To evaluate the performance of the Power Factor Correction functionality by comparing the results of Before and After Power Factor Correction by t-test.

The design and its application are expected to improve the overall efficiency of the electrical system by implementing power factor correction, energy monitoring, and remote- control access. This research can provide a methodology on how to design and build a system with power factor correction and disconnecting capability in a household outlet. This research will serve as a basis for future researchers in terms of developing household outlets that have energy monitoring device and wireless remote access functionality for Power Factor Correction and Disconnecting capability. Overall, our work will represent a significant contribution to the field of power quality and has the potential to improve the reliability and efficiency of power systems.

The design will focus on creating a convenient outlet-based energy monitoring device with remote access functionality for power factor correction. This design will also strictly focus on the power factor correction system and disconnecting capability of the proposed convenience outlet. The researchers will use Arduino and Bluetooth connectivity in developing the proposed design. The researchers limited the study to measuring the value of voltage, current, power, power factor, and energy consumption. The researchers limited the study to Single-Phase Systems, and power factor evaluation only.

Chapter II REVIEW OF RELATED LITERATURE

2.1 Wi-Fi-based Convenience Outlet

In this study, a Wi-Fi-based Convenience Outlet is brought forward as a part of intelligent technology as the world continues to evolve. It is an electrical outlet that records and observes plugged-in home devices with the help of the Internet of Things. This idea came from the integration of functions from AC power plugs, sockets, and Internet access to all connected devices and equipment.

2.2 Energy Management

Energy Management is an active practice that aims to regulate and monitor the energy consumption of an organization, company, or individual. The International Energy Association projects a significant increase in power demand for domestic appliances, with a 12% rise between 2000 and 2010, and a further 25% increase by 2020. This concerning trend emphasizes how urgently homes and buildings need to implement drastic energy-saving measures in order to protect the environment as well as energy [6]. The process of monitoring, regulating, and saving energy in a structure or organization is known as energy management [7].
Integrating energy management and power factor correction can create a synergistic effect, amplifying the benefits of each approach. Effective energy management strategies can identify areas where power factor correction is necessary, ensuring that electrical systems operate at peak efficiency. Conversely, implementing PFC can support broader energy management goals by reducing energy consumption and costs, enhancing equipment performance, and promoting sustainability.

2.3 Power Factor

The power factor is a measure of how effectively incoming power is used in an electrical system. In electrical engineering, it is defined as the ratio of the real power absorbed by the load to the apparent power flowing in the circuit [8].
Mathematically, it can be expressed as:

$$pf = \cos\theta = Real\ Power / Apparent\ Power \text{ ....eqn. (2.1)}$$

Real power is the average of the instantaneous product of voltage and current, representing the capacity of electricity for performing work [8]. Apparent power, also known as demand, measures the amount of power used to run machinery and equipment during a certain period [7]. It is found by multiplying voltage and current.

$$(kVA = V \times A) \text{ ....eqn. (2.2)}$$

A high power factor indicates that the power supplied to the electrical system is being used effectively [8]. Conversely, a low power factor means the incoming electric supply isn't being consumed effectively, resulting in losses. Power factor is usually expressed as a percentage—the lower the percentage, the less efficient power usage is. For example, a 96% power factor demonstrates more efficiency than a 75% power factor [8].
In most AC circuits, there is never a power factor equal to one because there is always some impedance (interference) on the power lines. Power-factor correction increases the power factor of a load through the means of improving its efficiency for the distribution system to which it's attached [9]. Because of the costs of larger equipment and wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers where there is a low power factor [9].

2.3.1 Types of Power Factor

An incoming power's effectivity in an electrical power system may be classified into three types which are as follows: leading, lagging, and unity power factor.

2.3.1.1 Leading Power Factor

A leading power factor is observed when the current in the circuit leads the voltage. This occurs when the load is capacitive.

2.3.1.2 Lagging Power Factor

When the current in a circuit is lagging the voltage, then the power factor is called a lagging power factor. This occurs when the load is inductive.

2.3.1.3 Unity Power Factor

When the current and voltage are in phase, the power factor is called a unity power factor. This occurs when the circuit has no reactive power and hence apparent power equals real power.

2.4 Power Factor Correction

Power factor correction is a technique used to improve the power factor of a power system, making it closer to unity. This is achieved by compensating for the reactive power consumed by inductive loads in the system.

The advantages of correcting power factors include reduced power system losses, increased load-carrying capabilities, and improved voltages [10]. Power factor correction is indeed an example of an energy management algorithm. It is a technique used to improve the power factor of a power system, making it closer to unity. This is achieved by compensating for the reactive power consumed by inductive loads in the system. The advantages of correcting power factors include reduced power system losses, increased load-carrying capabilities, and improved voltage. In the context of energy storage, an algorithm has been proposed that co-optimizes energy storage for performing energy arbitrage and local power factor correction [12]. This algorithm is non-convex but can be solved efficiently using McCormick relaxation and penalty-based schemes [12]. It shows that energy storage can correct power factors locally without reducing arbitrage profit [12].
Power factor correction can be considered an energy management algorithm as it involves using specific methods and techniques to optimize energy use in a system. Power Factor Correction (PFC) has widespread use in commercial applications within industrial facilities, office complexes, and the power distribution grid near commercial clients. In some regions of the world, residential PFC is also becoming more and more widespread [13]. A novel standard power factor correction scheme for homes and offices has been proposed, leading to lower harmonic distortion without installing expensive active rectifiers in each end- user device [14]. However, an analysis of the energy savings enabled by PFC equipment in residential applications suggests its added cost may not be justified [15].

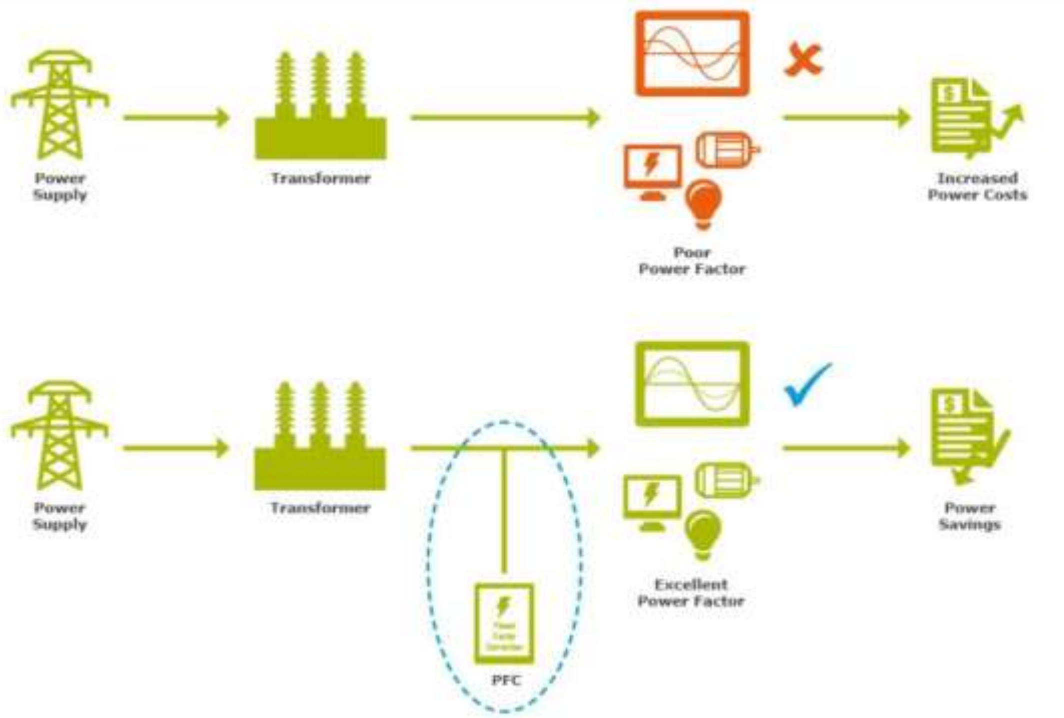

Figure 2.1 Power Factor Correction [16]

2.4.1 Capacitor Banks
A bank of capacitors can be installed to reduce the reactive power demand of the load, improving the power factor. The capacitors can be fixed or switched, depending on the load requirements [17].

2.4.2 Synchronous Condensers
A synchronous motor operating at no load and over-excited can be used as a synchronous condenser to improve the power factor of the system [17].

2.4.3 Switched Capacitor Banks
A switched capacitor bank uses automatic switching devices to vary the reactive power demand based on the load requirements, improving the power factor [17]. Capacitor switching involves interrupting capacitive currents and energizing capacitor banks in power systems. Challenges include inrush currents and overvoltages that can damage equipment. Techniques like synchronous switching and using resistors or reactances help reduce inrush currents. These methods ensure the safe and efficient operation of capacitor banks, managing capacitive loads effectively in power systems [18]. Capacitor switching is essential for power factor correction in electrical systems. By strategically connecting and disconnecting capacitors to the system, power factor correction capacitors can offset reactive power, improving the overall power factor of the system. This helps in reducing energy losses, increasing system efficiency, and optimizing the utilization of electrical power. Capacitor switching techniques play a vital role in maintaining a balanced and efficient

power factor in electrical networks.

2.5 Studies Related to Power Factor Correction

2.5.1 Automated Power Factor

In a study by B. Hani, and B. Naji Alhasnawi, entitled *"Automated Power Factor Correction for Smart Home"* " the authors have used the technique of relay switching method with a capacitor so that any drop in power factor can be sensed by the controller and switch the capacitor as required. It has been stated that this will not only help to improve the power factor but the demand for electricity supply on the utility side will also be reduced. The Significance of this study is to build an Automatic Power Factor Correction Unit (APFC) [19]. The results gave the authors an efficient technique of capacitor switching technique which is utilized in improving the power factor of the system to maintain it near unity as much as possible. Consequently, the system calibrates the power factor in real-time, and the connected capacitor banks get a power factor signal for switching.

2.5.2 Arduino-Based Automatic Power Factor Correction Device

In this study by P. Udenze, K. Genger, & M. Ekoja, entitled "An Arduino-Based Automatic Power Factor Correction Device", they used Arduino ATmega 328 for their Automatic Power Factor Correction system. The circuit works based on continuously checking the power factor of the system and starting the necessary adjustment when it falls below the preset value of 0.8. Based on the results, the authors have concluded that the low power factor in a power system is a highly undesirable condition as it places an unnecessarily high current demand, thus high active power losses are incurred in the system. By installing suitably sized power capacitors into the circuit, the power factor can be improved to a value close to unity. Precautions in correcting unity should be taken to prevent over-correction and thus, cause voltage and current to go out of phase causing the power system to become unstable, the life of the capacitor bank reduced, and the aim of the device to become defeated. [20] The authors have also concluded that this will be beneficial for industries and commercials.

2.5.3 Automated Power Factor Correction and Energy Monitoring System

The aim of this study by Y. Kabir & Y. Mohsin & M. Khan is to build an Automatic Power Factor Correction (APFC) Unit, which can be able to monitor the energy consumption of a system and automatically improve its power factor. In their study, a capacitor switching combination to get the desired capacitance in correcting the power factor was utilized. The APFC device calculates the reactive power consumed by a system's inductive load and compensates the lagging power factor using capacitance from a capacitor bank [21]. At the end of their study, they concluded that Automatic power factor correction techniques can be applied in industries, commercial lines, and power distribution systems to increase the stability and efficiency of the system. It has also been concluded that if the capacitors are subjected to quick on-off-on conditions or overcorrection, the lifespan of the capacitor bank will be severely shortened. The APFC device aids in removing high current consumption from the system and reduces utility costs.

Figure 2.2 Complete APFC and Energy Monitoring System [19]

2.5.4 Cloud-Based Automated Power Factor Correction and Power Monitoring

This paper presents a neoteric cloud-based automated power factor correction (APFC) and power monitoring system that utilizes a private cloud and neural network design to correct the power factor of homes in a single algorithm. The system supports multi-home correction in one central device, which decreases the used number of devices. The design is scalable and adaptable to different types of facilities, but further research may be needed to determine its feasibility and effectiveness in industrial or medical settings. The paper also discusses the shortcomings of previous APFC methods based on IoT and cloud and emphasizes the micro or mini-grid principle. The proposed system allows monitoring before and after the correction process of the power factor and can be extended to manage big data or big district power quality enhancement via power factor correction. The paper concludes by outlining the steps of the power factor correction process and the tools that must be used to implement the system [22].

2.6 Cloud Monitoring

A recently developed grid technology that performs a computation is a cloud monitoring model that will obviate the need for an on-demand system and store a variety of data that is accessible on the connecting device. The various smart meters in the grid use the data collected by the cloud [23].

2.6.1 Power Monitoring System in Cloud Environments

In [24], Fig. 2.7 describes the basic hardware structure of a power monitoring system in cloud environments. It includes a power monitoring platform, temperature, and humidity sensing systems, a host server, network devices, and electrical appliances. Moreover, the power monitoring platform device used a PIC24F single chip equipped with Ethernet connections.

Cloud database, monitoring, and control interface are the leading software of the system. Embedded into the host server are the monitoring and control interfaces. Computers, terminal-embedded devices, and handheld devices can access this interface to get information about electrical appliances' power status and utilization. The interface can monitor up to four sockets by setting parameters and scheduling functions. Cloud databases are commonplace for information about temperature, humidity, current, voltage, power, switching status, and switching time.

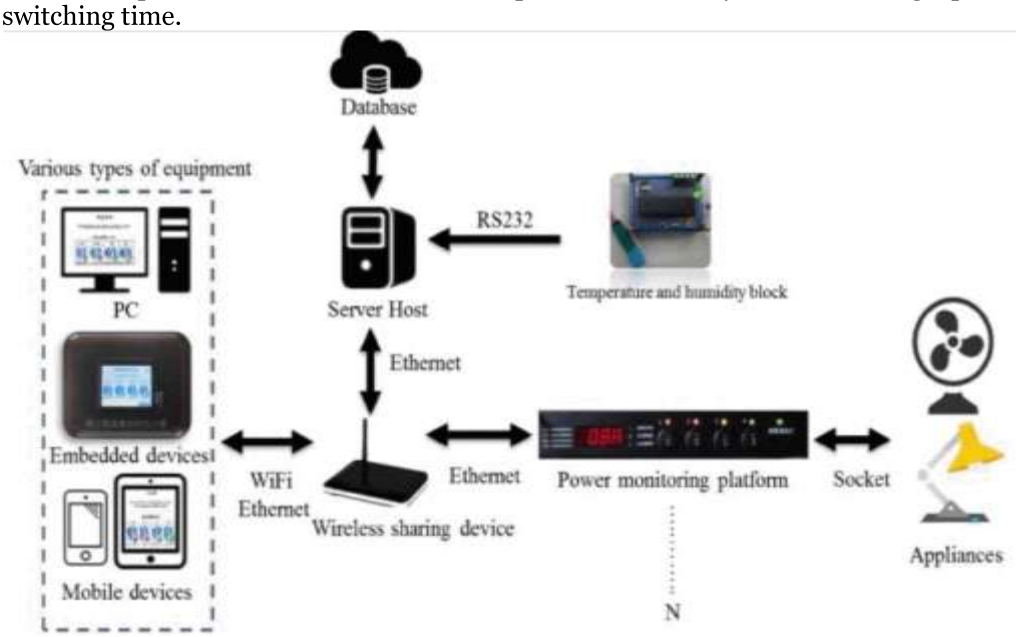

Figure 2.3 Power platform cloud environments in monitoring system schematic [23]

2.6.2 Properties of Cloud Monitoring

2.6.2.1 On-demand Function

Cloud computing provides the data stored at every provides the data stored at every stage to the consumer according to its requirement and it can be used to know the use of energy. Customers of cloud services can view their cloud services, track their usage, and provision and de-provision services by logging into their cloud accounts through a web self-service portal [24].

2.6.2.2Broad network access

Cloud can be handled through a browser which is available anywhere. A private cloud uses a local area network, whereas a public cloud uses the internet. Broad network access and cloud computing both rely heavily on latency and bandwidth because they have an impact on service quality [24].

2.6.2.3Rapid Elasticity

This function has control over the consumer who can read the data from the cloud. Data can be supported or stored in the memory device. Customers can use these capabilities whenever they want and, in any quantity, [24].

2.6.2.4Resource Pooling

There are no limits on the location of the consumer. They can be easily accessed with the cloud anywhere as well as read data. Memory, processing, and bandwidth are among the resources that customers can pool [24].

2.6.2.5 Measuring Device

In cloud systems, a metering capability optimizes resource use at an abstraction level suitable for the service being provided [24]. It allows the consumer to know their power usage which helps them control power saving. By use of meters, consumers can easily estimate the cost of power at home.

2.6.2.5.1 The cost of leaving appliances on standby

Standby power accounts for around 10% of the energy consumed in Australian homes, costs consumers over 950M per annum and generated more than 6.5M tons of carbon dioxide emissions in 2005. According to the following table, (depending on the electricity rate you pay, and the number of appliances left on standby), standby power could cost you well over $100 per year [25].

Table 2.1 The cost of standby power [23]

Appliance	Hourly standby consumption	Hourly standby cost	Annual standby cost*
Television (LCD)	2.3W	0.06c	$5.26
Microwave	2.4W	0.07c	$6.13
Games console	5.4W	0.15c	$13.14
DVD player	1.5W	0.04c	$3.50
Computer monitor	1W	0.03c	$2.62
Washing machine	1-6W	0.03c-0.17c	$2.62-$14.9
Clothes dryer	2.6W	0.08c	$7
Dishwasher	3W	0.09c	$7.88
Air conditioner	2W	0.05c	$4.88
Wireless modem	7-10W	0.2c-0.29c	$17.5-$25.4

2.6.2.5.2 Common Appliances Used in Home Energy

According to Perch Energy [26], Heating and cooling cover 50% of electricity consumption. Air conditioners and heaters make a large contribution to electricity consumption utilizing tons of energy to keep a home's temperature at the right degree; 12% for the water heater because water heaters are used for showering, washing dishes, using the sink, and laundry; 12% for the lighting being the far more energy efficient over the years; Refrigerator covering 8%; Washer and dryer at 5%; Electric oven at 3%; Dishwasher at 2%, and TV and cable box having the least percentage of 2%.

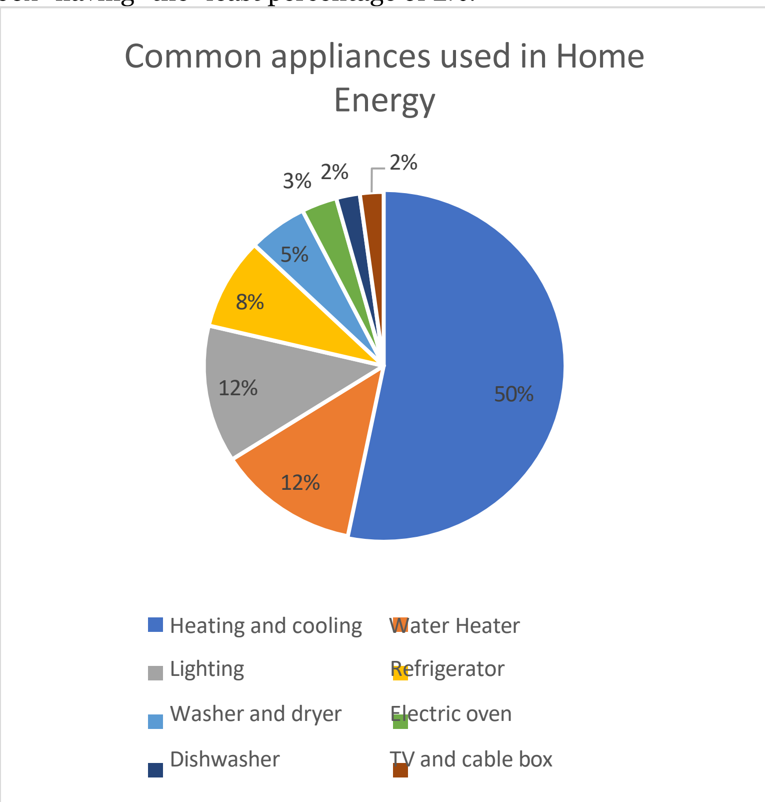

Figure 2.4 Common Appliances Used in Home Energy[26]

Chapter III Methodology

3.1 Conceptual Framework

Figure 3.1 Conceptual Framework

The conceptual framework of this study is shown in the figure above (**Fig. 3.1**). the conceptual framework is established in a way that the prototype utilizes a microcontroller, and various measuring devices to provide useful data and enable the disconnecting capability of the convenience outlet. The gathered data from supply and load and Power Factor Functionality Signals served as the input of the system. As per the process, the input of the system is used for calculation, monitoring, disconnecting capability command signals, and monitoring through Wireless Communication. This allows the user to connect and disconnect the convenience outlet. The data of supply and load are subjected to the calculation of the require capacity for power factor correction. The data of supply and load are also used to determine if there is a poor power factor. For the output, the data has been processed or the command that has been received is responsible for the disconnecting and connecting capability of the convenience outlet. The output displays the energy monitoring through Liquid Crystal Display (LCD) from the proposed prototype. Lastly, the evaluation of the performance of the Power Factor Correction functionality will take place.

3.2 The Process Flowchart of the Study

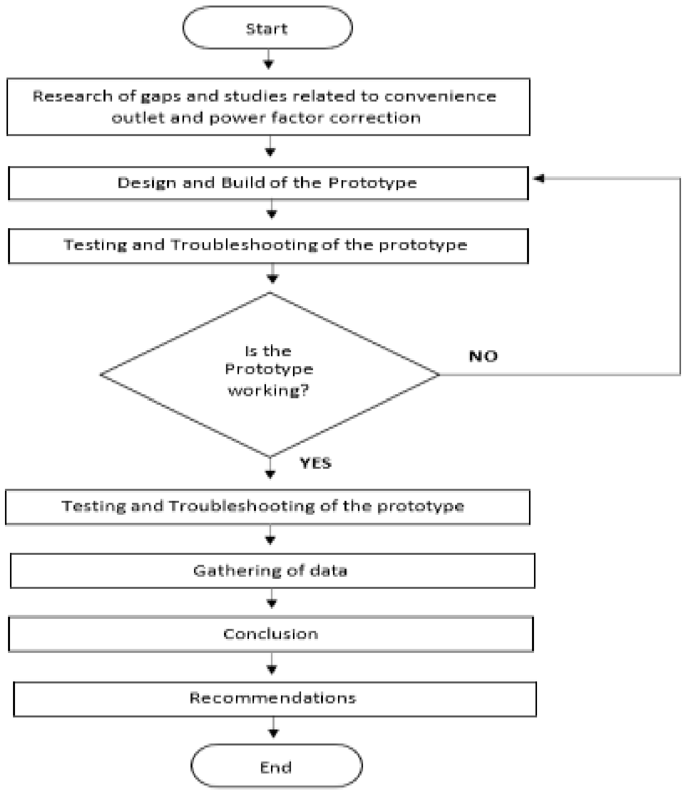

Figure 3.2 Process Flowchart of the Study

In the figure shown, the researchers reviewed different research studies related to smart outlets and focused on finding gaps. Once the gaps were established, the researchers designed and built the prototype based on the objectives made from the review of studies, gaps, and recommendations from the panelists. Next, the prototype was tested for its functionality test and accuracy test. If the prototype does not work as the researchers expected, the process will undergo again for design and build process to fix the problem. After testing and troubleshooting, the researchers proceeded with data gathering and analysis to come up with a conclusion. After coming up with a conclusion from data gathering and analysis, the study ended.

Objective 1: To design a Single-phase Energy Monitoring Device with Power factor correction functionality and wireless disconnecting capability.

In this objective, the researchers will design an energy monitoring device with Power Factor Correction functionality and disconnecting capability in a convenience outlet.

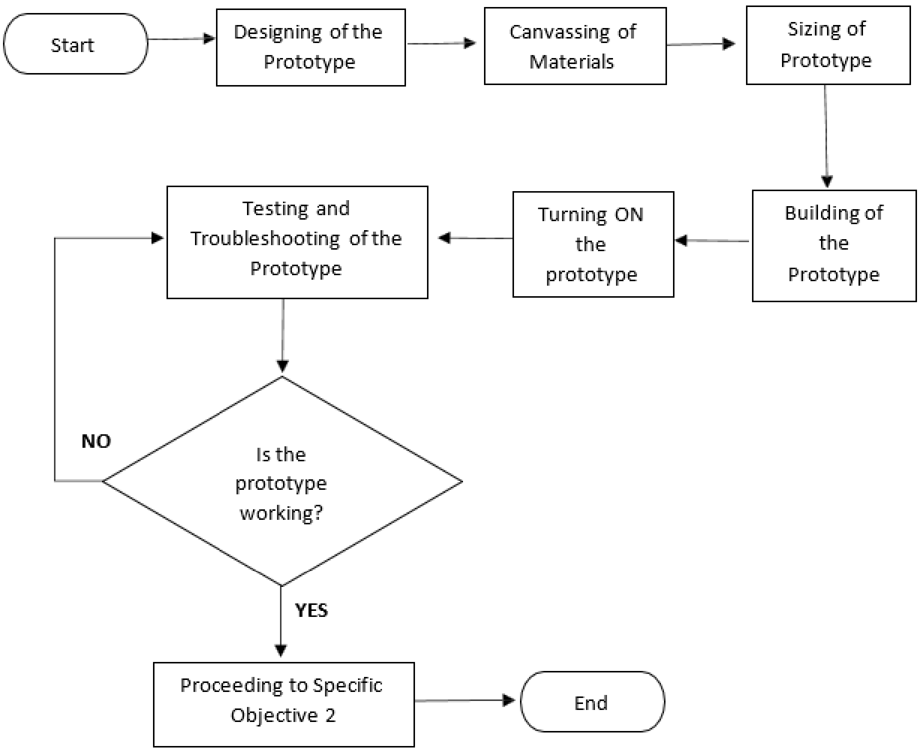

Figure 3.3. Process Flowchart of Specific Objective 1

3.3 Prototype Design

3.3.1 Actual Model of the Prototype

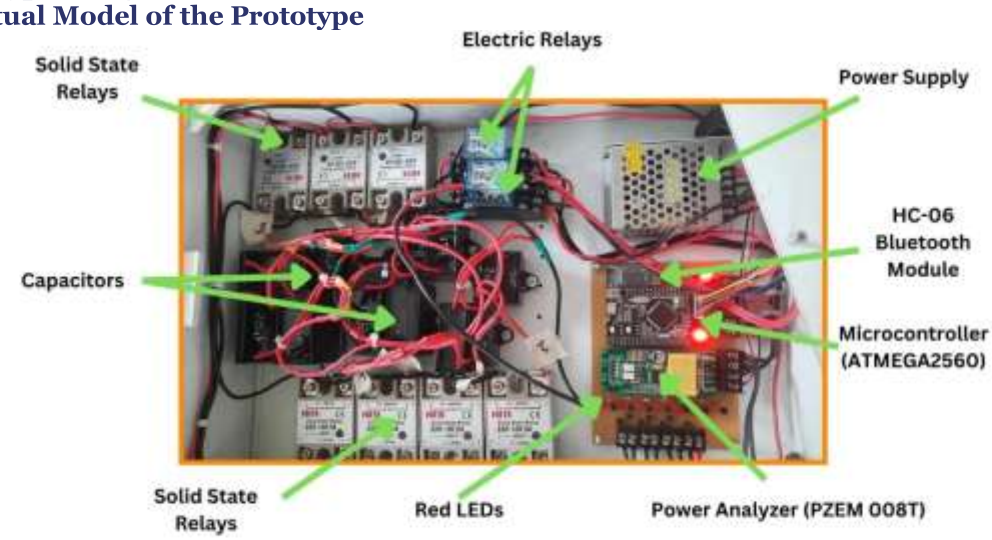

Figure 3.4 Hardware design of the prototype

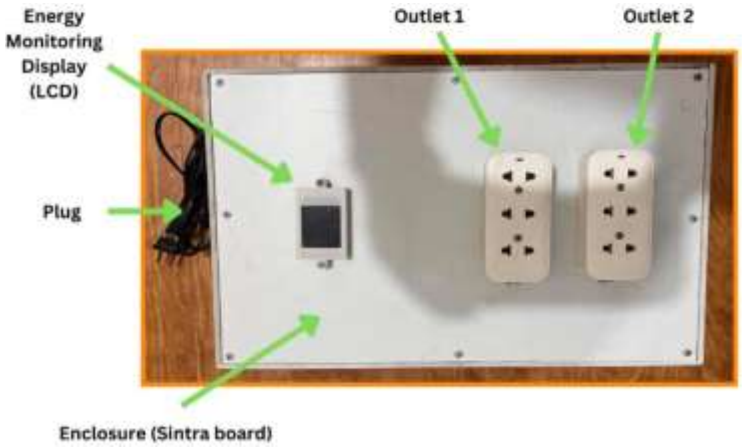

Figure 3.5 Exterior part of the prototype

As shown in **Figure 3.4**, The prototype is comprised of various components to develop a system that is capable of monitoring the voltage, current, power, power factor, and energy consumption of the user. Specifically, the device utilized an ATMEGA2560 microcontroller, Power analyzer, Bluetooth Module, Relays, and Connecting wires. The study also utilized various capacitors and solid-state relays to enable to correct power factor.

Each outlet can be turned on by connecting the device to a mobile phone via Bluetooth, Bluetooth connecting the Android application to the address of the device, and lastly by tapping the ON button via the Android Application.

Bluetooth's MAC address is essential in remote access functionality conditions as it provides unique identifiers for devices on the network. This allows for efficient data transfer. In this study, Bluetooth's MAC addresses remote access functionality.

The prototype is composed of various components to develop a system capable of monitoring electrical parameters such as Voltage (V), Current (mA), Power (W), Energy (K/Hr), Power Factor (PF), & Capacitor injected. Specifically, the proposed convenience outlet will utilize an ATMEGA microcontroller, Power Analyzer, Solid State Relays, connecting wires, and various components for the Power Factor Correction Unit (PFCU) to be placed parallel to the outlet.

However, in **Figure 3.5,** it shows the exterior part of the prototype.

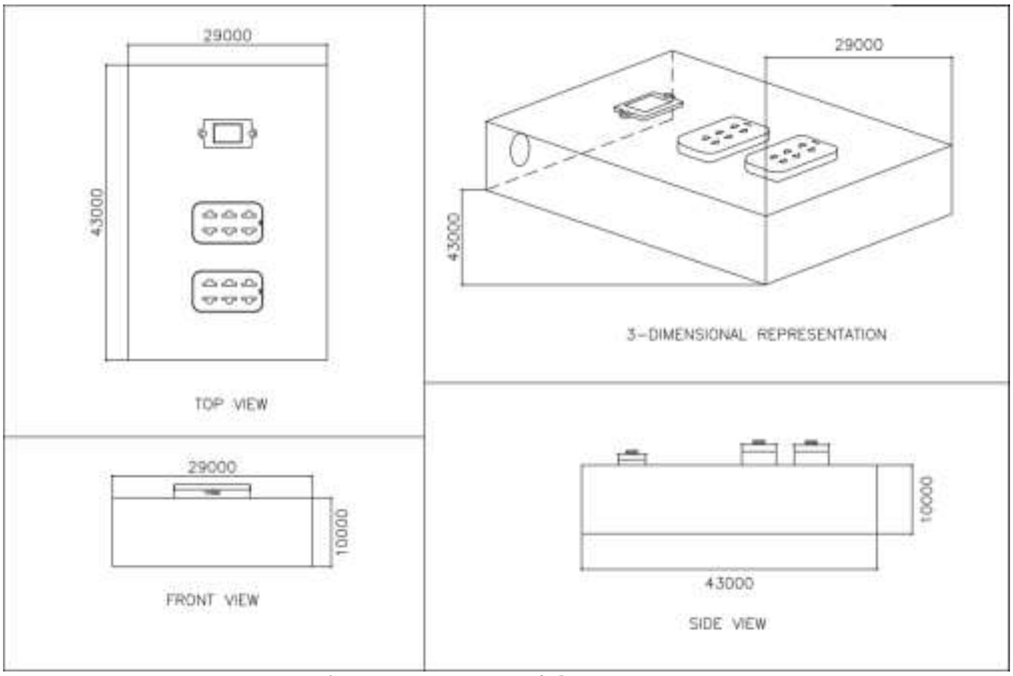

Figure 3.6 Sizes of the prototype

Figure 3.6 shown above is the model unit of the prototype. The Convenience Outlet casing model is proposedly 29 cm x 43 cm x 10 cm in size. The Convenience Outlet has been designed for Single-Phased Systems. The board for the enclosure of this prototype is the Sintra board.

3.4 Architecture of the System

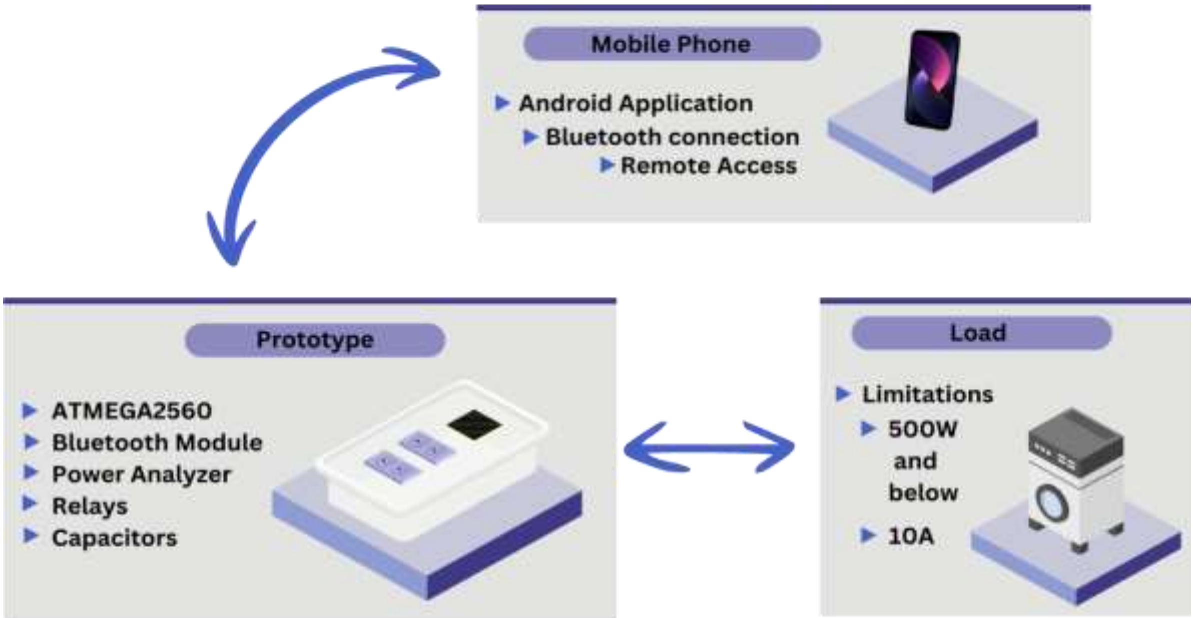

Figure 3.7 Architecture of the System

Figure 3.7 above shows the architecture of the system. Inside the model unit, a Microcontroller, Bluetooth module, and Power Analyzer are present. The microcontroller is responsible for sending information to the system. It processes and logs the information received. Whereas, the Bluetooth module enables wireless connectivity between devices. On the other hand, an Android application must be downloaded to a mobile phone to serve as a platform for the availability of Bluetooth as a medium between the mobile phone and the prototype. The Android application enables remote access functionality and disconnecting capability. The load's limitation is below 500W and 10A as this study only focuses on low- voltage systems.

3.5 Process Flowchart of the Prototype

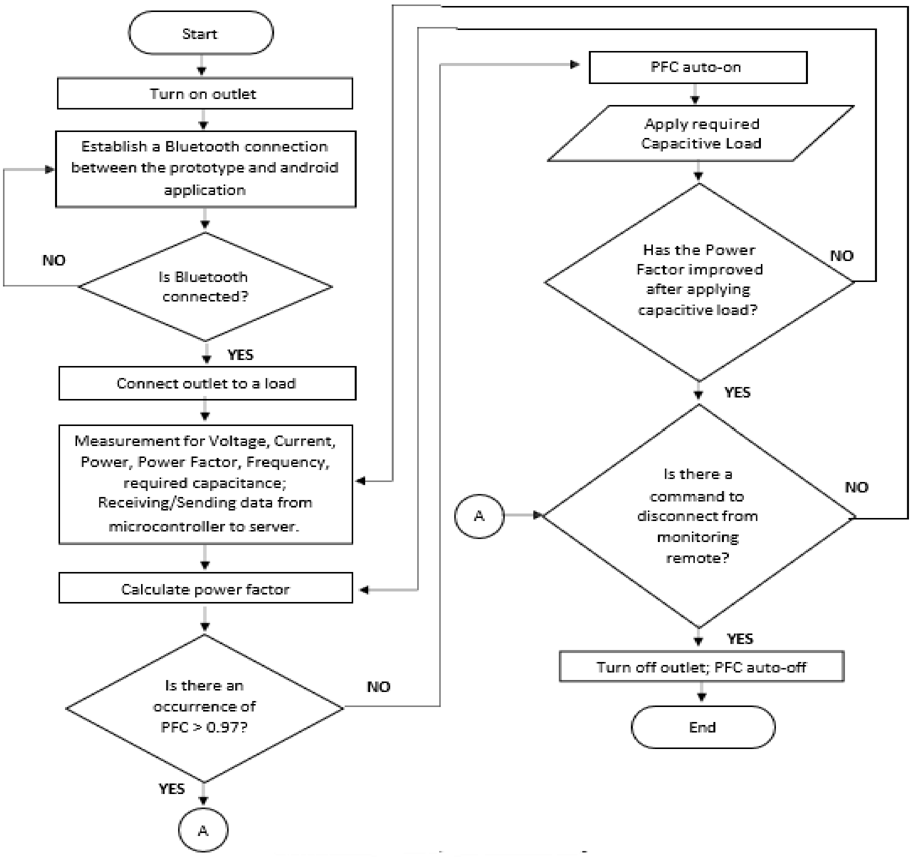

Figure 3.8 Process Flowchart of the Prototype

The Process Flowchart of the proposed Energy Monitoring Device with Remote Access Functionality for Power Factor Correction and Disconnecting Capability in a Convenience Outlet is shown in **Figure 3.8** above. The process starts with the outlet establishing a Bluetooth connection to the Android application. Once a connection has been established, the outlet shall be connected to a load. After connecting the outlet to the appliance, energy monitoring will be displayed through the Liquid Crystal Display (LCD) equipped in the prototype. Receiving commands from the Android application can also take place at this point. If the sensors detect that the Power factor is not greater than 0.97, the Power Factor Correction Unit (PFCU) will automatically turn on and apply the required capacitive load. As mentioned before, in case, there is a disconnection command from the Android application that serves as the remote access, the outlet will immediately be disconnected, as well as the Power Factor Correction Module (PFCM).

3.6 Schematic Diagram of the System

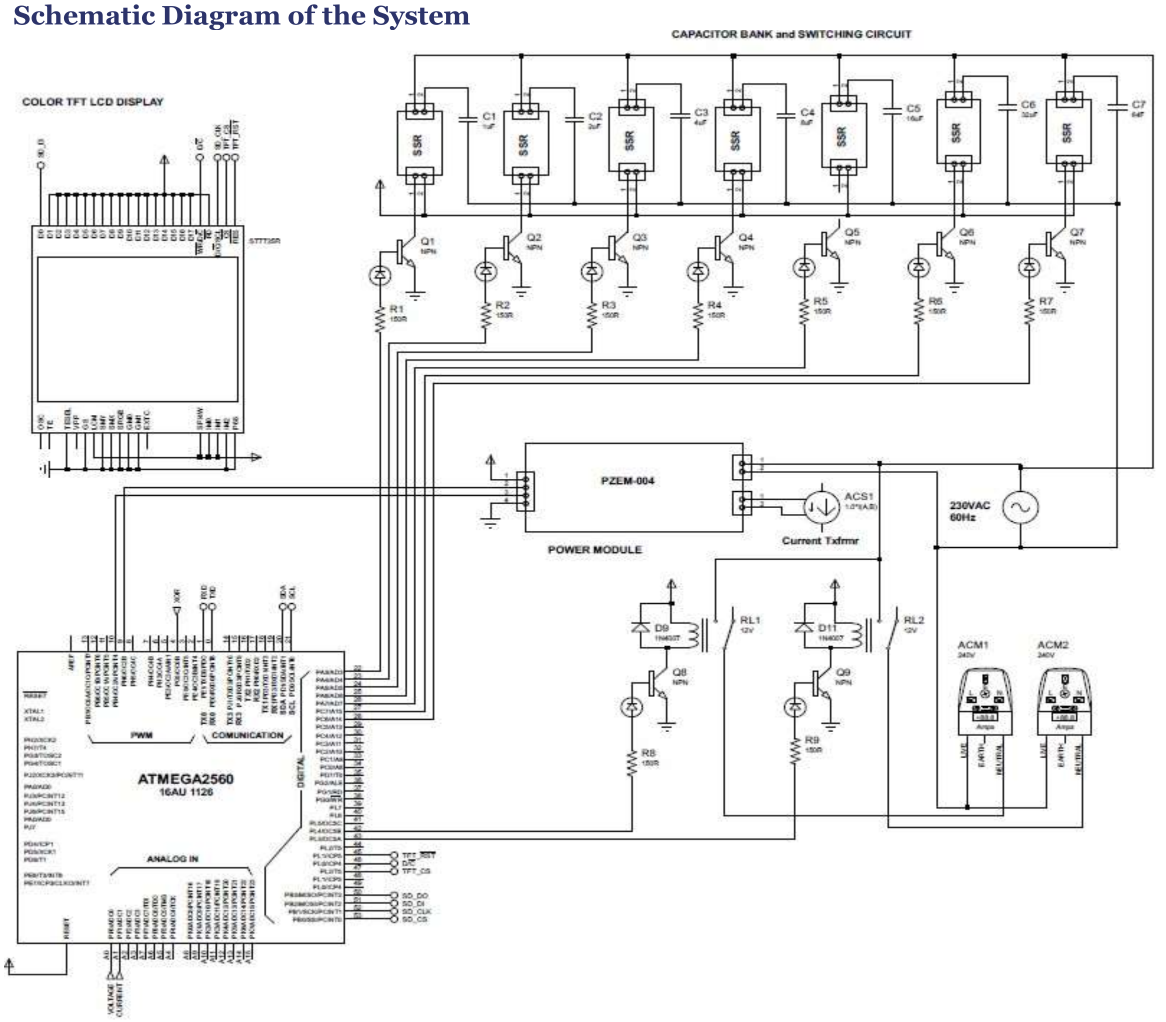

Figure 3.9 Schematic Diagram of the System

Figure 3.9 above shows the Schematic Diagram of the System. The system uses ATMEGA2560 as the main controller. The ATMEGA2560 is the microcontroller used for the system with different modules attached. To be able for the system to correct its power factor, a capacitor bank, and the switching circuit was built. The other modules attached are the Power Analyzer and Bluetooth Module. The Power Analyzer is mainly used for measuring AC voltage, current, active power, frequency, power factor, and active energy. Solid State Relays were also used in this system to enable the switching needed.

3.7 Components

3.7.1 Convenience Outlet

The development of a convenience outlet follows the parameters for the physical and wiring standards of a receptacle under the Philippine Electrical Code of 2017. A convenience outlet is a receptacle mounted in walls or floors connected to the main electrical wiring system of an establishment at which current is taken. It can be in a duplex, or triplex receptacle depending on the electrical wiring design. Special purpose outlets can be used based on the locations they will be installed, such as ground-fault circuit interrupter (GFCI) and, weatherproof convenience outlet.

Figure 3.10 Convenience Outlet

3.7.2 ATmega2560

The ATmega2560 is a high-performance, 8-bit microcontroller with 256KB of flash memory for storing program code, 8KB of SRAM for data storage, and 4KB of EEPROM for non-volatile data storage. It operates at a maximum clock frequency of 16MHz and features 86 general-purpose I/O pins, making it suitable for a wide range of embedded applications requiring high processing power and extensive connectivity. The ATmega2560 microcontroller, with its high processing power and numerous GPIO pins, is well-suited for controlling electrical loads. Its multiple communication interfaces facilitate data exchange with external devices, while built-in timers, PWM channels, and ADCs enable precise control and monitoring of the loads. This microcontroller's reliability and flexibility make it ideal for a wide range of load control applications, from simple on/off switching to complex control strategies.

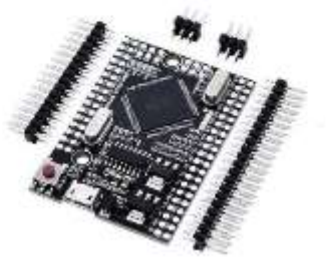

Figure 3.11 ATMEGA 2560

3.7.3 PZEM-008T

This component of the Power Analyzer is an AC communication module that measures AC voltage, current, active power, frequency, power factor, and active energy. This module does not display function, and the data is read through the TTL interface. The proposed measuring range of the researchers is at 10A (Built-in Shunt).

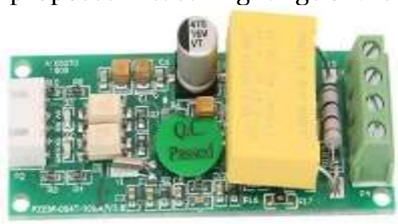

Figure 3.12 PZEM-008T

3.7.4 Solid State Relay

A solid-state relay (SSR) is an electronic switching device that controls electrical power without moving parts like those found in traditional electromechanical relays. Instead of using mechanical contacts, SSRs employ semiconductor switching elements, typically a combination of power MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistors) or thyristors (SCRs or Triacs). When the control signal is applied, the semiconductor switching element within the SSR activates, allowing current to flow from the input to the output terminals. Many SSRs include an optocoupler, which isolates the control input from the high-power output, ensuring safety and preventing interference between the control circuit and the load circuit.

Figure 3.13 Solid State Relay

In parallel to the Convenience Outlet is the Power Factor Correction Unit.

3.7.5 Capacitors

Capacitors are passive electronic components that store and release electrical energy in the form of an electric field. In AC (alternating current) circuits, capacitors can be strategically employed to offset the effects of inductive loads, such as electric motors and transformers, which can cause a lagging power factor. This lagging power factor results in inefficient power usage and increased energy costs for the consumer. By connecting capacitors in parallel with the inductive loads, a process known as power factor correction, the reactive power drawn from the system can be reduced.

This correction improves the power factor, bringing it closer to unity (1.0) and optimizing the efficiency of the electrical system.

Figure 3.14 Capacitor

In this objective, the researchers design a convenience outlet with a power factor correction functionality. The microcontroller is the one responsible for determining the required KVAR demand in correcting the power factor of a load appliance using equation 3.1. In this study, loads will be tested because these are the loads that are inductive and usually operate at a low power factor. However, the inductive nature cannot be changed. The inductive load can be minimized by increasing the power factor by having a capacitor.
The equation below is for KVAR Calculation.

Power Factor Correction

$$Power\ Factor\ (PF) = \frac{Real\ Power\ (W)}{Apparent\ Power\ (VA)} \quad (\boldsymbol{eq.3.1})$$

Wherein,
P = Active power (measured in watts)
S = apparent power (measured in volt-amperes)

Required KVAR Calculation

[5] The calculated power parameters are used to determine the required KVAR. If the current power factor is and targeted power factor is then, cos φ_1 … … ($\boldsymbol{eq.\ 3.\ 2}$)

cos φ_2
$Required\ KVAR = P\ (\tan \varphi_1 - tan\varphi_2)$
Capacitance in Farad,

$\frac{VAR}{C} = (\quad)^{2\pi f V}$ 2 **(eq. 3.3)**

Wherein,
P = Real power in KW f = frequency
V = voltage of the power system

Power Generated

$$\boldsymbol{W = V\ x\ I\ x\ p.f} \quad \textbf{(eq. 3.4)}$$

Wherein:
W = Wattage (W)
V = Operative voltage (V) I = Electric current (A)
P.F = Power Factor

The process of creating electricity from primary energy sources is known as electricity generation. It is the primary structure used by electric utilities in the electric power sector to deliver electricity to end customers; alternative arrangements include transmission, distribution, energy storage, and recovery.

Objective 2: To test the functionality of the developed convenience outlet by using a

load.
In this objective, the functionality test will be done by turning on the outlet and establishing a Bluetooth connection to the Android application downloaded on the respective mobile phone. Moreover, the disconnecting and connecting capability via the Android Application device is done by tapping the “ON” and “OFF” buttons of its respective outlets. Appliances were plugged in to test the functionality of the prototype's monitoring display, Power Factor Correction, and disconnecting capability.

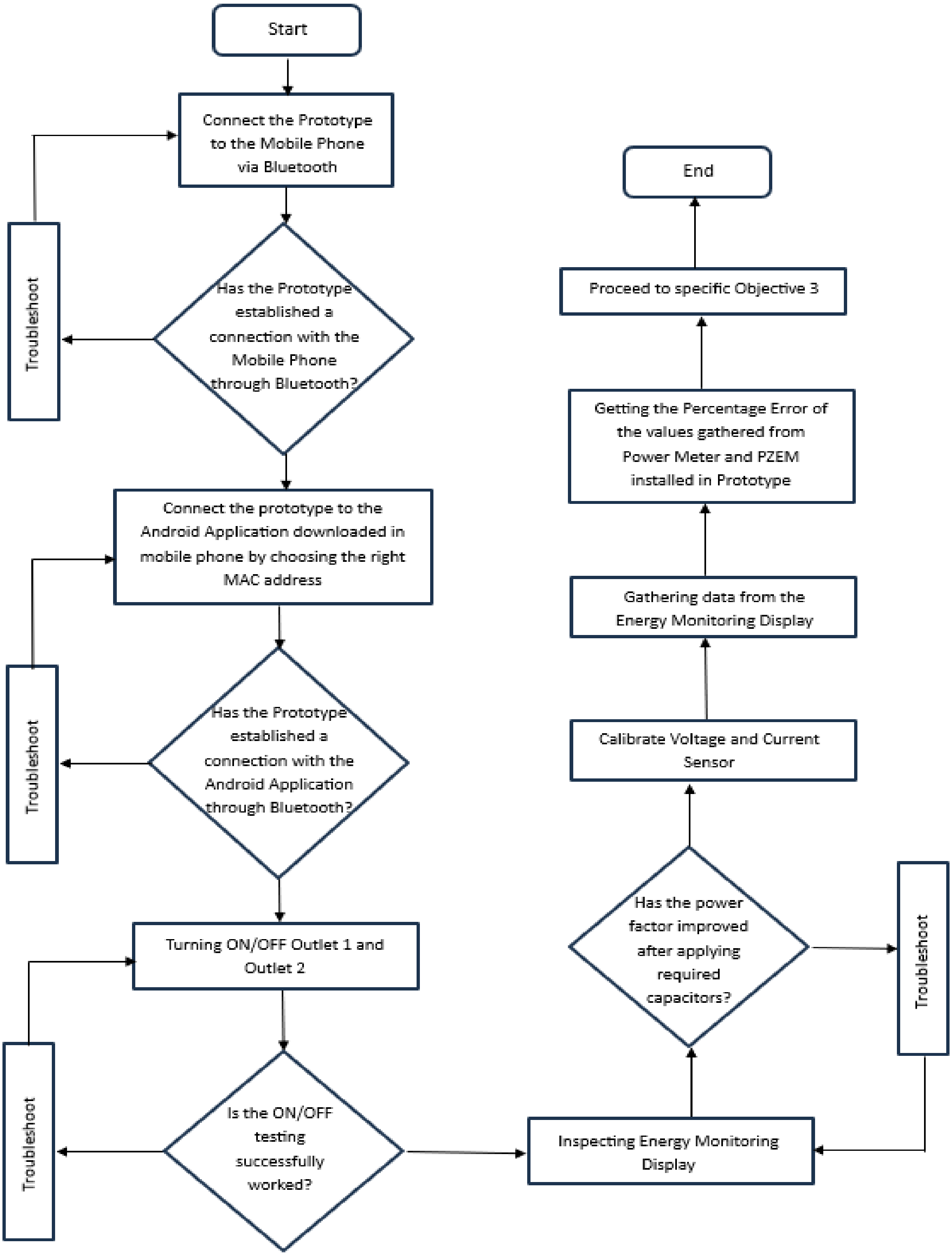

Figure 3.15 Process Flowchart of the Prototype

3.8 Functionality Test

3.8.1 Testing Set-up

Functionality test:

(a) Outlet connects via Bluetooth's mobile phone

Figure 3.16 Bluetooth Connectivity between Prototype and Mobile Phone

Figure 3.16, shows the Bluetooth MAC address of the prototype which must be connected to the mobile phone to enable the functionality of remote access through an Android application.

(b) Establishing a connection between the prototype and the Android application

Figure 3.17 Prototype and Android Application's Bluetooth Connectivity

In **Figure 3.17**, the Android application interface is shown. The establishment of connection starts with choosing the prototype's respective Bluetooth MAC Address.

(c) Mobile application's medium to the prototype

Figure 3.18 Prototype's address

In **Figure 3.18**, the prototype's Bluetooth MAC address is shown and must be chosen as the Bluetooth connection for the medium of the device and the Android application.

(d) Remote Access Functionality test by turning "ON" Outlet 1 via the Android application

Figure 3.19 Turning ON Outlet 1

Figure 3.19 above shows OUTLET 1 being ON. "OUTLET 1 ON" needs to be tapped to turn on OUTLET 1. Its corresponding LED must light whenever it is ON. As shown in the figure, the functionality test has successfully worked.

(e) Remote Access Functionality test by turning "OFF" Outlet 1 via the Android application

Figure 3.20 Turning OFF Outlet 1

Figure 3.20, above shows OUTLET 1 being OFF. "OUTLET 1 OFF" shown in Figure above needs to be tapped to turn off OUTLET 1. Its corresponding LED must not light whenever it is OFF mode. As shown in the figure, the functionality test has successfully worked.

(f) Remote Access Functionality test by turning "ON" Outlet 2 via Android application

Figure 3.21 Turning ON Outlet 2

Figure 3.21 above shows OUTLET 2 being ON. "OUTLET 2 ON" shown in Figure above needs to be tapped to turn on OUTLET 2. Its corresponding LED must light whenever it is ON. As shown in the figure, the functionality test has successfully worked.

(g) Remote Access Functionality test by turning "OFF" Outlet 2 via Android application

Figure 3.22 Turning OFF Outlet 2

Figure 3.22, above shows OUTLET 2 being OFF. "OUTLET 2 OFF" shown in Figure above needs to be tapped to turn off OUTLET 2. Its corresponding LED must not light whenever it is OFF mode. As shown in the figure, the functionality test has successfully worked.

(h) Energy Monitoring Display and Automatic Power Factor Correction

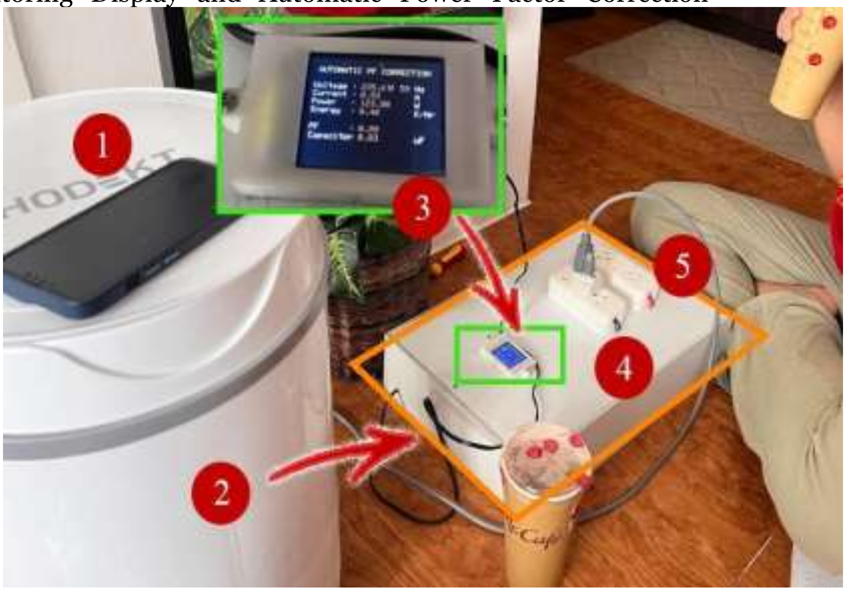

Figure 3.23 Set-up

In **Figure 3.23** above, it shows the setup of gathering the data. The load shown in point 1 is a mini washing machine with 50W input. In point 2, it shows the device in one. Whereas points 4 and 5, are the outlets. Specifically, point 4 is the outlet 1 and point 5 is the outlet 5. In point 3, it shows the monitoring display being functional. In this setup, outlet 1 was used to supply energy to the load. As the device is connected to the load, the required capacitance for correcting the power factor of the load is seen as successfully working.

(i) Monitoring Display

Figure 3.24 Monitoring Display

Figure 3.24 above, shows a monitoring display in a 2x4 Colored Liquid Crystal Display.

3.9 Accuracy test - Calibration of Current and Voltage Sensor

To accurately measure the parameters, the voltage and current sensor will be calibrated. A 220V Power Meter will be used to calibrate each of the ten trials. The percentage error will also be computed to calculate the difference between the two. The following table shows the percentage error formula.

$$Percentage\ Error = \frac{Actual\ Value\ (Voltage\ and\ Current\ Sensor) - Expected\ Value\ (Power\ Meter)}{Expected\ Value\ (Power\ Meter)} * 100 \quad \textbf{(eq. 3.5)}$$

Table 3.1 Calibration of PZEM Current Sensor

Trial	Actual Value of Current from PZEM-004t	Expected Value from Power Meter	Percentage Error
1	0.25	0.25	0%
2	0.73	0.725	0.68%
3	0.72	0.715	0.69%
4	0.71	0.723	0.41%
5	0.17	0.172	1.16%
6	0.16	0.158	1.26%
7	0.17	0.169	0.59%
8	0.24	0.241	0.41%
9	0.22	0.219	0.45%
10	0.24	0.241	0.41%

Table 3.2 Calibration of PZEM Voltage Sensor

Trial	Actual Value of Voltage from PZEM-004t	Expected Value of Voltage from Power Meter	Percentage Error
1	229.8	229.91	0.05%
2	231.7	230.90	0.34%
3	231.7	231.90	0.08%
4	231.7	232.80	0.47%
5	231.5	232.00	0.21%
6	231.4	232.00	0.25%
7	231.5	230.05	0.63%
8	231.2	232.10	0.50%
9	230.09	230.12	0.004%
10	231.0	230.82	0.60%

Objective 3: To evaluate the performance of the Power Factor Correction functionality by comparing the results of Before and After Power Factor Correction by t-test to assess its effectiveness.

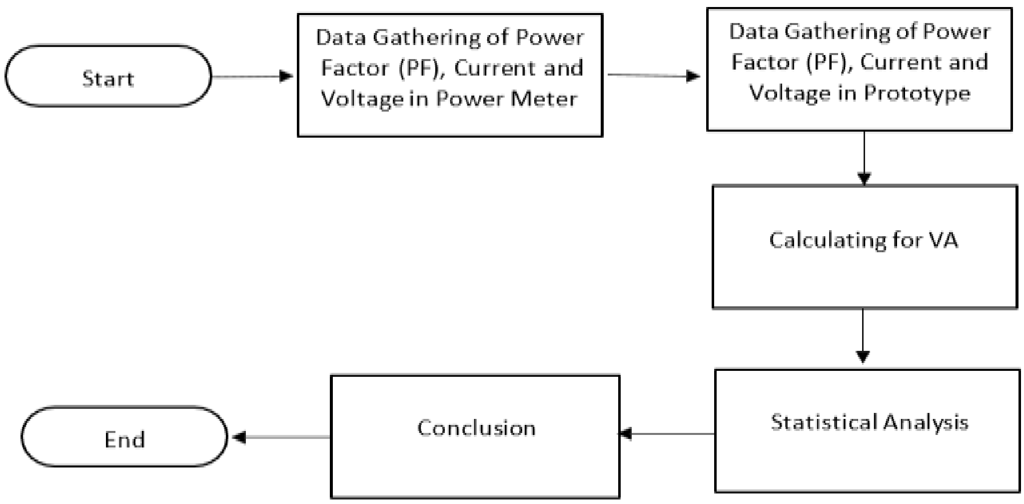

Figure 3.25 Objective 3 Flowchart

3.10.2 Power Factor Correction- Before and After

Table 3.3 Power Factor Correction – Before and After

Before Power Factor Correction			After Power Factor Correction			
	Power Meter			Power Analyzer		
Settings	Apparent Power (V.A.)	Power Factor (PF)	Settings	Apparent Power (V.A.)	Power Factor (PF)	Capacitor Injected
LOW	43.00	0.87	LOW	39.90	0.99	0.31
LOW	42.93	0.92	LOW	40.10	0.99	0.26
MEDIUM	42.82	0.96	MEDIUM	41.90	0.99	0.20
MEDIUM	42.66	0.87	MEDIUM	41.90	0.99	0.21
HIGH	45.28	0.90	HIGH	43.80	1.00	0.17
HIGH	45.20	0.91	HIGH	44.20	1.00	0.10
LOW	76.56	0.86	LOW	76.30	0.99	0.58
LOW	79.86	0.85	LOW	77.80	0.99	0.55
LOW	77.23	0.87	LOW	75.30	0.99	0.51
MEDIUM	86.54	0.95	MEDIUM	85.10	0.98	0.82
MEDIUM	88.93	0.95	MEDIUM	86.60	0.98	0.85
MEDIUM	86.22	0.94	MEDIUM	84.20	0.99	0.68
HIGH	81.48	0.97	HIGH	80.60	0.99	0.49
HIGH	94.58	0.96	HIGH	93.90	0.98	1.04
HIGH	81.48	0.97	HIGH	80.60	0.99	0.49
STABLE	167.37	0.95	STABLE	164.30	1.00	0.37
STABLE	153.34	0.99	STABLE	151.20	1.00	0.21
STABLE	162.66	0.94	STABLE	159.30	1.00	0.44
STABLE	165.256	0.95	STABLE	155.30	1.00	0.23
STABLE	151.123	0.85	STABLE	149.20	1.00	0.35
STABLE	159.53	0.84	STABLE	154.30	0.97	2.02
STABLE	154.37	0.90	STABLE	150.00	1.00	0.26
STABLE	178.725	0.97	STABLE	176.60	0.98	1.60
STABLE	170.856	0.98	STABLE	167.70	1.00	0.26
STABLE	149.24	0.95	STABLE	147.30	0.97	1.95
STABLE	156.043	0.97	STABLE	154.20	1.00	0.48

STABLE	161.370	0.98	STABLE	155.30	1.00	0.23
STABLE	169.26	0.97	STABLE	155.00	1.00	0.52
STABLE	176.49	0.88	STABLE	173.30	0.99	0.87
STABLE	136.99	0.96	STABLE	134.30	0.97	1.90

Table 3.3 above shows the Power Factor Correction Values Before and After. These values can be retrieved from the energy monitoring display. The system can detect and measure the exact power factor. The pre-programmed microcontroller can determine the capacitance required for raising the power factor to 0.97. It switches on capacitors. Some appliances tested already contain good power factors, and minor discrepancies were seen compared with before and after corrections. The prior power factor is retrieved through a power meter, whereas the corrected power factor is retrieved through the prototype.

$$Required\ capacitance:$$

$$\frac{(Load\ Current)\left(\frac{\sqrt{1-Real\ Power}}{(Load\ Voltage)(Load\ Currrent)}\right)(Real\ Power)/(loadvoltage)(Load\ Current)}{(load\ voltage)(377)} * 1{,}000{,}000) \quad \textbf{(eq. 3.6)}$$

Table 3.3 above shows the Power Factor Correction Values Before and After. These values can be retrieved from the energy monitoring display. The system can detect and measure the exact power factor. The pre-programmed microcontroller can determine the capacitance required for raising the power factor to 0.97. It switches on capacitors. Some appliances tested already contain good power factors, and minor discrepancies were seen compared with before and after corrections. The prior power factor is retrieved through a power meter, whereas the corrected power factor is retrieved through the prototype.

3.11 Statistical Analysis

Table 3.4 T-Test: Two-Sample Assuming Unequal Variances - Current

T-Test: Two-Sample Assuming Unequal Variances		
	Actual Value of Current from PZEM-004t	Expected Value of Current from Power Meter
Mean	0.362	0.3613
Variance	0.063195556	0.062659344
Observation	10	10
Hypothesized Mean Difference	0	-
df	18	-
T Stat	0.00629689	-
P(T<=t) one tail	0.497545058	-
T Critical one-tail	1.734063607	-
P(T<=t) two tail	0.995090115	-
T Critical two-tail	2.10092204	-

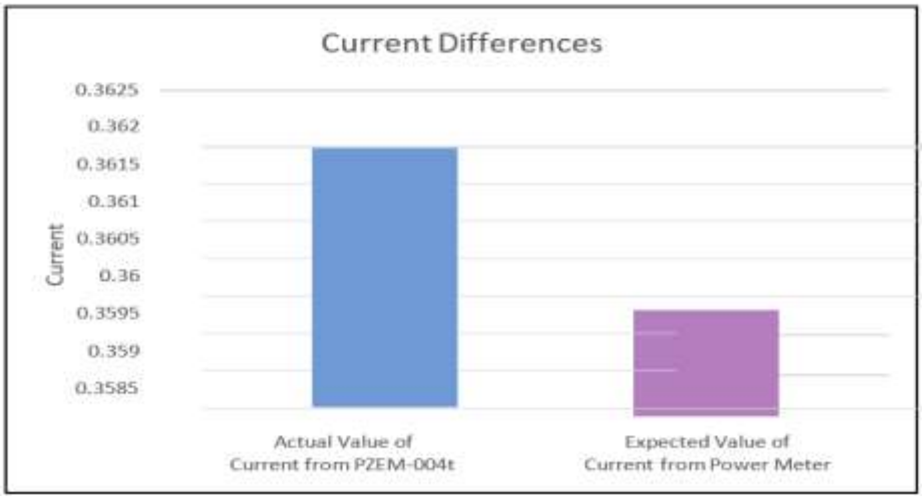

Figure 3.26 Current Differences

At the 5% level of significance, there is enough evidence to support the claim that the current from power analyzer and power meter has no significant difference. Looking at figure above, we can see the differences of the 2 groups from each other. The t-test stated that we need to accept the null hypothesis since the P-value is higher than 0.05. Comparing the Test result and the current differences in the figure, we can conclude that there really is no significant difference between the groups.

Table 3.5 T-Test: Two-Sample Assuming Unequal Variances - Voltage

T-Test: Two-Sample Assuming Unequal Variances		
	Actual Value of Voltage from PZEM-004t	Expected Value of Voltage from Power Meter
Mean	231.259	231.455
Variance	0.327476667	0.910516667
Observation	10	10
Hypothesized Mean Difference	0	-
df	15	-
T Stat	-0.557053514	-
P(T<=t) one tail	0.292853514	-
T Critical one-tail	1.753050356	-
P(T<=t) two tail	0.585707526	-
T Critical two-tail	2.131449546	-

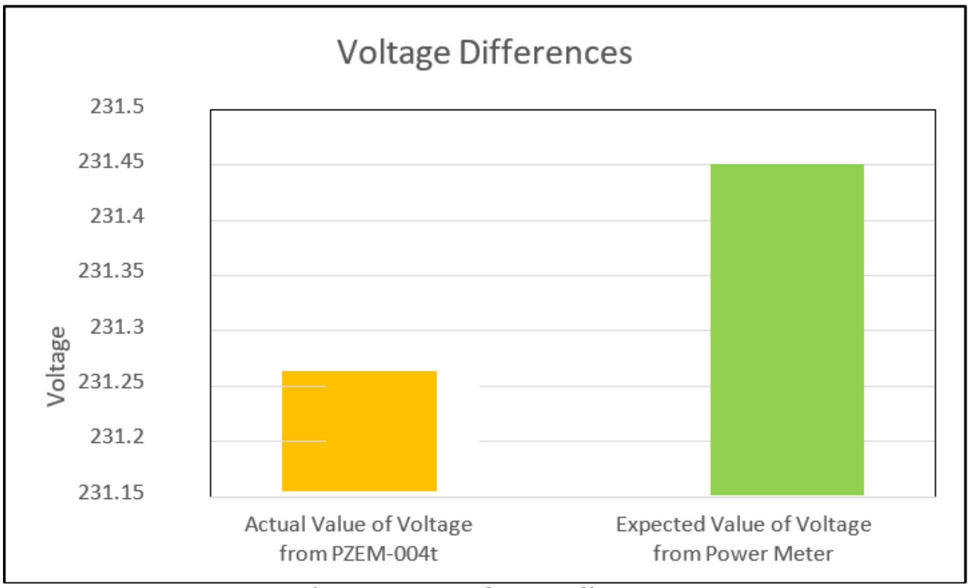

Figure 3.27 Voltage Differences

At the 5% level of significance, there is enough evidence to support the claim that the voltage from power analyzer and power meter has no significant difference. Looking at figure above, we can see the differences of the 2 groups from each other. The t-test stated that we need to accept the null hypothesis since the P-value is higher than 0.05. Comparing the Test result and the voltage differences in the figure, we can conclude that there really is no significant difference between the groups.

Table 3.6 T-Test: Two-Sample Assuming Unequal Variances

T-Test: Two-Sample Assuming Unequal Variances		
	Before PF Correction	After PF Correction
Mean	0.916666667	0.990666667
Variance	0.001843678	9.6092E-05
Observation	30	30
Hypothesized Mean Difference	0	-
df	32	-
T Stat	-9.202741329	-
P(T<=t) one tail	8.31134E-11	-

T Critical one-tail	1.693888748	-
P(T<=t) two tail	1.66227E-10	-
T Critical two-tail	2.036933343	-

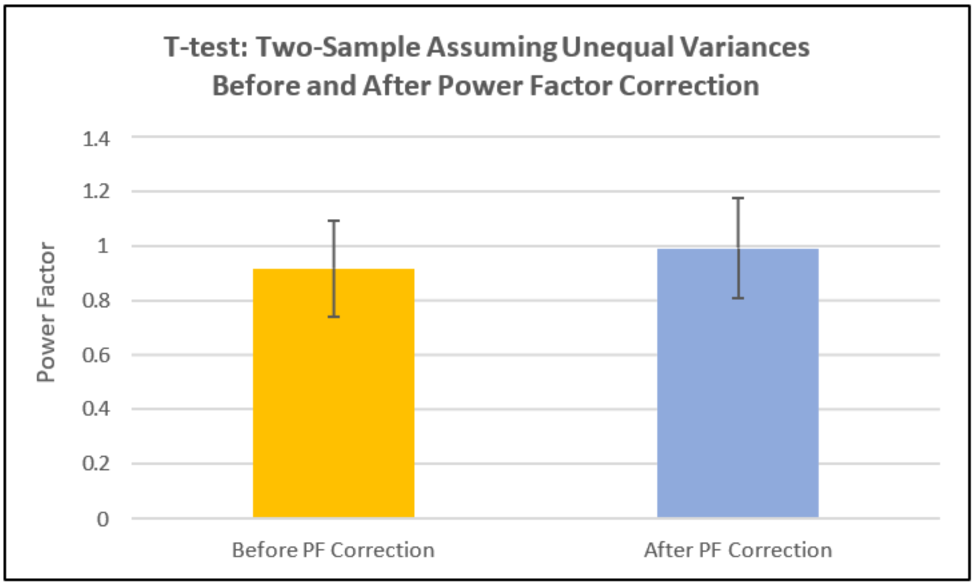

Figure 3.28 Objective 3 Flowchart

At the 5% level of significance, there is enough evidence to support the claim that the Before Power Factor Correction is different from the After Power Factor Correction. Looking at figure above, we can see the differences of the 2 groups from each other. The t-test stated that we need to reject the null hypothesis since the P-value is lower than 0.05. Comparing the Test result and the power factor differences in the figure, we can conclude that there really is significant difference between the groups.
Thus, the results of the t-test analysis are accepted, and shows significant difference in the value of the actual value of the power factor and the corrected power factor value. Thus, the power factor projected by the prototype/device from the appliances is reliable and can be used to determine the discrepancies between the actual value of the power factor and the corrected power factor.

3.12 Engineering Standards

IEEE PC37.26/D3 1. IEEE Guide for Methods of Power-Factor Measurement for Low-Voltage (1000 V AC or lower) Inductive Test Circuits

These methods are employed to determine the power factor during short-circuit current tests in high-power laboratories. The preferred approach involves using the methods specified here during short-circuit current testing. There are alternative methods including computerized or digital techniques, may be employed if they have been validated to produce results equivalent to those obtained using the methods described in this guide. These methods are primarily intended for use in low-voltage test circuits (under 1000 V AC) but can also be adapted for higher voltage applications.

IEEE Std 1159-2009 IEEE Recommended Practice for Monitoring Electric Power Quality

This recommended practice aims to provide users with a consistent set of terms and definitions for describing power quality phenomena. Understanding how these phenomena affect the power system and end-use equipment is crucial for effective monitoring. Proper measuring techniques are essential for safely obtaining useful and accurate data. Strategically locating monitors, conducting systematic studies, and accurately interpreting results will enhance the value of power quality monitoring. The purpose of this recommended practice is to assist users, equipment manufacturers, software developers, and vendors by detailing techniques for defining, measuring, quantifying, and interpreting electromagnetic phenomena within the power system.

IEEE Std 1889-2018 IEEE Guide for Evaluating and Testing the Electrical Performance of Energy-Saving Devices

This standard contains instructions for the measurement protocol of key electrical parameters such as voltage, current, kilowatts, and kilovars, which are essential for determining the energy consumption of Electrical Submersible Pumps (ESDs). Additionally, this guide offers guidance on measuring performance characteristics of various loads affected by the Energy Saving Devices, including lumens, rotations per minute (RPM), torque, temperature, and voltage.

Chapter IV CONCLUSION

The researchers successfully designed a Single-Phase Energy Monitoring Device with Remote Access functionality for Power Factor Correction and Disconnecting Capability in a Convenience Outlet.

The prototype successfully utilizes a microcontroller with a Power Analyzer to provide useful data and enable the disconnecting capability of the convenience outlet. The gathered data from supply and load, automatic power factor correction, and command signals of disconnection capability served as the input of the system. The system's input that is utilized for calculating, monitoring, disconnecting capabilities, and monitoring via wireless communication, are all in line according to the procedure. It allows the user to connect and disconnect the convenience outlet.

The data of supply and load are subjected to the calculation of power factor correction, and energy monitoring. The data of supply and load are also used to determine if there is a poor power factor. For the output, the data has been processed or the command that has been received is responsible for the disconnecting and connecting capability of the convenience outlet. The output also gives accurate electrical data and energy monitoring through a Bluetooth MAC Address that can be monitored through an Android mobile application and LCD from the proposed prototype. Lastly, the evaluation of the performance of the Power Factor Correction functionality took place. In testing the Power Analyzer, a power Using t- test: Two-Sample Assuming Unequal Variances, the actual power factor, and corrected power factor value were tested and showed significant differences.

Chapter V RECOMMENDATION

Although the prototype was successful in demonstrating the concepts, achieving objectives, and functionality of the proposed system, some features of the prototype can still be improved. The researchers suggest doing further research about other approaches in terms of the identification of appliances. Another functionality for monitoring would be implementing stored data so that the monitoring, remote-control access, and data records can be viewed and can be controlled everywhere. Another recommendation to add is to display the waveforms of the power factor signals in the energy monitoring display with the use of more easily observed visuals in a graphical user interface for monitoring time stamp recording of data for more easily gathering of data. Creating the system's capacity higher than 500W and testing highly inductive loads is also a recommendation.

ACKNOWLEDGEMENT

Our group would like to thank the Father Almighty for giving us the strength and knowledge to complete this study. It also wouldn't have been possible without the help of the people around us for their continuous support and kindness throughout the research.

To Engr. Ronald Vincent Santiago and Engr. John Christian Nicdao, our thesis adviser. We cannot finish this research project without your knowledge, patience, expertise, and encouragement. We thank you for your support and guidance throughout the thesis process.

To our panel members: Engr. Conrado F. Ostia Jr, Engr. Joseph Bryan G. Ibarra, Engr. Esperanza E. Chua. Thank you for your insightful comments and feedback, which helped us improve our thesis project and achieve the best outcome.

Finally, we thank our parents, who supported us emotionally, mentally, and financially. This thesis would not have been possible without them. Thank you for believing in us throughout the making of our thesis project. Your unending support helped us in this journey. Thank you.

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Appendix A Sample Computations

- Sample Calculations

This section shows the data obtained from the theoretical calculations, pre-testing and actual testing conducted based on the proposed methodology. To show the accuracy of the data the research, the actual data (collected using PZEM Sensor) was then compared to the supposed to be expected value (using power meter).

The percentage error between the two values from the PZEM current sensor and the power meter is acquired thru:

$$\text{PERCENT ERROR} = \left| \frac{Actual\ Value\ (Voltage\ and\ Current\ Sensor) - Expected\ Value(Power\ Meter)}{Expected\ Value(Power\ Meter)} \right| X\ 100$$

Comparison tables for both the voltage and current values is shown in the figure below.

Table 3.1 Calibration of PZEM Current Sensor

Trial	Actual Value of Current from PZEM-004t	Expected Value from Power Meter	Percentage Error
1	0.25	0.25	0%
2	0.73	0.725	0.68%
3	0.72	0.715	0.69%
4	0.71	0.723	0.41%
5	0.17	0.172	1.16%
6	0.16	0.158	1.26%
7	0.17	0.169	0.59%
8	0.24	0.241	0.41%
9	0.22	0.219	0.45%
10	0.24	0.241	0.41%

Table 3.2 Calibration of PZEM Voltage Sensor

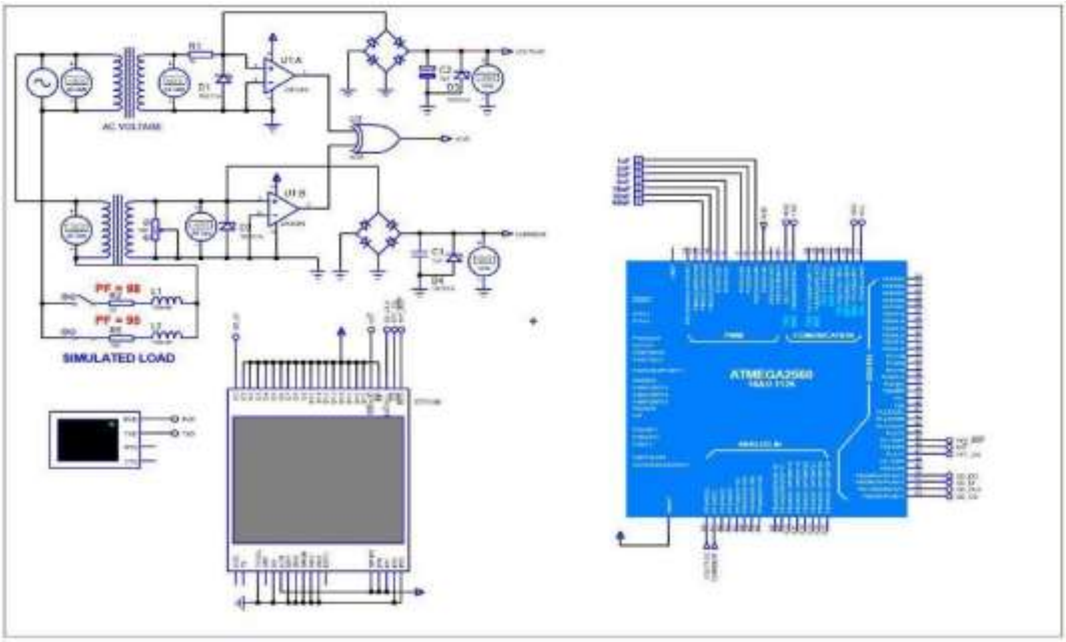
Trial	Actual Value of Voltage from PZEM-004t	Expected Value of Voltage from Power Meter	Percentage Error
1	229.8	229.91	0.05%
2	231.7	230.90	0.34%
3	231.7	231.90	0.08%
4	231.7	232.80	0.47%
5	231.5	232.00	0.21%
6	231.4	232.00	0.25%
7	231.5	230.05	0.63%
8	231.2	232.10	0.50%
9	230.09	230.12	0.004%
10	231.0	230.82	0.60%

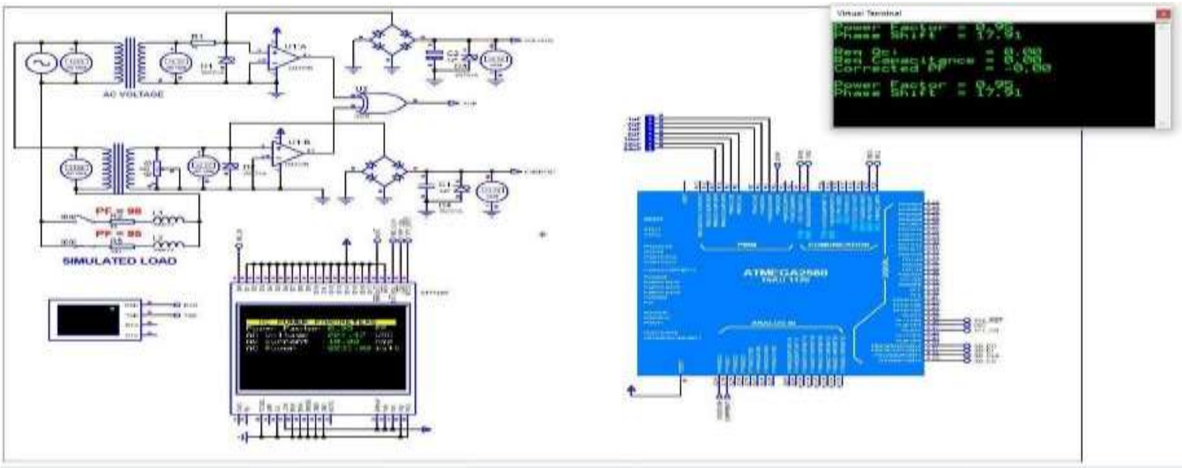
TRIAL	COMPUTATION
Current Sensor (Trial 1)	$\% \text{ Error} = \left\lvert \frac{Actual\ Value - Expected\ Value}{Expected\ Value} \right\rvert X\ 100$ $= \frac{0.25-0.25}{0.25}\ X\ 100$ $= 0\%$
Current Sensor (Trial 2)	$\% \text{ Error} = \left\lvert \frac{Actual\ Value - Expected\ Value}{Expected\ Value} \right\rvert X\ 100$ $= \frac{0.73-0.725}{0.725}\ X\ 100$ $= 0.68\%$
Current Sensor (Trial 3)	$\% \text{ Error} = \left\lvert \frac{Actual\ Value - Expected\ Value}{Expected\ Value} \right\rvert X\ 100$ $= \frac{0.72-0.715}{0.715}\ X\ 100$ $= 0.69\%$
Current Sensor (Trial 4)	$\% \text{ Error} = \left\lvert \frac{Actual\ Value - Expected\ Value}{Expected\ Value} \right\rvert X\ 100$ $= \frac{0.72-0.723}{0.723}\ X\ 100$ $= 0.41\%$
Current Sensor (Trial 5)	$\% \text{ Error} = \left\lvert \frac{Actual\ Value - Expected\ Value}{Expected\ Value} \right\rvert X\ 100$ $= \frac{0.17-0.172}{0.172}\ X\ 100$ $= 1.16\%$
Current Sensor (Trial 6)	$\% \text{ Error} = \left\lvert \frac{Actual\ Value - Expected\ Value}{Expected\ Value} \right\rvert X\ 100$ $= \frac{0.16-0.158}{0.158}\ X\ 100$ $= 1.26\%$
Current Sensor (Trial 7)	$\% \text{ Error} = \left\lvert \frac{Actual\ Value - Expected\ Value}{Expected\ Value} \right\rvert X\ 100$ $= \frac{0.17-0.169}{0.169}\ X\ 100$ $= 0.59\%$
Current Sensor (Trial 8)	$\% \text{ Error} = \left\lvert \frac{Actual\ Value - Expected\ Value}{Expected\ Value} \right\rvert X\ 100$ $= \frac{0.24-0.241}{0.241}\ X\ 100$ $= 0.4149\%$
Current Sensor (Trial 9)	$\% \text{ Error} = \left\lvert \frac{Actual\ Value - Expected\ Value}{Expected\ Value} \right\rvert X\ 100$ $= \frac{0.22-0.219}{0.219}\ X\ 100$ $= 0.45\%$
Current Sensor (Trial 10)	$\% \text{ Error} = \left\lvert \frac{Actual\ Value - Expected\ Value}{Expected\ Value} \right\rvert X\ 100$ $= \frac{0.24-0.241}{0.241}\ X\ 100$ $= 0.4149\%$

For comparison table between voltage sensors, the percentage error is computed as follows:

TRIAL	COMPUTATION
Voltage Sensor (Trial 1)	% Error = *Actual Value−Expected Value* | | *X* 100 *Expected Value* = 229.8−229.91 *X* 100 229.91 = 0.05 %
Voltage Sensor (Trial 2)	% Error = *Actual Value−Expected Value* | | *X* 100 *Expected Value* = 231.7−230.9 *X* 100 230.9 = 0.3465 %
Voltage Sensor (Trial 3)	% Error = *Actual Value−Expected Value* | | *X* 100 *Expected Value* = 231.7−231.90 *X* 100 231.90 = 0.08%
Voltage Sensor (Trial 4)	% Error = *Actual Value−Expected Value* | | *X* 100 *Expected Value* = 231.70−232.80 *X* 100 232.80 = 0.47%
Voltage Sensor (Trial 5)	% Error = *Actual Value−Expected Value* | | *X* 100 *Expected Value* = 231.50−232.00 *X* 100 232.2 = 0.21%
Voltage Sensor (Trial 6)	% Error = *Actual Value−Expected Value* | | *X* 100 *Expected Value* = 231.40−232.00 *X* 100 232.00 = 0.25%
Voltage Sensor (Trial 7)	% Error = *Actual Value−Expected Value* | | *X* 100 *Expected Value*
	231.5−230.05 = *X* 100 230.05 = 0.6303%
Voltage Sensor (Trial 8)	*Actual Value−Expected Value* % Error = | | *X* 100 *Expected Value* 231.20−232.10 = *X* 100 232.10 = 0.38%
Voltage Sensor (Trial 9)	*Actual Value−Expected Value* % Error = | | *X* 100 *Expected Value* 230.09−230.12 = *X* 100 230.12 = 0.013%
Voltage Sensor (Trial 10)	*Actual Value−Expected Value* % Error = | | *X* 100 *Expected Value* 231.0−230.82 = *X* 100 230.82 = 0.077%

Appendix C Simulation





Appendix D Source Code
Appendix E Turnitin Similarity Report
Appendix F Grammarly Report
Appendix G Materials and Costing

Quantity	Material	Cost
1 pc.	ATMEGA2560 high-performance, low-power Microchip	
1pc.	HC-06 Bluetooth Module	
1pc.	PZEM 008T	
1pc.	100A C.T.	
1 pc.	2.4TFT Color LCD	
1pc.	8Pin Male Header	
1pc	Prsnsitized PCB	
1 pack	Developer	
1pc	20pin Female Header	
1pc	16pin Female Header	
10 pcs	5mm LED red	
9pcs	C8050 NPN Transistor	
10pcs	150 ohms resistor	
10pcs	1N4007 Rectifier Diode	
10pcs	PCB Mount Terminal Block	
10mtr	#18 AWG Stranded wire RED	
10mtr	#18 AWG Stranded wire BLACK	
7pcs	100A SSR	

2pcs	**10A SPDT Relay**	
2pcs	**10A Relay Socket**	
1pc	**4ftx4ft 5mm Sintra Board**	
1pc	**Cord with Plug**	
2pcs	**Convenience Outlet**	
1pc	**5A SMPS Power supply**	
1pc	**1uf/600V Capacitor**	
2pcs	**2uf/600V Capacitor**	
2pcs	**4uf/600V Capacitor**	
3pcs	**8uf/600V Capacitor**	
1pc	**10uf/600V Capacitor**	
4pcs	**20uf/600V Capacitor**	