



**DESIGN AND EVALUATION OF AUTOMATED METERING, POWER
MANAGEMENT AND MONITORING SYSTEM**

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**DEPARTMENT OF COMPUTER ENGINEERING
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SEPTEMBER, 2023.

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FACULTY OF ENGINEERING,
UNIVERSITY OF BENIN, BENIN CITY,
EDO STATE, NIGERIA.**

SEPTEMBER, 2023.

CERTIFICATION

This is to certify that this research was carried out by Mr. Edemirukaye Ukeh Orodje, with matriculation number PG/ENG0502198 of the Department of Computer Engineering, University of Benin, Benin City, in partial fulfilment of the requirements for the award of the PhD degree in Computer Engineering.

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DEDICATION

I dedicate this research work to the Almighty God.

ACKNOWLEDGEMENT

I wish to express my profound gratitude and thanks to the Almighty God for giving me the needed wisdom, strength, divine health, and a sound mind to start and finish well. I also wish to acknowledge my supervisor, Professor S.T. Apeh for his fatherly role, mentoring, and support during this research. God bless you richly in Jesus' Name. I also wish to express my profound gratitude to my Co-supervisor Engr. Dr. E. Olaye, and Engr. Dr. I. A. Edeoghon for painstakingly reading the work. Special thanks to other member staff of the Computer Engineering Department for the support and encouragement you gave me. I must not fail to mention Prof (Mrs.) P.E. Orukpe, Engr. Prof. S.A. Ike and Engr. Prof. J.O. Egwaile, Engr. Dr. F.O. Agbontaen, for the valuable guidance and corrections, offered to improve this work. I am immensely thankful to all staff of the Faculty of Engineering too numerous to mention for chipping in one or two words of wisdom. Finally, I wish to thank my dear wife for being there always. I really appreciate your support and encouragement; you are a friend and blessing to me. I also appreciate my lovely children for their understanding and support.

ABSTRACT

Poor power management and monitoring have resulted in technical and non-technical electrical losses in the power distribution system, ranging from distribution line cuts to electricity theft and non-payment of electricity bills. As a result, stakeholders' reciprocal relationship and accountability have been severed in developing countries such as Nigeria. Therefore, the design and evaluation of an Automated Metering Power Management and Monitoring System (AMPMS) is critical in order to effectively manage, monitor and reduce the cost of power usage.

A well-structured questionnaire was developed and administered to selected members of the public in Edo state of Nigeria to investigate the effectiveness of the existing metering system as well as load consumption. The collected data was then analyzed using SPSS, and Microsoft Excel 2016. This was followed by the simulation and design of an automated open-circuit fault detection and reporting system on the service lines of the power distribution network using a MATLAB Appdesigner as a tool. Thereafter, the design of an automated digital energy meter for power management and monitoring system was undertaken. The meter utilized a Hall effect current sensor, voltage sensor, Wi-Fi module, and microcontroller. A cost-effective consumption planner was also developed based on a mobile software application for metering status, monitoring, load management, and a web-based system. The monitoring base station was interfaced with a long-range (LoRa) wireless transceiver to facilitate communication between the digital energy meters and the base station. The software was developed to generate customers' bills and reports, live comparison of energy usage on a centralized wireless-based system, tampering of meters, and faults on the three phases (Red, Yellow, and Blue) were detected, monitored, and shut down from the monitoring station.

By analyzing the energy value of 2.751 kWh, power consumption of 121.4W, current, and voltage associated with consumer usage, the utility company would be able to accurately determine load consumption using the AMPMS monitoring web-based system. To evaluate the system, it was tested with various datasets representing the energy and power consumption of different electrical appliances. The test results confirmed that the system could precisely measure power usage and provide users with real-time feedback. This was demonstrated by comparing the energy consumed by an automated meter (3.02 kWh) and an existing metering system (4.442 kWh) while measuring twelve loads over a four-hour period. Consequently, automated meters consume less energy compared to the existing meters. Furthermore, the system's effectiveness in reducing power consumption costs was assessed by comparing the

power and energy consumption of households using the system versus those not using it. The findings revealed a significant reduction in power consumption for households that utilized the system. Additionally, the system had the capability to alert users if an appliance was consuming excessive power, empowering them to turn it off and further decrease consumption costs. This system reduces the possibility of non-payment of electricity bills, meter tampering, labour costs, and electricity theft while also improving meter reading accuracy, awareness of electricity consumption, power monitoring, management, and economic viability.

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NOMENCLATURE

List of Symbols and units

n_o	Sample Size
V	Volts
μF	microfarad
V_{REF}	reference voltage
V_{IN}	Input voltage
f_c	frequency of Capacitor
V_{out}	Output voltage
nF	nanofarad
W	Watts
V_{OC}	Open circuit voltage
Ω	Ohms
R_{int}	Internal resistance of battery
E	Energy
Kg	Kilogram
H_0	Null hypotheses
H_A	Alternate Hypotheses
α	Significant Level

\bar{x} mean value of X

t Tim

LIST OF ABBREVIATIONS

AC	Alternating Current
AI	Artificial Intelligence
AP	Access Point
API	Application Programming Interface
BAS	Building Automation Systems
BEDC	Benin Electricity Distribution Company
CAT	Consumer Analysis Tools
CSS	Cascading Style Sheet
CT	Current Transformer
DC	Direct Current
DDDC	Distributed Direct Digital Control
DFR	Digital fault recorder
DHTML	Dynamic Hypertext Markup Language
DISCO	Distribution Company
EEPROM	Electrical Erasable programmable Read-only Memory
EMF	Electro Motive Force
FDFR	Fault Detection and Fault Reporting
GPRS	General Packet Radio Services
GSM	Global System for Mobile communication
GUI	Graphical User Interface
GUIDE	Graphical User Interface Development Environment
HEP	Home Energy Planner
HT	High Tension
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol

I and C	Instrumentation and Control
IDE	Integrated Development Environment
IP	Internet Protocol
JS	Java Script
JSP	Java Server Page
JVM	Java Virtual Machine
KV	Kilo Volt
KVA	Kilo Volt Amps
KW	Kilo Watts
LAN	Local Area Network
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LoRa	Long Range
LOS	Line of Sight
LT	Low Tension
LTC	Load Tap Changer
MATLAB	Matrix laboratory
MRI	Meter Reading Instrument
MYSQL	My Structure Query Language
NERC	Nigeria Electricity Regulatory Commission
NET	NET framework
OOP	Object-oriented Programming
PC	Personal Computer
PHP	Hypertext Preprocessor
POM	Page Object Model
RAM	Random Access Memory
RDMS	Relational Database Management systems
ROM	Read-only Memory
RF	Radio Frequency
RTC	Real Time Clock
SCADA	Supervisory Control and Data Acquisition

SCM	Source Code Management
SoC	System on Chip
SPSS	Statistical Package for the Social Sciences
SSID	Service Set Identifier
SQL	Structured Query Language
UART	Universal Asynchronous Receiver-Transmitter
UML	Unified Modeling Language
USB	Universal Serial Bus
W3C	World Wide Web Consortium
WAF	Web Application Framework
WBCSD	World Business Council for Sustainable Development
WWW	World- Wide Web
Wi-Fi	Wireless Fidelity
XHTML	Extensible Hypertext Markup Language
XML	Extensible Markup Language

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Automation is the use of computer-controlled equipment, systems, and processes to do tasks that were previously performed by humans by using combined diverse hardware and software components and other readily available computer tools for web-based servicing, trouble call management systems, Consumer Analysis Tools (CAT), and Radio Frequency (RF) communication between single and multi-point (Gomez *et al.*, 2019). The result should ensure that consumers receive service levels comparable to other businesses such as finance and telecommunications which will improve the reputation of utility distribution company if automation in service delivery is employed (Gomez *et al.*, 2019).

In a manufacturing system or production process, automation largely requires the use of automatic equipment with very little human intervention (Groover and Mikell, 2015). It includes the application of technology (Gomez *et al.*, 2019), Android phones, sensors, robotics, programs, and processes among many other things depending on the automation process to be achieved and the outcome with minimal human input (Groover and Mikell, 2015).

Almost any process or system can be automated and these include power system automation, distribution, metering, home, and lighting control systems (Dileep, 2020) Automation of the power system through

instrumentation and controlled machinery is referred to as power system control (Dileep, 2020). In a power system, there are substations. Substation automation refers to the management and control of automation capabilities inside a substation using information from Intelligent Electronic Devices (IEDs) of the power system components inside the substation (Mladen *et al.*, 2010).

With the sharp rise in global electricity use for buildings, businesses, and industries (Rajvikram *et al.*, 2020), Utility providers must now develop Building Automation Systems (BAS) with automated metering methods based on long-range (LoRa) Radio Frequency (RF) technology with an intelligent base station that uses superior, unobtrusive, and environmentally safe methods to manage and monitor utility usage in order to create correct bills, the system would be better controlled, monitored, and managed (Apeh and Mokogwu, 2013).

By 2050, the World Business Council for Sustainable Development (WBCSD) projects that all new buildings would be zero net energy. The WBCSD in 2009, built a structure as at today accounts for 40 percent of energy consumption in developed countries (Prajakta and Vasudha, 2018). This shows that energy consumption in buildings can be reduced by 60% by the year 2050. To do this, it advised tightening regulations and increasing the transparency of energy labels, which will promote innovative integrated design strategies such as automated metering, power management, and monitoring systems. To also develop and make use of advanced technology which will encourage consumers in maximizing energy efficiency (Amirah *et al.*, 2014),

In recent times, developing countries like Nigeria, due to poor maintenance culture, lack of proper power management and political willpower to prepare for future expansion, the power generation and distribution have become epileptic, and the power distributed falls below the electrical standard; not meeting the need of electricity consumers (Babatunde *et al.*, 2022). The cause of failure to meet the expectations of consumers may not be far-fetched. As a result of a poor consumer database, utility providers have not been able to adequately supply the needed power. In places where metering systems are installed, some are not read properly while those read have not been accurately reported and a larger number of consumers are without meters.

The existing meter reading strategy employed by utility providers in Nigeria is based on manual monitoring of electricity consumption with the following drawbacks:

- i. The Utility companies incur high costs in hiring, mobilizing, and transporting personnel who take readings of meters.
- ii. There is opposition since some clients have complained that having meter readers visit their homes violates their privacy (Ganguly and Arnab, 2013).
- iii. Some energy consumers frequently bypass the current meters without the utilities provider's knowledge. Electricity supplied and consumed but not paid for is a loss on the part of the distribution company.

Among Nigeria's eleven power distribution companies, there is no meaningful monitoring or feedback system for electricity consumers on

the power distribution network (Kachalla and Haruna, 2009). Technical and non-technical losses are rampant in developing countries like Nigeria and this includes electricity theft and inability to recover unpaid debts. As of today, some residential areas in Nigeria enjoy long hours of power supply while a larger populace do not have power supply. Power disruptions have actually taken on a very high embarrassment level (Abbass and Mohammed, 2012). Most electricity consumers in Nigeria are not aware of their electricity consumption rates within a month and this makes it difficult for consumers to manage or monitor their monthly consumption while using existing appliances. Consumers most times, when power is restored after a long period spent in darkness, tend to leave appliances and light bulbs on even when these appliances are not in use; they are of the opinion of gaining back the long periods of darkness once experienced. This attitude is due to the unavailability of a metering system to the consumer and inability of the utility providers to remotely monitor and control electrical power supply /distribution. Despite investments made by the Nigerian Federal Government in the distribution of prepaid meters, the majority of energy users do not have access to them (Ozan and Nikolaos, 2015). The constant supply of electricity is a major aspect to be considered if the smart metering system would be successful and the introduction of smart meters may not absolutely bring to an end the era of power wastage in Nigeria as most rural communities with poor signals would not be billed based on consumption but estimated.

To solve the aforementioned deficiencies and to complement the ongoing efforts of stakeholders in power management, the research titled ‘Design and evaluation of an automated metering, power management, and monitoring system is necessary. If implemented in Nigeria, it will bring to a barest minimum human error and improve power management, communication and bring about dependable monitoring and control options, which in turn saves time and money.

1.2 Statement of the Problem

Consumers in developing nations like Nigeria do not have access to the features necessary for planning their household appliances and other loads. Managing power consumption with existing loads is impossible as this makes it difficult for distribution companies to monitor the consumption of consumers’ loads (Oludamilare *et al.*, 2020). To ascertain the state of consumption as a result of this, some consumers do not pay accurate electricity bills, and this accounts for ineffectiveness in revenue collection by the utility staff (Ayodele *et al.*, 2021). When a fault occurs and it affects supply, consumers will have to visit the utility company to lodge complaints. However, the following are the specific problems this research seeks to address:

- i. Poor monitoring of what consumers of electricity consume daily, weekly, or monthly in relation to loads.
- ii. The experience by consumers in the area of planning, monitoring, controlling, and managing power consumption.
- iii. The ineffectiveness of revenue collection by utility company staff from the consumers.

- iv. The difficulty experienced by the utility company to detect and resolve open-circuit faults affecting supply on the service phase/low voltage section of the power distribution infrastructure.

1.3 Aim and Objectives

The aim of this study is to design and evaluate an automated metering, power management, open-circuit fault detection, and reporting system.

The objectives are to:

- i. investigate the effectiveness of the existing metering system as well as load consumption;
- ii. simulate an open-circuit fault detection of the service line of the power distribution network;
- iii. design and implement an automated meter, home energy planner, web-based system, and mobile Application for power management and monitoring;
- iv. evaluate the metering system.

1.4 Scope of the study

This research evaluates the problem of poor power management and automated monitoring of the low voltage section of the three-phase distribution lines. It generates data for experiments carried out and documented for evaluation of the automated metering system.

The research covers automation of metering via Radio Frequency (RF) based on long range (LoRa) automation of power management with a web-based system, automation of power planner via mobile App development technology, automation of open-circuit fault detection and reporting on the three-phase lines of the metering device.

This work however was carried out on only remote load data acquisition and control system for residential apartments.

1.5 Relevance of the study

In developing countries like Nigeria, utility companies and consumers lack effective monitoring and proper power management, leading to an epileptic power supply and the distribution sector's inability to meet the needs of energy consumers, including the elderly. Furthermore, consumers lack the necessary power management capabilities and are most often unaware of what they consume in terms of power. The Utility providers will be able to monitor all meters on a centralized wireless-based system with effective power management if the outcome of this study is utilized or implemented.

Modern technology is a great tool needed by utility firms in nations like Nigeria to monitor both the reliability of power delivery and the ease with which electricity bills may be paid via a web-based system. Consumers, particularly the elderly, will be able to program a timer to switch on and off loads automatically, manage usage, and be aware of when power is available on the service wire of the power distribution line using the home energy planner and Mobile App.

1.6 Outline of Thesis

Chapter Two presents a review of relevant studies from the literature to establish the background theory for the research work. The literature review covers Automation in Electrical power system, Automation in computer process control, Software components for automation, Data collection tools and analysis, Engineering simulation tools like MATLAB, web-based system components and design, Hardware components for automation, sensor technology and sensors, android system, android applications, and mobile smartphone that are relevant to the current research were also presented. Chapter Three contains a detailed presentation of the research methodology. The findings and results of this study were given in Chapter Four and discussed. Chapter Five contains the thesis's conclusion, recommendation, and contribution to knowledge.

CHAPTER TWO

LITERATURE REVIEW

2.1 Automation

Automation is the creation and application of technology using computers, sensors, and smartphones to monitor, control and manage how goods and services are produced and delivered without a human operator at the location where the system is installed (Alcácerac and Cruz-Machadoa, 2019). To participate in the creation and implementation of technology to monitor and regulate the production and delivery of goods and services via automation, includes numerous essential elements, systems, and job functions. Almost every industry, including utilities, manufacturing, transportation, defense, facility operators, and many more benefit from automation (Ali and Gianfranco, 2021).

Automation has an impact on all industrial functions, including design, procurement, and administration, as well as installation, integration, and maintenance. It employs a variety of technologies, such as telemetry and communications, robotics and expert systems, test measurement, wireless applications, process measurement, and control. For these industries to be able to manufacture final products based on the new standard, they need to have an updated automatic process. So, industrial automation is all about large-scale processes with a high degree of quality and consistent accuracy. For this study, the following section of the utility industries was discussed:

- i. Automation in Electrical power systems.
- ii. Automation in computer systems

2.1.1 Automation in Electrical Power System

This is the process of using instrumentation and control devices to automatically control the power system (Partha *et al.*, 2016). In an electrical power system, there are substations.

When reducing the high voltage of electrical power distribution to a level suitable for final users, substations are recognized as a type of equipment used in the electrical power grid. Power system components can be controlled via substation automation, which uses data from Intelligent Electronic Devices (IEDs) and remote users. (Partha *et al.*, 2016). Power generation, transmission, and distribution activities are all included in the automation of the electrical power system. (Ting, 2019). Alternating Current (AC) distribution systems are separated into primary and secondary types. The primary distribution system, which operates at slightly higher voltages than those used for residential purposes, is a crucial component of the AC distribution network. This system can handle larger blocks of electrical energy compared to the standard low-voltage distribution system. As per national specifications, common voltages for primary distribution include 11 kV, 6.6 kV, and 3.3 kV, all operating on a three-phase, three-wire system.

On the other hand, the portion of the AC distribution system known as the secondary distribution system is responsible for delivering electrical energy to the ultimate consumer, as measured by their electrical power meter(s). The secondary distribution system can operate with either a 50 Hz or 60 Hz system and supports a four-wire, three-phase such as 415/240V or 120/208V (Patrick *et al.*, 2018). The distribution of electricity occurs through distribution substations, which are equipped with step-down transformers to meet power requirements (Ahmad and Kawsar, 2019).

At each distribution substation, the high voltage, typically 66kV/33kV/11kV, is stepped down to 415V using a 3-phase, 4-wire system. Energy consumption is measured using both on-site and remote meter readings for both residential and commercial structures (consumers) (Ahmad and Kawsar, 2019).

To decrease the frequency of outages and lessen their duration when they do occur, power system automation, on the other hand, refers to the procedures for monitoring, controlling, and supervising the substation's power distribution system and on the pole.

The automation of a power system consists of numerous tasks:

- i. Data gathering
- ii. Supervision
- iii. Control
- iv.

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i. **Data Gathering:** Information acquiring is the process of gathering data (Andre, 2021). Locally collected data can be used by the device that collected it, or it can be sent from a substation to one or more devices so that operators, engineers, planners, and administrators can use it (Nouredine *et al.*, 2018).

ii. **Supervision:** Using the data obtained, computer programs and people supervise or keep an eye on the health and condition of the power system (Nouredine *et al.*, 2018). Operators and Engineers can locally use front-panel displays and laptop PCs to control information, or they can operate it remotely via computer displays, graphical wall displays, or both (xiao *et al.*, 2018).

iii. **Control:** The act of sending instructions to a device in order to operate an instrumentation and control system (I and Cs) and its power system components is known as control (Martin *et al.*, 2020). For instance, supervisory control and data acquisition (SCADA) systems depend on a user to monitor the system and issue control commands from the operator panel of a master computer. (Xuenyang *et al.*, 2016).

iv. **Integration:** Integrating refers to the action of transmitting data to or from remote users and Intelligent Electronic Devices (IED) within the I and Cs system. Substation integration, on the other hand, involves merging data from IEDs located in proximity to the substation, with the aim of establishing a centralized point of

contact for all I and C data within that substation (Partha *et al.*, 2016).

In power system automation, the physical connections of transformers and other hardware structures to the power system operators serve the purpose of converting actual power system signals. This conversion is achieved through instruments like instrument transformers, which transform AC current into DC voltage (Andre, 2021).

An instrument transformer's analog output, such as one that converts AC current to DC voltage (Mohammad *et al.*, 2015), from one magnitude or value to another. The major process instrumentation and control devices as well as the auxiliary contact of switch gears are used to gather the input data.

Intelligent Electronic Devices (IEDs) are instruments and controls that make use of microprocessors (Dragan *et al.*, 2019). Single-chip computers known as microprocessors enable devices to process data, take commands, and communicate data similarly to how computers operate. In IEDs, automatic processors can be used. IEDs used in power system automation include the following:

- i. Protective relays
- ii. Meter
- iii. Digital Fault recorder
- iv. Load tap changer for
controlling (output) devices

v. Communication processor for communications devices

i. Protective Relay: An IED called a protective relay, which is used to safeguard people and property, may detect weaknesses in the power system and automatically adjust the I and C and power systems (Dragan *et al.*, 2019). Because the Relay has local termination, it is not essential to read the copper conductors for each contact in the RTU's central termination panel.

ii. Meter: A meter is an IED that precisely measures the current, voltage, and power levels in a power system. Demand and peak metering measurements are recorded in the meter to offer historical data on how the electricity system has functioned (Dragan *et al.*, 2019).

iii. Digital Fault Recorder (DFR): This IED, often referred to as a digital fault recorder, keeps track of information on disturbances in the electrical system. When activated by conditions listed on the power system, it has the capability to capture data in digital format. DFR keeps track of information including harmonics, frequencies, and voltages (Dileep, 2020).

iv. A Load Tap Changer (LTC) for managing devices that produce output:

Transformer load tap changers are tools that help shift the transformer's tap position. Another local IED, a remote operator, or

a procedure can remotely control these devices or operate them automatically (Dileep, 2020).

v. Communication processor for communication device:

The functionality of many I and C devices is combined into a single IED by a form of substation controller called a communication processor for communication device. It contains a lot of connection ports, allowing for multiple simultaneous communication links (Dragan *et al.*, 2019). The communication processor gathers data, manages the other IEDs in the substation, and concentrates the data required for transmission to various masteries inside and outside the substation (Dileep, 2020).

2.1.1.1 Application of power system automation

Power system automation finds application in the following ways:

i. Feeder Monitoring: Tripping and breakdowns are examples of what can be monitored (Morteza and Masood, 2020). In general, both urban and rural areas have severe concerns about long-term outages and customer unrest, which can be addressed with feeder monitoring. Automation of the feeder control may be achieved by using auto reclosures close to the breakers and sectionalizes in the line (Dileep, 2020). For each momentary line hiccup, the auto reclosure travels first before closing after a predetermined amount of time. Sectionalizing helps isolate problems during enduring faults and restore supply to the remainder of the line.

ii. **Metering Technology:** Metering systems have evolved over time, transitioning from electromechanical meters to static meters, and ultimately to smart meters (Morteza and Masood, 2020). A suitable communication mechanism, ranging from simple energy recording to this, can be used by meters to transmit recorded energy to either a data gathering device or a billing computer. Smart meters can record energy usage and display utility pricing signals in addition to operating household appliances according to a user-provided program.

The capacity to program a microprocessor allows for the incorporation of a variety of functionalities, such as:

- a. Data tampering
- b. Time-of-day metering,
- c. Survey data

a. **Data tampering:** Data indicative of tampering, such as missing potential, reversed Current Transformer (CT) polarity, and reversed-phase sequence, can be found.

b. **Time of the day metering:** Energy usage for different times of the day is recorded in the meters' multiple registers by an inbuilt real-time clock. The user can establish their time zones according to their needs, and each time zone's duration can be programmed. Different time zones are set into the daily schedule. The meter monitors each time zone's energy usage separately and shows data as needed.

c. **Survey Data:** The meter can store billing and tamper information for 35 days at the selected logging frequency. Drawing the kWh, kVAh, and kVA load curves—which show the consumer's load pattern is made easier due to this.

iii. **Meter Reading Instrument (MRI):** This is used to analyze data, bill customers, and transport data from/to/from meters to/from the system (Benedikt *et al.*, 2019). A bar code reader can also be added, and the MRI can be programmed with meter numbers that need to be read. This will make the meter easier to find. When using High Tension (HT) services with load survey data, MRI is a must for the transfer of data from the meter to the computer. Low Tension (LT) energy meters can also be employed with MRI technology. Where a printer may also be added, allowing printing of the bill generated by the reading (Benedikt *et al.*, 2019).

The previous reading and meter serial number must be included in the MRI. At the end of the day, all the data can be offloaded (Dragan *et al.*, 2019).

iv. **Telemetry:** This requires sending metered data through a communication network to maintain continual observation. (Waseem *et al.*, 2016). The meter needs to be connected to a phone line at the consumer's end using a modem. At the system end, a modem also connects the computer and phone. The consumer phone number must be called, and the phone's modem must be connected to the meter, each time a computer wishes to access data. (Koren and Guo, 2018).

v. Over-current protection: Long-term over-current protection is necessary for all lines and electrical equipment. If the over-current source is fresh, the current is automatically cut off; however, if the source is outside of the immediate vicinity, a backup provision disconnects all impacted sockets after a predetermined period of time. (Mohammad *et al.*, 2015). Be aware that this connection may, regrettably, have a cascading effect that causes other connections to overheat and immediately disconnect. Additionally, because of this protection method, loads have been lost by generators (Dileep, 2020). They must suspend operations immediately, and it may take many hours to fully restore the system's demand and supply balance due in part to the necessity of accurate synchronization (Dragan *et al.*, 2019).

vi. Residential homes technology: The use of home technology to provide a range of services, such as energy efficiency and multimedia entertainment, to make citizens' quality of life better (Nisar *et al.*, 2019). In his talk, Sriskanthan discussed the use of wireless technology in the context of home automation and networking. He recommended a network with a mobile host controller that is located elsewhere and plenty of client modules (home appliances) (Sriskanthan *et al.*, 2002). A significant contribution has been made by the above-mentioned system and journal. Though, control was made to turn on and off appliances to save cost (See Table 2.1 for some electrical loads with rated wattage

and Table 2.2 for fixed loads and flexible loads possibly controlled remotely inside the house).

Table 2.1: Some Electrical Loads and Rated Wattage (Mazer and Arthur, 2007)

Devices	Running (Rated) Wattage	Additional Starting (Surge)
Electric dust cleaner	850	
Electric water heater	4000	
Washing Machine	1800	
Single door refrigerator	800	1200
Double door refrigerator	900	1300
Window Air conditioner	1200	1800
Wall-mountable air conditioner	1560	2340
Floor air conditioner	2340	3510
Floor deep freezer	800	800
Deep freezer	500	500
Electric oven	1500	
Water pump	1000	1000
Sump pump	800	1200

Table 2.2: Some fixed Loads and flexible loads (Mazer and Arthur, 2007)

S/N	Some fixed loads	Some flexible loads
1	Lightings	Washing machine
2	Tv	Dish washers
3	Heating system	Phone chargers

4	Refrigerators	Air-conditioner
5	Freezers	Dehumidifier
6	DVD	Heat Recovery Ventilation (HRV)
7	Coffee maker with bean grinder	Clothes driers
8	Satellite dish	Pool pumps
9	Standing or table fans	Plug-in Hybrid Electric Vehicle (PHEV)
10	Ceiling fans	Blenders

vii. System Planning: It helps to carry out load forecast which is an important parameter for system planning (Dileep, 2020). This requires accurate data of the system like energy consumption for the last 15 years, and maximum demand (Zhen *et al.*, 2018). In order to predict future demand and energy, load forecasting techniques include computing trends for the rise in energy and consumption based on historical data (Nisar and Ibrahim, 2018).

viii. Power system Components: Through the use of long-distance communication lines, remote switching, and telemetering improvements that show voltages, current, power, direction, and consumption in kilowatt-hours, power system components, from pole-mounted switches to the complete power plant, can be managed remotely (kWh), among other metrics. Some power distribution systems even use automatic synchronization (Mohammad *et al.*, 2015).

2.1.1.2 The Electrical Distribution System

During the initial stages of power distribution, direct current (DC) generators were connected to loads that operated at the same voltage. This was necessary because there were no means available to adjust the voltage levels of DC for generation, transmission, and consumption purposes (Nweke *et al.*, 2020).

The situation experienced a significant alteration when Alternating Current (AC) for power generation was introduced. By changing and raising the voltage, transmission, and distribution lines' currents were reduced, allowing for the use of smaller conductors and reduced distribution losses (Nweke *et al.*, 2020). The power generated cannot be used entirely by the generating stations and the area around them. Consequently, it is necessary to distribute electricity at an appropriate voltage to various locations and consumers. The distribution process involves converting high voltage to standard medium and low voltage levels using suitable transformers and related equipment.

2.1.1.3 Primary Distribution System

The most common distribution voltages are 11kV, 66kV, and 33kV, all of which are run on a three (3) phase, three-wire system and vary by nation. It differs from country to country. Transmission cables carrying high voltage connect these substations. The primary distribution system, which commonly supplies major industry clients including cement plants, refineries, breweries, grain mills,

steel rolling mills, and others, is made up of transformers, switchgear, and breakers. (Obadote, 2009)

2.1.1.4 Secondary Distribution System

These are low-voltage feeder networks that are built along major streets and roads using secondary transformers. Individual customers are linked to these networks through the utilization of service cables connected to the feeder lines (Dickert *et al.*, 2013). The AC distribution networks for residential customers encompass different types of systems, including:

- i. A single-phase 2-wire system
- ii. A single-phase 3-wire system
- iii. A three-phase 3-wire system
- iv. A three-phase 4-wire system

In Nigeria, the most prevalent types of distribution systems are single-phase two-wire and three-phase four-wire configurations. Despite its rarity, direct current (DC) distribution has applications (Thomas, 2013). To convert alternating electricity to direct current, rotating converters are employed.

AC power is received and distributed locally at substation bus bars through feeders, distributors, and service lines. The standard AC distribution is achieved using a single-phase, two-wire system

operating at 240 volts and a three-phase, four-wire system operating at 415/240 volts, respectively. The Nigerian electricity Distribution Companies (DISCOs) are shown in Figure 2.1.

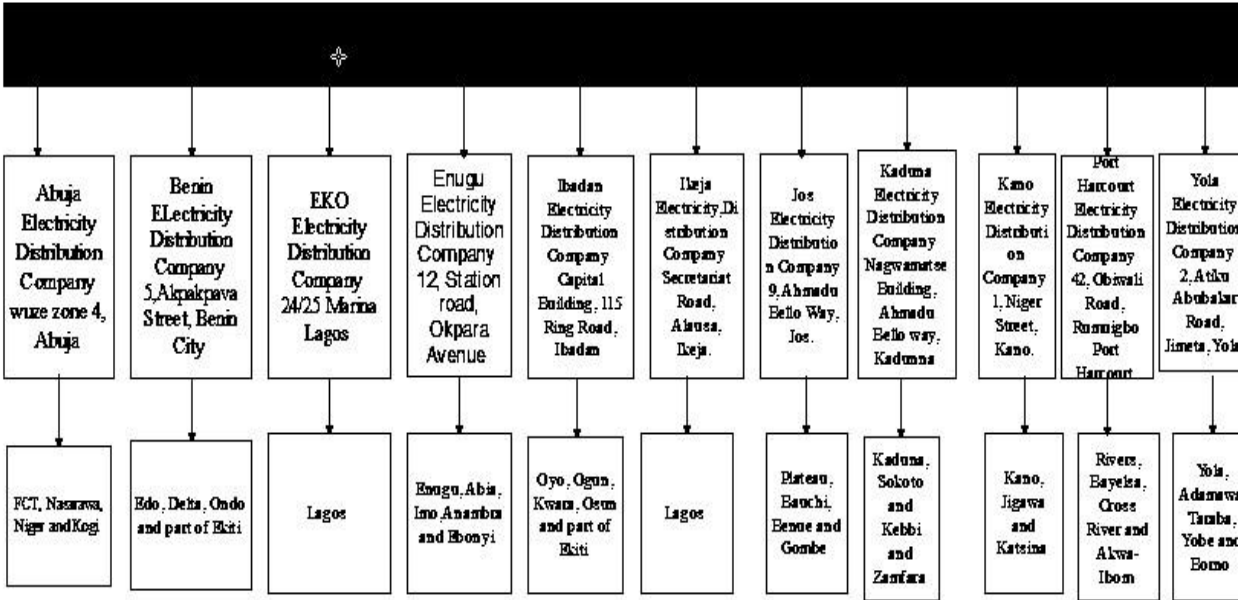


Figure 2.1: Electricity Distribution Companies in Nigeria (DISCOs)
(Aloa *et al.*, 2014).

2.1.1.5 Automation in Electrical Power Distribution System

With the use of the technology known as distribution automation, an electric utility is now able to remotely monitor, regulate, and coordinate various power system components. (Monsef *et al.*, 2016). The most promising aspects of such a system include load control, sectionalizing protective features, feeder switching, voltage and reactive power regulation, network supervision and control, and remote meter reading (Junhui *et al.*, 2014).

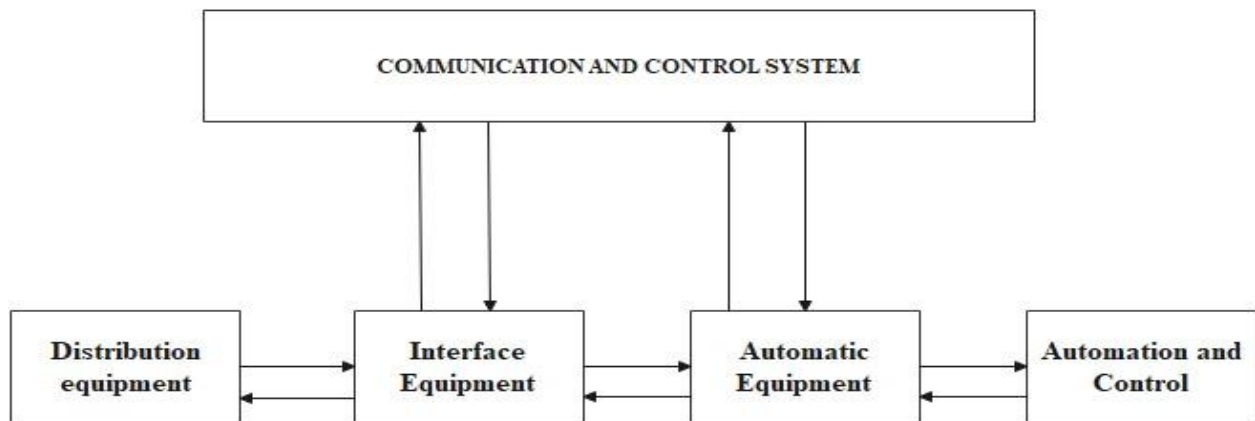


Figure 2.2: A typical Distribution Automation System (Junhui *et al.*, 2014)

Distribution automation refers to a set of integrated systems and concepts for digitally automating distribution substations, feeders, and user operations (Dileep, 2020). The idea encompasses distribution system control, monitoring, and protection, as well as load management and remote metering of consumer loads (Junhui *et al.*, 2014). Figure 2.2 depicts a typical distribution automation that incorporates distribution equipment, interface equipment, automatic equipment, automation, and control.

Sensors, connectivity, and switches are all part of the Distribution Automation family of technologies, which execute a variety of distribution system activities (Jianming *et al.*, 2020).

Modern communication and the usage of Intelligent Electronic Devices (IEDs) are what will liberate operational efficiency benefits such as real-time system configuration data, remote equipment diagnostics, real-time system performance data, and automated system restoration (Dileep, 2020). Not only can it detect problems, isolate faults in the case of temporary faults, and provide feedback,

but it may also correct power factor using the data acquired by the distribution automation system. The feeder faults, feeder loads, and feeder capabilities will all be provided directly by the distribution automation in the case of feeders where faults arise for scheduled repair (Asset condition monitoring). The distribution automation also performs automatic reactive power compensation and automatic switching, helps prevent outages, and reduces costs (Sung *et al.*, 2020). Figure 2.3 shows the functional structure of distribution automation, this includes data transfers, electrical protection, control, measurement, and monitoring

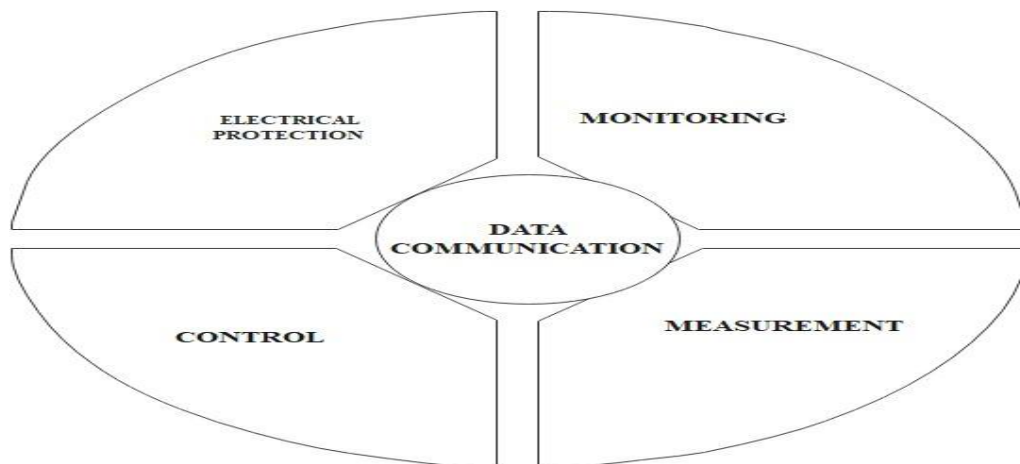


Figure 2.3: Functional structure of Distribution Automation (Monsef *et al.*, 2016)

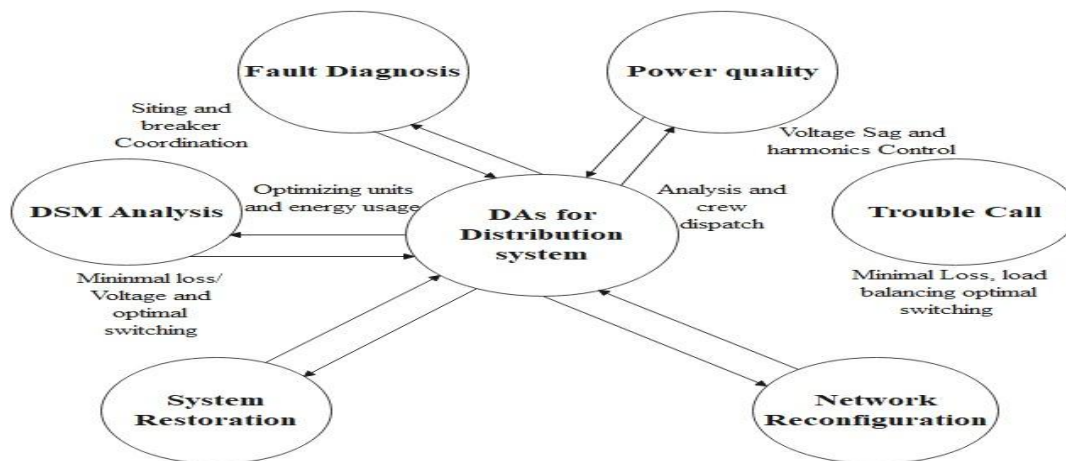


Figure 2.4: Distribution automation system interfaced (Monsef *et al.*, 2016)

An automated electrical distribution system ensures efficient and error-free power transmission. Finding and fixing transmission faults requires the least amount of human engagement possible (Suryan *et al.*, 2020). Figure 2.4 illustrates the distribution automation system through distribution equipment. After distribution equipment, there is a piece of interface equipment like Remote Terminal Unit (RTU) and sensors. After interface equipment, communication, and control between them there is established communication. Then finally, automatic switching relays will be used in automation equipment. Then on the left-hand side distribution equipment from there interfaces into the communication and control system through communication channels like RTU. From the distribution equipment, then sensing the fault by the use of sensors in communication and control systems (Dileep, 2020).

The Distribution Automation System (DAS) records various quantities (voltages, frequency, and temperature) in the field, and the recording in the field data acquisition system is known as the Remote terminal unit (RTU). These values are transferred to the base station via communication channels over the internet. Data can be sent over long distances using communication links (Fadul *et al.*, 2020).

2.1.1.6 Electrical Power metering and billing System

A meter is a tool that determines how much energy is consumed or supplied by a structure, a company, or a particular piece of equipment (Monsef *et al.*, 2016). In order to provide reports, invoices for management, and records like prepaid and postpaid meters for customers, a billing system consists of computer hardware and software that gathers data from calls, energy usage, and service delivery and groups it for individual accounts of consumers.

2.1.1.7 Electrical Power Meters

An electrical power meter or energy meter is responsible for measuring the amount of electrical energy supplied to or consumed by a household, business, or machine (Shekara and Soma, 2011). The kilowatt-hour meter is the most commonly used type of meter for this purpose. When it comes to electricity retailing, utility companies rely on these meters to record the measured values, which are then utilized to generate an invoice for the consumed electricity (Ofoegbu and Edward, 2016). The kilowatt hour, which

is the predominant unit of measurement on electricity meters, represents the amount of energy consumed by a load that uses one kilowatt for an hour, equivalent to 3,600,000 joules (Okolie, 2014)

2.1.1.8 Types of Electricity Meters

Energy meters are separated into two groups based on the

types of displays: i. Analogue meters

ii. Digital meters

2.1.1.9 Analogue Meters

The most popular type of meter is the analogue: often known as an electromechanical meter. The basic meter just spins forward during electricity usage. When a solar electric system is sending additional electricity back into the grid, the analogue meter will spin backward if it is bidirectional (Xiaofang *et al.*, 2022). The amount of electricity consumed or sent back into the grid is determined by how many times the disc spins forward or backward. For the utility provider to determine how much energy a building consumes, a meter reader must be sent out every month to ascertain the amount read by the analogue meter installed in the building (Pol and Erik, 2019). Digital meters, on the other hand, are much more interactive and multifunctional than the analogue meters.

2.1.1.10 Digital Electricity meter

Digital meters are tools that discretely measure electrical power usage and periodically send data to the utility provider (Xiaofang *et al.*, 2022). Electricity consumption can also be recorded over time on digital meters, which are typically faster. Additionally, digital

meters do away with interpolation mistakes, they do not contain any moving component that could break, and offers "auto-ranging" to guard against errors and meter damage in a situation where an incorrect range has been selected by the user (Sameek *et al.*, 2019). In order to attain higher measurement accuracy and a quicker response time to sudden voltage changes which are not found in analogue instruments such Electromechanical meters. Smart meters, single- and three-phase post-paid meters, and automated meter reading (AMR) are examples of digital energy meters

2.1.1.11 Electromechanical Meters

The electromechanical meter consists of four essential components: the driving system, moving system, braking system, and registering system (Quazi *et al.*, 2018). The driving mechanism, which is responsible for initiating motion, utilizes an electromagnet that becomes magnetized when an electric current passes through its coil. The pressure coil is the name of this coil. The copper band is on the magnet's central limb. The bands here can be adjusted. The moving system consists of an alloy shaft attached to an aluminium disc that generated eddy currents due to changes in the magnetic field (Quazi *et al.*, 2018). The disc's contact with the flux produces the deflecting torque. While the aluminium disc's spin is slowed down by the braking system's permanent magnet. Because they rotate, the aluminium disc creates the eddy current (Monsef *et al.*, 2016).

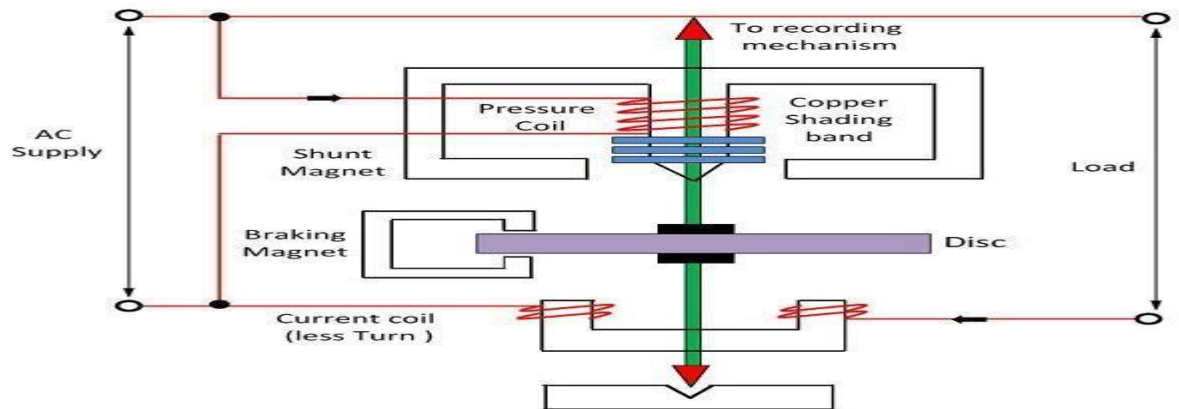


Figure 2.5: Diagram of an Electromechanical Energy meter (Quazi *et al.*, 2018)

Working principle of Electromechanical meters

The electromechanical induction meter functions by measuring the rotations of an aluminium disc, which spins at a rate directly proportional to the supplied power (Quazi *et al.*, 2018). Consequently, the ratio of energy consumption to disc revolutions remains constant. This type of meter operates with low power requirements, typically around 2 watts or less.

A lag coil is incorporated to introduce a 90-degree delay in the field of the voltage coil. This delay induces eddy currents in the disc, resulting in a force exerted on it that is inversely proportional to the instantaneous product of current and voltage. When the power supply is disconnected, a permanent magnet acts as a brake, exerting a counterforce equivalent to the disc's rotational speed. This ensures that the disc comes to a halt rather than spinning faster and continuously (Quazi *et al.*, 2018).

The supply voltage produces a 90° lag in the flow of the current I_p via the pressure coil. The two Φ_p are created by the I_p and are further separated into Φ_{p1} and Φ_{p2} . Due to low reluctance, the majority of the flux Φ_{p1} traverses the side gap (Xinghuo *et al.*, 2016). The flux Φ_p is 90° delayed and inversely proportional to the applied voltage.

Because of the alternating nature of the flux, the disc experiences an eddy current. The eddy current in the disc is generated by this flux.

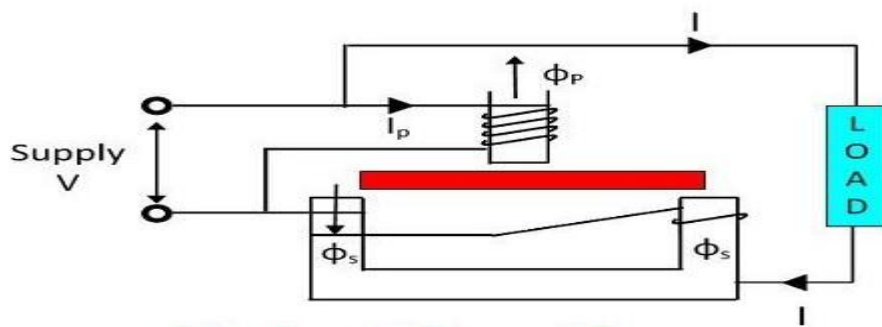


Figure 2.6: Working of an Electromechanical Energy Meter (Mary and Dempsey, 2001)

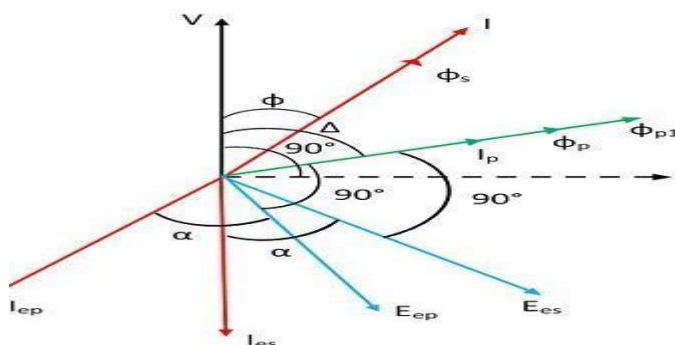


Figure 2.7: Phasor Diagram of an Electromechanical energy meter (Quazi *et al.*, 2018).

where;

V – applied voltage

I – load current

Φ – the phase angle of load current

I_p – pressure angle of load

Δ – the phase angle between supply voltage and pressure coil

flux.– frequency

Z – impedance of eddy current

α – the phase angle of eddy current paths

E_{ep} – eddy current induced by flux

I_{ep} – eddy current due to flux

I_{ev} – eddy current due to flux

I_{es} – eddy current due to flux

The net driving torque is expressed as:

$$T_d \propto \Phi_1 \Phi_2 f - z \sin \beta \cos \alpha = k_1 \Phi_1 \Phi_2 f - z \sin \beta \cos \alpha \quad (2.1)$$

Then, $K_1 = \text{constant}$, Φ_1 , and Φ_2 are the phase angle between the fluxes.

For energy meter, take ϕ_p and ϕ_s , $\beta = \text{phase angle between fluxes } \Phi_p$

and $\Phi_s = (\Delta - \Phi)$, therefore

$$\text{Driving Torque, } T_d = k_1 \Phi_1 \Phi_2 f - z \sin (\Delta - \Phi) \cos \alpha \quad (2.2)$$

But $\Phi_p \propto V$, and $\Phi_p \propto I$

$$T_d \propto k_2 V I f \sin (\Delta - \Phi) \cos \alpha \quad (2.3)$$

Similarly, k_2 , k_3 , and k_4 are constants unique to this meter's design.

If f , Z , and α are constants,

$$T_d = k_3 VI \sin(\nabla - \phi)$$

If N is steady speed, braking torque

$$K_B = K_4 N$$

At a steady speed state, the speed of the driving torque is equal to the braking torque

$$N = K_3 V_1 (\nabla - \phi)$$

$$N = KVI_{\sin} (\nabla - \phi) \text{ if } \nabla = 90^\circ,$$

$$N = KVI_{\sin} (90 - \phi) = N = KVI_{\cos\phi} = K \times \text{power}$$

The speed of the rotation is directly proportional to

the power,

$$\text{Total number of revolution} = \int N dt = K \int VI_{\sin}(\nabla - \phi)$$

$$\text{if } \nabla = 90^\circ,$$

$$\text{Total number of revolution} = K \int VI_{\cos\phi} dt$$

$$= K \int \text{power} dt = K \times \text{energy} \tag{2.4}$$

2.1.1.12 Reading Electromechanical Meters

The symbol "kWh," which stands for kilowatt-hours per revolution, represents the amount of energy corresponding to one rotation of the disc (Emmanuel *et al.*, 2014). It is commonly denoted by the value 7.2. By timing the disc's rotation using a stopwatch and utilizing the kwh value, it is possible to calculate the power consumption at any given moment. The equation for determining power in watts (P) is as follows when the time taken for one revolution of the disc is denoted as "t" in seconds:

$$P = \frac{3600xkh}{t}$$

(2.5)

where: t = time taken in seconds for one disc revolution; P = power in watts

For instance, if kh = 7.2 (as mentioned earlier) and one revolution takes 14.4 seconds, the power consumption would be 1800 watts.

This method can be employed to ascertain the power usage of household devices by sequentially switching them on and observing their individual power consumption (Mary and Dempsey, 2001).

2.1.1.13 Prepayment Meters

This type of meter is still in use in Nigeria; it was developed to replace the previous electromechanical meters. A prepayment energy meter is a device that allows customers to pay for their energy usage in advance. The customer loads a certain amount of credit onto the meter, which is then deducted as they use energy (Geno *et al.*, 2021). When the available credit is depleted, a relay automatically cuts off the flow of electricity until new credited is added. Figure 2.8 illustrates the schematic representation of the energy meter for prepayment. The meter comprises two Electrically Erasable Programmable Read-only Memory units, namely EEPROM 1 and EEPROM 2. Additionally, it includes an optocoupler, a microcontroller, a liquid crystal display (LCD) screen, a relay driver, a relay, and a load section

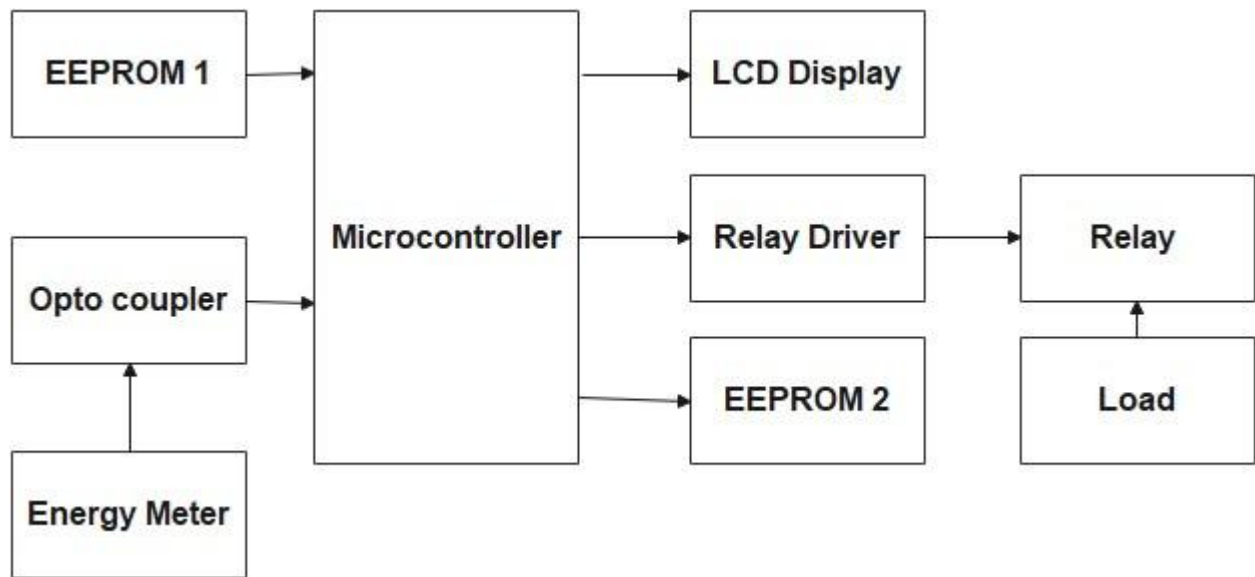


Figure 2.8: Diagram of a prepayment energy meter (Mary and Dempsey, 2001).

i. EEPROM

In prepayment energy meters, EEPROM 1 and EEPROM 2 are used to store critical data related to the energy consumption, payment transactions, and meter configuration. The purpose of EEPROM 1 is to store the current energy consumption data and other important information like the maximum demand, tampering attempts, and status of various components (Manoj and Shangufta, 2021). This data is updated at regular intervals by the meter and is used to determine the quantity of energy utilized by the user. The purpose of EEPROM 2 is to store the payment transactions and the status of the prepayment account (Manoj and Shangufta, 2021). This includes the amount of credit available, the last payment made, and any outstanding debts. The data in EEPROM 2 is updated whenever the user makes a payment or uses energy

(Elima *et al.*, 2022). Overall, the purpose of both EEPROMs is to ensure that the energy meter operates reliably and accurately, and that the prepayment system is fair and transparent for the users.

ii. Microcontroller

The microcontroller is the brain of the prepayment energy meter, which controls and monitors the energy consumption of the user. It receives data from the energy monitoring circuit and calculates the energy consumed. It also controls the communication between the user interface unit and the energy provider system (Chioma and Barida, 2022).

iii. Optocoupler

The optocoupler is an electronic component that is used to isolate the high voltage and low voltage circuits. It is used to interface the microcontroller with the energy monitoring circuit and provides isolation to protect the microcontroller from any kind of electrical interference or surges (Ajay *et al.*, 2022).

iv. Relay driver

The relay driver is used to drive the relay, which is a switch that turns on or off the electrical supply to the user's premises. The relay is used to disconnect the supply when the user has depleted their pre-paid energy balance or for any other reason determined by the energy provider (Daniel, 2020).

v. Relay

The relay is an essential component that disconnects the supply when the user has consumed their pre-paid balance or if there is an emergency. It is the last line of defence against any dangerous electrical situations and ensures the safety of the user and their appliances (Hassan and Dhar, 2022).

vi. Load

The load within a prepayment energy meter is utilized for quantifying the energy consumption of the user. Its function is to gauge the electrical energy passing through it and convert it into a digital signal that can be interpreted by the meter's microprocessor (Daniel, 2020). By being connected to the main power line, the load serves as the point of contact through which electrical energy is supplied to the customer's residence or establishment (Tanvir and Imran, 2022). Its purpose is to precisely assess the quantity of electricity consumed by the user and ensure that the appropriate prepayment is made for the energy utilized.

vii. LCD

The LCD in the prepayment energy meter is to display important information to the user. This information may include the amount of energy credit remaining, the cost per unit of energy, and the total amount of energy consumed (Manoj and Shangufta, 2021).

The LCD display allows users to easily monitor and manage their energy usage and remaining credit balance. Additionally, the display may show warnings or alerts when the credit is running low or when the meter needs maintenance.

The prepayment meter is similar to the prepaid meter which will be discussed next. The main difference between a prepayment meter and a prepaid meter is the way they handle credit depletion. Prepayment meters automatically disconnect the power when credit runs out whereas prepaid meters provide a grace period. A grace period refers to a certain period of time given to the consumer to top up or recharge their meter without being disconnected from the power supply. Next is to review the prepaid in details.

2.1.1.14 Prepaid Meters

The prepaid energy meter requires customers to pay for energy usage in advance, although it operates slightly differently than the previously discussed prepayment meter. Customers who use prepaid meters can put credit onto the meter with a card or online and check their energy usage in real-time (Geno *et al.*, 2021). The customer receives a warning message and they are given a grace period to add more credit before the power supply is disconnected.

i. Simple Prepaid Energy Meter Kits

Two electrically erasable, programmable read-only memories (EEPROMs) connected to a microcontroller make up the prepaid energy meter. The amount of the subscribed balance is stored in one EEPROM. The microprocessor reads this balance and saves it, together with the tariff, in the other EEPROM (Zanero *et al.*, 2018).

The subscription card is an EEPROM that stores both the allocated energy units and the balance amount. The microcontroller reads the balance amount and stores it along with the tariff and the energy units allotted in its RAM (Monsef *et al.*, 2016). It is also programmed to remove the data from the EEPROM (Making the card invalid for further use) (Guduru *et al.*, 2018). The energy meter provides electrical signals to an opto-isolator made of an LED and an opto-transistor combination so that for each electrical signal the energy meter receives, the LED illuminates and emits light (which sends an electric signal for every unit consumed). Once it begins to conduct, the opto-transistor delivers high- and low-frequency pulses to the microcontroller (Patent No. US8606891B2, 2013).

The microcontroller is set up so that for each pulse rate, a counter is kept incrementing, providing the amount of energy used (Levinzon *et al.*, 2012), The balanced amount and the energy units consumed are kept in another EEPROM that is likewise connected to the microcontroller; with each increase in count, the balanced amount in this EEPROM is subtracted (Patent No. US20190043306A1, 2019). The microcontroller provides a low signal to the relay driver to cause it to output a high signal that turns off the relay when the balance is zero. As shown in Figure 2.9, the load is disconnected from the mains supply when the microcontroller sends a high signal to the input pin of a transistor relay driver, causing the relay coil to ignite.

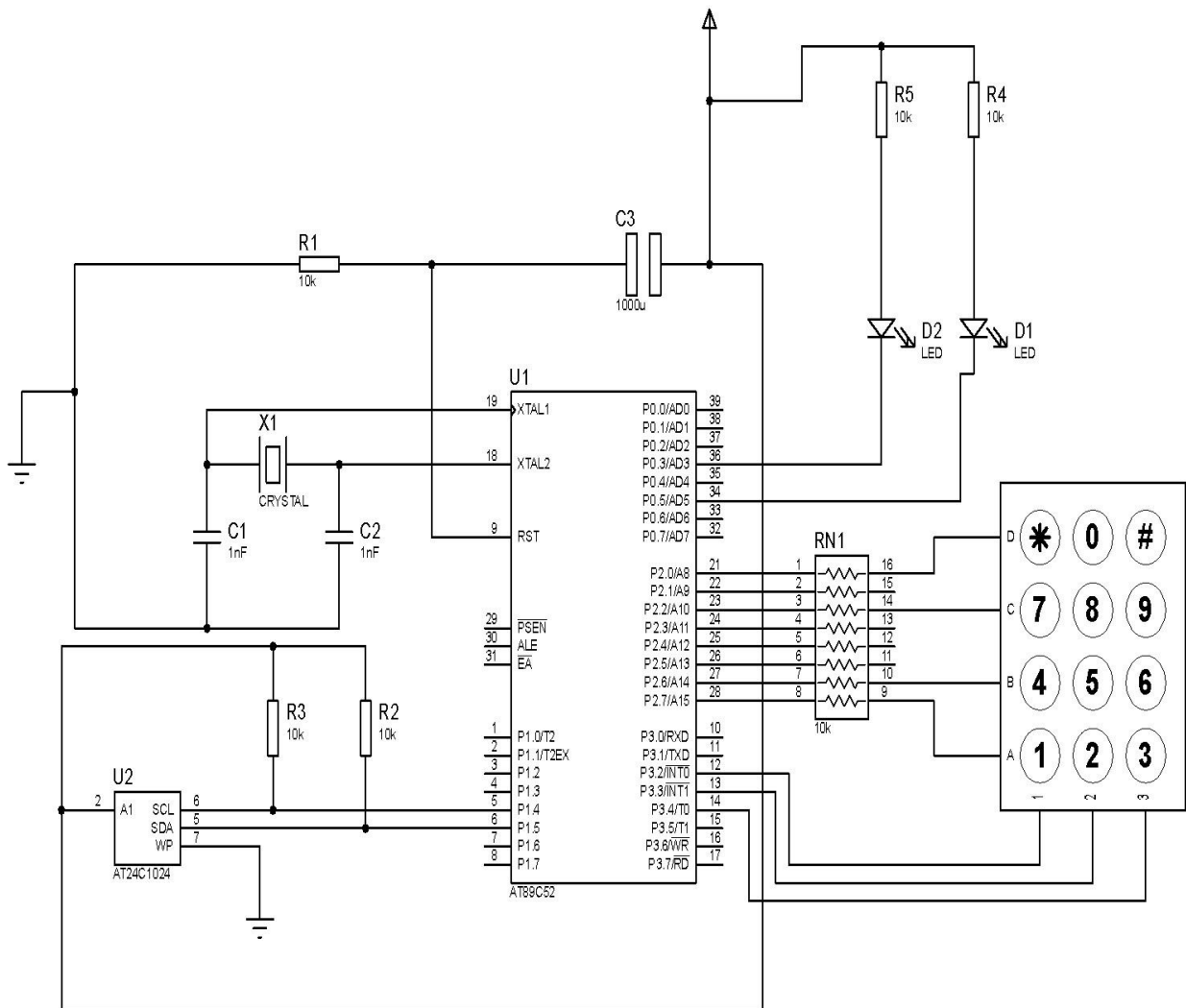


Figure 2.10: Schematic of Prepaid Meter Card Programmer (Xinghuo *et al.*, 2016)

2.1.1.15 Postpaid Meters

The traditional postpaid energy meter reading is an analogue electrical reading meter that the official from the utility company would come to the consumer's premises to take reading of the meter for the purpose of calculating the amount of power utilized

(Emmanuel *et al.*, 2014). The most typical method of paying for electrical services is called post payment, in which customers use electricity first and are charged for it at regular periods like monthly, and quarterly. (Monsef *et al.*, 2016).

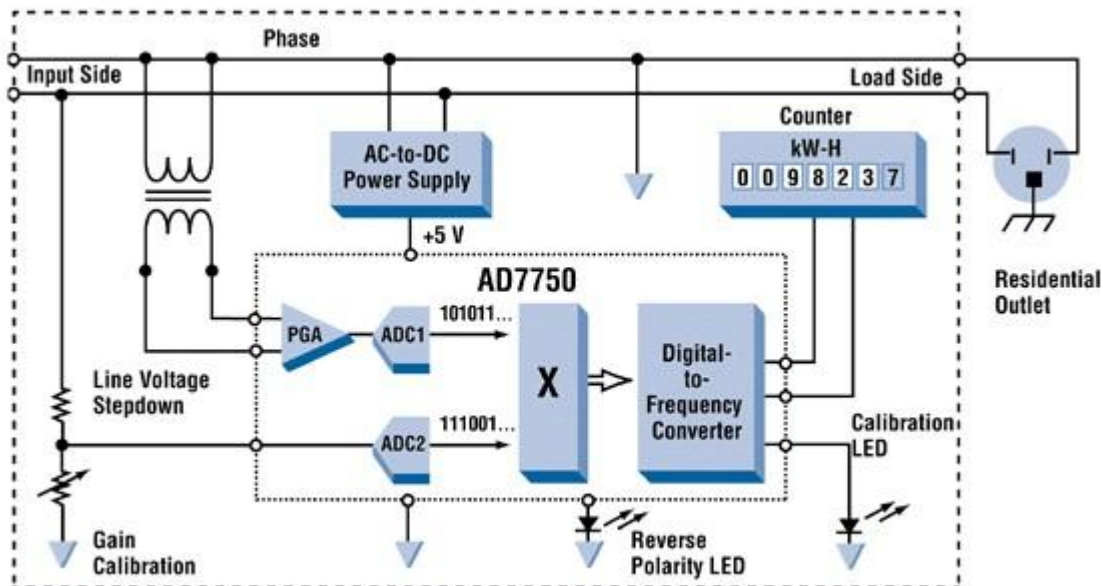


Figure 2.11: Diagram of a Postpaid Energy Meter (Emmanuel *et al.*, 2014)

2.1.1.16 Solid-State Meters

Contemporary electricity meters function by constantly sensing the immediate voltage (measured in volts) and current (measured in amperes). They then determine the product of these two values and integrate it over time to compute the consumed energy measured in kilowatt-hours (Bourdillon, 2013). Certain modern electricity meters employ solid-state technology and exhibit the power consumption

on an LCD screen, while others are electronic meters that can be read automatically.

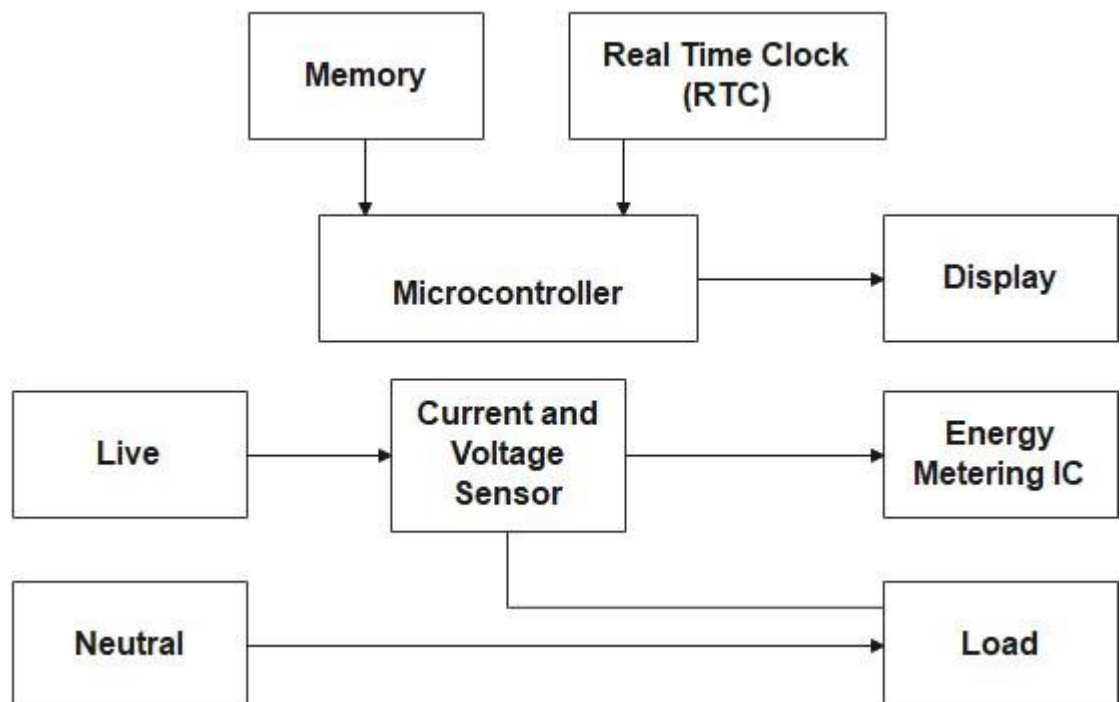


Figure 2.12: Block diagram of a Solid-State Energy Meter

(Muna *et al.*, 2021)

The diagram in Figure 2.12 illustrates various components of the meter, such as a clock that operates in real-time, a liquid crystal display, communication ports or modules, and multiple supplementary modules. These supplementary modules encompass a metering engine, power supply, and processing and

communication engine, which typically consists of a microcontroller. (Monsef *et al.*, 2016).

2.1.1.17 Smart Meters

According to Muna *et al.* (2021), a smart meter is an advanced electrical measuring device that performs various functions, such as logging significant events like power outages, managing demand on the consumer side, and monitoring power quality. It also establishes real-time communication with utility servers, enables remote connection and disconnection capabilities, and records electricity consumption at regular intervals. Additionally, smart meters can control smart appliances based on pre-programmed schedules. These meters encompass features like demand response, theft monitoring and control, local area network (LAN) and home area network (HAN) integration, automatic switching, and other functionalities related to advanced metering infrastructure (AMI) (Muna *et al.*, 2021). A crucial aspect of smart meters is their bidirectional interaction with the utility, ensuring continuous monitoring and sending alerts in case of any tampering attempts (Dincer *et al.*, 2020).

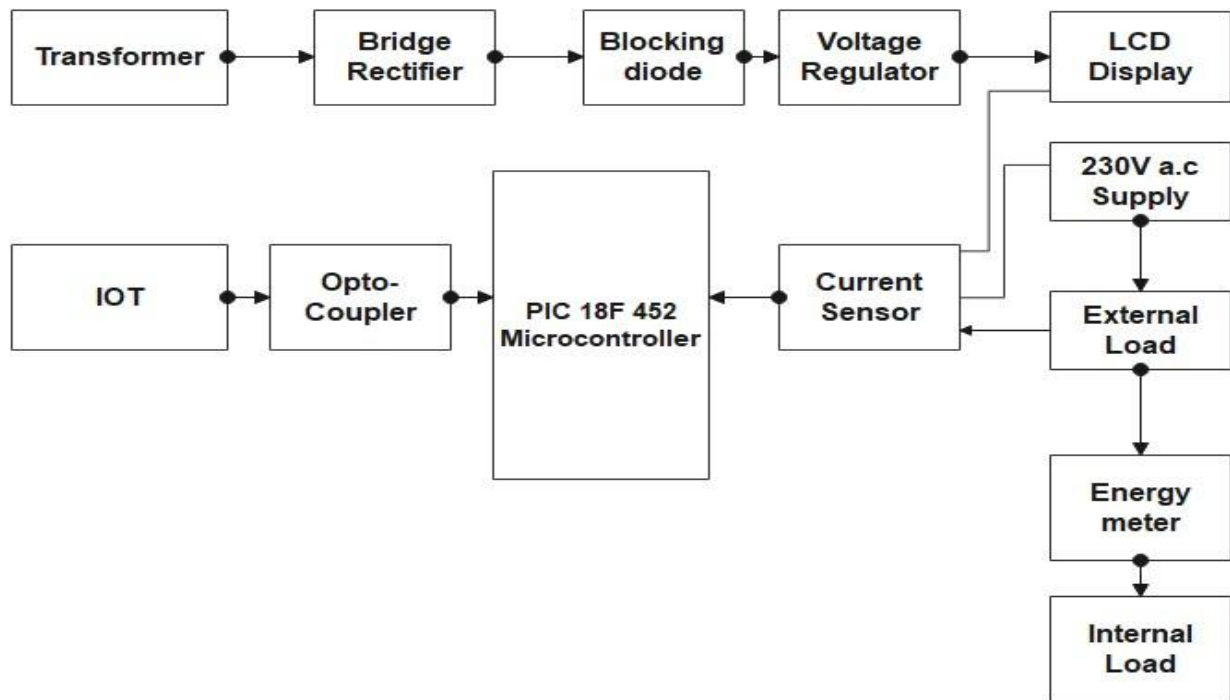


Figure 2.13: Diagram of an Internet of Things (IoT) smart meter

(Xinghuo *et al.*, 2016)

2.1.1.18 Automatic Meter Reading

The phrases "Automatic Meter Reading" (AMR) and "Remote Meter Reading" (RMR) denote various techniques that allow meters to be monitored and assessed without the need to send a meter reader on-site. Off-site metering systems, which consist of an electronic meter installed at the location where all connections originate and which is inaccessible to the end user, can effectively accomplish this. The utility receives the readings via AMR technology, which will be discussed in some metering design technology using the ADE7757 metering IC (Levinzon *et al.*, 2012).

2.1.1.19 On-site and remote meter reading of electrical power consumption and billing

The utility provider bills for power consumption based on meter reading billing and collection. They deal with millions of utility customers; thus, their services must be adjusted to meet their needs. Quality service not only enhances the utility's public image and goodwill, but it also helps to increase revenue in a variety of ways. To cut costs and increase value, all customer-related responsibilities must be consolidated and delivered as a single point of contact. CRM, or customer relationship management, is a term that represents such a comprehensive service. Consumption on-site and remote meter reading are two of the most recent advancements in metering technology.

2.1.1.20 Metered Consumption on site

This is known as on-site consumption metering, and it's typically done with electronic meters, which don't have any moving parts and thus eliminate money lost from stuck meters, and prepaid meters with Moulded Case Circuit Breakers (MCCB). The MCCB is opened by the meter's software after a particular amount of energy is delivered. It is designed with a keypad system, in which the credit vending machine generates a number that the client enters on the meter's keypad, and the meter continues to provide electricity until the user's payment amount is reached. This technology provides no feedback on the consumer's consumption patterns or the amount of energy consumed. For example, split meters are subdivided into the metering unit and the display unit. They're kept in a dust- and

moisture-proof enclosure installed on a pole. In addition, each meter can be supplied with a suitable Miniature Circuit Breaker (MCB) to disconnect the service in the event of an abnormal condition. Each consumer premises that is connected to the pole has a user interface unit fixed with an energy recording device (counter).

2.1.1.21 Remote meter reading

Individual meters in this system are fitted with a wireless device that operates at an appropriate frequency. A Meter Reading Instrument (MRI) is carried by the meter reader. Meter readings from the meters are acquired by MRI as the meter reader goes down the street alongside the MRI (Steve, 2021). The MRI is outfitted with interrogate/receive software as well as "Routing" software, which provides the meter reader with information about the customers along that route. The system's benefit is that it makes meter reading easy and efficient. The system's downside is that it's difficult for the utility to detect attempts to circumvent the meter and steal energy (Muhammad, 2020). Because of the widespread use of this system, it may not be acceptable. Due to widespread energy theft and pilferage in the utilities, this approach may not be appropriate (Muhammad, 2020).

2.1.1.22 Electrical Power consumption management in residential and commercial buildings

Power consumption management is the process of monitoring and controlling a large number of power-consuming devices to reduce

the cost of energy (Mouderik and Albert, 2010). The control of various electric devices, referred to as "loads," is done in two methods to save money: demand limiting and consumption limiting. Demand refers to the aspect of power measurement for electricity consumers, whereas consumption refers to the aspect of energy use. (Apeh and Olaye , 2015).

The current prepaid meters are used to manage electrical power consumption in residential buildings, rather than estimated billing, when electricity consumers take into account the name of loads (appliances), Power rating of the load (appliance), Number of loads (appliances), Running Hours of the loads (appliances), and total consumption per day, month, or year (Timothy *et al.*, 2021). The following methods can be used to minimize household energy use and save money in a home: Use a power strip, unplug electronics even when they are off, unplug chargers, switch off standby power on TVs, microwaves, scanners, and printers, and put automated light sensors or timed sensors on outdoor lights. Users should get energy-saving gear, switch off their computers at night, and use LED bulbs, which are the best energy-saving bulbs (Timothy *et al.*, 2021). Prepaid meters are used to regulate electrical power use in business buildings; however, the billing is commercial rather than an estimated billing system. In a commercial setting, Power consumption management involves routinely checking all machinery and controls to make sure they are operating as planned (Apeh and Olaye, 2015).

2.1.1.23.1 Electrical Power consumption management models

Electricity rates have been steadily increasing in recent years, with further rate hikes expected in the future. Consumption and demand prices constitute a significant portion of total costs, as seen in utility bills (Robin *et al.*, 2020). Consumption is measured in kilowatt-hours (kWh) and can vary in cost, while demand refers to the instantaneous power requirement based on utility rate plans and location (Shuaijia *et al.*, 2020). Understanding how these billing components are calculated can help customers monitor and save on their energy usage.

Accurately modelling residential and commercial electricity consumption is crucial for policy decisions, distribution system planning, and assessing the impact of technologies like automated metering and smart grids. Residential usage accounts for a substantial proportion of total electricity consumption, but the complexity of factors such as variables and tenant behaviour make modelling residential electricity usage challenging (Laura *et al.*, 2020).

This research aims to examine existing models developed by researchers for residential buildings. Muzhir *et al.* (2012) proposed an internet billing system that utilized a virtual bank to facilitate money transfers, account balance determination, and secure authentication rules. Through e-commerce, users could compare products without limitations, such as time constraints or

intermediaries (24 hours x 365 days). There are four primary categories of e-commerce:

- i. A Business to Business (B2B)
- ii. Trade Between Businesses (T2B)
- iii. Customer to customer (C2C)
- iv. Customer to Business (C2B)

The billing system utilizes a database to store essential information such as client data, call detail records of usage, rate tables, and pre-invoicing billing records. Despite the fact that a communication system's events decide the charges (Arram *et al.*, 2021). In order to determine the price for on-peak, shoulder-peak, and off-peak hours. Time-of-Use (ToU) pricing model based on Game Theory (GT) was created (Adia *et al.*, 2019).

For both the ToU real-time and non-real-time pricing schemes, time-of-use billing was computed based on used loads. Due to additional costs associated with consumers' load demands during specified hours. There are adjustments made for shoulder-peak and on-peak hours per hour unit

The existing method for modified ToU price signal is given as:

$$EP^h(\text{hour}) = \begin{cases} ToU(\text{hour}) & \text{if } H_{poff} \\ \vartheta^h(\text{hour}), & \text{else} \end{cases}$$

(2.6)

(Adia *et al.*, 2019).

where *off* stands for the off-peak hours, during which time the price is set based on H_p demand. The price is directly proportional to demand, it is high during on-peak and low during off-peak.

Load shifting is a Demand Side Management (DSM) technique used to lower the price of electricity. where the Energy Management Controller (EMC) is located for scheduling appliance and house load. With the installed EMC, the loads were scheduled, however, to restrict power demand and reduce rebound peak. In light of this, the objective function for cost minimization is as follows:

$$\text{Min } E. C_{total}^h$$

(2.7) Subject to Constraint:

$$E. L^h \geq \text{limit} \quad \text{if } H_p^{off}$$

(2.8)

$$E. L^h < \text{limit} \quad E. L^h \geq \text{Limit} \quad 2 \quad \text{Otherwise}$$

$$(2.9) \quad \text{Limit} = \text{mean} \quad (E. L^h)$$

(2.10)

$$\text{Limit} \quad 2 = \text{std} \quad (E. L^h)$$

(2.11)

where std denotes standard deviation: $E. L^h$ denotes total combined load of N housing units. The threshold for both on-peak and off-peak to reduce the loads from reversal peak. As a result, the power load for each home might be determined as follows:

$$E. L^h_{hour} = \sum_{d=1}^n (App_{prate}^d \times \vartheta)$$

(2.12)

where $\vartheta = [0,1]$ represents the appliance's on/off status for consumers. The entire

price of electricity $E.C_{total}$ could be calculated as:

$$E.C_{total}^h = \sum_{hour=1}^n E.C_{hour}^h$$

(2.13)

The formulation of equation (2.13) was made to determine the $E.C_{hour}^h$

$E.C_{hour}^h$

$$E.C_{hour}^h = EP^h \text{ (hour)} \times E.L_{hour}^h$$

(2.14)

where EP^h (hour) is the electricity price per hour.

Hence, the GT-based price model for ToU tariff is written as:

$$\Theta_{hou}^h = \sum_{S \subset N \setminus \{h\}} \frac{\{S\}!(N-\{S\}-1)!}{\{N\}!} (v(S \cup \{h\}) - v(S))$$

(2.15)

where;

Θ_{hou}^h referred to the cost of electricity (pay-off) for the home h , where N is a set of N homes and v is a function of subsets of N . From Equation (2.15) the complexity of the electricity bill could be determined.

The bill determination model offers solutions to various payment-related issues. However, implementing load-shifting methods to reduce electricity bills may lead to unfavourable rebound peaks as customers aim to minimize costs. Even with the proposed constraints-based approach, it is not guaranteed to achieve absolute

cost reduction due to potential network failures. The implementation of the online billing system involves logical implementation, but practical logistics arising from human factors may impact its effectiveness. Although the researcher's work is commendable, customers should be aware of the billing structure, which was not addressed. To ensure security and mitigate risks, encryption measures must be implemented to prevent unauthorized access

2.1.1.1.24 Power consumption charging method

There are two (2) fundamental ways to charge electricity users for their energy usage:

i. Postpaid consumption

charging method

ii. Prepaid consumption

charging method:

(a) Estimated consumption and

(b) Automated consumption charging method

2.1.1.25 Postpaid Consumption charging method

The postpaid consumption charging technique has users paying their electricity bills after consumption (Maina *et al.*, 2020). They would receive bills on a monthly, quarterly, or other schedule, and after

receiving a bill, they would have a certain length of time to pay the charge.

2.1.1.26 Prepaid consumption method

The Prepayment consumption charging technique, also known as Prepaid, requires power users to have units in their accounts prior to using the service, and when those units are depleted, the supply is cut off from a distance. In the 1980s, the community's low-income residents were to receive electricity at a reasonable price thanks to the prepaid energy billing system (Richard, 2018). Prepaid metering systems were first widely distributed by the Distribution in 2006 as a result of a worrying consumer debt profile and issues with revenue collection. This is thought to have enhanced revenue collection (Festus *et al.*, 2020).

2.1.1.27 Estimated consumption charging method

The estimated consumption method is stated to resemble fraud, when consumers are required to make payments for their consumption in excess of what they consumed on a monthly basis.

Customers in this system lack meters, and visits to their houses to monitor energy usage over the payment period are frequent (Arimoro *et al.*, 2021).

2.1.1.28 Automated consumption charging method

This is a billing system that enables for the streamlining of billing procedures in order to automate routine billing functions for increased efficiencies and cost savings. Provisioning, dunning, approvals, customer-event triggers, invoicing, and payment

collection are all examples of this method (Dirko *et al.*, 2017). The Nigerian Housing Corporations Association (AHCN) continues to employ an automated electricity billing system. The procedure is carried out using the Electricity Control Management Interface (ECMI), a window-based management system (Application Program) that is designed to compete with other existing management systems while also improving on their shortcomings.

2.1.1.29 Billing in single Phase Meter

The utility providers can charge customers for electricity based on use with the single-phase prepaid Energy meter (Damina *et al.*, 2016). It goes beyond automated meter reading and includes prepaid recharge capabilities and information sharing with utilities concerning client consumption specifics (Mejbaul *et al.*, 2011). The following equation can be used to determine how much energy or units are required to produce one unit of power: P: can be acquired as follows:

$$1\text{-watt} \quad \text{sec} \quad = \quad \frac{1\text{kwsec}}{1000}$$

(2.16)

$$1\text{-watt} \quad \text{sec} \quad = \quad \frac{1 \text{ kWh}}{1000 \times 3600}$$

(2.17)

$$\text{Energy} = \frac{P \times \text{Sec}}{1000 \times 3600} \quad \text{Units}$$

(2.18)

(Mejbaul *et al.*, 2011)

In Omijeh and Ighalo (2013), a mathematical model for a GSM-based Energy Recharge for a single-phase prepaid metering system was built using MATLAB Simulink. The utility determines the Recharge Amount, which is the amount that customers recharge their prepaid cards with (RA). The card has already been fed with the tariff rates. The prepaid card continually transforms the units consumed by the load into expenditure (E) at each instant, then subtracts that amount from the recharged amount to determine the balance (B).

$$\text{The model: } R_A - E = B$$

(2.19)

The phrase: "Expenditure in Nigeria billing structure" (Nwaoko, 2006) provides information.

$$E = N_A + \text{VAT} + C_c$$

(2.20)

$$C_c = E_c * E_N * M_F$$

$$(2.21) \quad E_c = L_R - P_R$$

$$(2.22)$$

where:

NA = Net Arears, VAT = Tax, C_C = Current Charge, E_c = Energy Consumed, L_R = Last Reading

P_R = Present Reading, E_N = Energy Charge per kWh, M_F = Multiplier Factor.

The simulation results of the energy model $E_B = E_R - E_C$, where: E_B = Energy balance, E_R

= Energy Recharge and E_C = Energy Consumed

The energy billing system could assist energy distribution businesses in increasing efficiency and accuracy of metering and billing while decreasing expenses (Ndinechi *et al.*, 2011).

The Electricity billing in single phase metering system in developing country like

Nigeria is on the increase see Table 2.4 for approved tariff by Nigeria Electricity

Regulatory Commission (NERC) for Residential of R2S (single-phase), Commercial C1S (single-phase), Industrial D1S (single-phase) and Special A1S (Single-phase) electricity consumers.

2.1.1.30 Billing in three-phase Meter

Residential electricity consumers that used three phase appliances requires three phase meters with three incoming phases (that is, red, yellow, blue phase and neutral) (Sajid *et al.*, 2018). A three-phase connection has the advantage of allowing for the flexibility to divide the load and for effective phase balancing to prevent overloading of successive phases (Xinghuo *et al.*, 2016). For instance, if there are three air conditioners, each one can be installed

on a different phase (Sajid *et al.*, 2018) avoiding overloading any particular phase. The other two phases continue to operate in the event that one phase fails owing to a problem at the distribution point, preventing a total blackout of the setup. This only applies to single-phase loads (Zhengtian *et al.*, 2020). However, as it offers great benefits for extra loads, there are charges associated with the three-phase connection. First, as the load provided to the house increases, so the rate of consumption will increase which definitely affect the tariff. In some areas, utilities have monthly meter rent, whereas, in others, there is an upfront charge for postpaid three-phase meter. So, the charge on meter may either an upfront (postpaid) charge or it will be charge on the consumption (prepaid) (Muna *et al.*, 2021). In (Ali *et al.*, 2020) developed enhanced three phase electrical measuring system using existing energy meter. The meter pulses are fed to the raspberry Pi 3 microcontroller and counted using the built-in interrupt function. The kWh monthly consumption was calculated as:

$$\text{kWh} = \text{monthly received pulses} \times \text{meter constant}$$

$$(2.23) \quad \text{Monthly bill cost} = \text{kWh} \times A$$

$$(2.24)$$

Where the anticipated residential customer tariff is AN/kWh

Additionally, the system can, if necessary, be programmed for various consumer categories with various tariffs, including domestic, commercial and industrials loads. While Dike *et al.*, (2017) using phase-constrained billing system develop a model from first

principle, the exponential forms of energy consumed, E_c and the basic energy consumption cost, E_{cc} for a composite load as:

$$E_c = nIVTe^{j\theta} \quad (2.25)$$

$$E_{cc} = nIVTRte^{j\theta} \quad (2.26)$$

where:

E_c = Energy Consumed

E_{cc} = Energy consumption cost.

n = number of loads.

I = current.

V = voltage

T = Tariff.

e = base of the natural logarithm and has a value approximately equal to 2.71828.

j = imaginary unit,.

θ = Phase

R = Residence.

t = time

By combining some of the cost parameters stipulated by the electricity market regulates and decomposed complex exponential operator using Euler's theorem, the electricity cost model (Billing) for three-phase constrained billing scheme as:

$$\text{Bill} = (1 + R_v) (nk_nIVTRt\cos \theta + Fc) - Cmr + (1 + \alpha) Arr \quad (2.27)$$

where:

Bill = Total electricity bill or cost to be calculated using the model.

R_v = Residential variable rate factor

$nknt$ = Billing coefficients.

I = current

V = voltage

T = Tariff

t = time

R_t = Total residential apartment or meter

θ = Phase.

F_c = Fixed charges.

C_{mr} = meter rent or cost

α = factor

Arr = Arrears or outstanding balance on the bill from previous periods.

The Electricity billing in three-phase metering system in developing countries like Nigeria is on the increase (Orukpe and Agbontaen, 2013) as shown in Table 2.3 and Figure 2.14, the effect of approved tariff by Nigeria Electricity Regulatory Commission

(NERC) for Residential of R2T (Three-phase), Commercial C1T (Three-phase), Industrial D1T (three-phase), and Special A1T (Three-phase) electricity consumers.

Table 2.3: Approved tariff by Nigeria Electricity Regulatory

Commission (NERC) (Ali *et al.*, 2020)

CLASS	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
R1	4	4	4	4	4	4	4	4	4	4
R23	14.82	24.08	31.27	31.26	30.98	30.88	27.29	24.49	24.34	24.14
R21	14.82	24.45	34.4	34.4	34.08	33.97	30.02	26.94	26.78	26.56
R3	26.52	38.56	40.46	40.46	40.08	39.96	35.32	31.69	31.5	31.24
R4	26.52	38.56	40.46	40.46	40.08	39.96	35.32	31.69	31.5	31.24
C1S	20.72	33.87	34.9	34.9	34.58	34.47	30.46	27.34	27.17	26.95
CIJ	20.72	34.19	36.27	36.27	35.94	35.83	31.66	28.41	28.24	28.01
C2	24.65	40.67	38.11	38.11	37.76	37.64	33.27	29.85	29.67	29.43
C3	24.65	40.67	38.11	38.11	37.76	37.64	33.27	29.85	29.67	29.43
D1S	19.89	32.51	35.62	35.62	35.29	35.18	31.09	27.9	27.73	27.5
D1T	19.89	32.82	37.29	37.94	37.59	37.47	33.12	29.72	29.54	29.3
D2	25.84	38.56	37.71	39.29	38.92	38.8	34.29	30.77	30.59	30.34
D3	25.84	38.56	33	39.29	38.92	38.8	34.29	30.77	30.59	30.34
A15	19.04	31.12	33.97	33	32.7	32.59	28.81	25.85	25.69	25.48
A1T	19.04	31.42	35.27	33.97	33.66	33.55	29.66	26.61	26.45	26.24
A2	19.04	31.42	35.27	35.27	34.95	34.84	30.79	27.63	27.46	27.24
A3	19.04	31.42	35.27	35.27	34.95	34.84	30.79	27.63	27.46	27.24
L1	19.62	32.07	36.26	36.26	35.93	35.81	31.65	28.4	28.23	28

where:

R1 = Residential Life-Line (50 kWh) Not Applicable

R23 = Residential of Three-Phase

R21 = Residential of Single - Phase

R3 = Residential Low Voltage (LV) Maximum Demand

R4 = Residential High Voltage (HV) Maximum Demand (11/33kv)

C1S = Commercial Single-Phase

C1T = Commercial Three-Phase

C2 = Commercial Low Voltage (LV) Maximum Demand

C3 = Commercial High Voltage (HV) Maximum Demand (**11/33 kv**)

D1S = Industrial Single-Phase

D1T = Industrial Three-Phase

D2 = Industrial Low Voltage (LV) Maximum Demand

D3 = Industrial High Voltage (HV) Maximum Demand (11/33 kv)

A1S = Special Single- Phase

A1T = Special Three-Phase

A2 = Special Low Voltage (LV) Maximum Demand

A3 = Special High Voltage (HV) Maximum Demand (11/33 kv)

L1 = Street Lighting (Single and Three-Phase)

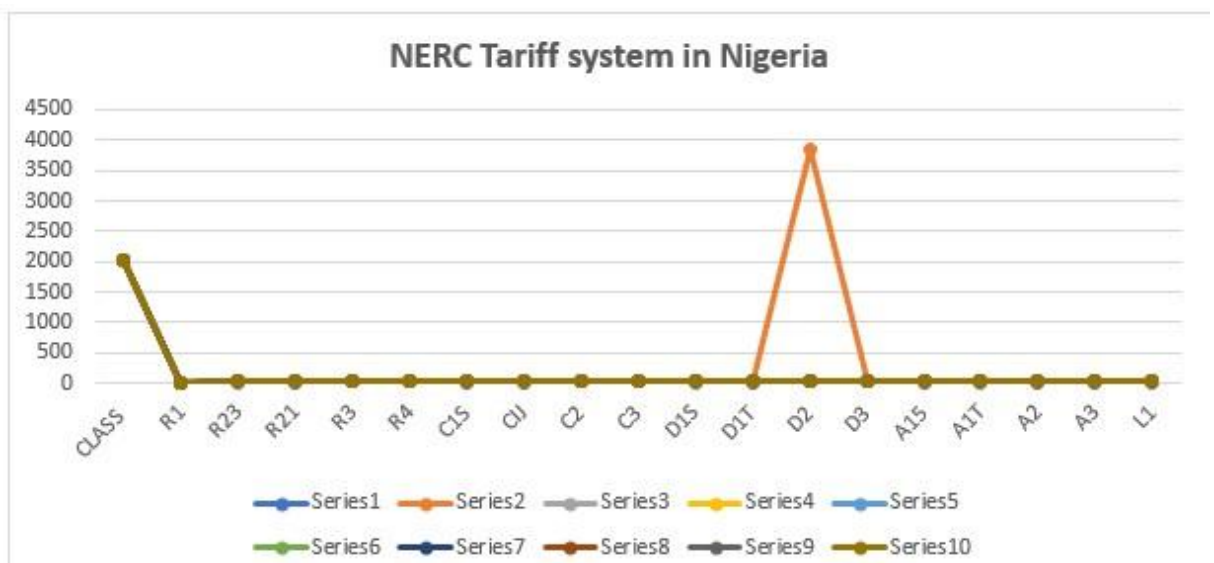


Figure 2.14: Effect of the approved Nigeria Electricity Regulatory

Commission

(NERC) tariff on consumers (Ali *et al.*, 2020)

2.1.1.29.1 Fault detection in Power distribution system

In distribution lines, unnoticed faults can sometimes occur, and if left unaddressed, these minor flaws can eventually lead to transformer damage, endanger human life, and even cause fires (khedkar *et al.*, 2019). Presently in Nigeria, there is a lack of a real-time mechanism to identify and notify utility providers when faults

occur in service cables (Orukpe and Agbontaen, 2013). The absence of an accurate timing system is concerning as it not only affects the underlying technology but also poses a threat to human safety (Leonardo *et al.*, 2012). To mitigate such risks, regular maintenance and inspection of distribution lines are carried out with the aim of minimizing such incidents to the greatest extent possible (Subramanya *et al.*, 2018), necessitating the implementation of an automated system.

However, it is important to note that line failures can occur due to factors beyond control, such as rain or fallen trees (Leonardo *et al.*, 2012). Energy losses in the power distribution system encompass both technical and non-technical forms, are outlined in

Table 2.4 (Leonardo *et al.*, 2012). For instance, in Edo State, Nigeria, distribution lines

pass through forested areas (Sammy *et al.*, 2013), while severe rainfall in Delta State, Nigeria, can disrupt operations (Sammy *et al.*, 2013)

Table 2.4: Energy losses in the power distribution system (Leonard *et al.*, 2012)

Technical Losses	Non-Technical Losses
11 KV/ 415V line losses	Theft by direct tapping.
Distribution transformer losses (iron and copper losses)	Theft by tampering meters.
Low Tension (LT) line losses.	Non-performing meters.
Losses due to loosen jumper connections.	Under-performing meters.
Short circuit and earth fault losses.	Meters not read.
Losses in service mains and energy meters.	Mistakes in billing, etc.

2.1.1.32 Determination of Technical Losses on 11kv/415v Feeder (Jens *et al.*, 2017).

By performing load flow analyses on each individual 11kV/415V feeder, which includes the distribution transformer and losses in Low Tension (LT) distribution, contributes to overall energy losses., technical losses on the 11kV/415V feeder are determined (Subramanya *et al.*, 2018).

To identify technical losses, the network's steady-state model is used.

- i. The loads' impedance is assumed to be constant.
- ii. A transformer's load factor is calculated by taking into account the energy input, the peak load, and the duration of transformer operation in hours.

The following formula is used to calculate the load-loss factor:

$$LLF = 0.3(LF) + 0.7(LF)^2 \text{ (Luista et al., 2015).}$$

(2.28) non-technical losses are quantified by subtracting technical losses from the overall losses of the feeder. This involves calculating the discrepancy between the energy distributed and the energy sold.

Technical losses, on the other hand, are estimated by subtracting losses from the total losses of the feeder.

2.1.133 Technical loss

It is necessary to compute the dynamic wind effect on electricity distribution lines in order to improve the design and accuracy of the wind effect on distribution lines in strong wind areas (Luista et al., 2015). The effect of the wind on the conductor is determined as shown in Table 2.5.

Table 2.5: Results showing Faults in Power Distribution Network (Luista et al., 2015).

S/N	Fault Types	Responsible Factor	Calculated distance in km from a substation
1	Red Phase down	Wind	1.6542
2	Red Phase down	Wind	0.4520
3	Blue Phase down	Wind	1.0776
4	Yellow Phase, Red Phase down	Excavation digging	1.5887
5	Yellow Phase down	Wind	0.5056
6	Blue Phase and Red Phase down	Vehicle collision	0.6314
7	Yellow Phase down	High Power	0.5564

		Demand	
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2.1.1.36 Overview of Power metering system

Consumer protection and efficient service delivery are essential aspects in maintaining proper service standards and preventing consumer exploitation. These principles align with Nigerian consumer protection laws and Presidential directives concerning power metering for all Nigerians. Citizens have the right to accurate and timely information regarding their electricity readings and bills, as well as the right to fair treatment and protection from unfair, unreasonable, or unjust practices. The responsibility lies with the utility company to provide meters to households, enabling them to access electricity through billing. Efforts have been made by Nigeria's utility companies to increase demand for electricity and address the metering gap. However, some residents still complain about excessive electricity bills, defective infrastructure such as poles and cables, meter shortages, and continued estimated billing in rural areas. In some instances, consumers resort to illegal connections and bribe utility staff for access to power. Additionally, there are cases where consumers are billed for electricity during outages in areas without power.

Furthermore, consumer dissatisfaction is expressed regarding the unavailability of prepaid meters after payment. In line with President Muhammadu Buhari's guidelines on power metering, the government, through its agencies and stakeholders at all levels,

plays a crucial role in infrastructure planning for successful power generation, transmission, and distribution. Nigerians have the right and responsibility to protect themselves against exploitation in all forms.

When comparing different types of energy meters, electro-mechanical meters are known for their resilience and durability. They are particularly robust compared to newer energy meters. On the other hand, disk meters can withstand voltage fluctuations, and their sturdy coils make them difficult to tamper with. However, electro-mechanical meters do not require a battery for their mechanical dial, but they lack upgradability and have limited accuracy. While some consumers benefit from prepayment meters, there are several disadvantages to consider.

Firstly, the meter must always maintain a credit balance to ensure continuous energy supply, and daily standing costs are incurred. Secondly, if a consumer plans to be away for a few days, they need to top up their meter in advance to cover any residual charges and maintain essential appliances like refrigerators or freezers. Thirdly, during colder seasons, more frequent top-ups are required. Misplacing the top-up card may necessitate obtaining a replacement from the utility company, potentially incurring additional costs. Prepayment rates can also be higher due to the increased operational expenses for the utility company.

Prepaid electricity meters provide consumers with a readout of units consumed and power usage levels, enabling effective monthly

budgeting. Prepaid meters offer the advantage of keeping track of energy costs and preventing the accumulation of electricity debt. However, they may be more expensive to operate compared to other meter types, and in case of a credit exhaustion during a power outage, consumers must physically visit the meters to restore power, which may not always be convenient.

Solid-state power meters employ either analog or digital signal processing technologies. Signal processing techniques, such as multiplication and filtering, are utilized to extract required information like kilowatt-hours (kWh) and reactive power (VARs). Digital technology offers more straightforward, cost-effective, and consistent calibration features compared to analog meters.

The conversion of sampled input signals to binary words in power metering often involves the use of successive approximation ADC (Analog-to-Digital Converter). While this technique provides fast conversion rates of up to 1 million conversions per second, achieving high resolution (>14 Bits) can be costly, and transducer output signals may require extensive signal processing, adding to the overall expense.

Implementing automated meter reading methods may lead to meter damage, vegetation overgrowth, and faulty meters. Some utilities have reported receiving defective meters from manufacturers. Customer resistance and infrequent meter inspections also contribute to issues in meter reading accuracy. Smart meters

eliminate the need for consumers to manually submit readings to suppliers as they transmit readings automatically.

2.1.1.37 Overview of the billing system

The primary objective of an electrical billing system, whether it pertains to single-phase, three-phase, prepaid, or postpaid services, is to determine the consumed units of electricity over a specific time period and the corresponding amount owed to the utility company. The three types of electricity billing systems are kWh billing, kVAh billing, and kVARh billing. Kilowatt-hour (kWh) is the unit of measurement for energy consumption. In kWh billing, only active energy costs are billed, while utility companies provide both active and reactive power. Active power usage is billed based on the kWh tariff, while reactive power is not. This billing structure often includes Power Factor (PF) incentives, which encourage consumers to improve their PF and reduce reactive power consumption. The ideal scenario is to maintain PF close to unity, resulting in high PF incentives and minimal reactive power usage. Electrical energy is divided into two categories: active energy (kWh) and reactive energy (kVARh). The sum of these components yields apparent energy, expressed in kVAh.

In kVAh billing, energy charges are assessed based on apparent energy consumption, while fixed or demand fees are assessed on apparent power (kVA). This approach eliminates the separate billing of active and reactive energy and aligns charges with apparent energy consumption (kVAh). Utility companies prefer kVAh billing,

which encourages consumers to maintain a high PF to consume more kVAh. This, in turn, promotes the generation of reactive power by consumers. The kVAh tariff structure includes charges for reactive power consumption, and the PF incentive is integrated into the tariff, eliminating the need for a separate PF incentive. As a result, the kVAh tariff is typically lower than the kWh tariff.

In kVARh billing, kVARh represents kilovolt-ampere reactive hours, which measure reactive energy consumption in industrial settings. The premise is that low power factor leads to higher reactive power consumption, resulting in additional charges on the bill. This is primarily attributed to transformers, motors, relays, and other equipment.

While reactive power is necessary in the electrical distribution system, it must be minimized to maintain infrastructure efficiency. Since PF penalties do not fully compensate utilities for unaccounted reactive energy, the kWh-based tariff system does not account for reactive power consumption. In the kVAh-based pricing scheme, utilities compensate for reactive power, and consumers are encouraged to maintain a power factor below a certain threshold scheme (kulkarni *et al.*, 2020).

Regarding connections, prepaid connections require upfront payment, while postpaid connections do not require advance payment but necessitate payment after the billing cycle. Other differences may include plans, costs, and internet connection speeds, among other factors. Prepaid connections are often a cost-effective

choice for students and individuals seeking affordable solutions, although specific requirements can vary among different power providers. It is important to note that this does not necessarily imply that postpaid connections are more expensive, although they may become more costly in the future.

2.1.2 Automation in Computer Process Control

Automation in computer process control refers to implementing technology and software for controlling and monitoring industrial processes such as manufacturing, production, and distribution. This automation process requires the use of sensors, microcontrollers, actuators (relays), and other computer systems capable of automating various functions such as pressure, flow, temperature control, and other process parameters. Automation in computer process control helps improve efficiency, reduce errors, increase productivity, and enhance safety by minimizing the need for manual intervention in hazardous or complex operations (Harrison *et al.*, 2021). Automation in computer systems refers to the application of technologies for data gathering and analysis through the use of technical tools like Artificial Intelligence (AI) and image recognition software to convert data into a format that can be used by computers. Compared to manual data entry, it is much faster and less prone to mistakes (JavierGil, *et al.*, 2017). Furthermore, it gives programmers the ability to examine each element of the software in terms of how consumers will use it. In terms of computer process

control, it carries out many different functions divided into the following group as shown in Figure 2.15:

- i. Monitoring via data collection and interpretation from the technical process
- ii. Control some parameters of the technical process
- iii. Automatic control via connection of the process input and output data with feedback

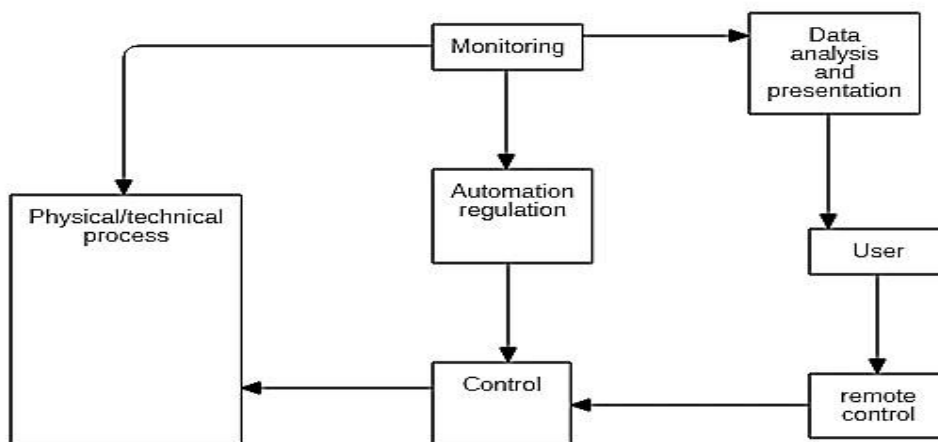


Figure 2.15: Computer Process control system (Harrison *et al.*, 2021).

2.1.2.1 Physical/ Technical Process

A physical process is a collection of actions used to influence and alter anything in the physical world. It is a system's collection of interconnected activities that modify, move, or store matter, energy, and information (Eleonora, 2014). A technical process is described as "a procedure, in which the physical values can be obtained and affected by technological means." The distinction between a physical and a technical process thus arises from the fact that a physical process does not always require external control, whereas a

technical process incorporates information processing for control. 'Every physical process is characterized by its input and output elements in terms of materials, energy and information according to Figure 2.16.

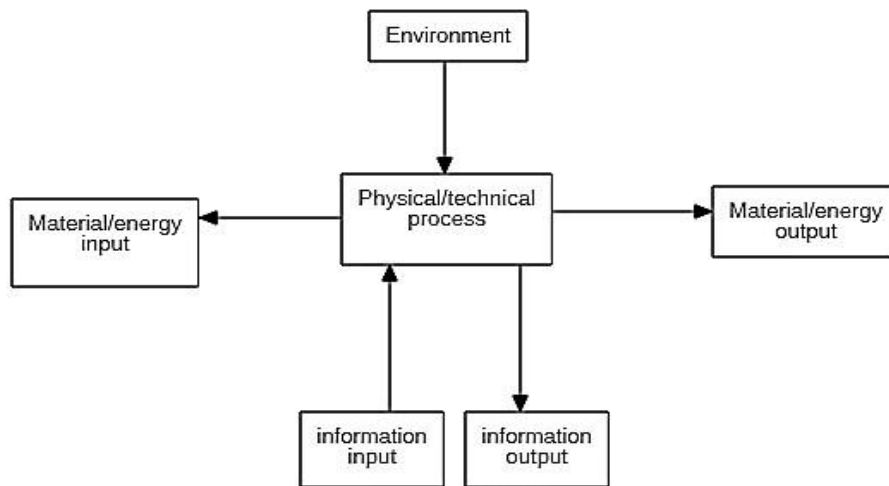


Figure 2.16: Model for generic physical/technical process (Eleonora, 2014)

2.1.2.2 Monitoring

Monitoring is the collection of the physical process variables, storage and presentation in suitable form to human operator. Monitoring is fundamental for all other data processing. Monitoring can be limited to displaying raw or processed data on a terminal screen or printing them out on paper, but can also include more sophisticated analysis and presentation functions (Wei, 2020). When a process control system's capabilities are restricted to data collection and presentation, an operator must make all control

decisions (McKeec *et al.*,2011). This control mode, known as supervisory control. Supervisory control is still useful, particularly in relatively slow Processes with great complexity and where human interaction is essential. An example are biological processes, where part of the observations cannot be carried out automatically (Moustris *et al.*, 2011). As soon as new data is collected, their value is examined with respect to alarm limits.

2.1.2.3 Control

Control is the reverse of monitoring; strictly speaking, in control, commands from the computer are sent to the actuators to affect the physical process (Xing *et al.*, 2021). The needed process parameters are frequently only indirectly able to be modified by other control factors.

2.1.2.4 Automatic Regulation/Control

A system that acts autonomously and without the direct intervention of a human operator is called automatic. Automatic control can consist of simple control loops (one for each input-output variable pair from the process) from Program such as Java, C++ and Matrix Laboratory (MATLAB) and Scripts for automation, but also in more complex controllers with many inputs and outputs (Cyrille *et al.*, 2020). There are two different principal techniques to implement feedback control in computer systems. The direct digital control (DDC) the central computer calculates the control signals for the

actuators (Rossa, 2020). The monitoring data has to be transmitted all the way from the sensors to the central control units and the control signal back to the actuators. Whereas in Distributed Direct Digital Control (DDDC), the computer system has a distributed design, and the local processors—those close to the technical process—are where the digital process regulators are implemented. (Michael, 2011).

2.1.2.5 Software Components in Automation

The utilization of software components is integral to the implementation of automation in various domains such as workplaces, homes, power distribution companies, traffic and transportation systems, banking, healthcare, telecommunications, defence, and other industries (Madhav and Amit, 2022). The key factors driving the production and deployment of these components include their detachment from specific contexts, independent development, testing, configuration, subsequent reusability, as well as upgrading and replacement within active automation systems (Constantin *et al.*, 2017). It is essential to automate the creation, quality control, and deployment of software components (Christopher *et al.*, 2017). Examples of software components include programs, scripts, and the application of object-oriented programming (OOP) frameworks in automation (Ushio, 2019). Consequently, a detailed analysis of these software components follows.

2.1.2.5.1 Scripts

Scripting programming languages employ high-level functionalities to interpret and execute individual commands sequentially. By leveraging web-based services, scripting can be used to generate scripts that automate a wide range of tasks on computers or the Internet (Padma, 2018). Primarily, scripting is employed to automate procedures related to websites and web applications. This encompasses various aspects of web environments and web development, such as managing pages, sites, apps, games, system administration, multimedia, plugins, and extensions (Ethan, 2019). Additionally, scripting skills are advantageous for both front-end and back-end developers, particularly when it comes to manipulating data within a dataset or utilizing pre-existing software for specific purposes as well as computer programmers and software developers (Tuan, 2022). JavaScript, C++, and Hypertext Pre-processor (PHP) are examples of scripting languages that need to be installed on the computer in order to be interpreted. Scripting languages are quicker and simpler to learn when coding for automation. Scripting languages (Ayush *et al.*, 2021), Like all scripts, they are generally used to automate processes within individual applications. They can utilize a web server to run programs at the command line or through a web-based service, then display the required results to the users. For end developers, the use of scripting language is suitable (end developers are individuals who are not experienced, programmers). Scripting languages fall

under this category, where commands are written for an operating system or browser runtime environment.

Scripting languages, sometimes known as "scripts," have simple syntax and semantics, making them simple to learn, change, and employ with less sophisticated algorithms.

Scripts run without a specific entry point from beginning to end.

Interactive scripts make it simple to construct complicated online apps and web pages. Typically, byte code or source code is used to interpret scripts.

Scripts are referred to as supporting languages since they are made to interact and work with other programming languages. Scripts enable Application Programming Interface (API) calls and other primitives to combine with other programs in this communication process (JavierGil, *et al.*, 2017).

2.1.2.5.2 Creating a program

Creating a software application such as Robotic Process Automation (RPA) software utilizing MATLAB and Object-Oriented Programming (OOP) languages like C++ and Java. This involves defining workflow and providing support for the automation of a process. (Ayush *et al.*, 2021). This software can automate many tasks in organization. However, for more complex tasks and improved speed the user needs to learn how to program and a compiler to compile the program for the platform running the program (Ayush *et al.*, 2021). This will be discussed further in this study. Application program known as automation software can be

utilized in a variety of ways in almost every industry to reduce the need for human input (Tuan, 2022). Automation software's can be carried out by writing code, scanning it for errors, starting a code review, compiling files, running automated tests, and notifying contributors of problems so they can fix them (Ethan, 2019).

2.1.2.5.3 Object-Oriented Programming Concept in Automation framework.

In object-oriented programming, there are four fundamental principles known as the pillars: inheritance, encapsulation, polymorphism, and abstraction. These pillars, as described by Ethan (2019), play crucial roles in structuring and designing applications. Abstraction involves simplifying reality and concentrating on relevant data and processes specific to the application being developed. Inheritance allows a class to inherit methods and properties from another class, forming a hierarchical relationship among classes. Polymorphism enables multiple subclasses of the same superclass to implement their own version of shared interfaces by modifying the code of the inherited methods. These principles form the foundation of object-oriented programming, facilitating modular and reusable code structures.

Concerning object-oriented programming (Kate *et al.*, 2008), any item of interest to the software program that may be saved, processed, and transformed into data is referred to as an object. In the field of object-oriented programming, it is also known as an entity (Pankaj, 2012).

2.1.2.5.4 Polymorphism

In Java, there are two different types of polymorphism: method overloading and method overriding (Ethan, 2019).

Multiple ways to complete tasks are possible thanks to polymorphism. Examples of both overloading and overriding polymorphism techniques are as follows:

i. Compile time Polymorphism or method overloading: A class is said to be method-overloaded if it has many methods with the same name but different parameters. Java Virtual Machine (JVM) looks at the method's signature to decide which method to call at compile time. In any automation framework, it is implicit wait that is used. This is a classic example of method overloading (Pankaj, 2012). In implicit wait, there is a need to pass different parameters such as SECONDS, MINUTES ,and HOURS depending upon the requirement of the automation framework.

ii. Runtime Polymorphism or method overriding: Method overriding is the act of declaring a method that is already existing in the parent class in a child class (Ethan, 2019). Simply put, overriding refers to replacing a method's functionality with a different one.

2.1.2.5.5 Encapsulation

Code and data are bound together as one unit by encapsulation. In other words, these classes will have an equivalent public getter and softer methods and private instance variables (Pankaj, 2012).

Encapsulation is demonstrated by all Page Object Model

(POM) classes in every framework. Data members are initialized using a constructor in the POM classes that are demonstrated, and they are declared using (Ethan, 2019). All instance variable are set as private variables so that these private variables cannot be accessed directly by other TestNG classes. Then generate getter and setter methods corresponding to this private variable (Ethan, 2019). As variable are set as private variables and hide their implementation from other classes, this way encapsulation is achieved in automation frame work.

2.1.2.5.6 Abstraction

Abstraction is a technique for hiding the implementation of internal details while yet allowing users to see the functionality. Each page class in the Page Object Model (POM) design has locators like id, name, xpath,. These locators are used in the POM class, but they are not visible during the execution of the tests. Literally, locators are hidden from test. Hence, abstraction concepts are implemented in automation framework with all these locators (Ethan, 2019).

2.1.2.5.7 Inheritance

For every manual test case, there should be a develop class. But in every class, there will be some common methods that need to be reused across the automation frameworks. For instance, a base Class can be created to initialize the webDriver interface. The OOPs concept of "inheritance" is employed to allow for the reuse of these interfaces and classes throughout the framework.

Inheritance or an IS-A relation is the process of extending one class into another, and it is accomplished by using the term extends. Because there are no test methods, it is not suggested to execute the "BaseTest" class directly. As a result, classes in the framework are extended from Base Class. Every test method for class must use the @Test annotation, as is common knowledge. These methods' names ought to begin with test and end with the class name. With the aid of Aggregation or a HAS-A relationship, the appropriate POM class will now be invoked for each Test case upon execution. Hence, the concepts of IS-A relation and HAS-A relationship will be utilized by any automation framework. However, object-oriented programming was utilized for the implementation in the design of the web-based system and the mobile software application in this study. Chapter three has a record of the design details, while Chapter four contains the results.

2.2 Data collection tools and Analysis

Data collection is the methodical process of acquiring and evaluating information on important factors in order to determine the answers to research questions, test hypotheses, and evaluate results. Tools or equipment used to collect data include computer-assisted interviewing systems and questionnaires, among other examples. In addition to surveys and questionnaires, other means of data collection include case studies, checklists, interviews, and occasionally observation. A collection of graphs, maps, and diagrams are used as data gathering and analysis tools to collect,

analyses, and present data for a variety of reasons. In this study, the questionnaire was employed as a data collection tool (Appendix A), and SPSS version 22 was used to evaluate consumer responses on power consumption management and power distribution business customer service delivery.

There are many methods that can be employed for data collection and analysis. Most of them are constructed with a few basic tools. Among the techniques utilized are interviews, focus groups, observation, photography, video, records and documents, oral histories, and case studies. Data can be produced by direct measurement, appraisal of secondary data, and informal project/program management procedures. Table 2.6 shows the summary of some data collection tools and details:

Table 2.6: Some data collection tools (Sunyoung *et al.*, 2013)

S/N	Tools	Details
1	Interviews	The most frequently used tool for planning, monitoring, and evaluating is probably an interview. Interviews can be conducted one person at a time, one-on-one, or in a group. They could be spoken in a formal or informal setting. They can be conducted live, over the phone, or over Skype.

2	Focus Group Discussion (FGD)	Focus Group Discussions (FGDs) are moderated discussions with a small number of people who have expertise in or an interest in a certain topic. They are employed to discover more about the beliefs and values of a certain group of people. FGDs, which are typically conducted with 6–12 people and are designed to gather in-depth information, use a short set of leading questions.
3	Observation	At its most basic level, observation is explicitly recording information after "seeing" things like objects, processes, relationships, and events.
4	Photography and video	Both fixed and moving pictures can be seen in photographs and films. Photographs can be used alone, even though they are frequently accompanied by writing explanations that add more detail. A commentary is commonly included with videos.

5	Case studies and stories of change	<p>A case study by itself is not a technique for data collection. It's a piece of writing that can go into great detail describing something. It frequently makes use of data gathered from sources like observations and interviews. The majority of the time, case studies are given in writing, though they can also be displayed as images, films, or videos. Case studies usually focus on individuals (individuals, households, communities). They may, however, concentrate on any other analysis unit, such as places, companies, rules, or the environment.</p> <p>Comparable to case studies and change stories. Nevertheless, they are typically only created after a project or program has begun, and they have a distinct transformational purpose.</p>
6	Surveys and questionnaires	<p>These are made to consistently collect and record data from a huge number of people, groups, or organizations. A questionnaire is a form with questions on it. It can be an online form that can fill out. Sending surveys can be done in a number of ways. On the other hand, a survey is often a significant, planned project. A standard questionnaire to ensure that data is gathered and recorded consistently, an approved sampling method to ensure that the survey is representative of a larger population and a set of analysis</p>

		techniques to enable the generation of results and findings are the three main components that are typically included.
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2.3 Engineering simulation tools

Simulation is the practice of utilizing computer-based models to understand a system's behaviour and predict the impact of changes. Simulation is a useful tool for learning about, constructing, and running complicated systems (Jonathan *et al.*, 2020). Building a model of a physical system, executing it on a computer using software, and evaluating the results are all essential uses of computer simulation (William *et al.*, 2020). All physical effects that exist in the real world are faithfully replicated by simulation software. Instead of testing ideas or plans on a real system, which can be costly, time consuming, and impractical, it can be simulated by using simulation. Examples of simulation tools include specialized real-time or non-real-time computer applications and tailored generic modelling environments (Federico, 2020). In recent years, using computer simulation as a teaching tool has gained popularity. With the development of digital computers, simulation software in the domains of space, biomedicine, electrical, electronics, computer science, mechanical engineering, civil engineering, and technology has become more accurate and easier to use (Zhang *et al.*, 2021). The scope of this study is the automation of electrical power metering and distribution systems for educational and scientific purposes. The matrix laboratory/simulation link

(MATLAB/SIMULINK) and other simulation tools are used to automate electrical power metering and distribution systems. Personal computer simulation programs with a focus on integrated circuits include PSPICE, Power Simulator, SABER, ANSYS Simplorer, SIMSEN, MICROCAP, Scilab, Octave, and KREAN. Examples of simulation tools for automated power systems and FACTS Controllers include MATLAB/SIMULINK, Real-Time Digital Simulator (RTDS), Matdyn, PAST, Network Torsion Machine Control (NETOMAC), Electrical Transient Analyzer Program (ETAP), PSpice, MiPower, MATPower, EDSA, and Supervisory Control and data acquisition (SCADA). Table 2.7 shows the summary of some simulation Engineering tools and us.

Table 2.7: Some Engineering Simulation tools (Ruslan *et al.*, 2019)

S/ N	Tools	Uses

1	MATLAB and SIMULINK	High-level programming language MATLAB has an interactive environment for technical calculation and visualization., while SIMULINK is an interactive tool for modeling, simulating, analyzing, and designing dynamic systems. The built-in block library can be used to build systems utilizing a set of tools provided by SIMULINK. Additionally, it makes it possible to create unique blocks using C/C++, FORTRAN, JAVA, or MATLAB code. Due of these qualities, MATLAB/SIMULINK is a desirable choice for power systems research. The latest recent version of MATLAB is R 2020a.
2	PSIM	A simulation tool called PSIM was created primarily for motor control and power system studies.

3	PSPICE	It is a Microsoft Windows-based analog and digital simulation software tool. It's a tweaked version of SPICE for the PC. It is widely used in both analog and digital systems.
4	COMSOL MULTIPHYSICS	In addition to simulation of Partial Differential Equations (PDE) and physics-based interfaces, the software offers an IDE for mechanical, electrical, fluid, and chemical applications.

5	CASPOC	Power system and electric drive modeling and simulation are done using the CASPOC simulator. Additionally, it is utilized in electrical and mechatronic devices.
6	SIMSEN	It's a piece of digital simulation software for analyzing power systems, variable-speed drives, and hydraulic systems.
7	ANSYS Simplorer	For researching and simulating entire power electronics and control systems, there is simulation software that spans multiple domains and technologies. It can incorporate system-based modeling methods and modeling languages into the same schematic.
8	SABER	Modeling, simulation, and analysis of physical systems are all done with SABER. It can be used in analog electronic/power systems, and Mechatronics.
9	SCADA	A plant's activities may be portrayed by a computer program known as a Supervisory Control and Data Acquisition system (SCADA) simulator, which is based on a Human Machine Interface.

2.3.1 Relevance of MATLAB Tools

MATLAB is the go-to tool for industry research, development, and analysis with a high rate of productivity. In MATLAB, there are many kinds of application-specific solutions called toolboxes. The majority

of MATLAB users depend on toolboxes because they enable them to comprehend and utilize particular technologies. MATLAB includes the following tools:

2.3.2 Graphical user interfaces with MATLAB

User interface is a technology that facilitates human-machine communication. It is the visible portion that serves as the user's interface for communicating with, reading, and sending commands to the technology or machine (processor) hidden behind the surface. The user interface allows the computer and user to communicate and exchange instructions. There are three techniques to create user interfaces in MATLAB. The processes for creating Graphical User Interfaces with MATLAB have evolved along with the program's advancements. These three methods include using Graphical User Interface Development Environment (GUIDE) and App Designer programmatically. Each of these approaches to app development differs slightly in terms of functionalities and the development process. Depending on the requirements, a method may be chosen.

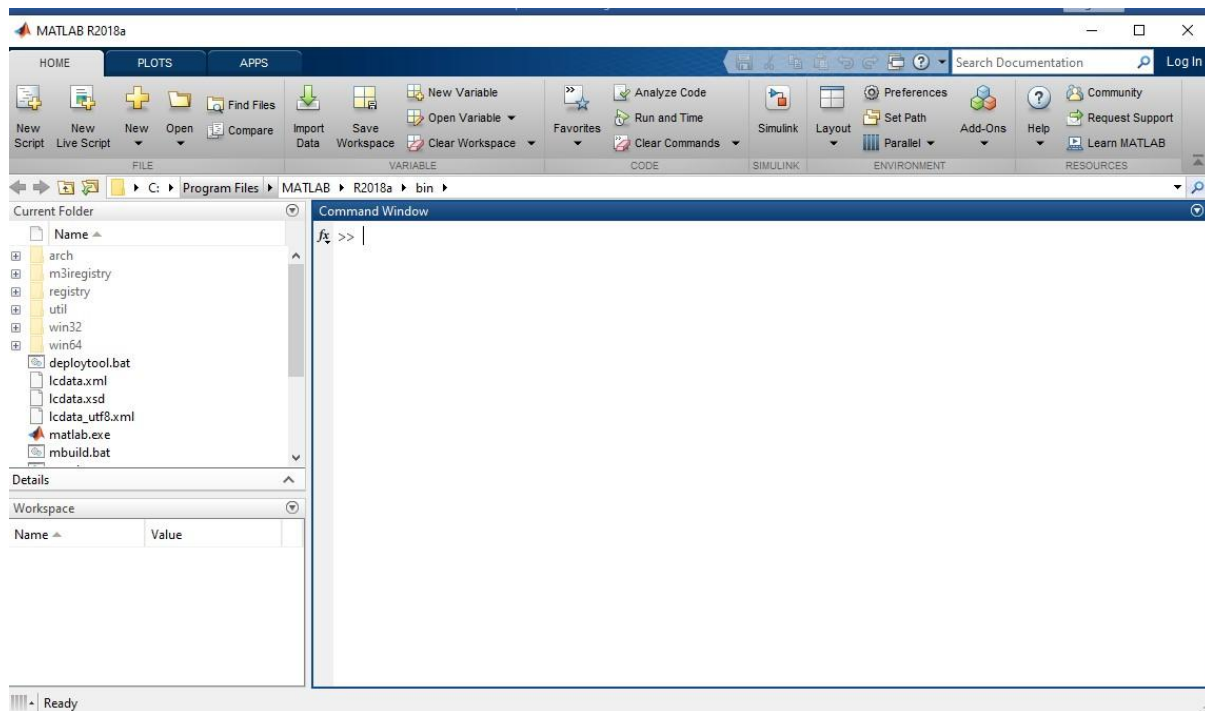


Figure 2.17: MATLAB environment

2.3.3 Programmatically

Making an application programmatically entails creating its whole structure and functionality using MATLAB functions in the code editor. Making a function and adding code to it to create the figure window is the first step in constructing an application programmatically. Figure refers to a window that appears as a result of an application or another output (MathWorks, 2019).

2.3.4 GUIDE

The Graphical User Interface Development Environment (GUIDE) for MATLAB allows users to design, build, and modify user interfaces. By entering guide into the command window in MATLAB,

user may either access an existing GUI or create a brand-new one. The basic components of graphical user interfaces can be easily added to interfaces with the use of GUIDE. In comparison to the programmed approach, adding the buttons and designing the window layout are easier (Marko , 2020). The GUIDE program for building a graphical user interface consists of two files: a regular MATLAB file (M-file,.m) and a figure file (F-file,.fig), which is the file containing the graphical user interface's figure.

2.3.5 App designer in MATLAB

The Appdesigner (Marko , 2020) is structured to make effectively an expert programming application in MATLAB (variant > 2016). It almost shares the same philosophies and controls as GUI (Graphical User Interface) The App Designer has two main functions. A tool bar has a visual component that is ready to use with the program it has integrated. The component is activated by dropping it on the work surface. The editorial manager for embedded programming allows for the addition of new properties, callbacks, and other features. It is easier to understand, modify, and use because of the quick transitions between the application code and the visual plan. Additionally, the MATABL Compiler enables the conversion of this program into a standalone work area and online apps with their own installation package and the provision of eminence-free versions of both (Tara *et al.*, 2017)

The components' layout is contemporary, and there are more of them overall. New parts like gauges, lamps, knobs, switches, and indicators are included in Appdesigner. The software creates object-oriented code automatically to manage these components. A callback function is used to manage the program's functionality. When a user interacts with a user interface component, the function callback is called. All components, with the exception of those that merely display information, allow callbacks (MathWorks, 2019).

2.4 The Web-based system

This is a system that uses internet web technologies and provides a range of multimedia technology benefit. Modern broadband connections enable the streaming of attractive and well-designed content to a computer from any location in the world. For many people, this is advantageous because they can access the information whenever and whenever it is convenient for them, which might be important for a busy executive. The internet now provides a sizable volume of interactive multimedia information (Epstein, 2022). One or more web apps, intricately functional components, information components, and other non-web components are typically included. Typically, a web browser is used as the front-end and a database as the back-end. A web site is the frontend, content displaying interface through which global users interacts with an entity over the internet (Sandra and Jayasudha, 2012).

A web-based system engages users and assigns duties in addition to delivering information to help businesses achieve their goals. Compared to catalog, directory, and advertisement websites, which frequently provided information to customers in a unidirectional manner, its analysis and design process adopt a totally different methodology. The website accomplishes the goal of enabling energy users to buy units without going to the utility company in order to have power in their own homes.

2.4.1 Technologies for Web-based systems

The tools and programming technologies used in a web-based system are crucial. For any proposed system, a set of criteria for the development environment, libraries used, and technologies must be established.

Web technologies are frequently classified into categories based on their intended usage. Web applications may experience this on either the client or server side. Understanding web development technologies such as browsers, HTML and CSS, programming languages, frameworks, web servers, databases, protocols, and data formats is important. Figure 2.18 presents some of the summary of web technologies.

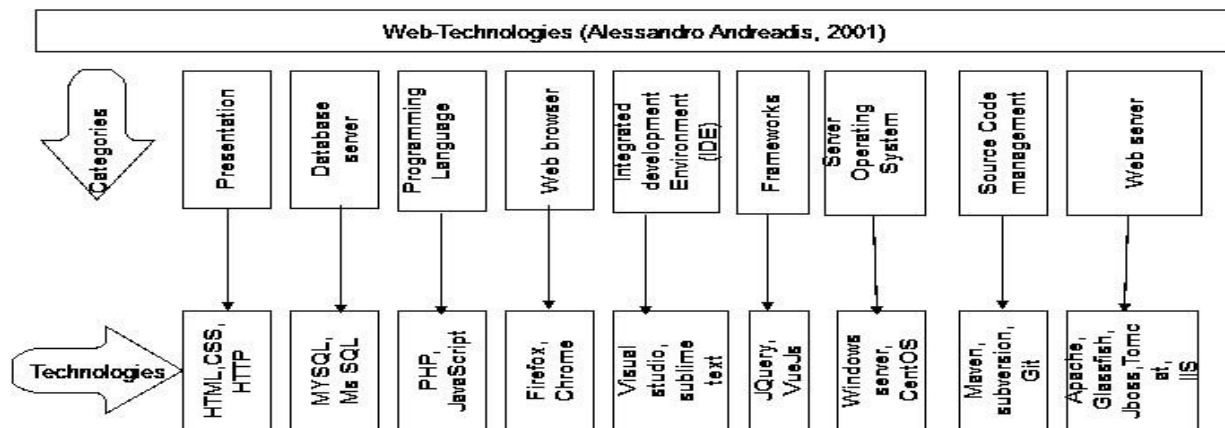


Figure 2.18: Summary of Web technologies (Elena *et al.*, 2014).

The following is a brief description of the Web technologies categories:

i. The Presentation

One of the most common presentation formats is Hypertext Markup Language

(HTML). The most popular markup language for online pages is HTML Others include

Dynamic Hypertext Markup Language (DHTML), a web technology that uses

JavaScript to create animatedly changing websites. CSS and the document object mode

(DOM), as well as the extensible Hypertext Markup language (XHTML) (XHTML).

After a page has been designed, the HTML instructs the browser what to display.

ii. Database Servers

In relational database management systems (RDMS), a database server is a piece of software that runs database applications and stores data. RDMS implementations include MYSQL, Oracle database, Sybase, Informix, Postgres, and Microsoft SQL (Ginige and Murugesan, 2001).

iii. Programming Languages

Web programming is the writing, coding, and markup involved in creating websites; popular languages include XML, Perl, Python, PHP, JavaScript, and ASP.NET. The two types of computer languages utilized in the development of automated metering, power management, and monitoring systems are server-side scripting languages and client-side scripting languages. Java server page (JSP), ASP, PHP, and ASP.NET are examples of server-side scripting languages. Together with HTML, the client-server scripting language JavaScript is used to build Web-based systems.

iv. The Web Browser

An application called a web browser enables users to look for, access, and view web pages. Browsers are commonly used to view and access webpages on the Internet, as well as other content published in HTML, XML, and other related technologies.

v. The Integrated Development Environment (IDE)

An aid for developing applications is the Integrated Development Environment (IDE) (Nginx, 2015). An IDE, in general, is a

workbench with a GUI that aids developers in creating software by providing an integrated environment with all necessary tools.

Popular IDEs include Sublime Text, NetBeans, Eclipse, and Microsoft Visual Studio.

Language-based IDEs such as Java Development Environment include JDK, OpenJDK, and JRE. A debugger, build automation tools, and a source code editor are all components of an IDE.

vi. Frameworks

A software framework called the Web application framework (WAF) helps programmers create web applications including web services, web resources, and web APIs.

vii. The Server operating system

Server operating systems are used to run web application software. Windows operating systems can support web servers, although Linux based operating systems are popular for Web base systems. Some examples are CentOS (Community Enterprise System), Arch Linux, Ubuntu 15.04, Slackware Linux 14.1 to mention a few.

viii. The Source Code Management (SCM) Systems

These are systems which provide resources and tools to manage source codes artifacts for a given project. Like in the case of SCM includes Git, Maven and Subversion (SVN). Git and Subversion provides resources for managing source codes while Maven

facilitates lifecycle management and dependency management during the development process of a systems.

ix. The Web Server

The Web server is the software that runs on server machines and provides the basic function of serving web pages over the internet.

All web applications run on a web server. Such as SAP, BPEL4WS, SOAP, CBSE, J2EE, .NET, Apache, Lighted, Cherokee, Glassfish, jboss, Tomcat, IIS, Hiawatha and Nginx.

2.4.2 The Design Methodologies for Web-based systems

The waterfall, iterative development, and evolutionary approaches are the origins of the development process and design methodologies (Howard *et al.*, 2017). The object-oriented programming, and agile software are some of the more contemporary methodologies. For web-based applications, these models are rarely employed. Model-driven web development and component-based engineering are two more design methodologies highly advocated for web-based systems.

2.4.3 The Architecture, Implementation, and Deployment of Web-based systems

Architectural design requires comprehending how a system should be structured and creating the overall structure of that system. Typically, this is the initial stage of the software development process. It acts as a crucial link between design and requirement engineering by defining the system's essential structural components and their interactions. Software architecture has an impact on a system's performance,

resilience, and maintainability (Sergio and Giuditta, 2012). A web-based system's service has two distinct components from the standpoint of implementation: a logical component that provides the service's fundamental functionality and an XML interface that defines how to make a request to the service and the format of the expected response (Giuseppe *et al.*, 2016). Traditional web-based systems provide functionality by executing scripts on the server or client side, and this can be done in the cloud. They provide web portals with advanced functionality with some basic features. Web pages and other web material make up a web-based system.

2.5 Hardware Components in Automation

Automation fills in large gaps in present manual operations by using hardware systems and components, such as Actuators (for example, relays), Sensors for wireless technology, and Microcontrollers (Sangeetha *et al.*, 2022). Error propensity: Because so many of the steps are performed manually, the process is extremely prone to error (Sangeetha *et al.*, 2022). As a result, there are a sizable number of unnecessary, meaningless, and expensive recursions. Innovation roadblocks, waste of skills necessitating the hiring of more skilled hardware developers, and a relatively small scope of the innovative element of development that creates consumer value (David, 2021). As a result, more details about these hardware components will be covered.

2.5.1 Actuators

These are pieces of hardware that transform the signal from a controller command into a modification of a physical parameter (Fan *et al.*, 2018). Additionally, it's a device that modifies energy and signals before introducing them into a system to generate motion. (Ruiyang *et al.*, 2021) as shown in Figure 2.19. It can provide either linear or rotational motion. Typically, linear actuators travel in a straight path back and forth. Rotatory actuators, on the other hand, move in angular degrees in relation to a circle's midpoint. Binary actuator, which has two states, is another illustration of an actuator. A relay is an example of a binary actuator since it can only have one of two stable states—either it is powered on and latched or it is powered off and unlatched (Ahmed *et al.*, 2020).

The binary actuator that was used in this investigation is a relay.

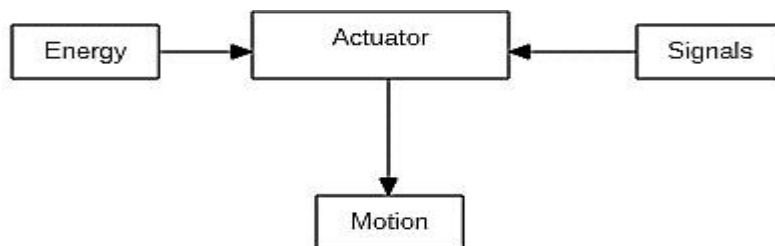


Figure 2.19: An Actuator (Ruiyang *et al.*, 2021)

2.5.2 Wireless Technology

When there isn't an electrical conductor between two or more places, information or power can be transmitted wirelessly between them (Nan *et al.*, 2015). The most widely utilized wireless technologies make use of radio waves. Communication at extremely short distances,

like a few meters for Bluetooth, or extremely large distances, like millions of kilometers, is made possible via radio waves. Radio wireless technology is used by two-way radios, personal digital assistants (PDAs), mobile phones, and GPS systems (Abdurahman *et al.*, 2022). It is neither feasible nor practical to provide the long-range communications and other services made possible by wireless operations using cables. Although, it can also be implemented for short ranges in which wires can be used.

Microwaves, which change the characteristics of electromagnetic waves conveyed through space, can also be used for wireless communication. It can also be done using free-space optical (FSO) communications, an optical communication method that employs light to wirelessly convey data for telecommunications by propagating in free space.

2.5.3 Sensor Technology

A sensor captures a physical amount and converts it into a signal that an instrument or observer can decipher (Chugh *et al.*, 2019). The objectives of sensor include provide more safety, utilize maximum time and increase productivity in industry. Sensors are an innovative choice for measuring current and voltage in a medium voltage power system as used in Automated Metering power management and monitoring system (Nikolay *et al.*, 2022).

A field of study known as sensor technology uses sensors to identify amounts of physical, chemical, or biological qualities and transform

them into auditory signals. For nearly any industrial need, there are numerous types of sensors available, including smart sensors, tilt sensors, motion sensors, position sensors, temperature sensors, heat sensors, ultrasonic sensors, and wireless sensors.

The basic components used in sensor network: Microcontroller, Transceiver, External memory, power source and sensor. as shown in Figure 2.20.

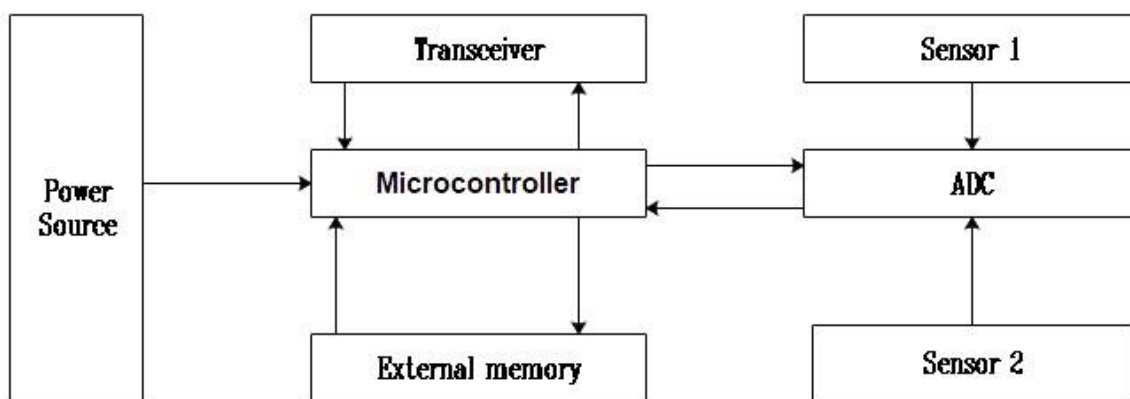


Figure 2.20 Flow diagram of Sensor Technology (Nikolay *et al.*, 2022).

In the flow diagram, there are two sensors, a transceiver, a microcontroller, external memory, and a power source. The sensor detects the signal, the microcontroller responds to the signal by the transceiver, and the external memory stores the data.

Sensor technology systems can provide improved maintenance, safety, time

saving in life and industry. As a result of the signal received via Sensors attached to a computer, that commands are given via the computer to transceiver actuators based on the analysis of the signal

received. Sensor technology has an important role in our daily life. Sensor sensitivity indicates the responses of sensors to changes in measured quantity through its output. For instance, the skin, ears, eyes, and nose act as sensors as they feel a sense of touch, heat, light, noise, and smell as well as react to each feeling accordingly. For accuracy, most of the sensors in a computer are calibrated against some known standards.

2.5.4 Sensors Network

The wireless communication network has many benefits over the conventional wired network, and it makes it possible to create compact, affordable, low-power, and multipurpose sensing devices (Ian *et al.*, 2007). These tiny sensors are capable of sensing, processing, self-organization, and communication. A sensor is a very small device that measures the ambient conditions in its environment, collects data, and processes it to provide some useful information that may be used to identify occurrences in the environment (Priyanka *et al.*, 2013). Using mesh networking protocols, these sensors can be joined together to create a network that communicates wirelessly across radio frequency channels. Wireless sensor network (WSN) is the term used to describe the aggregation of this homogeneous or heterogeneous sensor node (Zia and Zomaya, 2020). The sensor nodes can be placed in a high number in an area that has to be explored due to their low cost, small size, and ease of deployment

2.5.4.1 Components of a Wireless Sensor Network (WSN)

The sensor nodes, sink (base station), and events being monitored make up a general WSN's major parts.

2.5.4.2 The functional units of a sensor node

In a WSN, each sensor node is equipped to collect, process, and transfer data to the desired location. The fundamental components of sensor nodes include units for sensing, power, computing, and memory.

i. Sensing Unit

Sensors are crucial to sensor networks because they establish a link between the physical world and the computing world. A piece of hardware that keeps an eye on and responds to changes in the environment of a particular area. Sensors collect information by sensing the environment, transforming it into basic information (such as current or voltage), and transferring it to be analysed. It transforms the analogue data into digital data before sending it to the microcontroller for additional processing. Various sensors may be used, depending on the sort of operation that is intended. When selecting sensors, the size and energy needs are the two most crucial considerations.

ii. Memory Unit

This sensor node unit stores data as well as program code. Data packets from nearby (other) nodes are stored in Read Only Memory (ROM). The computer code is also stored in flash memory or Electrically Erasable Programmable Read-Only Memory (EEPROM).

iii. Power Unit

In order to compute and transmit data, the relevant sensor node units require power.

A power unit that is responsible for supplying electricity to all of the other

units in a node. The two main power-consuming processes at the node are computation and transmission, with transmission at the sensor node using the most power. Most sensor nodes run on batteries, but they can also use solar cells to harvest energy from the environment (Manikandan and Purusothaman, 2010).

iv. Processing Unit

A microcontroller that has a processing unit, memory, converters (analogue to digital (A/D), timer, and Universal Asynchronous Receive and Transmit (UART) interfaces) performs the processing tasks for the sensor node. Data collection, information processing, routing information implementation and modification, and consideration of transmission performance circumstances are all the responsibility of this unit.

2.5.4.3 The sink (Base Station)

An interface between the computational world, which is a sensor network, and the external world management center is the sink. The sink is a resourceful node with unrestricted energy and computing capabilities (Xiangui *et al.*, 2018). A network may contain a single base station or several. Employing many base stations practically

reduces network delay and improves performance when using robust data collection.

2.5.4.4 Wireless Sensor Network (WSN) Operation

WSN functioning typically entails base station and sensor node communication. The sensor node analyzes its surroundings, makes some calculations as needed, and relays the information to the base station. If the base station is connected to an actuator that activates in the case of an interesting event, raising the alarm for human action (Kiran *et al.*, 2011).

2.5.4.5 Communication Model

Despite being identical, each sensor node has unique properties within the network topologies. The positioning of sensors, their coverage, power transmission, computing, reporting, addressing, and communication patterns all have a big impact on how the routing protocol behaves at nodes and base stations. The one-to-one, one-to-many, and reverse-multicast routing protocols used by WSNs are all supported.

i. Node-to-Node

In multi-hop communication, which involves data transfer from a device through an adjacent node to a final destination node, each node selects a destination and these may be the destination of multiple streams of data.

ii. Node-to-Base Station

This form of communication, which involves numerous based stations, is also known as unicast. Reversed multicast communication occurs when many sensor nodes relay their responses back to the base station.

iii. Base Station-to-Node

Any available nodes get this form of communication from the base station. with the information the base station needs. Anycast (one-to-many) is the name of this type of communication, and unicast or multicast communication patterns are both possible.

2.5.4.6 Classification of Sensor

Active and passive sensors are the two main types. Passive sensors are further divided into different groups based on their technological properties, output signals, sensor materials, and fields of application.

2.5.4.6.1 Active Sensors

Active sensors stimulate their surroundings in order to gather data. Examples include sonars, seismic sensors, laser scanners, infrared sensors, and other tools.

2.5.4.6.2 Passive Sensors

These sensors can generate data even in the absence of external triggers. Thermometers, humidity sensors, light sensors, pressure sensors, and other sensor types are some examples of these.

2.5.4.6.3 Narrow Beam Sensors (Passive)

For this kind of passive sensor to gather information from its surroundings, a clear direction is necessary. Cameras and ultrasonic sensors are two examples.

2.5.4.7 Application of Wireless sensors network

Wireless sensors are used in a wide range of real-world applications, such as power distribution, home automation, business environments, air pollution monitoring, fire detection, landslide detection, and military contexts. The program addresses numerous problems in engineering and other disciplines.

2.5.4.7.1 Line-of-Sight (LOS) with RF wireless transceiver devices

A clear Line-Of-Sight (LOS) and low power in wireless communication are required for long-distance microwave point-to-point link performance. The signal must be received along the selected link path with a clear line of sight and without any interference. Future network architecture changes would be required in the event of any unanticipated performance issues, adding to the overall cost. Despite the apparent visibility of the distant site, a Fresnel zone object may obstruct radio line-of-sight (s).

The line-of-sight passage between the end node and the gateway is surrounded by the Fresnel zone, an elliptical-shaped body. Depending on the link distance and frequency channel, the elliptical area immediately surrounding the visual link path changes. For instance, even though there is a direct line of sight between the end node and the gateway, a hard object in the shape of a barrier, such as a mountain ridge, trees, hilltops, or building(s), too close to the signal path can decrease the broadcast signal. Thereby reducing the strength of the radio signal and the planned received signal level will not be achieved: Even though the obstacles does not obscure the direct visual line-of-sight (direct wave). As illustrated in Figure 2.21, the clearance needed

for the Fresnel zone should be determined and taken into consideration while building the link path (Bor and Roedig, 2017)

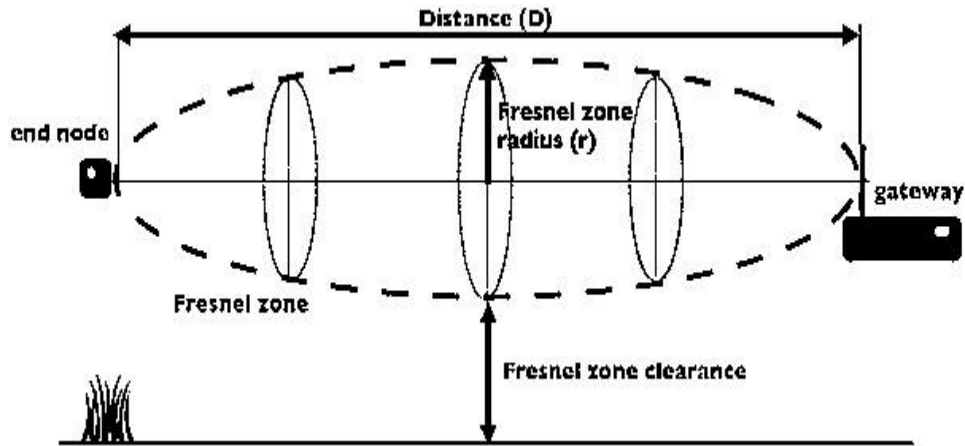


Figure 2.21: The Fresnel zone calculation (Bor and Roedig, 2017)

The maximum radius of the Fresnel zone, which is halfway between the end and the gateway, is determined by Equation 2.37:

$$r = 8.657 \times \sqrt{D} / f$$

(2.37)

where:

r =

Radi

us in

meter

D =

Dista

nce

in km

f = frequency in GHz. The Fresnel zone radius in equation 2.37 is based on a flat earth. It does not take curvature of the earth into consideration.

As part of the RF long-range (LoRa) wireless transceiver's dependability testing. The wireless sensor used in the design of the Automated metering, power management, and monitoring system (AMPMS) was LoRa RF transceiver module based on SEMTECH's SX1278 chip. Figures 2.22 and 2.23 depict the Fresnel zone with no interference and earth curvature.

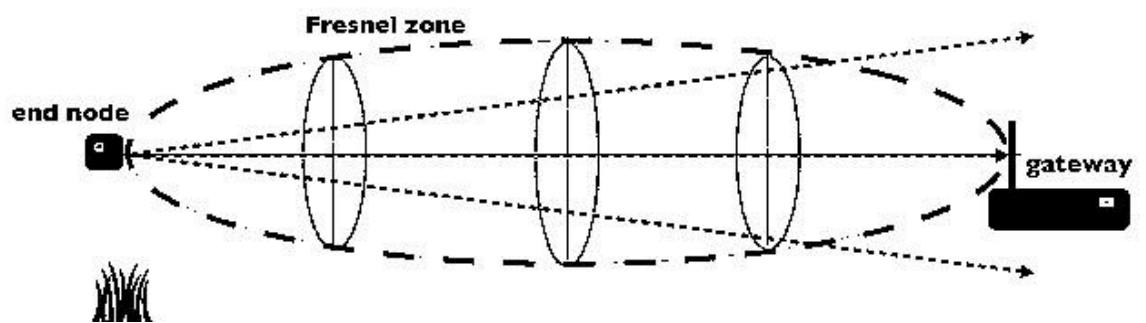


Figure 2.22: The Fresnel zone without interference (Bor and Roedig, 2017).

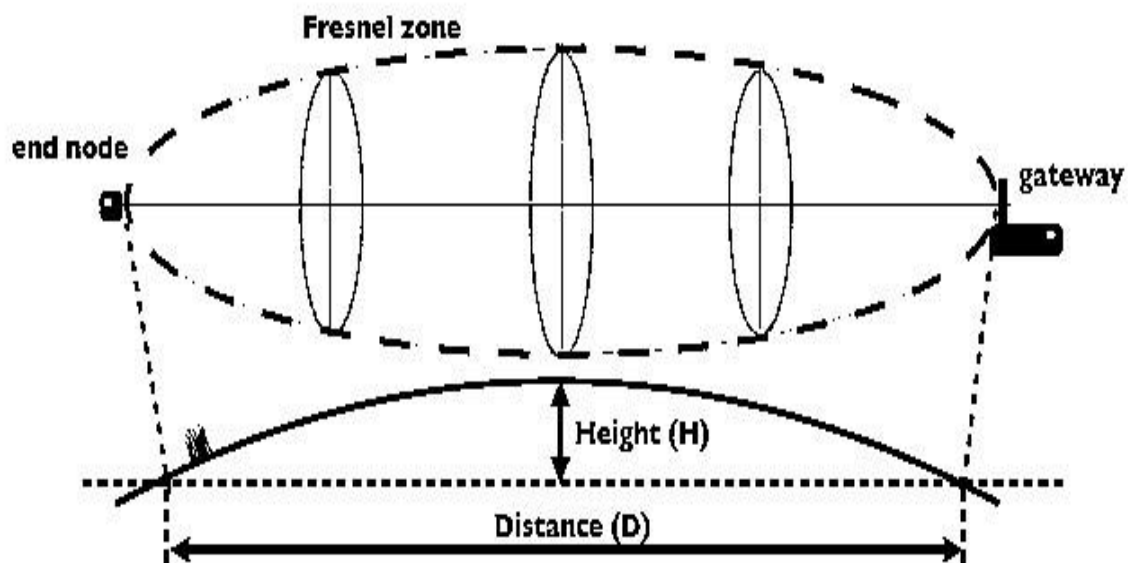


Figure 2.23: The Fresnel zone with the Earth Curvature (Bor and Roedig, 2017)

2.5.6 Microcontroller

A microcontroller refers to a compact microcomputer that is employed for controlling embedded systems across diverse products such as automobiles, robotics, office equipment, and home appliances (Hari *et al.*, 2021). It comprises various components, including a CPU, memory, and peripherals. These components typically include a clock, input/output (I/O) ports, read-only memory (ROM), random access memory (RAM), and a central processing unit (CPU) are some of the components that make up a microcontroller (Torikpa, 2022). Microcontrollers are classed based on their memory, architecture, bits, and instruction sets. This applies to microcontrollers such as the 8051 and Advanced Virtual RISC (AVR) Microcontrollers used in Arduino,

the latter of which is merely a physical platform for an AVR microcontroller (i.e., a breakout board) (Balwinder *et al.*, 2019). Figure 2.24 and Figure 2.25 show the 8052 Microcontroller and its memory map while Table 2.8 and Table 2.9 depict the Arduino Microcontroller with its features and Atmega328p pins description. Also, the block diagram of AVR-based Arduino nano ATmega328p and pin map are shown in Figure 2.26 and 2.27 while Table 2.10 shows some tools of Android -Architectures.

2.5.6.1 The 8052 Microcontroller

The 8052 is an 8-bit microcontroller widely used in the development of embedded systems

Features of the 8052 are summarized below

- i. 8K Bytes of In-System Reprogrammable Flash Memory
- ii. Endurance: 1,000 Write/Erase Cycles
- iii. Fully Static Operation: 0 Hz to 24 MHz
- iv. 256 x 8-bit Internal RAM
- v. 32 Programmable I/O Lines
- vi. Three 16-bit Timer/Counters
- vii. Interrupt Sources
- viii. Programmable Serial Channel
- ix. Low-power Idle and Power-down Modes

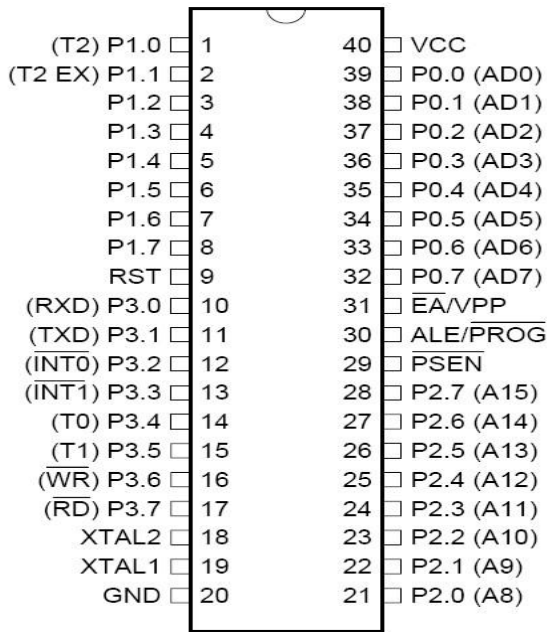


Figure 2.24: The 8052 Microcontroller (Hari *et al.*, 2021).

0F8H								0FFH	
0F0H	B 00000000							0F7H	
0E8H								0EFH	
0E0H	ACC 00000000							0E7H	
0D8H								0DFH	
0D0H	PSW 00000000					SPCR 000001XX		0D7H	
0C8H	T2CON 00000000	T2MOD XXXXXX00	RCAP2L 00000000	RCAP2H 00000000	TL2 00000000	TH2 00000000		0CFH	
0C0H								0C7H	
0B8H	IP XX000000							0BFH	
0B0H	P3 11111111							0B7H	
0A8H	IE 0X000000		SPSR 00XXXXXX					0AFH	
0A0H	P2 11111111							0A7H	
98H	SCON 00000000	SBUF XXXXXXXX						9FH	
90H	P1 11111111					WMCON 00000010		97H	
88H	TCON 00000000	TMOD 00000000	TL0 00000000	TL1 00000000	TH0 00000000	TH1 00000000		8FH	
80H	P0 11111111	SP 00000111	DP0L 00000000	DP0H 00000000	DP1L 00000000	DP1H 00000000	SPDR XXXXXXXX	PCON 0XXX0000	87H

Figure 2.25: Memory map of the 8052 microcontrollers (Hari *et al.*, 2021).

2.5.6.2 8052 Microcontroller On-Chip UART for Rs-232 Serial Communications

The main processor of the microcontroller supports serial communication. A universal asynchronous receiver/transmitter (UART) package is also available (Dawoud and Peter, 2022). The data transfer uses port 3. Transmit is bit one, and receive is bit zero.

Since this port is full duplex, it can send and receive data concurrently (Roberts and Suraweera, 2022). Due to its receive-buffered nature, the system has the ability to commence the reception of a second byte even before reading the previous byte from the receive register.

Software implementation is fairly straightforward because the microcontroller is designed for communications. A message is transferred using the buffer, the speed is set, and a flag is checked to see if the message has been completed. The only thing needed for integration is a technique for converting the higher voltages of serial RS232 to the chip's Vcc (Roberts and Suraweera, 2022). A discrete circuit can be created, however commercial interface chips are far more affordable. Serial communications use a number of ICs, including MAX232.

2.5.6.3 Generating Baud rates Using the 8052 Microcontroller

The UART's mode of operation is controlled by the serial control register (SCON). This establishes whether the baud rate is fixed or changeable. The numerical value is entered into timer 1 if the rate is variable.

Timer 1 would be utilized in the auto reload mode for serial connections. The serial communications can run continuously in this

auto-reload timer mode without further program activity. Auto reload is set up as mode 2 for timer 1 in the timer mode (TMOD) register.

1. MODE 0

$$(2.38) \quad \text{Baud Rate} = \frac{\text{Oscillator frequency}}{12}$$

2. MODE 1

The baud rate for eight-bit data in Mode 1 is configurable. If available, either Timer 1 or Timer 2 can provide the baud rate.

$$(2.39) \quad \text{Baud Rate} = \frac{\text{Oscillator frequency}}{132 \times 12 \times [256 - TH1]}$$

The estimated baud rate can be doubled using a multiplier (K). The power controls

(PCON) register contains the SMOD bit. K is equal to 1 if SMOD = 0.

K is equal to 2

if SMOD = 1. While the PCON register cannot be used to address bits,

logically ORing the PCON register (orl PCON, # 80H) is one method

of setting the bit. PCON may be found at 87H. The high byte of Timer

1 contains the baud rate reload time

(TH1). The formula for calculating TH1 may be expressed as:

$$(2.40) \quad TH1 = 256 - \frac{\text{Oscillator frequency}}{32 \times 12 \times \text{Baud Rate}}$$

3. Mode 2

In Mode 2, the baud rate is predetermined when using 9-bit data. The specific baud rate is determined based on the value of the SMOD bit found in the PCON register, it is either 1/32 or 1/64 of the oscillator frequency. None of the timers are utilized in this mode; instead, the internal phase-2 clock serves as the timekeeper. SMOD = 1 and 1/32 Osc Freq is the Baud Rate. SMOD = 0 and 1/64 Osc Freq is the Baud rate. Use or 1 PCON, # 80H to set the SMOD bit. PCON may be found at 87H.

4. Mode 3

Mode 3's variable baud rate is configured exactly like mode 1. Hence, 9-bit data transfer is possible.

2.5.6.4 Timer/Counter 2 Baud Rates

It is possible to use Timer 2 in baud-rate generating mode. The following equation gives the baud rate when Timer 2 is clocked through pin T2 (P1.0).

$$(2.41) \quad \text{Baud Rate} = \frac{\text{Timer 2 Overflow Rate}}{16}$$

The following equation provides the baud rate for internal clocking of serial communications

$$(2.42) \quad \text{Baud Rate} = \frac{\text{Oscillator frequency}}{32 \times [65536 - (RCAP2H, RCAP2L)]}$$

Table 2.8: Arduino microcontrollers and features (Islam and Mustaqal, 2017).

S/N	Types of Arduino Microcontroller	Features
1	Arduino Micro	Its features are identical to those of the Arduino Leonardo. The absence of a DC input jack is the only distinction.
2	Arduino MKR Zero	A development board called the Arduino MKR Zero is designed for music-making or music-related projects. It includes a built-in SD connector and a specific SPI interface for I2S communication. The most popular digital audio communication protocol is I2S.
3	Arduino MKR WIFI 1010	For fundamental IoT and pico-network applications, use the MKR Wi-Fi 1010. It can run when a LiPo battery is used as power.

4	Arduino Nano	The Arduino Nano is a compact version of the Arduino UNO that can be easily accommodated on a breadboard. The main distinctions between the Nano and the UNO are the presence of a USB-TTL converter chip and the utilization of a Mini USB connector instead of a USB B port. The Nano incorporates an FT232 chip, which is a dedicated USB-UART bridge chip manufactured by FTDI, in place of an ATmega16U2. It is a pretty well-liked option among developers as well. It is compact, easily accessible, and reasonably priced.
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2.5.6.5 Overview of the Microcontroller

The aforementioned microcontrollers' features have been carefully examined. Although other microcontrollers have some excellent qualities for use in different applications, the Arduino Nano Microcontroller is the most appropriate option for this study's main objective. The Arduino is really simple to use and understand. It employs a flexible, condensed version of the C/C++ programming language.

The goal is to produce these designs with minimal programming or microcontroller knowledge. The Nano features pin headers, making it practical for PCBs or breadboard prototyping when using a socket. For larger applications, Arduino Nano boards are cost-effective because they are frequently the least expensive alternative.

2.5.6.6 The AVR-based Arduino Nano ATmega328p Microcontroller

The microcontroller is constructed on the RISC architecture with AVR enhancements and operates as an 8-bit, low-power CMOS device. It achieves a processing speed of 1 MIPS per MHz by efficiently executing robust instructions within a single clock cycle. This capability allows system designers to strike a balance between power consumption and processing speed according to their requirements. (Islam and Mustaqal, 2017).

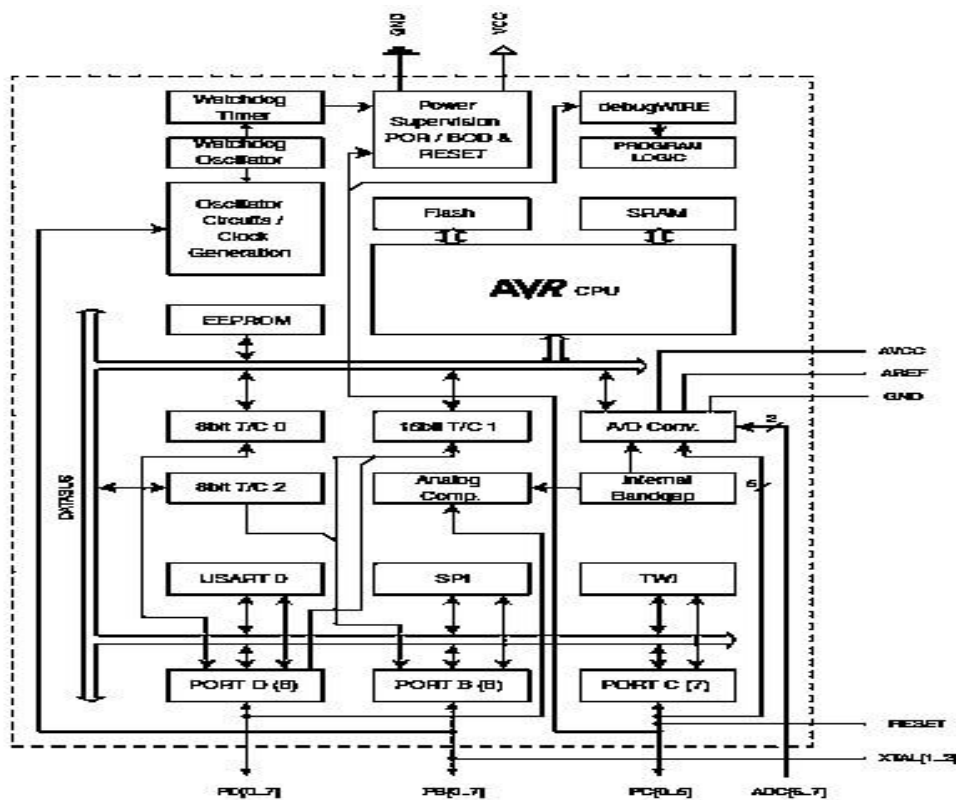


Figure 2.26: Block diagram of AVR-based Arduino Nano Atmega328p

(Islam and Mustaqal, 2017).

The AVR core incorporates a diverse instruction set along with 32 general-purpose working registers. These 32 registers are directly connected to the Arithmetic Logic Unit (ALU), enabling

simultaneous access to two independent registers in a single instruction executed within a single clock cycle. In this design, a 16Mhz microcontroller was used and it was programmed using Arduino IDE with C/C++ programming language. To use Arduino to program Atmega328p, the Arduino-toAtmega328p pin mapping must be taken into consideration. The mapping is shown in Figure 2.27.

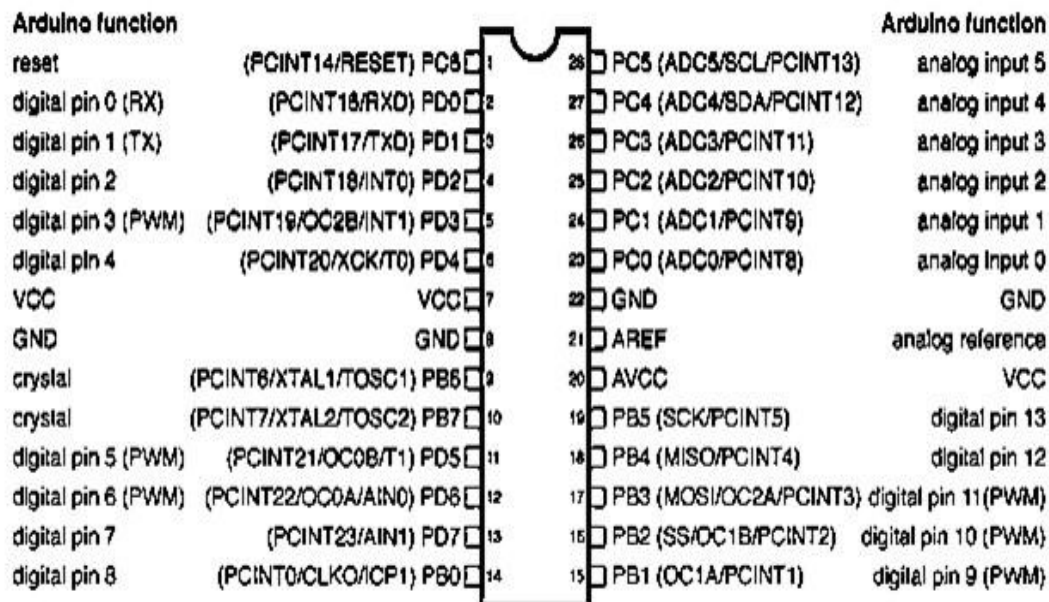


Figure 2.27: ATmega328p Arduino pin map (Hossain *et al.*, 2022)

A module incorporating the ATmega328p, crystal oscillator, and other programming-related components is used for this work to simplify the programming and interfacing of the microcontroller. A 28-pin, 8-bit microcontroller with 32kb of flash memory and read-write functionality, the ATmega328p has these features (Hossain *et al.*,

2022). The pins on the ATmega328p microcontroller are described in Table 2.9.

Table 2.9: ATmega328p Pins Description (Hossain *et al.*, 2022)

Pin Number	Description	Function
1	PC6	Reset
2	PDO	Digital pin (Rx)
3	PD1	Digital pin (Tx)
4	PD2	Digital pin
5	PD3	Digital pin (PWM)
6	PD4	Digital pin
7	VCC	Positive Voltage (Power)
8	GND	Ground
9	XTAL1	Crystal Oscillator
10	XTAL2	Crystal Oscillator
11	PD5	Digital pin
12	PD6	Digital pin
13	PD7	Digital pin
14	PB0	Digital pin
15	PB1	Digital pin (PWM)
16	PB2	Digital pin (PWM)
17	PB3	Digital pin (PWM)
18	PB4	Digital pin
19	PB5	Digital pin
20	AVCC	Positive voltage (ADC) power
21	AREF	Reference voltage
22	GND	Ground
23	PC0	Analog input
24	PC1	Analog input
25	PC2	Analog input
26	PC3	Analog input
27	PC4	Analog input
28	PC5	Analog input

A 1000 write/erase cycle endurance rating for the ATmega328p microcontroller indicates that it may be erased and programmed 1000 times without suffering any damage. Due to its widespread use on the Arduino board, the ATmega328p microcontroller is frequently referred to as an Arduino-based microcontroller. This design is an embedded system solution to the

problem of power management, monitoring, and billing. The design code can be found in Appendix B.

2.5.6.1 Time Delay using Timer on Arduino Nano with ATmega328P (C Language)

The timers on the Arduino nano microcontroller can be used to generate PWM signals or measure the passage of time. The internal clock source controls the timing of this timer. In this instance, the Timer is a unique countdown timer (Khan, 2020). The device features three timers with the following specifications:

Timer 0: It is an 8-bit timer that supports PWM functionality on chip pins 11 and 12.

Timer 1: It is a 16-bit timer that enables PWM on chip pins 15 and 16.

Timer 2: This is an 8-bit timer that supports PWM on chip pins 17 and 5.

The delay function uses mill's, which itself uses Timer 0.

The Clock Frequency of ATmega328P = 16MHz

$$\text{The clock frequency} = \frac{\text{Clock}}{1024}$$

(2.43)

$$\frac{\text{Clock}}{1024} = 15625\text{Hz}$$

The clock period can be calculated $(\frac{\text{Clock}}{1024})^{-1} = 6.4 \times 10^{-5s} = 15625$

cycles

This implies that for one-second delay = $(15625 - 1) \text{ cycles} = 15624 \text{ cycles} = 0x3D08$. The real-time is also stored alongside energy and power consumed.

2.6 The Android System

Android is an open-source mobile operating system that was primarily created by the

Google Company. Since the system's source codes are all open-source, anyone can use

it for free in accordance with the GNU license. Google creates two components to support the Android operating system: Google Mobile Service (GMS) and the Android Open-Source Platform (AOSP) (Canapa, 2017). The kernel and certain essential user functions are contained in AOSP. Because Linux, which is open source can be used for free.

The GMS component bundles all of Google's fundamental tools and applications for consumers and developers, but it costs money. The built-in capabilities of smartphones and tablets typically provide connections for users to easily access Google services on their phones including search, Gmail, maps, and other sophisticated services. On the computer side, using these features is comparable. (Pawel and Lucasz, 2020).

2.6.1 Android Applications

It is a type of software program created for usage on gadgets connected to Google's Android platform. Android smartphones, tablets,

and other gadgets can all run Android applications. Some of them can be downloaded for free, while others require payment. Users now have access to a wide range of features through Android applications on compatible devices, including gaming and media editing. (Moritz *et al.*, 2021).

Table 2.10: Some tools of Android – Architectures (Moritz *et al.*, 2021)

S/N	Tools	Features
1	Development tools	Proguard, Sqlite 3, Draw 9-patch, Android, ddms, emulator, msd card, and Adb
2	Android emulator	Creating AVD, changing orientation, Emulator commands, sending SMS, making calls, Transferring files
3	Image Effect	Copy, create Bitmap (display, and metric displays), create Bitmap (int width, height, and config), create Bitmap (Bitmap src), extract Alpha, get config, get density, getRowBytes, SetPixel, SetDensity
4	Image Switcher	Setimage drawable, set image Resource, set image URI, image switcher, oninitialize Accessibility Event, oninitialize Accessibility Node info
5	Internal Storage	Writing file, Reading file
6	PHP/MYSQL	Creating tables, inserting values in tables, ` connecting MYSQL
7.	SDK Manager	System image, SDK tools, SDK platform-tools, and SDK samples
8	Sensors	Motion sensors, Environmental sensors, position sensors
9	UI Design	View control, content area, main action bar, and split action bar

10.	UI Pattern	action bar, acknowledging and confirming, settings, assistance, and choice
11	UI Testing	UI Automator viewer, UI Automator
18	Wi-Fi	Add Network, create Wi-Fi lock, disconnect, enable network, get Wi-Fi state, Is Wi-Fi enabled, Set Wi-Fi enable, update network
19.	Widget	XML File, Layout file, Java file
20	XML Parser	XML Elements. Parsing

2.6.2 Mobile Smartphone

In recent years, the word "Smart" has evolved into a prefix that is added to products to denote that they include sensors, actuators, and communications capabilities that provide some level of embedded intelligence. In addition to the aforementioned, define a smartphone as having an identifiable open OS with Application Programming Interfaces (APIs) that enable outside developers to create software that can operate on the OS of the device. Similar to how a personal computer (PC) functions, applications can be installed and removed, and the phone must support numerous tasks at once. Many individuals now consider smartphones to be essential devices; in 2016, 1.4 billion smartphones were sold worldwide (Monika and Ruth, 2021). The research design methodology used to accomplish the goals of this study is described in the next chapter.

2.6.3 Review of related works

Katie *et al.* (2006) conducted a study on the analysis platform for electricity tariffs, focusing on organizing data at different levels (group, block, and utility tariff) to enable multiple conditions to be applied to the same inputs. The study aimed to develop a database analysis tool specifically for electricity tariffs. The findings revealed that each block has a limited input range, while the group consists of consecutive blocks covering the entire range from zero to infinity.

In a comparable study, Odior *et al.* (2010) examined various aspects of the electricity power supply system in Benin City, Nigeria, including transformer operation, substation loading, and safety precautions during outages. The objective was to enhance the effectiveness of the power supply system in that region. The results identified two classes of outages, one related to emergency protection and the other involving external faults. Common electrical issues in three-phase power distribution were found to be open and short-circuit faults.

Guseva *et al.* (2010) focused on load determination and transformer substation selection in Riga City, aiming to predict the total number of loads in the city until 2020. The goal was to identify optimal load selection for urban area growth. Apeh and Mokogwu (2013) developed a home power management system using a microcontroller, which provided real-time power consumption management based on user-defined timing parameters. The objective was to influence energy users' behavior to promote energy conservation. The system successfully controlled power supply based on the inputted time parameters, demonstrating its effectiveness.

Georgievski *et al.* (2013) investigated the reduction of energy expenses for buildings connected to the smart grid through statistical analysis. They observed a 35% reduction in energy consumption by evaluating individual device usage and generation units. Nguyen *et al.* (2013) synthesized various studies on building energy and comfort management systems to create an Energy Intelligent Buildings framework based on user activity. The simulation results indicated a significant reduction in energy usage for lighting and HVAC systems.

Chou and Yutami (2014) examined smart meter adoption and deployment strategies in Indonesian residential buildings, aiming to provide remote energy consumption control for urban users. The study aimed to enhance policymakers' and energy utility corporations' understanding of consumer attitudes and behaviors to develop effective smart meter programs. Oseni (2015) highlighted the issue of arbitrary taxation for unmetered electricity users in Nigeria and emphasized the importance of charging based on average usage in the area. The billing system was found to provide valuable insights into energy-saving and energy-wasting behavior.

Zhang *et al.* (2015) analyzed the power consumption structure of various companies in Beijing using ecological network analysis and carbon footprint approach. Fabiano *et al.* (2015) developed a wireless industrial monitoring system using intelligent sensor modules and remote data acquisition units. The system successfully transmitted data to the supervisory controller within an 80-meter distance. Apeh and

Olaye (2015) designed a power inverter with an automated power consumption control system, achieving efficient load management.

Stefan *et al.* (2016) discussed the application of time-domain reflectometry (TDR) for detecting electrical wiring and network problems. Umesh *et al.* (2016) proposed a GSM-based signalling system for detecting changes in voltage-current parameters and identifying faults in distribution substations. The system provided nearly real-time fault detection and precise location information.

Verdejo *et al.* (2017) used a statistical parametric linear model to predict home power demand in Chile. Aydinalp *et al.* (2020) investigated power consumption in homes at national and regional levels. Martiskainen (2017) emphasized the importance of energy consumption behavioural models in understanding and influencing energy usage.

Fan *et al.* (2017) employed the divisi decomposition approach to investigate the impact of urbanization on changes in domestic electricity power consumption. They evaluated the factors influencing residential electricity consumption. Consequently, many countries require energy policies that promote efficient electricity usage in the residential sector to address the consequences of global warming and ensure energy supply security (Zhang *et al.*, 2017).

Shaffer *et al.* (2017) considered energy input from foreign countries, total energy supply, and electrification level in their study. They analyzed energy intensity rates, average electricity prices, and the affordability of electricity for households. The findings revealed

significant variations in power types between Poland and Vietnam. However, the study acknowledged limitations in data gathering and the need for further statistical analysis.

Nilsson *et al.* (2017) emphasized the importance of highlighting the characteristics of household power consumption. They estimated that residential electricity consumption accounts for nearly one-third of global electricity consumption. By voluntarily improving electricity efficiency, both service customers and industrial sectors can achieve cost savings.

Massaki (2017) introduced an innovative antenna-based fault detection device as an alternative to established methods. The device simulated communication wire defects and breakdowns to detect faults, achieving a precision of approximately 40 meters. Bangi *et al.* developed a smart GSM-based fault detection and locating system, enabling precise identification of problem locations. Similarly, Emmanuel *et al.* proposed an underground cable fault detector capable of measuring cable resistance, identifying fault types, and accurately determining fault locations up to 50 meters away.

Sperando and Lopes (2018) developed a method that combined data from computer analysis with monitored protection devices. They employed self-organizing maps (SOM) to train simulated variables reflecting distribution system components in each neuron.

Hassan *et al.* (2018) designed a wireless smart metering system using the MSPEXP430GS Microcontroller (MCU) and Zigbee wireless transceiver. The study demonstrated wireless data transmission and

communication between the smart meter and the main computer within a 10-meter range.

Lü *et al.* (2019) utilized a physical model to investigate the underlying mechanisms of energy flows and predict building energy consumption under different weather conditions. Swan and Ugursal (2019) provided an overview of modeling strategies for home electricity usage. Dintchev *et al.* (2020) found that power-saving education significantly influenced energy-efficient behavior and awareness when computing direct and indirect electricity power consumption.

Gillingham (2020) proposed more stringent regulation of market-driven electricity prepayment metering programs in New Zealand to mitigate their drawbacks while preserving consumer advantages. Zhou *et al.* (2021) emphasized the importance of energy policy focusing on residential electricity power consumption to promote energy savings and address environmental concerns.

Singu and Stella (2022) developed an IoT-based Home Automation system utilizing an Arduino UNO microcontroller, cloud networking integration, and the I2C communication protocol. Their system enabled remote control of lights, fans, and other appliances. Chioma and Bariba (2022) conducted a comparative analysis of energy meters and metering systems to ensure effective services to electric power consumers by selecting appropriate metering solutions based on performance.

2.6.4 Research Gap

Katie *et al.* (2006) conducted commendable research; however, the data collection period was insufficient, and the study relied on simulation without validating the statistical variables. Odior *et al.* (2010) successfully addressed the research goal but also relied on simulation, and the limited average number of working transformers in specific locations compromised the validity of data collection in rural areas.

Apeh and Mokogwu (2013) developed a home power management system utilizing a PIC16F887 microcontroller, allowing real-time power consumption management based on user-defined timing parameters. However, the system is not suitable for large houses with load capacities exceeding 5 kVA. Fabiano *et al.* (2015) established a wireless industrial monitoring system employing intelligent sensor modules (ISMs) and Remote Data Acquisition Units (RDAUs) for data collection. The results demonstrated successful transmission of data to the supervisory controller within an 80-meter range, irrespective of antenna direction. Nevertheless, the short distance limitation of 80 meters and the inability to reset during power outages are notable drawbacks.

Similarly, Massaki (2017) developed an antenna-based defect detection device, using a metal electrode to simulate a fault on the communication wire and an artificial void to create a break. The device achieved an accuracy of approximately 40 meters for distance detection.

Bangi *et al.* designed a smart GSM-based fault detection and locating system capable of pinpointing the exact location of a problem. Furthermore, Emmanuel *et al.* proposed an underground cable fault detector that could measure cable resistance, identify the type of cable fault, and precisely determine its location up to a distance of 50 meters using readily available materials.

In light of this, Gillingham (2020) proposed the widespread deployment of demand management technologies. However, this approach had limitations as it was based on simulation and unimplemented assumptions, making it less suitable for African developing countries like Nigeria. Singu and Stella (2022) developed an IoT-based Home Automation system utilizing an Arduino UNO microcontroller to interface with various home devices. However, the suggested solution faces limitations in terms of the number of loads it can handle due to application constraints. Chioma and Bariba (2022) conducted a comparative analysis of energy meters and metering systems, focusing on performance efficiency. The study overlooked rural areas and developing African countries like Nigeria, where signal quality can be poor at times.

However, upon review, it was observed that researchers primarily focused on designing metering systems, implementing tariff methods, and exploring power management and monitoring strategies. While their results were noteworthy, none of the studies considered an integrated design that combines automated metering with home

energy planning and mobile software applications for both utility companies and consumers.

Furthermore, it was identified that most of the web-based systems developed lacked effective monitoring of open-circuit faults detection and metering devices, as well as efficient power management for both utility companies and consumers. These aforementioned findings served as the motivation for this research work.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Workflow of Research Process

The research work's objectives were accomplished by utilizing a workflow and design plan that was divided into stages. Each stage included iterative activities, as illustrated in the research process workflow depicted in Figure 3.1.

The first phase involves conducting a survey and developing a questionnaire regarding electricity usage by consumers. This is done to examine the effectiveness of the existing metering system and understand consumers' load consumption. Afterward, the system architecture for an Automated Metering, Power Management, and Monitoring System (AMPMS) is developed, along with the design plan for a home energy planner as depicted in Figures 3.2 and 3.3.

The subsequent phase focuses on simulating a fault detection and reporting system for identifying open-circuit faults in the power distribution network's service lines. This is followed by selecting appropriate materials and designing automated prepaid meters, a home energy planner, a web-based system, and a mobile software application. The design calculations for the hardware section can be found in Appendix N.

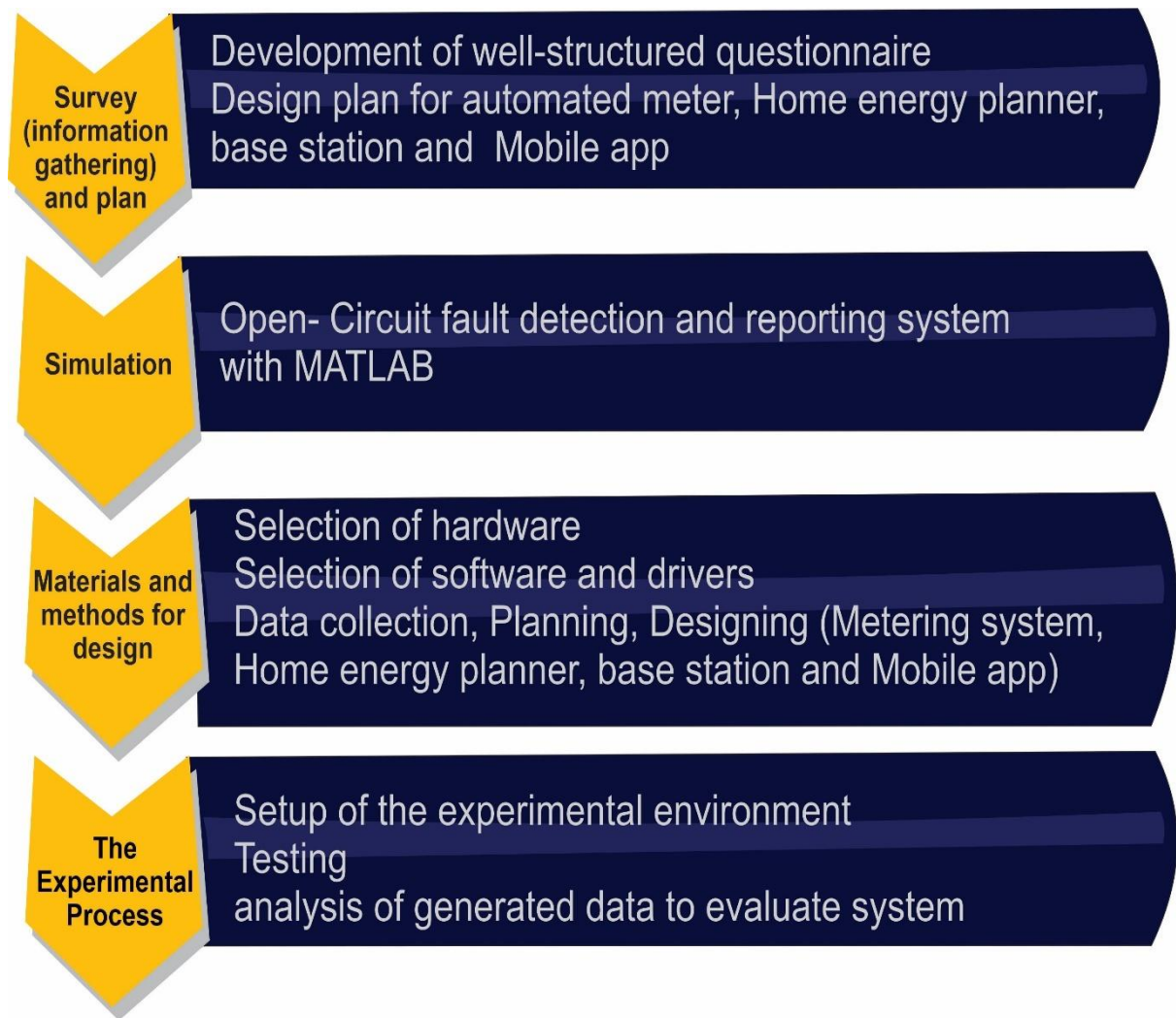


Figure 3.1 Workflow of Research Process

3.2 Survey

The development of a well-structured questionnaire, the analysis of the generated data from questionnaires administered, and the analysis of the generated data from consumers of BEDC (Benin Electricity Distribution Company) of the Distribution Companies (DISCOs) in Nigeria are the main activities in this survey stage.

3.2.1 Development of questionnaires

A total of twenty-five (25) questions were designed for the questionnaires, with the questions ordered in a way that flows from general to specific topics in order to establish the respondent's level of awareness and everyday experience with the utility company.

This made it easier to identify the problems and needs of electricity users.

The survey was conducted by handing out questionnaires to the general public.

The survey's primary coverage regions were Evbuobanosa and Benin City and its vicinity in Edo State, Nigeria. A representative sample for proportions was calculated using a Cochran formula.

$$no = \frac{z^2 pq}{e^2} \quad (3.1)$$

where $q = 1 - p$, no is the sample size, e the desired level of precision, z the chosen critical value of the desired confidence level, p the estimated proportion of a characteristic that is present in the population, and "q" represents the estimated proportion of the population that does not have the characteristic.

The maximum variability, which is equal to equal to 50% ($p = 0.5$),

was assumed in order to compute the sample size for an infinite area, such as our enormous population, with an unknown degree of variability.

The 95% confidence level with a 5% precision was also used.

Substituting $P = 0.5$, $q = 1 - 0.5$, $e = 0.05$ and $z = 1.96$ in (3.1) gives:

$$\frac{96^2 * 0.5 * 0.5}{0.05^2} = 384.16 \approx 384$$

Anticipating 25% return rate (Singh and Masuku, 2014), four times the number of required (1,540) questionnaires were distributed. The results and findings are reported in Chapter four (4), with sample of the questionnaire in Appendix A.

3.2.2 Method of analysis of generated data

The following application and statistical tools were used to analyze the survey respondents' data responses: Microsoft Excel (2016) was used for the graphical analysis and regression, while the Statistical Package for the Social Sciences (SPSS 22 version) was used for consumer load consumption responses. The analysis results are reported in chapter four (4).

3.2.3 The System Architecture

The system Architecture consists of the home energy planner, mobile software application, and metering system. The specifics will be covered in a later part of this chapter

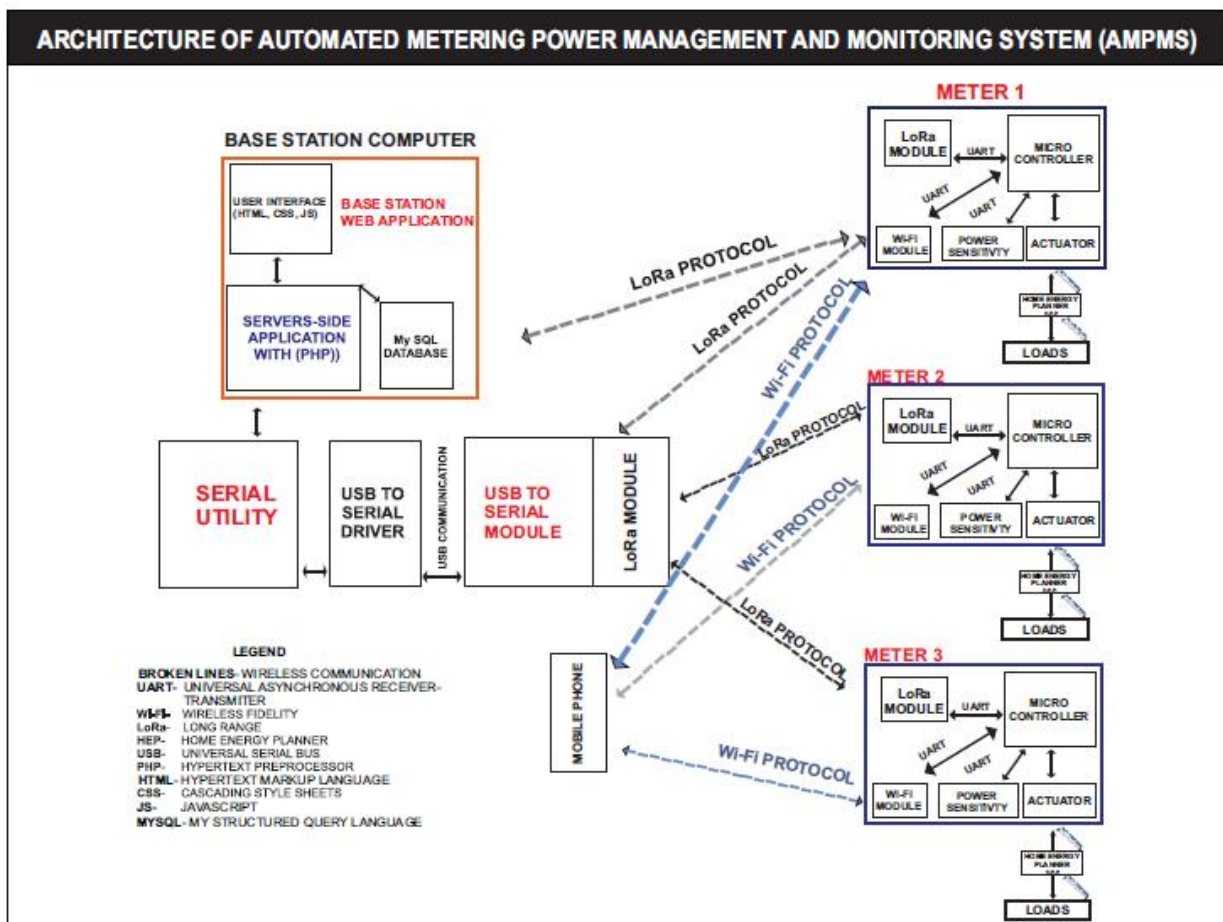


Figure 3.2: The Architecture of Automated Metering Power Management and Monitoring system (AMPMS).

3.2.3.1 The Design plan for the home energy planner

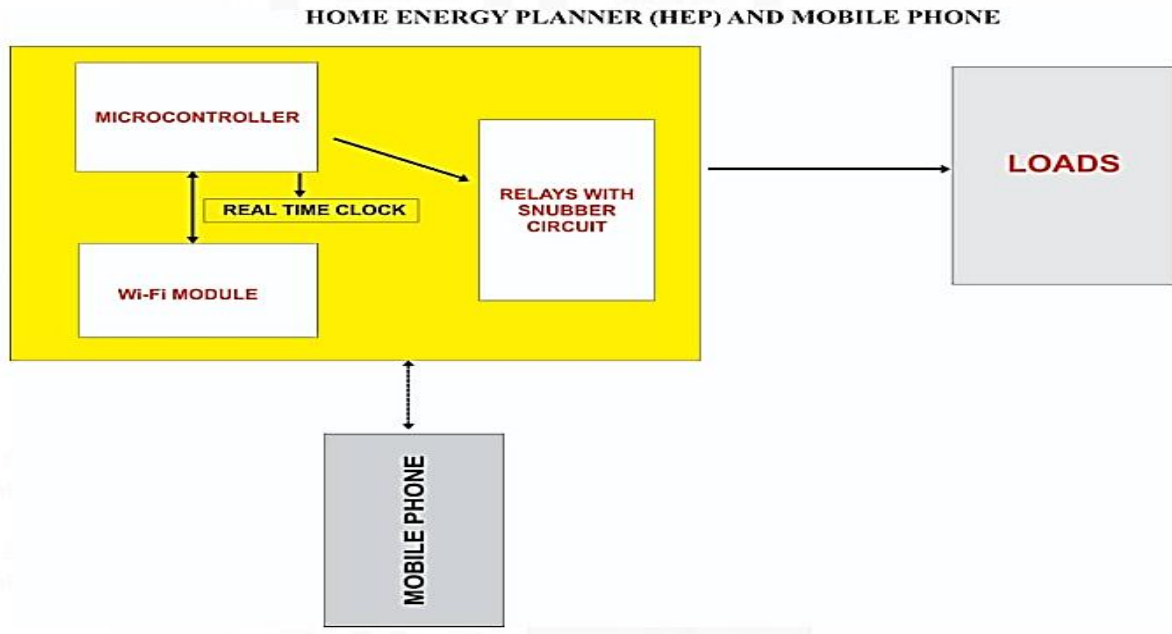


Figure 3.3 Design plan for the home energy planner

The Home Energy Planner (HEP) contains various components that play different roles in monitoring and controlling energy usage:

Microcontroller: The microcontroller ATmega328p is a small integrated circuit that acts as the brain of the energy planner system. It receives input from sensors, processes data, and controls the overall operation of the system. It executes programmed instructions to monitor energy consumption, communicate with other components, and make decisions based on predefined logic.

Real-time clock (RTC): The real-time clock is a component that keeps track of the current time and date. It provides the system with an accurate reference for scheduling

energy-related tasks and time-based operations. The RTC enables the energy planner to execute actions at specific times, such as turning devices on or off automatically based on predetermined schedules.

Relays with snubber circuit: The relays are electromechanical switches used to control the flow of electricity to specific devices or loads. In an energy planner, relays are utilized to remotely switch power on or off to connected loads or appliances. The snubber circuit is an additional component connected in parallel with the relay contacts to suppress voltage spikes and protect the relay from damage caused by inductive loads.

Wi-Fi module: The Wi-Fi module enables wireless communication between the energy planner and other devices or networks. It allows the planner to connect to the internet and transmit data, receive updates, or communicate with a central server or mobile app. The Wi-Fi

module facilitates remote monitoring and control of the energy planner system, providing real-time energy usage information and allowing users to make adjustments from anywhere with internet access.

Loads: Loads refer to the electrical devices or appliances that consume power in a home connected to the HEP. These can include lights, HVAC systems, refrigerators, televisions, and more. The energy planner monitors and manages the power consumption of these loads to optimize energy usage, reduce wastage, and potentially save costs. By controlling the activation and deactivation of loads based on user preferences or automation, the energy planner helps ensure efficient energy utilization.

Mobile Phone: A mobile phone can be integrated with the energy planner system through a dedicated mobile application. The mobile app allows users to remotely monitor and control the energy planner, receive notifications about energy usage, view historical data, and adjust settings. It provides an intuitive interface for users to interact with the energy planner system, even when they are away from home.

By combining these components, a home energy planner enables efficient energy management, automation, and remote control of various electrical loads, ultimately promoting energy savings and optimizing power consumption in a household.

3.2.3.2 The Block diagram of the metering system with home energy planner

The system block diagram is shown in Figure 3.4 and 3.5 respectively

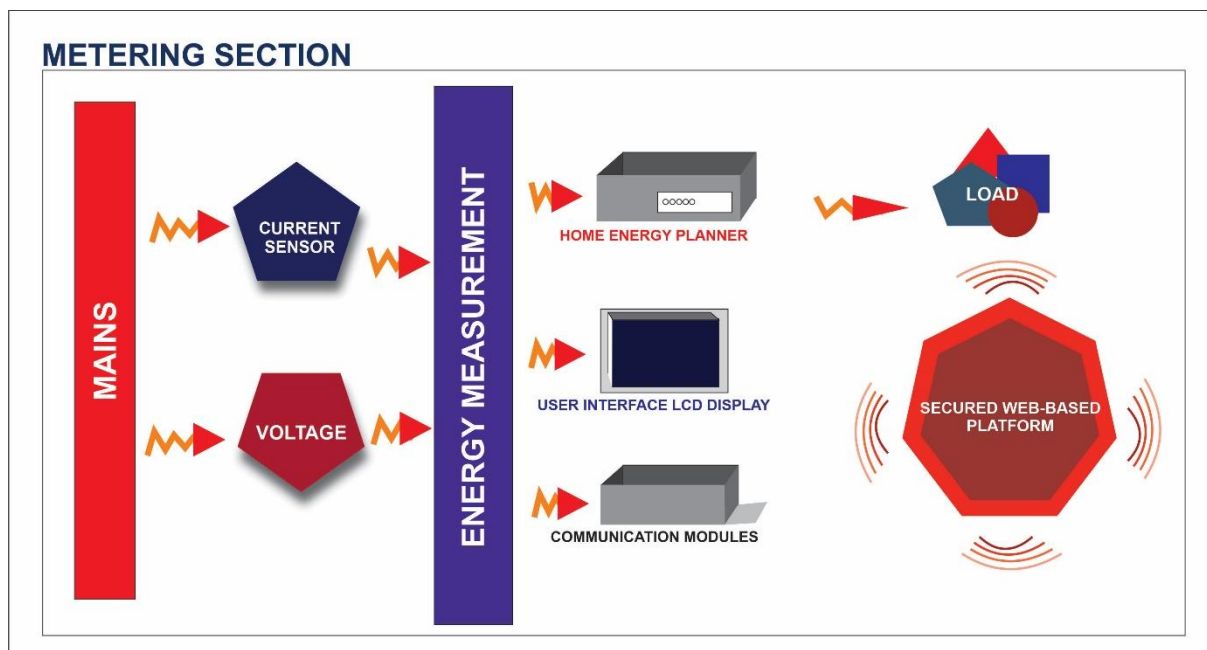


Figure 3.4: Block diagram of the metering system with home energy planner

In the metering system interface with a home energy planner and web-based platform, several components work together to measure and monitor energy usage.

Three-Phase mains: The three-phase mains refer to the electrical power supply coming into a building or home. In the metering system, it serves as the primary source of electricity that powers the loads and allows the measurement of energy consumption.

Current sensor: The current sensor is a device that measures the amount of electrical current flowing through a circuit. In the context of the metering system, current sensors are used. In order to gauge the current consumed by the devices linked to the three-phase power supply, measurements are taken. They provide accurate current data, which is essential for calculating energy consumption.

Voltage sensor: The voltage sensor responsible for measuring the electrical voltage across a circuit. In the metering system, voltage sensors are used to measure the voltage supplied by the three-phase mains. The voltage data, combined with the current measurements, allows for the calculation of power and energy consumption accurately.

Energy measurement device (IC): An energy measurement device, often in the form of an integrated circuit (IC), is responsible for calculating the energy consumption based on the current and voltage measurements obtained from the current and voltage sensors. This IC typically contains dedicated circuitry and algorithms used in this research work to accurately calculate the energy usage.

Home energy planner: The home energy planner is a central component of the system that receives data from the energy measurement device (Automated meter). It processes the energy consumption data, stores it, and analyzes it to provide insights and recommendations for efficient energy usage. The home energy planner controls the loads based on predetermined schedules or user-defined preferences.

Loads: Loads are the electrical devices or appliances in a home that consume power. These can include lighting systems, HVAC (heating, ventilation, and air conditioning) units, kitchen appliances, and more. The metering system interface measures and monitors the energy consumption of these loads to provide information for analysis and optimization.

Communication module (RF) wireless transceiver: The communication module acts as a bridge between the metering system and the home energy planner or web-based platform. It enables wireless communication, typically using radio frequency (RF) technology, to transmit energy consumption data and other relevant information from the metering system to the home energy planner or web-based platform.

User interface LCD: The user interface LCD (Liquid Crystal Display) provides a visual display for users to view relevant information related to their energy consumption. It can show real-time energy usage data, historical trends, alerts, and other system information. The LCD interface allows users to interact with the system and access important details at a glance.

Secure web-based platform: The secure web-based platform serves as a central hub for energy monitoring, analysis, and control. It receives the energy consumption data transmitted by the communication module and provides a user-friendly interface accessible through a web browser. The platform displays energy usage statistics, allows users to set energy-saving goals, provides recommendations for efficient usage, and may offer additional features such as energy cost tracking, bill analysis, and integration with other automated home systems.

By integrating these components into a metering system interface with a home energy planner and web-based platform, users can gain better visibility and control over their energy usage, make informed decision for efficient energy management, and potentially reduce their overall consumption and costs.

3.2.3.2 The Block diagram of the monitoring base station

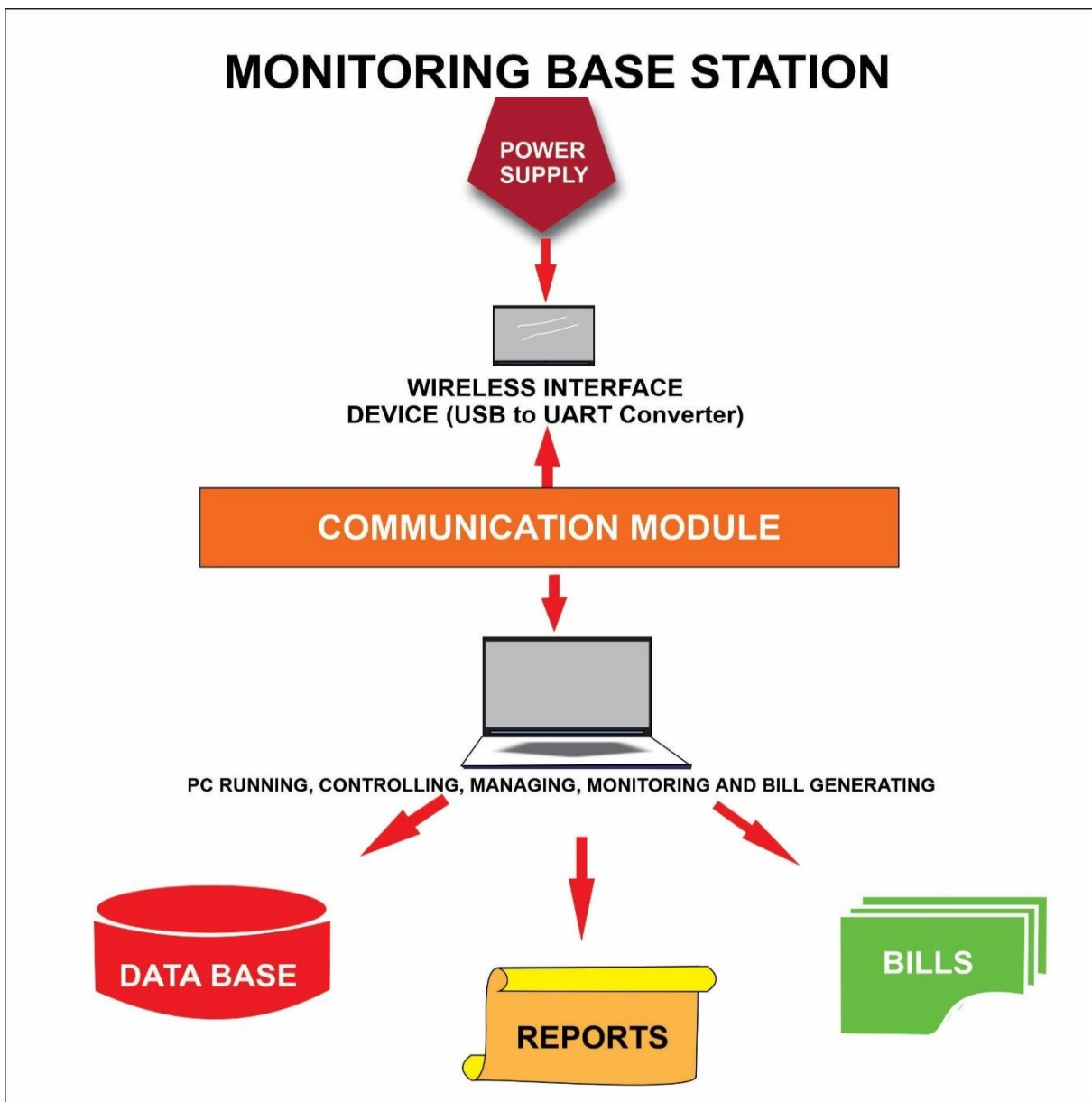


Figure 3.5 Block diagram of the Monitoring web-based station

In the monitoring base station, several components work together to facilitate the monitoring, management, and billing processes:

Wireless interface Device (USB to UART Converter):

This component acts as a bridge between the monitoring device and the base station. It is responsible for wirelessly receiving data from various remote devices or meters that measure electrical parameters such as energy consumption, voltage, and current. The wireless interface device, often utilizing radio frequency (RF) technology, receives the data and converts it into a format compatible with the base station's communication protocols. The USB to UART converter is an intermediary component that facilitates the connection between the wireless interface device and the base station's computer via a USB port.

Personal computer (PC): The personal computer serves as the central processing unit of the monitoring base station. It is responsible for running the software applications necessary for managing, controlling, and generating bills. The PC receives the data transmitted by the wireless interface device, processes it, and stores it in the appropriate sections of the system. The PC also hosts the user interface, enabling operators to interact with the system and perform tasks related to monitoring, analysis, and billing.

Database section: The database section is where all the collected data is stored. This section of the monitoring base station contains a database management system that organizes and manages the data received from the wireless interface device. The database stores information such as energy consumption readings, voltage levels, customer details, and historical data. It provides a reliable and structured repository for efficient data retrieval and analysis.

Report section: The report section is responsible for generating reports based on the collected data. This component utilizes the stored data from the database section to generate various types of reports, such as energy consumption trends, load profiles, power quality analysis, and any other relevant information required by the utility company. These reports assist in identifying patterns, making informed decisions, and addressing issues related to power distribution and consumer energy usage.

xiv. Bills generated section: The bill's generated section is where the billing process takes place. Using the data stored in the database section, this component generates utility bills for individual customers based on their energy consumption. The billing section may apply tariffs, discounts, or other billing rules defined by the utility company. It calculates the charges owed by customers and generates bills that are then sent to the respective customers.

3.3 Simulation method to design open-circuit fault detection and reporting systems

The following procedure was used to design the open-circuit fault detection and reporting system:

- i. The development processes.
- ii. The design workflow.

- iii. Internal interface framework.
- iv. Simulation flow diagram

3.3.1 The development processes

The system was built by selecting logical parameters and components that would be sufficient for simulating the system's correct operation. The Appdesigner tool in MATLAB (Figure 3.6) was used to create an open-circuit fault detection and reporting system using the MATLAB programming language and the HTTP protocol for communication with the base station, as illustrated in Figure 3.7.

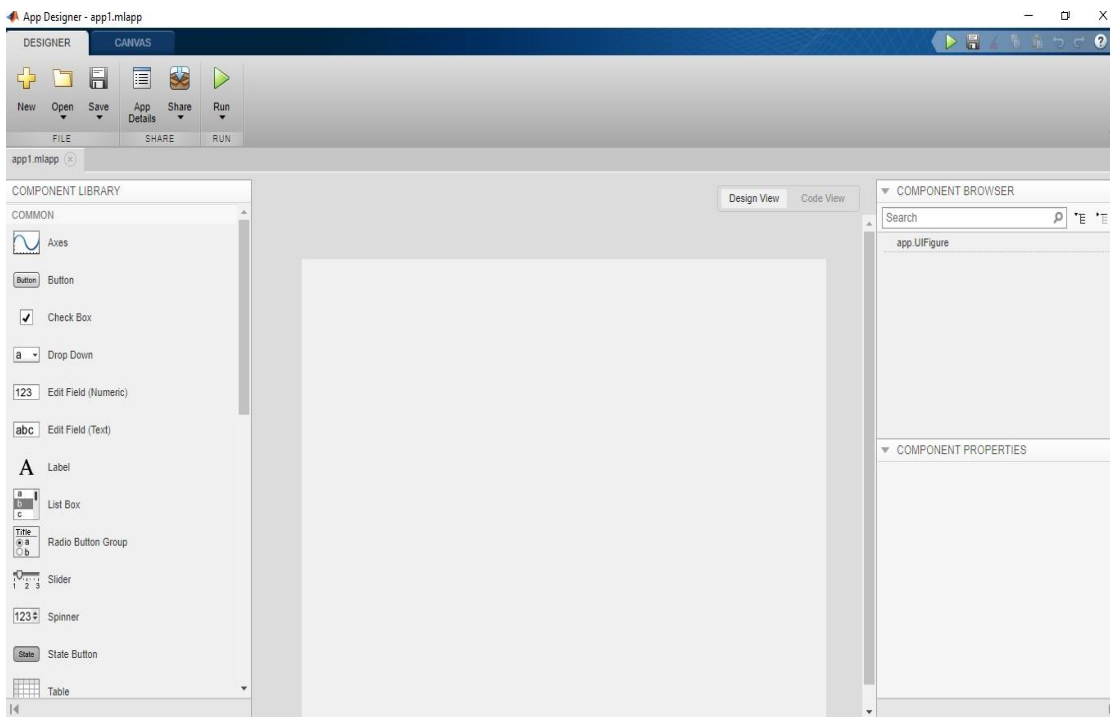


Figure 3.6: The Appdesigner tool page

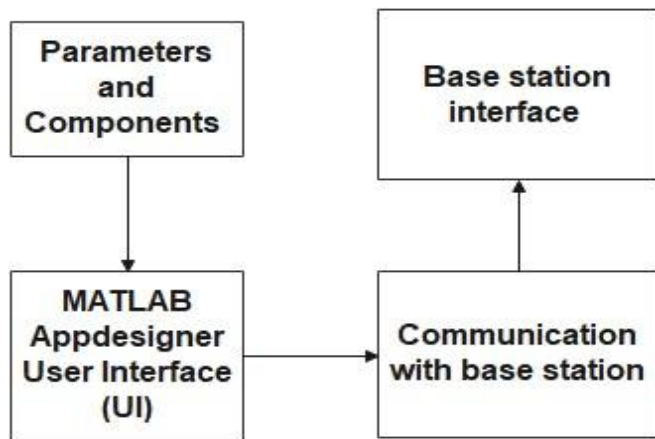


Figure 3.7: Development process

3.3.1.1 Parameters and components

In order to simulate fault detection and reporting operations, certain characteristics and components were used to represent the physical attributes of the system. Error-detection sensors and communication techniques are included. A customized push button generated with the MATLAB appdesigner tool was used to simulate fault detection in the simulation environment, while the reporting system was handled with the MATLAB HTTP protocol API.

3.3.1.2 MATLAB Appdesigner User interface (UI)

The appdesigner tool in MATLAB provides a drag-and-drop interface for creating customized user interface (UI) for MATLAB Apps and simulation interface. The UI is designed to integrate the power distribution lines that are red, yellow, and blue phase (R, Y, B) as well as the neutral line in the fault detection and reporting simulation. Figure 3.8 depicts the Appdesigner user interface. The sensors are mounted on these lines to detect fault. Hence, the customized push button to trigger faults on the line for this purpose and also to trigger fault reaction (repair). The simulation results of the fault detection and reporting is recorded in Chapter four, Appendix G and H. The algorithm for the interface response corresponding to the line status is as follows:

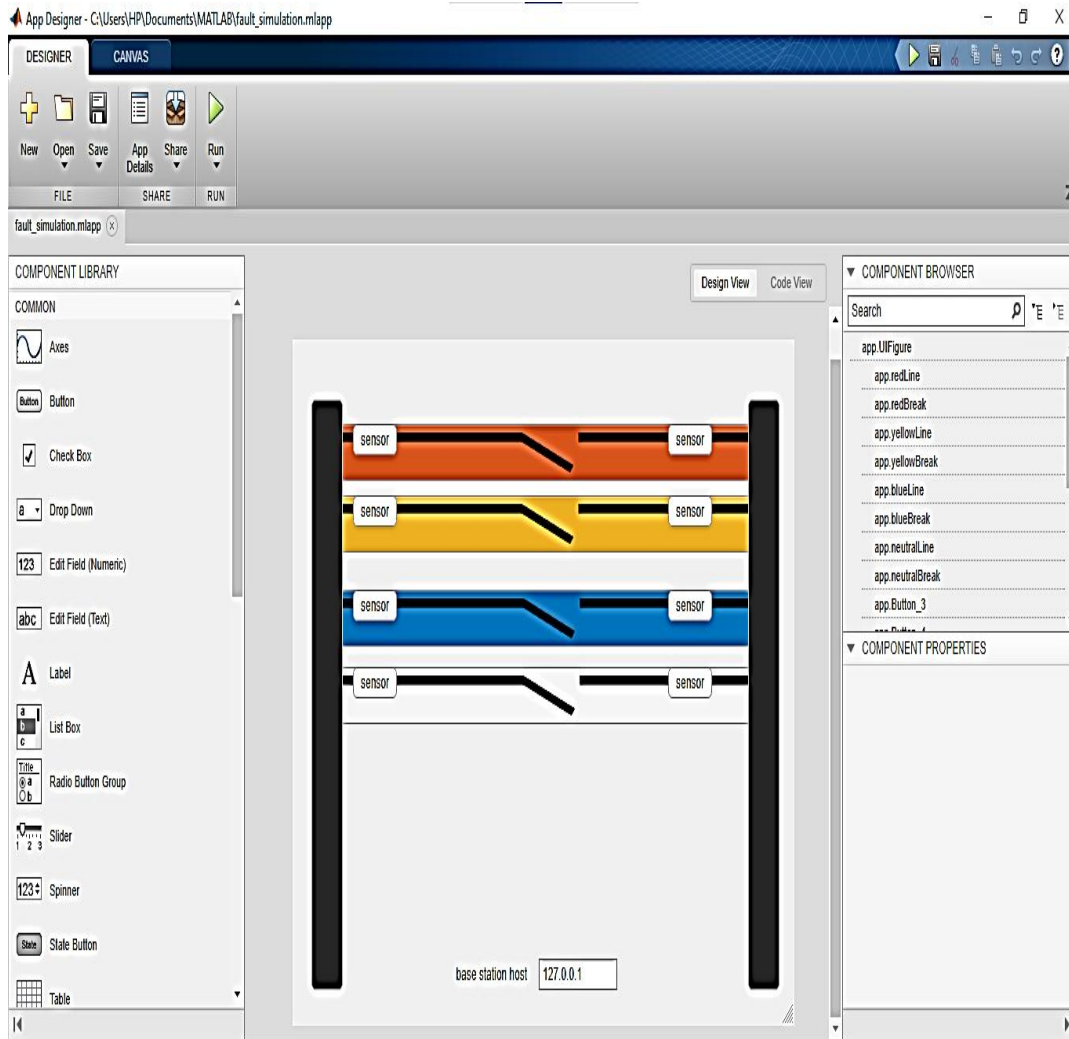


Figure 3.8 The Appdesigner user interface

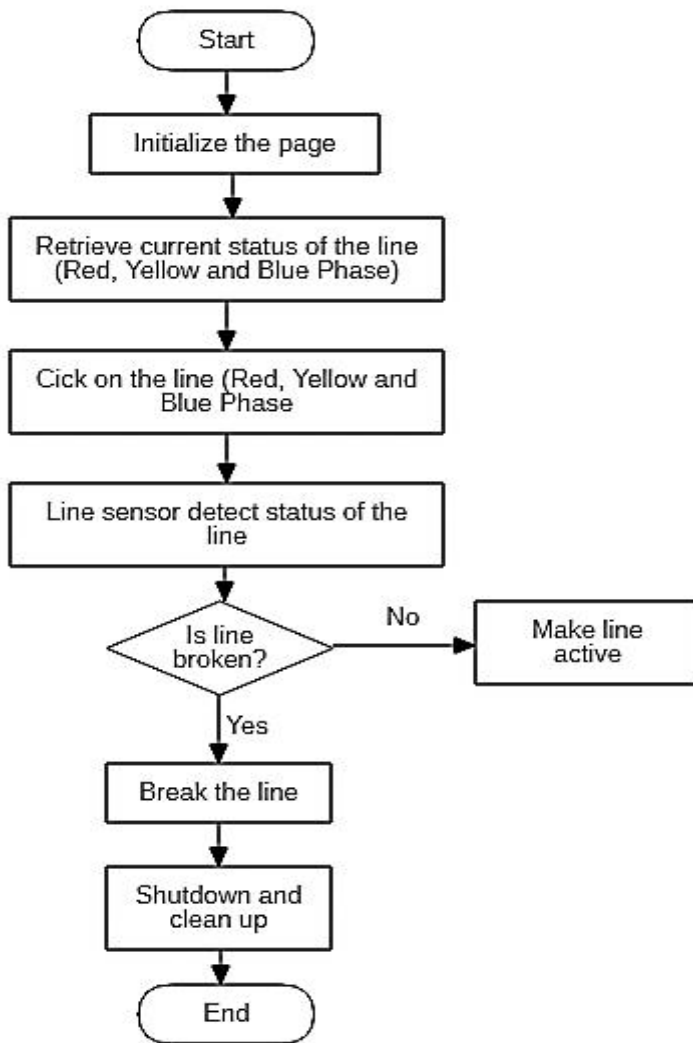


Figure 3.9 Open-Circuit fault detection Simulation flow chart

Initialization: In this phase, initialize all necessary components, including the AMPMS system, MATLAB interface, web-based monitoring system, and the fault detection module.

Main Program Loop: This is the core of the system's operation. It continuously acquires power data, checks for open-circuit faults, and responds accordingly.

Open-Circuit Fault Detected: If an open-circuit fault is detected during data acquisition, the system generates reports of the status and send a message to the monitoring web-based system.

No Fault Detected: If no open-circuit fault is detected, the system continues to monitor.

Shutdown and Cleanup: This phase is for closing and cleaning up all system components when the system is no longer in operation and ends

3.3.1.3 Communication with base station

The base station implements an HTTP server with database and dashboard status of the lines. In order to communicate status of the lines to the base station a HTTP client is used in the simulation implementation. The HTTP client UI is provided by MATLAB, the program response to the event on the user interface (UI) by sending the error status of the line through HTTP post request to the URL of the base station section. On reception at the base station section the status is stored in the database.

3.3.1.4 The base station interface

The base station interface consists of a dashboard designed using web technology (HTML, CSS and JavaScript), the base station interface displays the status of the power distribution lines received from the fault simulation interface (running on the Appdesigner in MATLAB).

3.3.2 The design workflow

The workflow design for the visual steps in the fault detection and reporting system from start to finish as shown in Figure 3.10. The work flow starts with research on system requirements and specifications. A model is developed for different parts of the system in a modular way and using interconnections, these

“subsystems” are united together to function as a whole in the entire system. Then the design facilitates the testing, verifying designs and ideas before actually implementing the system. The design of the simulation includes logical components, algorithms, and simulation environment (MATLAB Appdesigner). The logical components include customized push buttons for the sensors, the power distribution lines, and the representative for the poles. An algorithm is written in MATLAB programming language to send fault status of the lines on the base station server. The environment of the simulation (base station) designed with PHP and MySQL database at the backend (HTTP server) while the frontend designed with HTML, CSS and JavaScript’s and MATLAB Appdesigner tool. The results are presented in Chapter four (4) and in Appendix H.

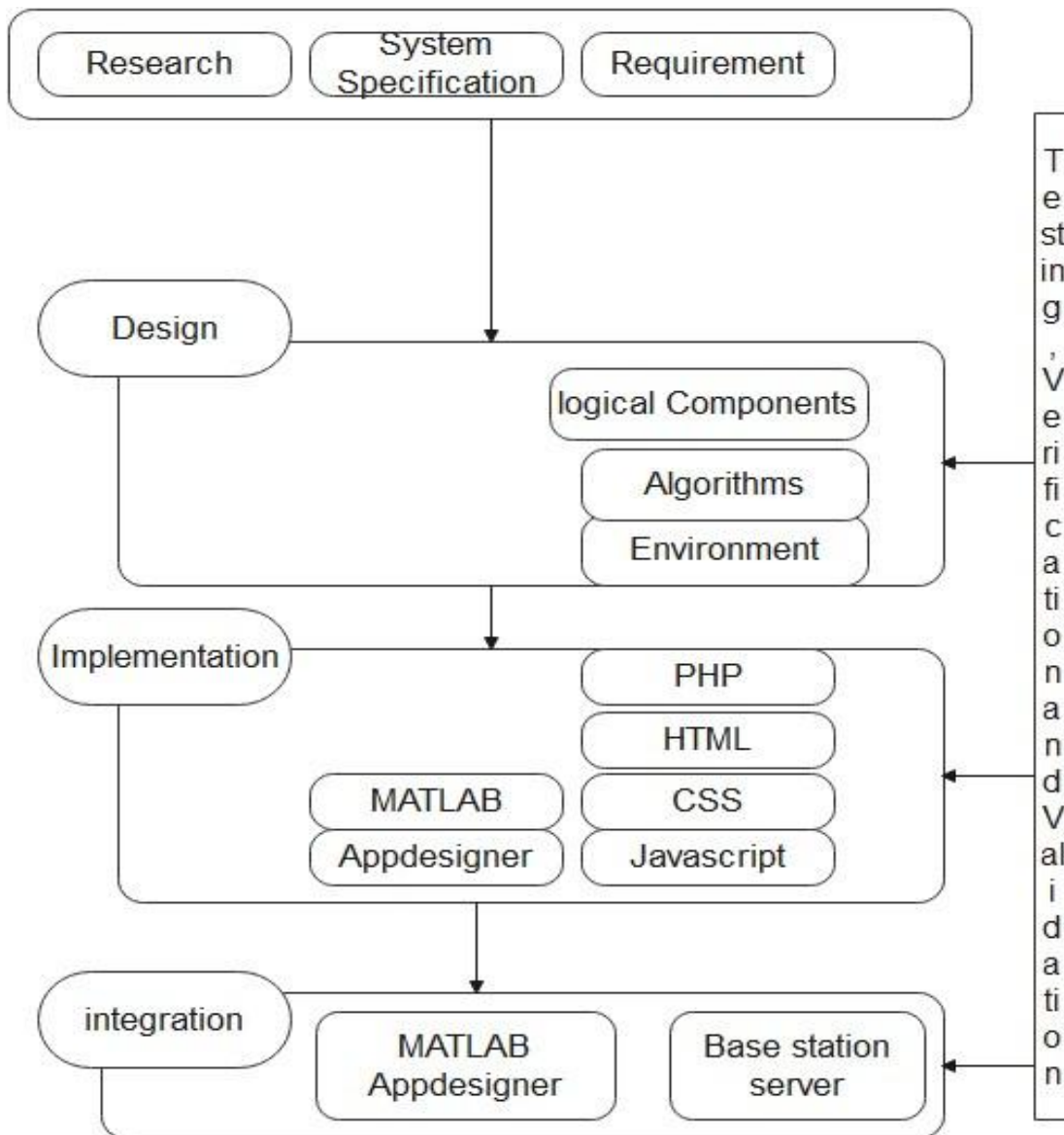


Figure 3.10: The design Workflow

3.3.4 Simulation workflow

The simulation starts by initializing the Appdesigner window and initialize the logical components for the sensors, power distribution lines and poles. The callback for the sensor components is set-up. The callback is programmed to respond to users' events on the sensors to trigger faults and resolve faults. After decoding the fault, it is converted into an HTTP request and formatted accordingly. This formatted request is then transmitted to the base station via the base station URL. The base station server format the data and record it in the database while displaying the status on the dashboard. The dashboard receives the power distribution lines status and display it on the frontend (user interface). The fault reporting is implemented in the system on the dashboard as a message describing the state of the power distribution lines with a diagram

showing the state of the lines. After a fault is reported. The user interface waits for another events fault to trigger or the process of resolving a fault, as depicted in Figure 3.11, is undertaken.

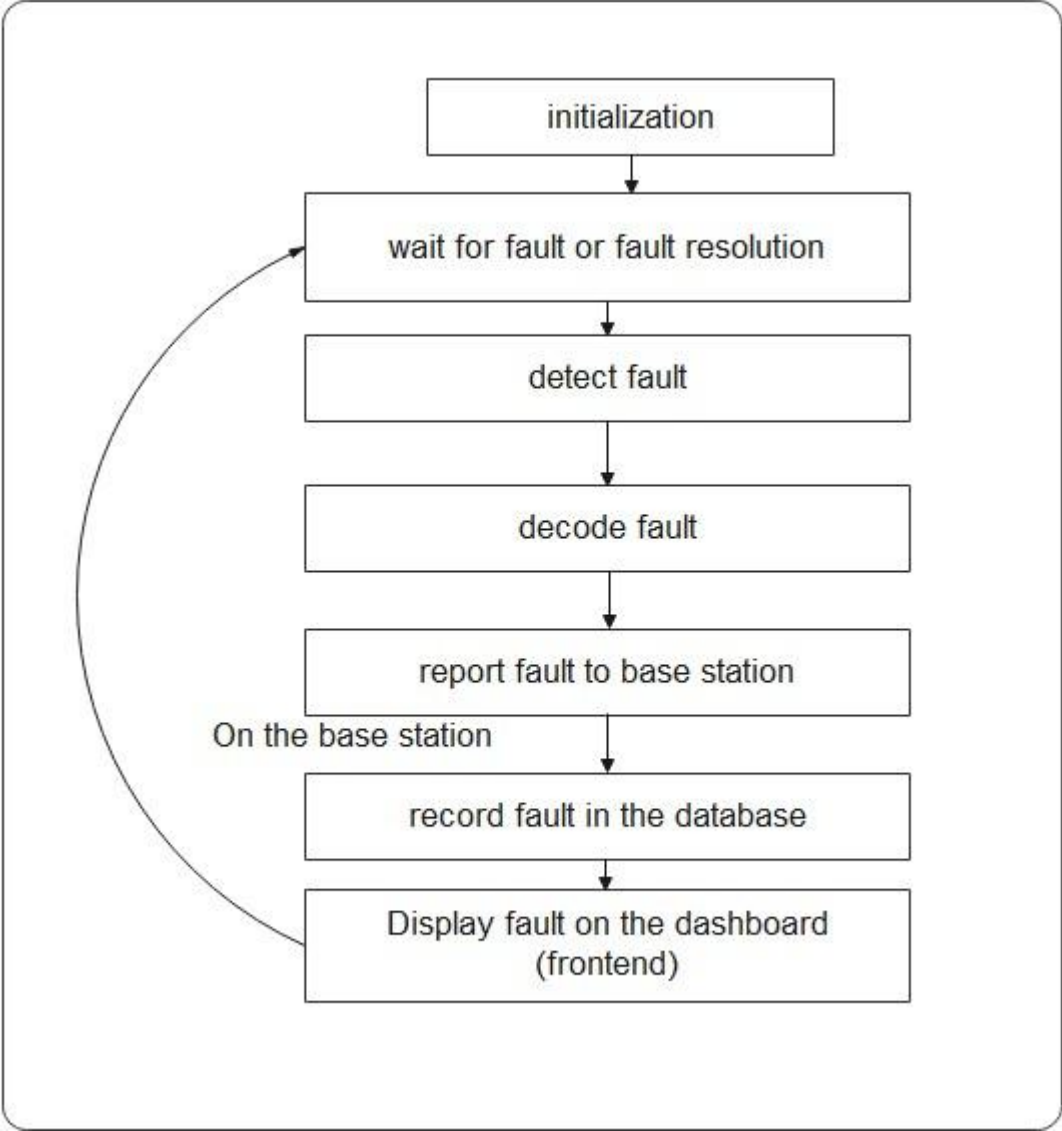


Figure 3.11: Simulation flow diagram

3.4 Material Selection for evaluation process and design

The material selection process for the evaluation and design stage includes hardware, software, and driver selection. Data collection, planning, metering system design, home energy planner design, web-based system design, and mobile app design are all part of the process for power management, customer load monitoring, and metering status.

3.4.1 Selection of Hardware

Support for planned software, compatibility with planned network, upgradeable and future expansion to meet the needs of the design duration, routine assessments and availability in terms of upgrade, maintenance by local or remote vendor, for possible replacement of faulty components, and availability of manufacturers' data sheet are among the criteria for selecting hardware for this research's design.

Some hardware Components used in the design includes:

Integrated Circuits (Op-amps)

Light Emitting Diodes (LED).

Microcontrollers (Atmega328p on Arduino Nano board)

Wi-Fi modules ESP8266,

Wireless LoRa RF transceiver modules SX1278 series,

Relays (Normally open and normally closed)

Opto-couplers

USB-to-UART converter module.

3.4.2 Selection of Software

In order to achieve monitoring and control of the meters from a central computer (base station), there is need to develop appropriate software solutions. The software must provide the required functions which include; provision of a customized user interface for monitoring of the meters, sending commands to the meters, and storing the state of the meters in a form it can be easily accessed and modified. This software and technologies used for building and running the software must also support licenses that are compatible with research projects. In accordance with the criteria above, a web-based application used to design the interface for monitoring and control of the meters, while a custom Windows Application (serialutil) is used to exchange data between different protocols (between RS232 protocol and HTTP). The Laravel Framework and PHP were both utilized in the creation of the web application's backend while the frontend was created using the VueJs JavaScript library along with HTML/CSS. The state of all meters, client information, and voucher pins

(encrypted) are stored in a MySQL database. The results are presented in Chapter four (4), and the code can be found in Appendix E.

The Windows application was designed using WPF (Windows Presentation Foundation) and it helps to collect the data from the LoRa RF transceiver which is connected to the Serial port of the base station computer, it sends the data to the base station software through HTTP protocol. It also performs the reverse operation when information is sent from the base station to the meters.

3.5 The system Design Process

The hardware and software designs of the automated metering, power management, and monitoring system are described in this section. In order to finish the assignment, an analysis of the various units used will be conducted. The system is made up of the following elements:

- i. The Automated Metering system
- ii. The Wireless Interface Device (WID)
- iii. The centralize system for power management and monitoring (base station).
- iv. The mobile App for power management, control and monitoring

3.5.1 The Automated Metering System

The Atmega328 microcontroller is coupled to the energy metering IC, It calculates and stores the amount of energy utilized by the customer while simultaneously measuring the current and voltage flowing in the power supply line. Figure 3.12 shows the schematic of the metering system. The Atmega328 is set up to accept metering data from the metering IC, show the amount of energy used on the LCD display screen, and send the measured data through UART (RS232) to the LoRa Module, which then sends the data to the base station. The Arduino IDE is used to program the microcontroller in C++. To protect the circuit the RC network and voltage protection circuit (Figure 3.17 and 3.16). while for accuracy and stabilization of the circuit for the microcontroller (Figure 3.19, Figure 3.20) and the ladder network (Figure 3.21). To buffer the circuit (Figure 3.22, Figure 3.24 via biased unity gain buffer (Figure 3.23) should be set to limit the current flowing into the Analogue input of the microcontroller via the current limiting operation of the buffer circuit (Figure 3.25). The serial communication process, open-circuit fault detection, and reporting system are shown in Figure 3.29, Figure 3.33 while the design of the microcontroller unit, relay driver (transistor), and optocoupler transistor base are shown in Figure 3.27, Figure 3.31, and Figure 3.32. Details of the designs follow in the subsequent sections of this chapter. The results are in Chapter Four (4), and the code is in Appendix B.

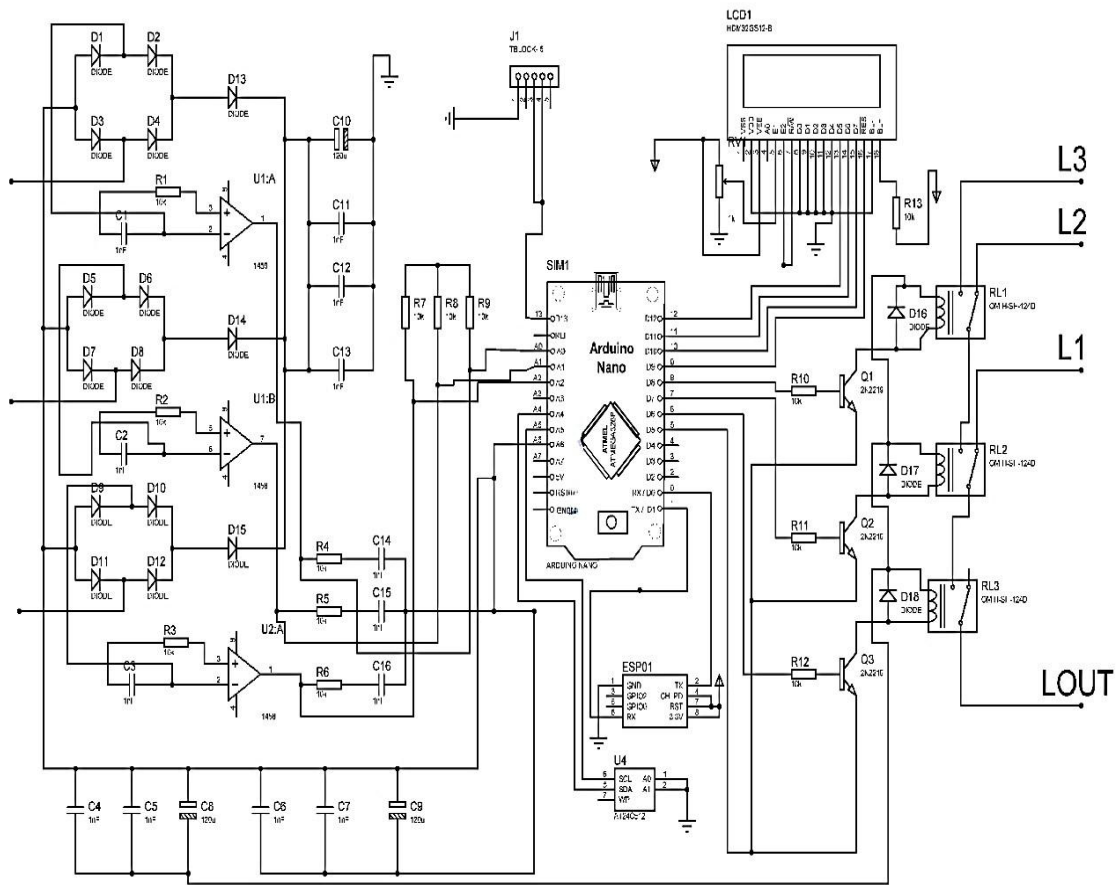


Figure 3.12: Schematic diagram of the metering system

3.5.1.1 The Design of the power supply

The three fundamental sub-units that make up this unit are the voltage sensor, current sensor, and power supply unit. Figure 3.13 shows how AC electricity (230v, 50Hz) is transformed into a DC-regulated power source.

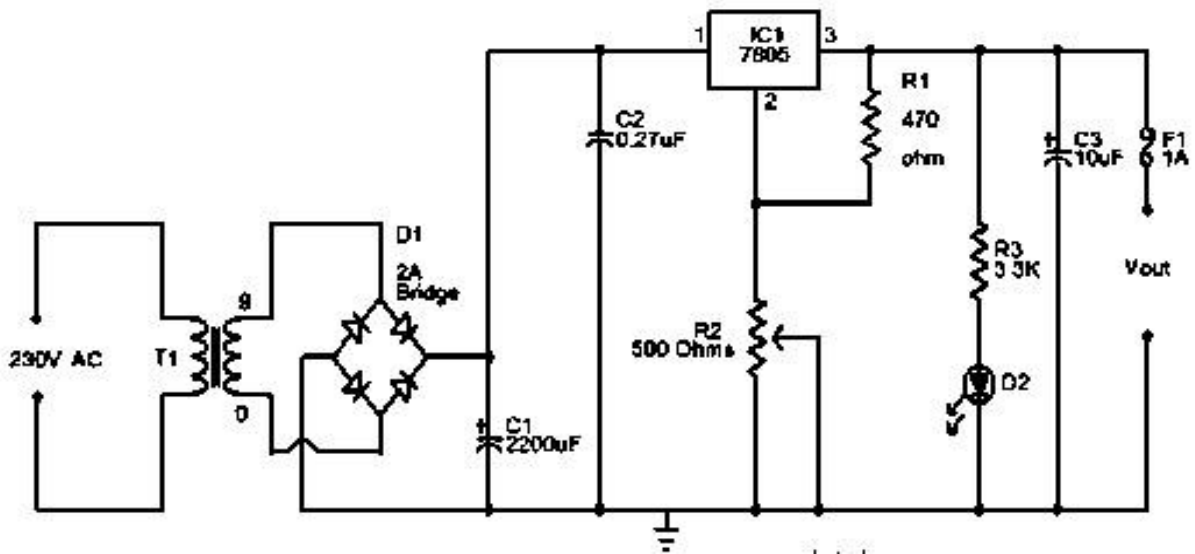


Figure 3.13: The power supply unit

3.5.1.2 Transformer

The step-down transformer utilized in this design has a 240v, 1500mA rating. The transformer lowers the mains voltage from 220-240 volts to 12 volts. Its job is to adjust the AC supply voltage to meet the needs of circuits powered by DC. It also provides separation from the supply line, an essential safety component. According to the specifications, the load resistance of the power supply transformer was estimated as follows:

$$V_{rms} = 12v$$

$$I_{rms} = 1500mA$$

$$V_{Peak} = V_{rms} \times \sqrt{2}$$

The load resistance R_L is given by:

$$R_L = \frac{V_{peak}}{I_{peak}} \quad (3.2)$$

$$R_L \cong 8.00\Omega$$

3.5.1.3 Rectification

A bridge rectifier was used to do full wave rectification. It is necessary to generate 5V at the voltage regulator's output. The voltage regulator utilized is the LM7805, which consumes a maximum current of 1.5A from the power source. As a result, a 3N245 bridge rectifier with a maximum current of 6A was chosen as shown Figure 3.14.

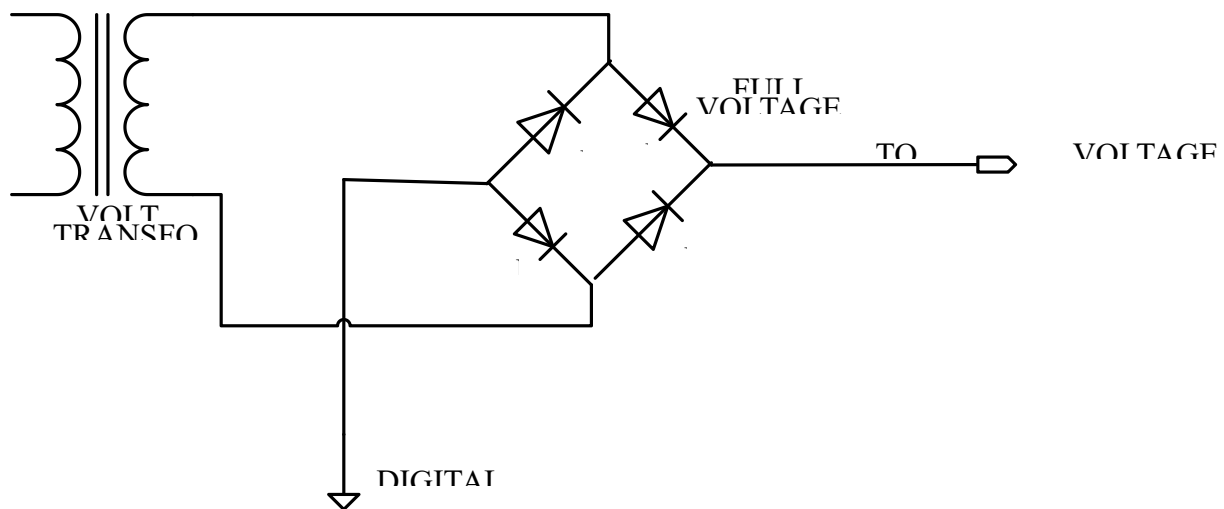


Figure 3.14: Schematic Diagram of the Full Wave Voltage Rectifier

Voltage after rectification V_{dc} given by:

$$V_{dc} = \frac{2V_{peak} - 2V_d}{\pi} \quad (3.3)$$

where V_d is the bridge rectifier's voltage drop across the two diodes a positive half cycle ($V_d = 0.7$)

$$V_{dc} = 9.4v$$

The current after rectification I_{dc} is given by:

$$I_{dc} = \frac{V_{dc}}{R_L} = 1.175A$$

3.5.1.4 Choice of capacitors

The purpose of this circuit element (capacitor) is to eliminate the fluctuation or pulsation (known as ripple) in the rectifier's output voltage. It was decided to use a capacitor filter. C1 is chosen as the output capacitor because it has a very low reactance to the ripple frequency.

Hence filtering is done by C1.

Since the peak voltage is $V_m\sqrt{2}$ at alternate half cycle of the voltage, the voltage rating

at capacitor should be $1.5-3 V_m \sqrt{2}$.

$$\text{Capacitor voltage (VC)} = 1.5 [V_m \sqrt{2} - 2V_d \text{ (in)}] \quad (3.4)$$

where V_d (in) is the forward voltage drop of a diode. In power electronics it is taken to be 1 volt.

$$V_1 = 1.5 (V_m \sqrt{2} - 2)$$

$$\approx 47.9$$

Chose $V_C = 50$ volt as the near preferred value (NPV)

Capacitance Rating

From the approximate ripple voltage formula

$$V_r = \frac{I_o}{2F_c} \quad (3.5)$$

Where $I_o =$ Dc element from regulator

$F =$ mains frequency

$c =$ capacitance in microfarad

$V_r =$ Ripple voltage

$$\text{From equation 1} \quad C = \frac{I_o}{2FV_r} \quad (3.6)$$

Where $V_r = 20\%$ of Vdc

$I = 500$ mA (Assumed maximum current drain from the regulator)

$f = 50$ Hz

Therefore,

$$\begin{aligned} C &= \frac{I_o}{2FV_r} \\ &= 781 \times 10^{-6} \end{aligned}$$

As a result, 1000uf, 50v is a close second choice. Due to a lack of available components, 2200uf was used.

3.5.1.5 Voltage regulation

The fixed regulator type 78xx series is the sort of voltage regulator used in this design. They have a 3-volt internal voltage and a 500-mA maximum current. The output voltage of the 7805 is stated as:

$$V_{in} = V_{out} + 3$$

Where 3 is the limiting input voltage

$$V_{in} = 5 + 3 = 8v$$

This indicates that the LM7805 requires 8 volts as the lowest input value in order to create a 5-volt output

The variable regulator (LM317) output's voltage (V_{out}) to the ATmega328p microcontroller is determined by:

$$V_{out} = 1.25 \times (1 + \frac{R_2}{R_1}) \quad (3.7)$$

Where 1.25 is a constant

R_1 and R_2 's values are yet to be determined from the equation. A 5-volt output voltage is anticipated for the ATmega328p microcontroller. R_2 's value is determined by:

$$R_2 = \frac{V_{out}}{I_{dc}}$$

If $V_{out} = 5v$, and $I_{dc} = 1175mA$ (Power Supply Unit (PSU))

$$R_2 = 4.26\Omega$$

Equation (3.7) is then used to determine the resistance of resistor R_1 .

$$V_{out} = 1.25 \times (1 + \frac{R_2}{R_1}) \quad (3.8)$$

$$R_1 = 1.42\Omega$$

But R_1 and R_2 were both given a standard value of 1.4 and 4.2 in the design respectively.

3.5.1.6 The Voltage Sensor Unit

The voltage across the power supply lines must be measured in order to measure the electrical energy utilized across a consumer's load. This section covers the circuit that senses the voltage and sends it in a suitable format to the metering IC for further processing. The transformer's principal input voltage is estimated to be in the range of 220-240 volts. The 12V, 1500mA transformer stated under power supply unit above step down the 220V input voltage to 12 volts. A voltage divider network of resistors used to reduce the 12V to the required voltage, as shown in Figure 3.15.

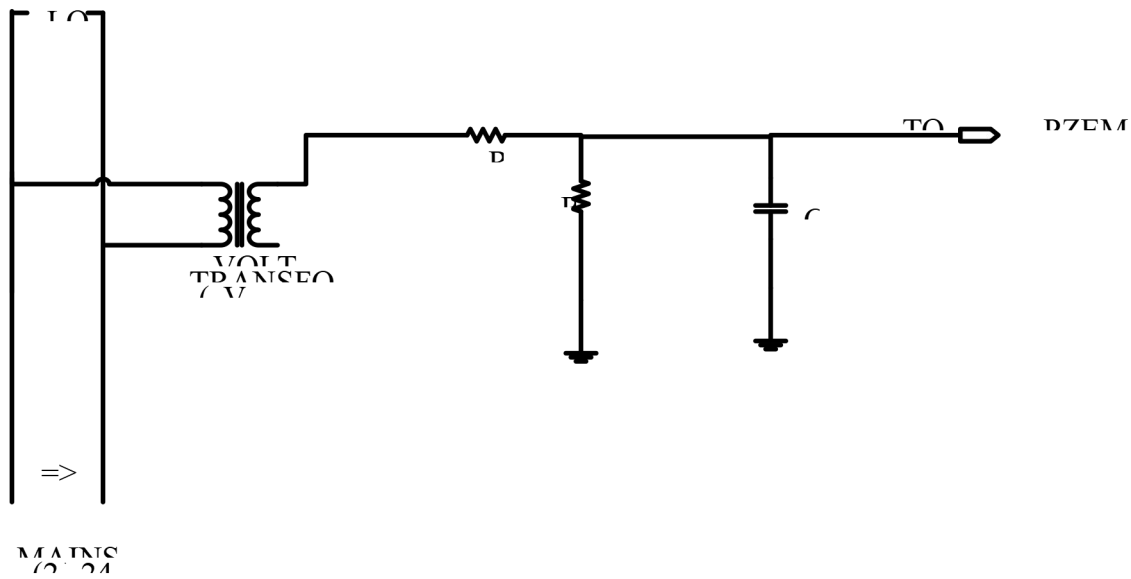


Figure 3.15: Schematic diagram of the voltage sensor circuit

3.5.1.7 The Choice of resistors and capacitor

In this design, $R_5 = 200$. From the datasheet, capacitor $C_4 = 150\text{nF}$. The resistor R_4 required to obtain the voltage be calculated.

Let transformer output voltage = V_1 ,

Applying voltage divider principle,

$$\text{Voltage drop across } R_5 \text{ is } V_2 = \frac{R_5 \times V_1}{R_4 + R_5} \quad (3.9)$$

$$\text{Hence, } (R_4 + R_5) = R_5 \times \left(\frac{V_1}{V_2}\right)$$

$$R_4 = R_5 \times \left(\frac{V_1}{V_2 - 1}\right)$$

$$R_4 \cong 21\text{k}\Omega$$

To calculate the amount of electricity used by a consumer's load, the current flowing in the lines must be monitored. Maximum input current is 100 A. This is the maximum current that can flow in a home building. A sensor with a linear output current is used in this design. Hall Effect sensors are capable of detecting currents as low as 250 mA and as high as about 100 A.

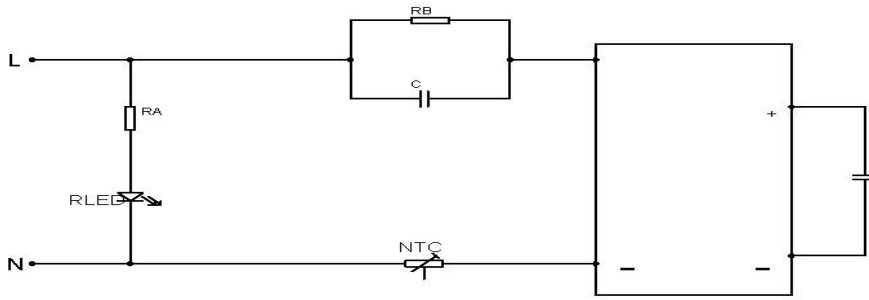


Figure 3.16: Voltage Protection circuit

The input RC network to feed the bridge to produce the DC voltage. It serves to protect the system from power surges.

From datasheet, the current consumption of ATmega328p is $< 250mA$, LCD display

10mA,

$$\text{total current} = 265mA$$

From impedance formula,

$$Z = \sqrt{R^2 + XC^2}$$

$$XC = \frac{1}{\sqrt{2\pi f_c}} \tag{3.10}$$

where:

$$f = 50Hz$$

$$XC = \frac{1}{100\pi c}$$

From the impedance formula,

$$Z = \sqrt{R^2 + XC^2}$$

$$XC \gg Ra$$

$$Z = \sqrt{XC^2}$$

$Z = XC$, C determines the current that flows into the bridge rectifier

From Ohm's Law,

$$V = IR \tag{3.11}$$

$$I = \frac{V}{R} \tag{3.12}$$

$R = Z$ impedance of the circuit

$I_z = 265\text{mA}$ (Approximate value)

$V = 220\text{v}$ (Mains Voltage)

$$R = Z = X_C = \frac{220}{65\text{mA}} = 8.38\text{k}\Omega$$

$$X_C = \frac{1}{\sqrt{2\pi f_c}} = \approx 2.2\mu\text{f} \text{ (npv)}$$

Calculating R_A , R_B and C are in parallel, the same voltage flow

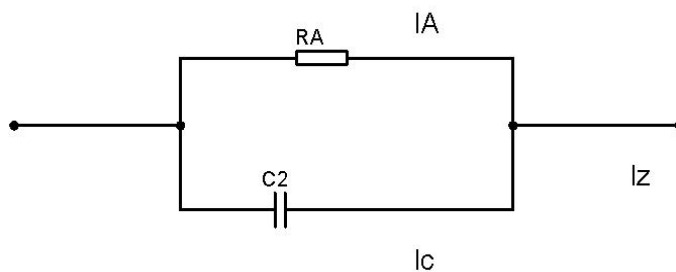


Figure 3.17: RC network of Voltage Protection circuit

$I_a + I_c = I_z$, Where I_a is the current flowing the R_A , I_c is the current flowing through C , and I_z is the total current,

$$I_a = 10\% I_z = 6.5\text{mA}$$

$$R_A = \frac{V}{I_c} = 38\text{k}\Omega \approx 330\text{k}\Omega \text{ (npv)}$$

$$PR_A = (I_a^2 \times R_A) = 0.21\text{w} \approx 0.25\text{w} \text{ (npv)used}$$

The Negative Temperature Coefficient (NTC) thermistor at the neutral line is to absorb surge from the mains and the range from $1-10\Omega$, 5Ω used for the design

3.5.1.8 Voltage Stabilization

The output voltage from the bridge is unstable. It varies according to the mains.

To operate the circuit, there is need to stabilize the voltage via the use of Zener diode and BJT transistor, the circuit as shown in Figure 3.18

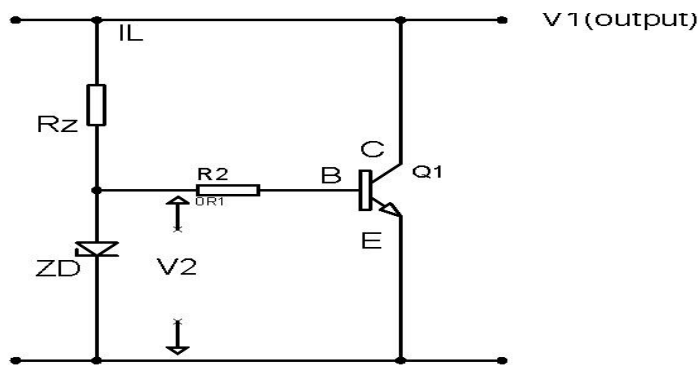


Figure 3.18: Current buffer for the circuit

3.5.1.9 Current buffer for the circuit

The circuit operate at 12volts for the relay and 5volts for the microcontroller (Atmega328p), for this application, high voltage Zener diode is needed

From the circuit, RZ and RD are in series.

This implies, I_z is the source current through the Zener and RZ is the biasing resistor.

From Ohm's Law,

$$V = IR$$

$$I = \frac{V}{R}$$

Computing for I_z

$P_z = I_z V_z$, where P_z is the power of the Zener diode

$$I_z = \frac{P_z}{V_z} = 0.42A$$

$I_z = 10\% I_{max}$ (biased the diode for proper operation)

$$I_{(min)} = 42mA$$

$$R_z = \frac{V_{cc} - V_z}{I_z} \quad (\text{Ohm's Law})$$

With 220uf 50v capacitor, the output voltage V_o is 38volts

$$R_z = 476\Omega \approx 470\Omega \text{ (npv)}$$

$$PR_z = R_z^2 \times I_z^2 = 0.829 \approx 1w \text{ (npv)}$$

The transistor D_1 buffers the current. The output voltage is still 12Volts is emitter connected to the ground. 5volts stabilization, because the microcontroller runs

from 3-5volts. 5-volt was used for the microcontroller.

The display is not up to 50mv, Zener diode of 1w chosen

$$V_Z = 5v$$

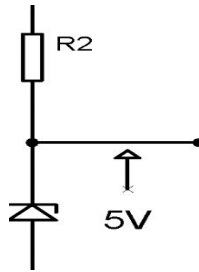


Figure 3.19: stabilizing 5-volt circuits

$$P_Z = 1w$$

$$I_Z = \frac{P_Z}{V_Z} \tag{3.13}$$

$$I_Z = \frac{1}{5} =$$

$$I_Z = 200m$$

$$I_{Z(min)} = 10\% \text{ of } I_{ZD1} = 10\% \text{ of } 200 = 20mA$$

$$R_Z = \frac{12-5}{20mA} = 476 = 350\Omega \approx 330\Omega \text{ (npv)} \quad \text{as shown in Figure}$$

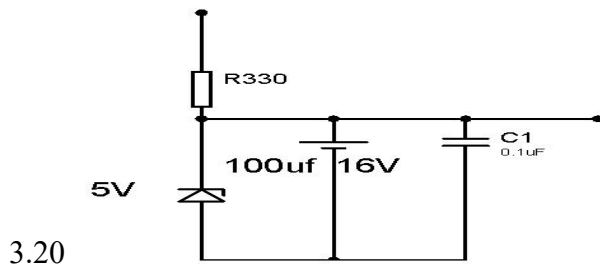


Figure 3.20: Stabilizing circuit for the microcontroller

3.5.1.10 The ladder Resistor

The ladder resistor (resistor network) was used to divide the voltage to ensure accuracy and stability of the measured output of the bridge rectifier to level of 0-5volt, For the input of the microcontroller:

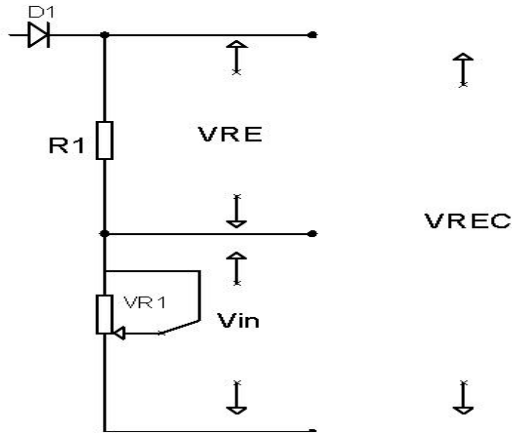


Figure 3.21: ladder resistor network

V_{R1} = Voltage drops across R_1

V_{R1} is representing the mains bridge of the red phase

V_{R1} = 1-5volts (Assumed input to the Analogue input of the microcontroller)

$V_{R1} - V_{RE}$ - Rectified output voltage from bridge rectifier (V_{REC})

$$V_{REC} = V_{RE} + V_{R1} \quad (3.14)$$

where:

$V_{R1} = 5v$ (Maximum input to the microcontroller)

$$V_{RE} = V_{REC} - 5v$$

At peak value surge on the line

$$V_{REC} = 45v$$

$$V_{RE} = 40v$$

$R_s = \frac{V_{RE}}{I_s}$, where I_s = series current, if R_1 is chosen to be $10k \Omega$

$$I_s = 0.5mA$$

Hence, $R_E = 30k \Omega \approx 100k \Omega$ (npv)

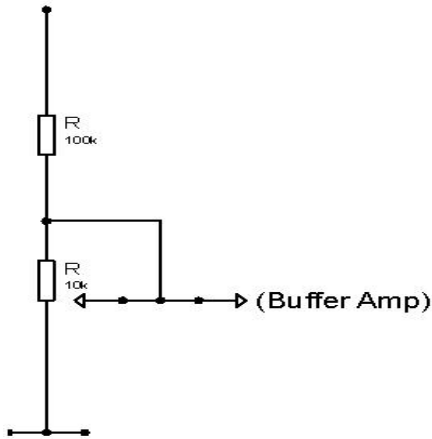


Figure 3.22: Series current resistor to buffer amp

The buffer Amplifier is used to isolate the variable input voltage from the ladder resistor into the Op-amp.

The buffer uses Lm324 quad op-amp as biased unity gain buffer.

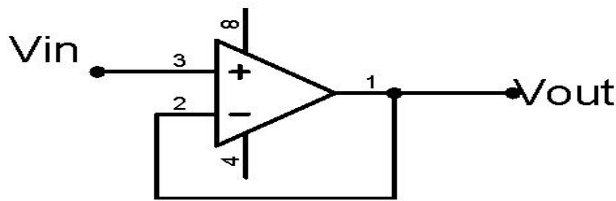


Figure 3.23: Unity gain op-amp

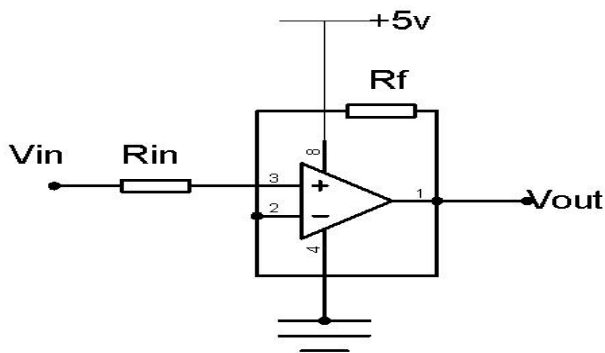


Figure 3.24: The buffer circuit

$$V_{out} = \frac{V_{in} R_f}{R_{in}} \quad (3.15)$$

If $R_f = R_{in}$, this implies $V_{out} = V_{in}$ (unity gain)

$$R_{in} = 10k \Omega, R_f = 10k \Omega$$

The $1k\Omega$ is to limit current flowing into the Analogue input of the microcontroller.

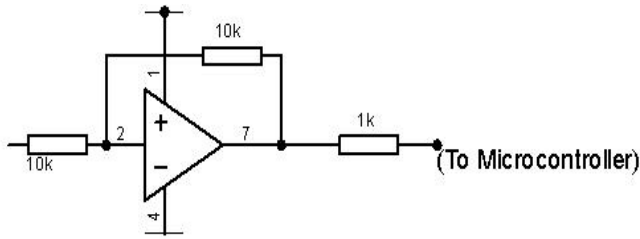


Figure 3.25: The current limiting operation of the buffer circuit.

3.5.1.11 The Metering IC

The metering IC contains serial interface UART with a speed of 9600 baud, a 5V

supply voltage, and the ability to connect an LCD or LED display. It can be used for load capacity with rated power of 20kW and can measure currents up to 100A. Its function is to digitally transform the analogue current and voltage signals generated by current and voltage sensor circuits, multiply those signals, and create a digital signal whose frequency fluctuates with the amount of power acquired. The measurement result is read using the master's command format, which is (total of 8 bytes). The organization of the measurement results recorded shown in Table 3.1.

Table 3.1: Metering IC measurement

Register Address	Description	Resolution
0x0000	Voltage value	ILSB correspond to 0.1V
0x0001	Current value low 16 bits	ILSB correspond to 0.001A
0x0002	Current value high 16 bits	

0x0003	Power value low 16 bits	ILSB correspond to 0.1W
0x0004	Power value high 16 bits	
0x0005	Energy value low 16 bits	ILSB correspond to 1Wh
0x0006	Energy value high 16 bits	
0x0007	Frequency value	ILSB correspond to 0.1Hz
0x0008	Power factor value	ILSB correspond to 0.01
0x0009	Alarm Status	0xFFF is alarm, 0x0000 is not alarm

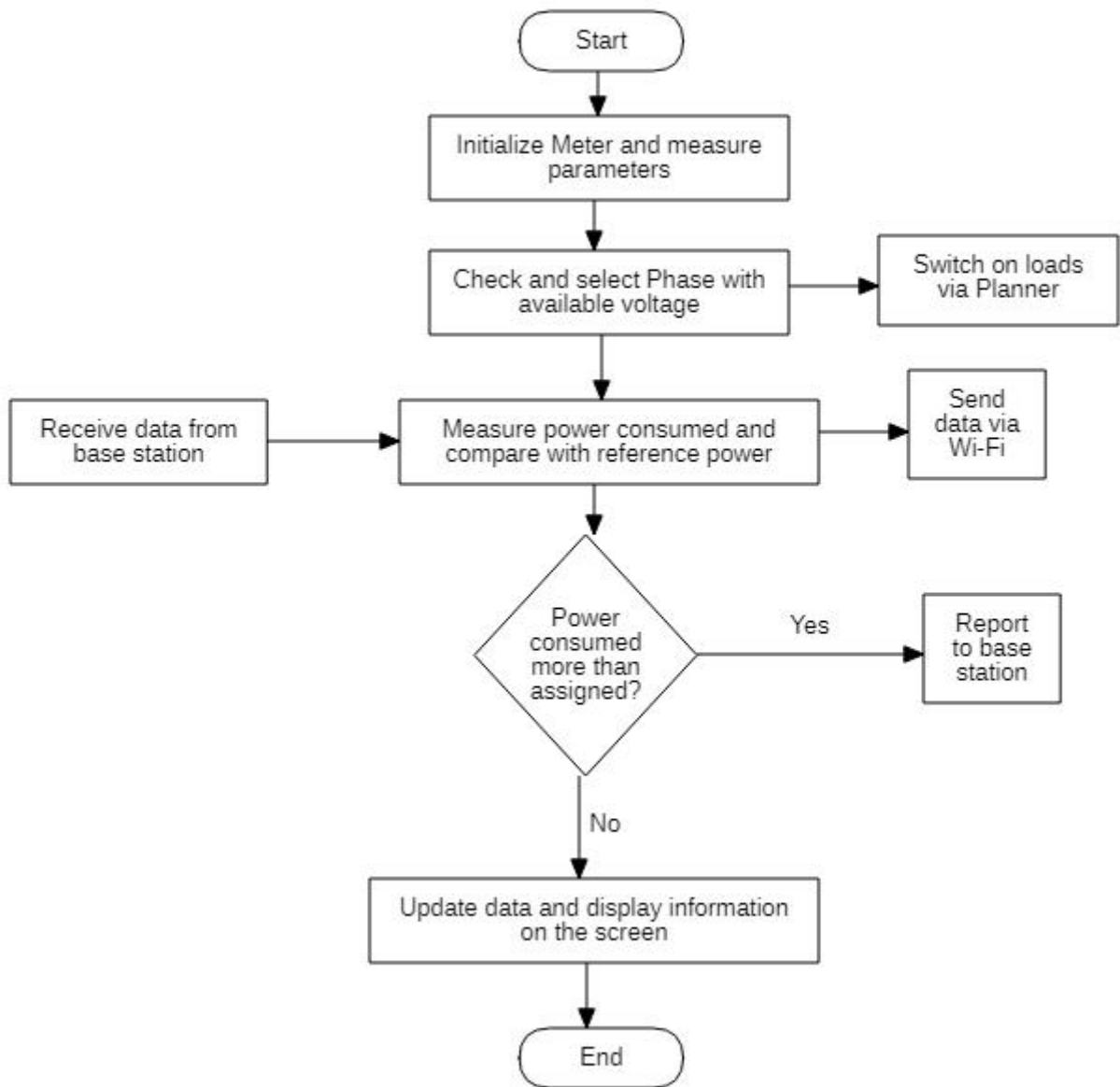


Figure 3.26: Flowcharts depicting algorithm of metering system.

3.5.1.12 Principle of operation of metering system

The metering system is an Automated Energy Meter that send and receive data from its Base station via Radio network. The meter is controlled by the base station to control power used by consumer (s), the system resets and sends a notification to the base station when the power consumed exceeds the power allotted.

The metering system uses a microcontroller Atmega328p, the system's control is carried out by the microcontroller. The microcontroller chooses the available phase voltage across Phases One, Two, and Three based on data from the three phase sensors. If there is no voltage in the three phases, it shuts down the system but if there is voltage it selects it and switch ON relay that

control the phase output voltage of either Phase one, Phase two or Phase three according to selected phase voltage, to switch on the load via the home energy planner (HEP).

The microcontroller obtains the current consumption data from a current sensor, which measures the current flowing through the system. To determine the power usage of the load, the microcontroller compares the current and phase voltage values.

The system incorporates a precise and low-offset linear Hall-Effect sensor circuit that is situated near the surface of the microcontroller's die. This circuit measures the magnetic field generated by the current flowing through the copper conduction line and converts it into a proportional voltage using an integrated Hall IC.

The wireless transceiver module employed in the system utilizes a Radio Frequency

(RF) chip and supports various transmission modes. It operates at a frequency above 433MHz and utilizes Long-Range (LoRa) chirp spread spectrum (CSS) technology, which is a Low-Power Wide Area Network (LPWAN) technology.

Additionally, the meter includes an ESP8266 Wi-Fi module that enables wireless connectivity with an Android device. Through this module, the meter can transmit the power consumption information to the consumer. The ESP8266 module is equipped with antenna switches, RF baluns, power amplifiers, low noise receiver amplifiers, filters, and power management modules. The high-frequency clock necessary for the transmit and receive functions of the ESP8266 is generated by an external crystal and an internal crystal oscillator, operating at frequencies ranging from 24 to 52 MHz. Furthermore, the meter is equipped with an onboard liquid crystal display (LCD) controlled by the microcontroller. The LCD provides information such as the phase status (R, Y, B), the available or optimal phase voltage, the current drawn, and the power consumed by the load. The LCD utilized in the meter is a 20x4 size display, allowing for clear and readable characters for the user.

3.5.1.13 Design of the Microcontroller Unit

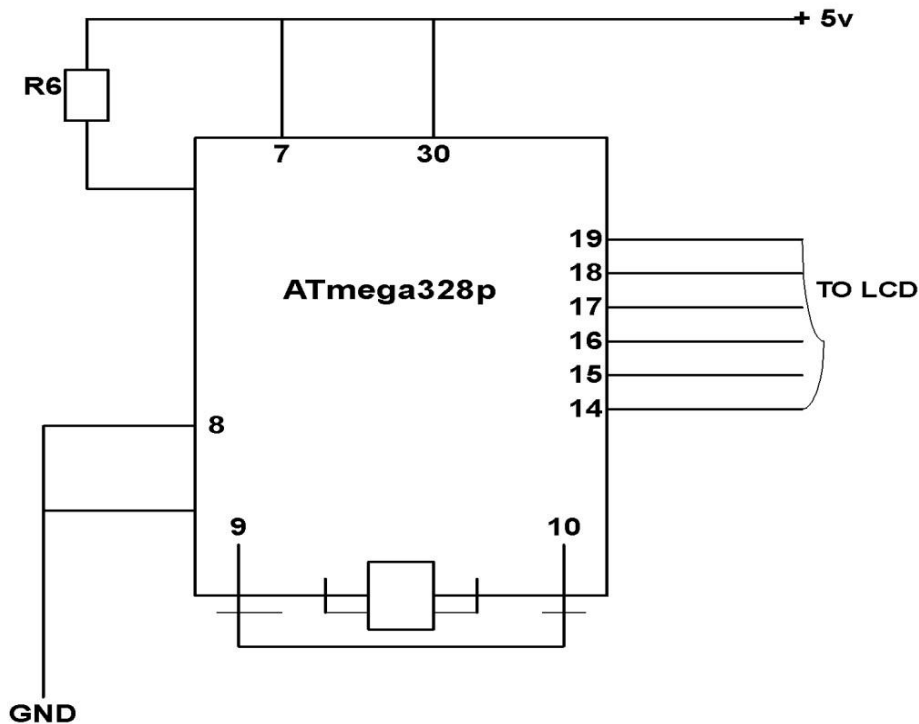


Figure 3.27: The design of the microcontroller unit

The ATmega328P microcontroller is the brain of AMPMS. It's responsible for collecting data from various sensors, processing the data, managing power consumption, and displaying information on the connected LCD. LCD Connection (Pin 14 to Pin 19): These pins are connected to the Liquid Crystal Display (LCD). The ATmega328P communicates with the LCD to display information about power consumption, voltage, current, or any other relevant data. The specific pins used as follows:

Pin 14 (PORTB.0) - RS (Register Select): Used to select whether data or commands are being sent to the LCD.

Pin 15 (PORTB.1) - RW (Read/Write): Used to control the direction of data transfer (read or write). Typically set to write mode for sending data.

Pin 16 (PORTB.2) - EN (Enable): Used to enable data transfer to the LCD.

Pins 17-19 (PORTD.0, PORTD.1, PORTD.2) - Data lines (D4, D5, D6): Used to send data to the LCD.

Power Supply (Pin 30 and Pin 7): Pin 30 (Vcc) is connected to a 5V DC power supply. This voltage powers the microcontroller and other components in the system. Pin 7 (RESET) is used for reset functionality, and it pulled high with a resistor (often in the range of 10k ohms) to prevent accidental resets. Ground (Pin 8 and Pin 11): Pins 8 and 11 are connected to the ground (0V). Ground serves as the reference voltage for all components in the system and ensures a common voltage reference.

Crystal Oscillator (Pin 9 and Pin 10): Pins 9 (XTAL1) and 10 (XTAL2) are connected to an external crystal oscillator or ceramic resonator. This provides a precise clock signal to the microcontroller, allowing it to execute instructions accurately and manage timing-related tasks effectively. The crystal oscillator frequency matches the microcontroller's clock requirements, typically 8MHz or 16MHz. The external crystal oscillator ensures accurate timing for data acquisition and processing, which is crucial for reliable measurement and monitoring of power consumption.

3.5.1.14 Programming the Microcontroller

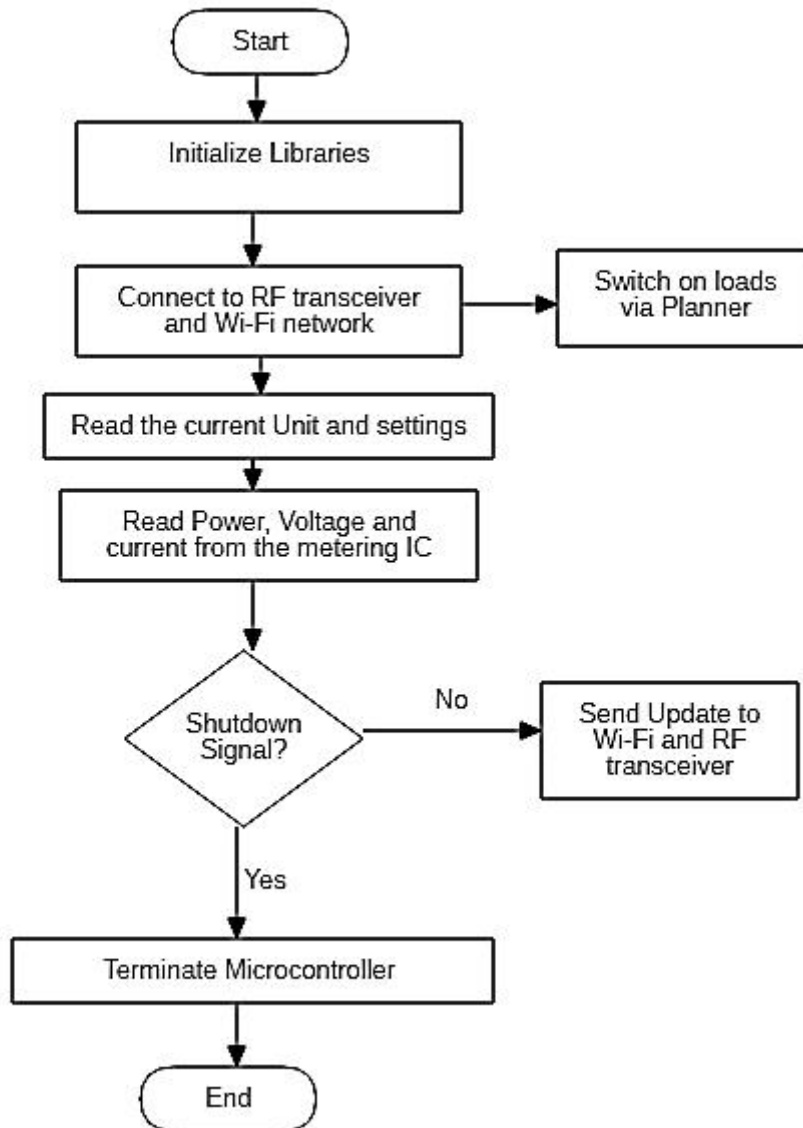


Figure 3.28: Flow chart of the algorithm of microcontroller programming

The program starts by setting up the external libraries. The libraries include Wire.h for I2C communication, LiquidCrystal.h for communicating with the LCD, and Software

Serial.h for communicating with the RF module through the serial port. Software Serial.h library was used with the RF module as the inbuilt serial port already used with module of the Wi-Fi.

After initializing the libraries, the program initiates a connection request with the RF module and reads the available units in the meter from the EEPROM. The program then enters a loop where it reads the Power Module's parameters (Energy, Power, Current, Voltage, and Power Factor), displays them on the LCD screen, transmits them to the RF module and Wi-Fi module upon request, and responds to any requests from both the RF module and the Wi-Fi module. The code is contained in appendix B.

The microcontroller is an embedded design programmed in C programming language; it receives the measured energy from the metering IC programmed on Arduino Nano board which supplies a pulse train frequency output proportional to the measured power. Given is the average power in relation to the average frequency output:

$$\text{Average frequency} = \text{average power} = \text{counter}/\text{time}$$

This value is stored and displayed on the LCD at intervals. The amount of energy used expressed as:

$$\text{Energy} = \text{average power} \times \text{time} = \frac{\text{counter}}{\text{time}} \times \text{time} = \text{counter} \quad (3.16)$$

3.5.1.15 The communication protocol between meter and base station

It was implemented as a straightforward call-and-response system with an infinite loop. This method was simple to use because the base station and the energy meter both had transceivers. If the base station receives some data but it is partial or seems distorted, it sends a request for retransmission and the meter receives a request from the base station at every five seconds.

Following is a description of the protocol:

When the energy meter's receiver isn't transmitting, it listens for requests.

The microcontroller software verifies the header information to see if it is valid when it receives one.

The data obtained are used to extract the meter ID.

The received meter's ID is compared to the receiving meter's ID to see if they match. If they are different, step one is repeated.

If the meter ID is the same, the energy meter's transmitter sends packets with the energy reading.

Step 1 is repeated as the energy meter returns to receiving mode.

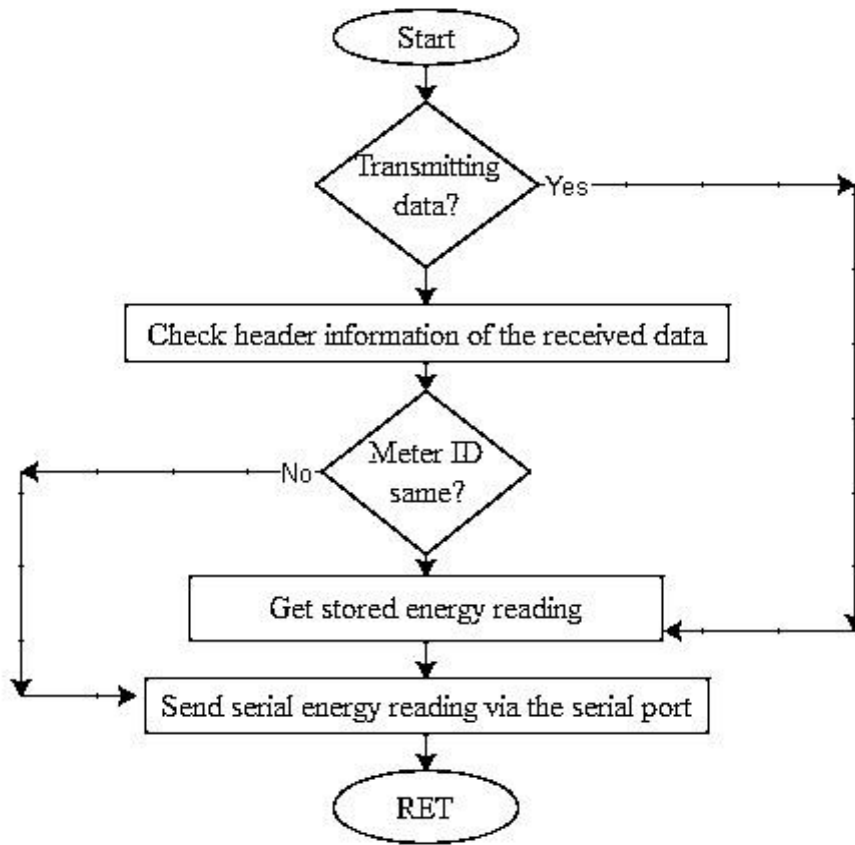


Figure 3.29: Flowchart of Serial communication process

The Liquid Crystal Display (LCD)

The LCD display device, which comprises of a 16x2 LCD screen

A 10k variable resistor (VR) set to 2/3 of the supply voltage

Given,

$$V_R = 10k\Omega$$

The set resistance

$$= 10 \times \frac{5}{6.67} = 6.67k\Omega$$

The current needed for the LCD's brightness is determined by:

$$I_{LCD} = V/R = 0.749A$$

$$I_{LCD} = 750mA$$

It takes that current to change the LCD's brightness or contrast so that it can display information without overheating or suffering other damage



Figure 3.30: The Liquid crystal display (LCD) unit

3.5.1.16 Design of the Relay Driver (Transistor) and Optocoupler transistor base

A 2N2222 transistor links the ATmega328p microprocessor to the rest of the circuit. The output power from the transistor-powered relay is switched on and off because of the transistor to ensure proper control. On the LCD, currents, voltages, power, and total cost are shown in real time. The lowest current necessary for energizing the relay coil can be calculated from the transistor base resistor value by computing the threshold current required to successfully drive the relay. To produce the required current to saturate the transistor, the resistor value was calculated as follows:

Base-emitter voltage $V_{be} = 0.7V$

Collector-emitter voltage $V_{ce} = 0.25V$

Amplification factor $\beta = h_{fe} = 100$

The V_{be} , V_{ce} and h_{fe} values are from the 2N2222 transistor's data sheet.

At saturation, I_C is designed to be greater than or equal to 100 mA so that it can give enough current to the relay or load.

The amplification factor of the transistor is given as:

$$\beta = \frac{I_C}{I_b} \tag{3.17}$$

$$I_b = \frac{I_C}{\beta} = h_{fe} = \beta = 100 \text{ and } I_C = 100 \text{ mA}$$

$$I_b = \frac{100 \text{ mA}}{100} = 1 \text{ mA}$$

From the voltage equation:

$$V_o = VR_b + V_{be} = I_b R_b + V_{be} \tag{3.18}$$

Where V_o = microcontroller output voltage

V_{R_b} = Voltage across the base resistor

R_b = base resistor

I_b = base current

V_{b_e} = Base emitter voltage,

$$R_b = \frac{(V_o - V_{b_e})}{I_b}$$

$V_o = 5\text{ V}$, $V_{b_e} = 0.7\text{ V}$ and $I_b = 1\text{ mA}$

$R_b = 4.3\text{ k}\Omega$

For the transistor to be in saturation, or maximum current, R_b must be less than $4.3\text{ K}\Omega$. As a result, $1\text{ K}\Omega$ resistor was used

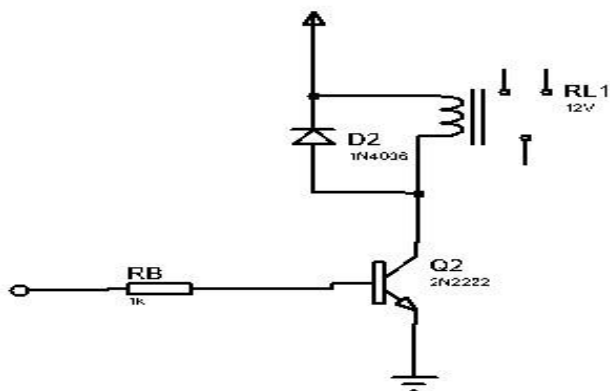


Figure 3.31: The relay driver (transistor)

As illustrated in Figure 3.32, an optocoupler is utilized, specifically a photo-transistor device of the transistor-base type. This optocoupler operates by allowing current from the source signal to flow through the input LED, generating infrared light with intensity corresponding to the electrical signal.

The emitted light strikes the photo-transistor, causing it to turn on and function similarly to a bipolar transistor. For maximum sensitivity to the infrared light energy from the LEDs, the connection of the photo-transistor can be left open (unconnected). Alternatively, to adjust the switching sensitivity, it can be connected to ground through an appropriate external high-value resistor. This configuration enhances its robustness and minimizes the risk of false triggering due to external electrical noise or voltage fluctuations.

When the current through the LED is interrupted, the photo-transistor ceases to conduct, thereby switching off the emitted infrared light. The photo-transistor can be used to control the current in

the output circuit. It is important to note that optocouplers provide electrical isolation between the input and output, enabling isolation levels of up to 10kV due to the absence of direct electrical coupling between the two.

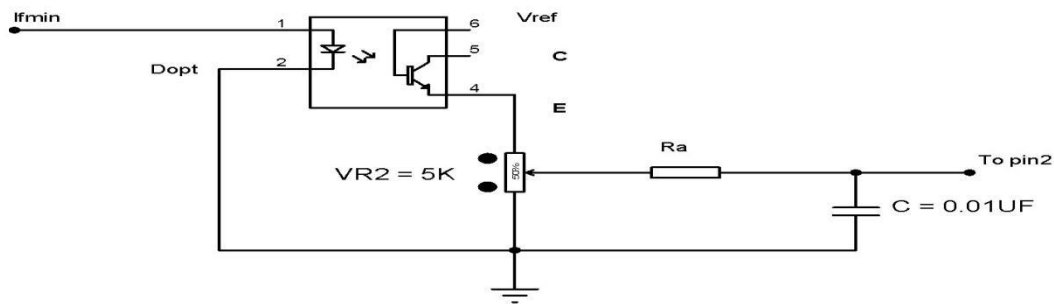


Figure 3.32: Optocoupler transistor base.

If D_{opt} is forward biased,

$$V_E = V_{ref} - V_{BE} \quad (3.19)$$

Where, $V_{ref} = 5$ volts from voltage regulator (LM7805) output

$$V_{BE} = 0.7\text{volt for silicon transistor}$$

$$V_E(opt) = (5 - 0.7)$$

$$= 4.3\text{volts}$$

$$V_{R2}(opt) = R_1 = 4.71\text{K}\Omega \quad (\text{to produce the same base input current})$$

$$V_{R2}(opt) = 4.71\text{K}\Omega$$

$$V_{R2}(opt) = 5\text{k}\Omega \text{ (NPV)}$$

3.5.1.17 Design of the open-circuit fault detection and reporting system

A software computer program is used to design the fault detection and reporting system. The algorithm for running the program is shown in a flow chart in Figure 3.33.

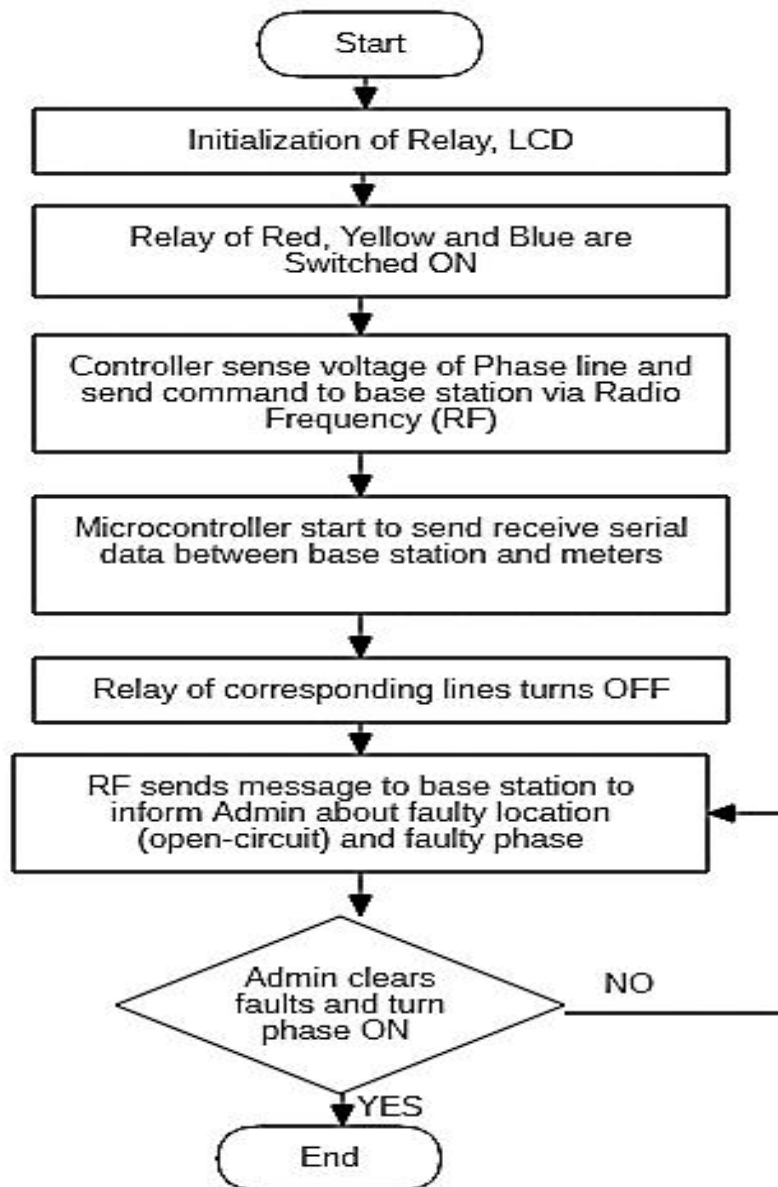


Figure 3.33: Flow chart of the open-circuit fault detection and reporting system.

3.6 Programming the module of the Wi-Fi

The Wi-Fi module used in this study is the ESP-01. This module is based on the ESP8266 System on Chip (SoC). Esp8266 consists of a 32-bit RISC processor and TCP/IP network stack driver. ESP-01 integrates esp8266 with a PCB antenna and 1MB flash memory. This work, it was programmed using the Arduino IDE with ESP8266 board tools.

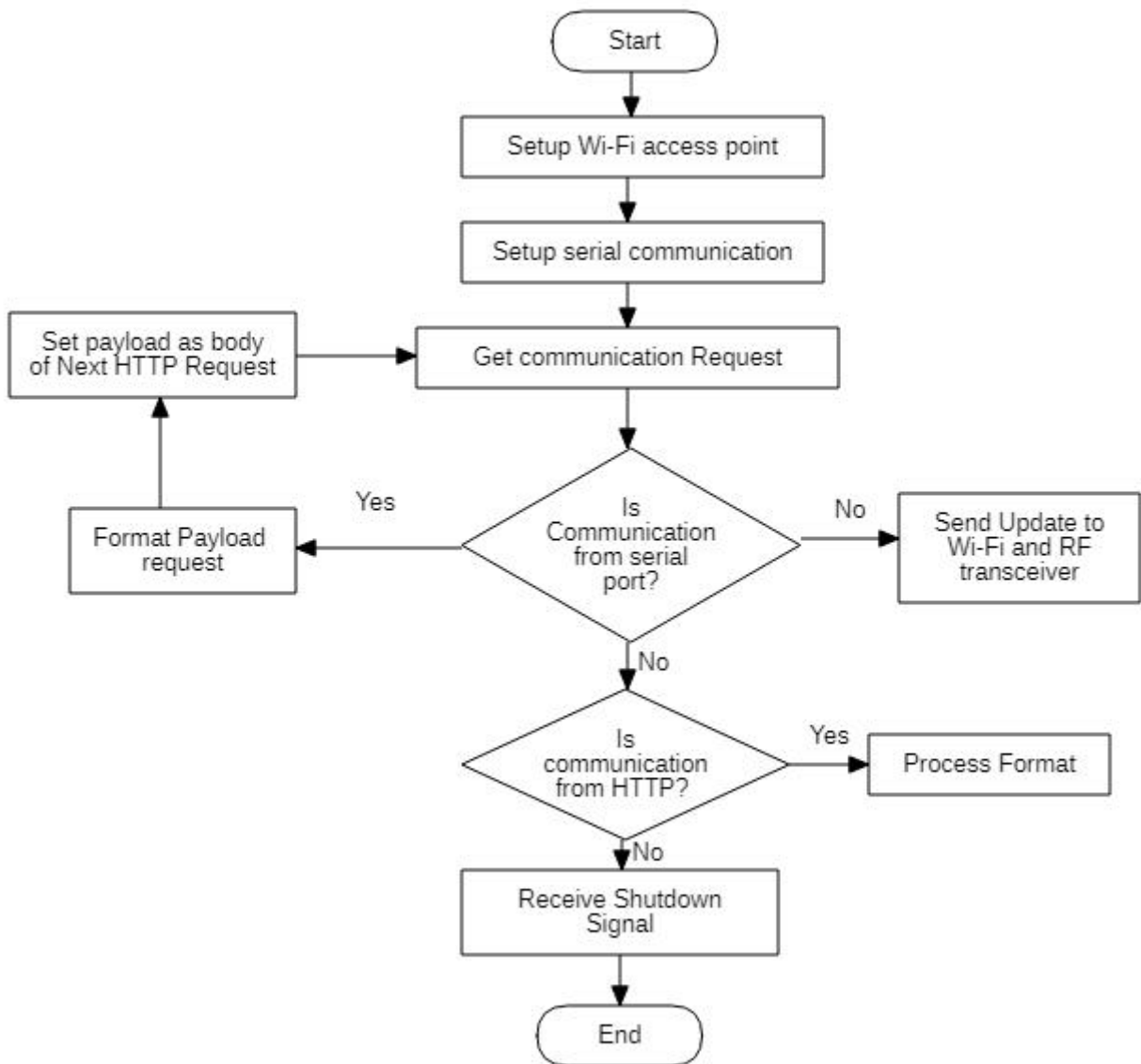


Figure 3.34: Flow chart of the Wi-Fi Module program.

From the diagram above, the program starts by setting up the Wi-Fi connection and broadcasting on the network as Access Point (AP). This enables it to accept connections from Other Wi-Fi devices using the specified SSID and password. Then it sets up the serial port for communication with the main microcontroller (AYmega328p) and creates an HTTP server. The operation after the setup is straight forward. It simply forward any data transfer from serial port to http server.

3.7 The Wireless Interface Device

The base station wireless interface device is a device that serves as a link between the automated metering device and the base station of the energy billing and monitoring system. For communication, it uses LoRa RF transceivers, one of which is connected to the base station and

the other ones to the individual meters. When using a computer without a dedicated serial port, a USB-to-serial converter is used to connect the LoRa module to the base station. The serialutil application is used to exchange data between the serial port and the base station software. The circuit diagram of the wireless interface device for the base station as shown in Figure 3.35.

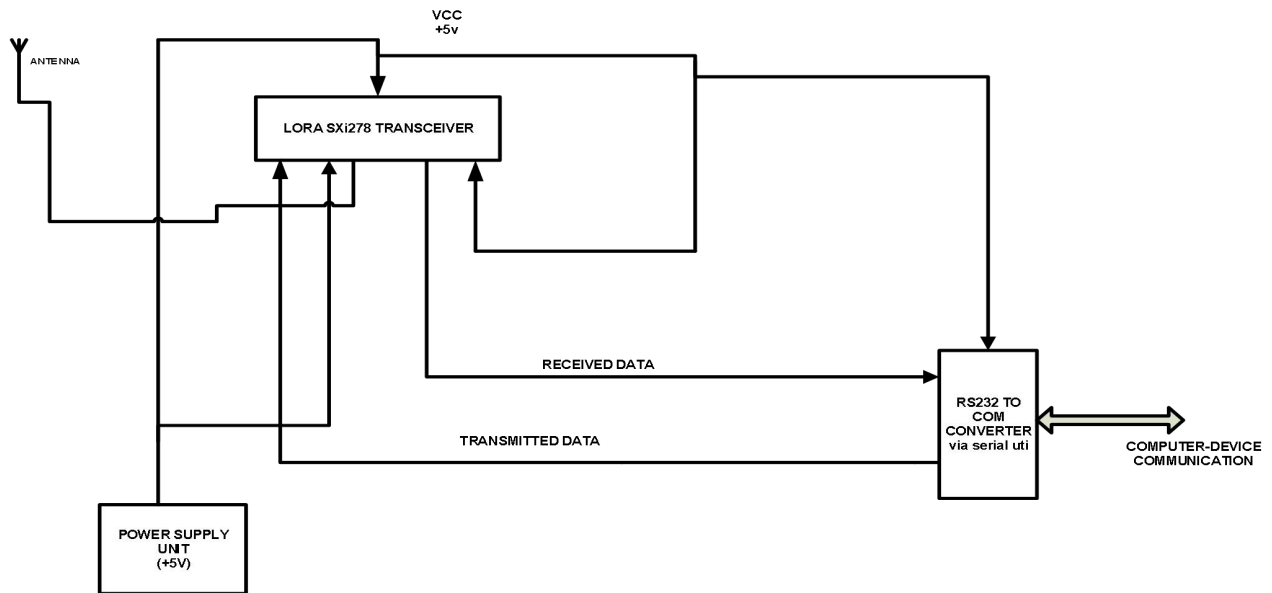


Figure 3.35: Diagram of Wireless Interface Device of the Base Station

3.8 The LoRa RF wireless transceiver

Based on the SX1278 RF chip from SEMTECH, the LoRa RF transceiver module supports a variety of transmission modes., operates at a frequency of 525MHz. The module adopts a long range (LoRa) chirp spread spectrum (CSS) technology. The details about the transceiver can be found in its datasheet in Appendix L. This transceiver was chosen for this design because of the following need:

To achieve transmission and reception within a distance of 2km

To work with a device that is compatible with the RS232.

To work with a device to fit into the meter conveniently.

To work with a protocol that support multi-channel communication while
avoiding collision of data between channels

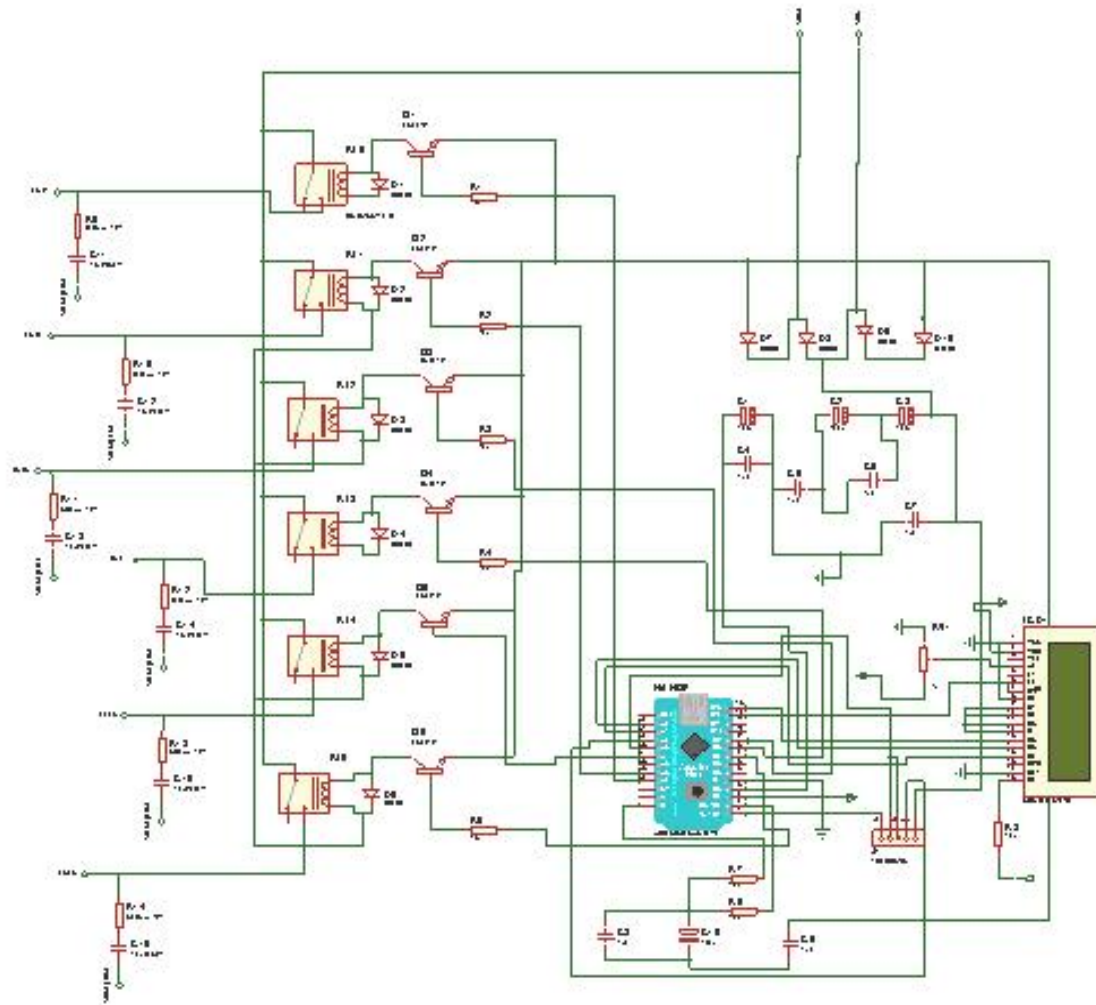


Figure 3.36: Schematic diagram of the Home Energy planner

3.9 The design of the home energy planner

To simplify and streamline the design process, the home energy planner is divided into five (5) sub-units: the power supply unit, connectivity unit, controller unit, relay unit, and the RC snubber circuit. The system's circuit diagram, depicted in Figure 3.36. The relay driver (transistor) and the RC snubber circuit shown in Figure 3.31 and Figure 3.32.

3.9.1 The power supply unit

To get a constant output voltage of 5V for the microcontroller, the voltage regulator LM7805 was utilized. To defend against back EMF, output capacitors were employed to reduce output voltage ripple caused by ac transient changes, and diodes were utilized to avoid reverse polarity. The Power Supply Unit is made up of a full-wave rectifier circuit to convert AC 12V to DC 12V, and AC 220/12V step-down transformer.

3.9.2 Transformer

The transformer used in this design was purchased from a local electronics store. a stepdown transformer rated at 220v and 2000mA. The transformer reduces the mains voltage to 12 volts from 220 volts. The transformer's output voltage can be computed as follows:

Transformer ratings:

$$V_{rms} = 12v$$

$$I_{rms} = 2000mA$$

$$V_{peak} = V_{rms} \times \sqrt{2}$$

$$V_{peak} = \sqrt{2} = 16.97v$$

The transformer's output voltage is 16.97 volts. Next is the stage of rectification.

3.9.3 Rectification

Despite the power requirement being 5V DC, the power is obtained by converting it from 220V AC to 12V AC (12V RMS with a peak of approximately 17V). This conversion involves transforming the 17V AC power into DC power and subsequently reducing it to 5V DC. The Diode IN4001 is the component used in the design, and its maximum operating voltage and current are 30V and 1A, respectively. This diode was chosen since this system required a 5v and 1A output dc voltage. The total voltage drops, V_d , for the two diodes involved in the rectification process in either of positive or negative cycles,

$$V_d = 2V_{BE}$$

$$V_{BE} = 0.7 \text{ for silicon diode}$$

$$V_d = 2 \times 0.7V = 1.4V$$

From the output of the transformer,

$$\sqrt{2} = 12v = V_{rms}$$

$$V_{peak} = V_{rms} \times \sqrt{2}$$

$$V_{peak} = 12 \times \sqrt{2} = 16.97v$$

$$V_{peak} \approx 17v$$

$$V_{Lm} = (V_{peak} - 2V_{BE})$$

$$V_{Lm} = 17 - 1.4$$

$$V_{Lm} = 15.60v$$

The rectifier circuit's output therefore has a peak voltage of about 15V. The next phase is the filtering stage.

3.9.4 Filtering stage

The diode's output is a pulsing DC, or a DC with ripples. This pulsating DC can be filtered using a capacitor to eliminate the ripples. Because the component values are the same as in Automated metering, the design calculations for filtering, regulation, optocoupler in Figure 3.29, relay driver (transistor) in Figure 3.28, microcontroller, and LCD in Figure 3.27 are the same. Hence, From the approximate ripple voltage formula:

$$V_r = \frac{I_o}{2F_c} \quad (3.20)$$

Where: I_o = Dc element from regulator

F = mains frequency

c = capacitance in microfarad

V_r = Ripple voltage

$$\text{From equation (3.20)} C = \frac{I_o}{2FV_r} \quad (3.21)$$

Where $V_r = 20\%$ of Vdc

$$= 1.88 \text{ volts}$$

$I = 500\text{mA}$ (Assumed maximum current drain from the regulator)

$f = 50\text{Hz}$

Therefore,

$$C = \frac{I_o}{2FV_r}$$

$= 781 \times 10^{-6}$. Hence, 1000 μf , 50v is the Near Preferred Value (NPV)

3.9.5 Voltage regulation

The fixed regulator type 78xx series is the sort of voltage regulator used in this design. They have a 3-volt internal voltage and a 500mA maximum current. The output voltage of the 7805 is stated.

$$V_{in} = V_{out} + 3$$

Where 2 is the limiting input voltage

$$V_{in} = 5 + 3 = 8v$$

This indicates that the LM7805 requires a minimum input voltage of 8 volts to create an output is 5v.

The variable regulator (LM317) output's voltage (V_{out}) to the ATmega328p microcontroller is determined by:

$$V_{out} = 1.25 \times \left(1 + \frac{R_2}{R_1}\right) \quad (3.22)$$

Where 1.25 = constant

R1 and R2's values cannot be determined from the equation. A 5-volt output voltage is anticipated for the ATmega328p microcontroller. The value of R2 is given by

$$R_2 = \frac{V_{out}}{I_{dc}} \quad (3.23)$$

If $V_{out} = 5v$, and $I_{dc} = 1175mA$ (from the power supply unit)

$$R_2 = \frac{5}{1175mA} = \frac{5}{1175 \times 10^{-3}} = 4.26\Omega$$

The value of resistor R1 is then obtained from equation 2

$$V_{out} = 1.25 \times \left(1 + \frac{R_2}{R_1}\right)$$

$$5 = 1.25 \times \left(1 + \frac{4.26}{R_1}\right)$$

$$R_1 = \frac{4.26}{3}$$

$$R_1 = 1.42\Omega$$

But in the research, R1 was given a standard value of 1.4 Ω and R2 a value of 4.2 Ω .

3.9.6 The Connectivity Unit

An ESP8266 Wi-Fi module, an Arduino Nano, and an Android device are the components of this gadget. The Wi-Fi module is connected to the Microcontroller by first connecting the Arduino's transmission pin to the ESP8266 module's reception pin, and then the Arduino's reception pin to the ESP8266 Wi-Fi module's transmission pin. Power for the ESP8266 Wi-Fi Module comes from an external 5V power source. An Android device is used to access the home energy planner webpage,

which acts as an IoT interface between the Android device and the Wi-Fi module's internet functionality. It serves as a remote control through the Internet and displays important data such as consumer loads, metering settings, and the three-phase power distribution lines. The connectivity's dependability can be calculated as follows:

Reliability of connectivity Unit,

$$R_{CU} = \frac{\text{Number of Successful Connections}}{\text{Total number of trials}} \quad (3.24)$$

Number of connections made successfully = 10

Number of trials made = 10

$$R_{CU} = \frac{10}{10} = 1.0 \text{ or } 100\%$$

3.9.7 The Relay unit

A 1K resistor connects the Arduino Nano to the NPN transistor in the relay device. Relays, diodes, resistors, and transistors make up the relay unit (since the transistor is in the saturation area). In this design, relays are used to control the lighting and other loads by turning them on and off. Diodes are also utilized to shield the transistors from back EMF. Relays in use have a 12V rating. The transistor utilized is a 2N2222, which is widely utilized for switching and has a rating of Low Power, Medium Current, and Medium Voltage

To produce the required current to saturate the transistor, the resistor value was calculated as follows:

Base-emitter voltage $V_{be} = 0.7V$

Collector-emitter voltage $V_{ce} = 0.25V$

Amplification factor $\beta = h_{fe} = 100$

The V_{be} , V_{ce} and h_{fe} values are from the 2N2222 transistor's data sheet.

At saturation, I_C is designed to be greater than or equal to 100 mA so that it can give enough current to the relay or load.

The amplification factor of the transistor is given as:

$$\beta = \frac{I_C}{I_b} \quad (3.25)$$

$$I_b = \frac{I_C}{\beta} = \frac{100 \text{ mA}}{100} = 1 \text{ mA}$$

$$I_b = \frac{100 \text{ mA}}{100} = 1 \text{ mA}$$

From the voltage equation:

$$V_o = VR_b + V_{be} = I_b R_b + V_{be} \quad (3.26)$$

Where V_o = microcontroller output voltage

V_{R_b} = Voltage across the base resistor

R_b = base resistor

I_b = base current

V_{b_e} = Base emitter voltage,

$$R_b = \frac{(V_o - V_{b_e})}{I_b}$$

$V_o = 5 \text{ V}$, $V_{b_e} = 0.7 \text{ V}$ and $I_b = 1 \text{ mA}$

$R_b = 4.3 \text{ k}\Omega$

For the transistor to be in saturation, or maximum current, R_b must be less than $4.3 \text{ k}\Omega$. As a result, as illustrated in Figure 3.33, a $1 \text{ k}\Omega$ resistor was used.

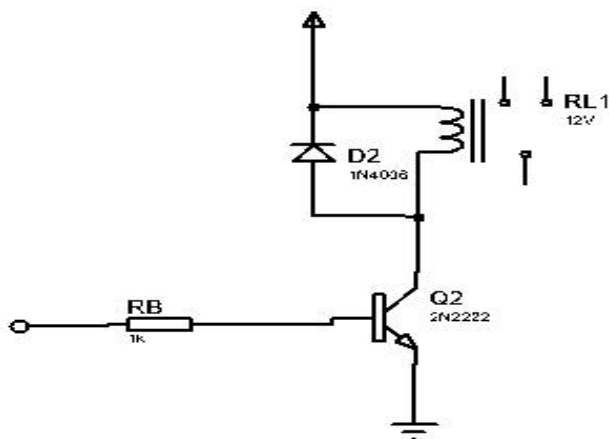


Figure 3.37: The relay driver (transistor) for home energy planner

Then, power is applied to the relay to test its delay time; the time is then measured and recorded.

Table 3.2: Relay Unit Voltage

Component	Expected Input Voltage (V)	Measured Input Voltage (V)	Expected Output Voltage (V)	Measured Output Voltage (V)
Transistor	12	12.3	23	24
Diode	4	5	3	3.4
Relay	8	8.2	12	11.8

Table 3.5: Relay Unit Current

Component	Expected Input Current (A)	Measured Input Current (A)	Expected Output Current (A)	Measured Output Current (A)
Transistor	34	33	44	43
Diode	56	52	44	47
Relay	12	14	44	42

The reliability of the Relay unit was determined by the ratio of successful trials to the total number of trials.

Thus,

Reliability of Relay Unit,

$$R_{RU} = \frac{\text{Number of Successful Connections}}{\text{Total number of trials}}$$

Number of successful connections = 10 total

Number of trials = 10

$$R_{CU} = \frac{10}{10} = 1.0 \text{ or } 100\%$$

3.9.8 Snubber circuit design

The snubber circuit guards against inrush or surge current in the circuit

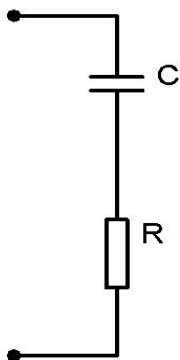


Figure 3.38: RC Snubber Circuit

RC series circuit acts as short to high voltage spark and it's frequency dependent

$$Z = \sqrt{x_1^2 + R_1^2} = \text{Total input impedance of the circuit} \quad (3.27)$$

$$x_C = \frac{1}{2\pi f_c}$$

C is chosen so that it does not short the mains supply.

$$x = \frac{1}{2 \times 50 \times 3.142c} \frac{3.2 \times 1000}{V_c}$$

$$V_C = 0.1 \mu f$$

$$x_C = 32k\Omega$$

$$R = 0.1\% \text{ of } x_C = 32\Omega = 33\Omega \text{ (npv)}$$

$$x_C \gg R$$

$$Z = \sqrt{x_C^2 + R^2}$$

$$\sqrt{(33000)^2 + (33)^2}$$

Since

$$x_C \gg R$$

$$\sqrt{(33000)^2}$$

$$Z = 33k\Omega$$

$$I = \frac{V}{Z} = 6.875mA$$

Power across the resistor,

$$P_R = I^2 R = 1.559mw$$

During surge (spike) due to the relay making contact, the frequency generated is greater than that of mains.

$$\text{Assuming } F = 1kHz = 10^3 Hz$$

$$x_C = 1.5k\Omega$$

$$x_C \gg R$$

$$I = \frac{V}{R} = 147mA$$

$$P_R = I^2 R = 0.7w$$

The voltage of the capacitor chosen based on 2 times the mains voltage

$$V_C = 2 \times 220 = 440volts \approx 400v \text{ (npv)}$$

$C = 0.1\mu f, 400v$

$R = 33\Omega, 1.559mw$

This would absorb the energy due to the load connected to the relay contact to suppress voltage spikes and protect the circuit from damage caused by inductive loads.

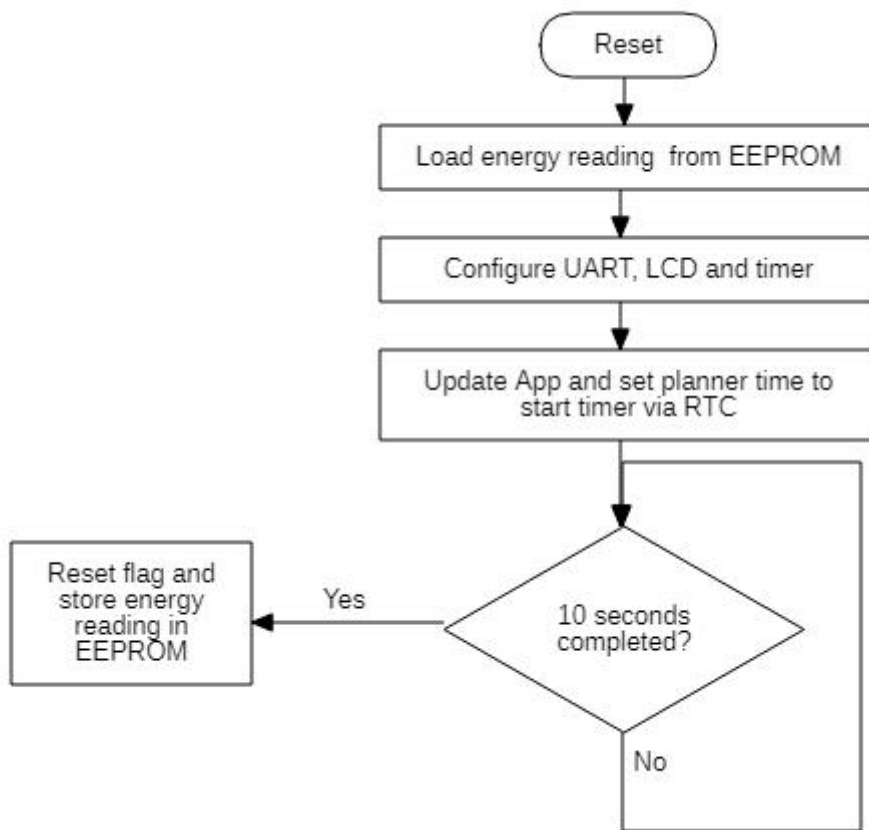


Figure 3.39: Flow chart of Microcontroller program on Home Energy planner

3.9.9 Principle of operation of home energy planner (HEP)

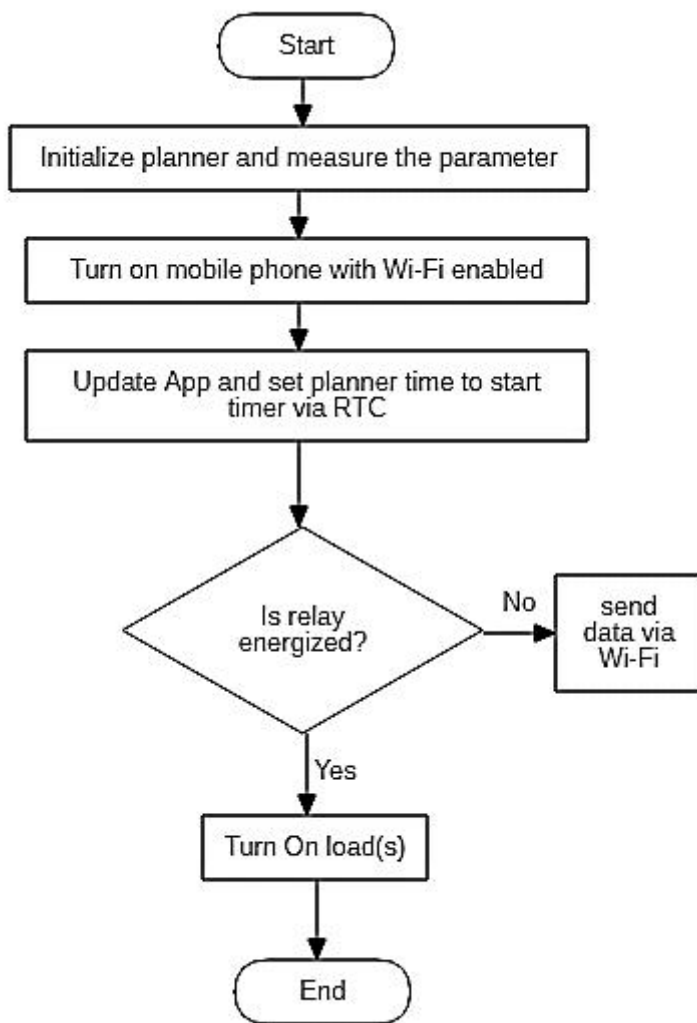


Figure 3.40: Principle of operation of the Home Energy planner

The Home Energy Planner (HEP) is a home automation device which receives power from the energy meter as input and sends power to various loads. The home energy planner considers all energy uses in the home, including heating, ventilation air conditioning, lightings, washing machines, televisions and other appliances.

The HEP uses an Arduino Nano as microcontroller which controls the load according to the received command from a wireless device (Android mobile App). The microcontroller uses an ESP8266 to communicate through Wi-Fi network to either PC or Android phone.

In order to create an effective home energy planning system for power optimization, the home energy planner uses a Real Time Clock (RTC) that is attached to the microcontroller and enables the user to select the time at which a certain load can be switched ON and OFF. The user sends the timing through Wi-Fi to the ESP8266 microcontroller so that it can turn on and off the load at the appropriate times.

The ESP8266 allows the user to manage loads via relays by sending commands to the microcontroller over a Wi-Fi network. The ESP8266 also allows the user to get load status information, such as the average power used by each load. The HEP also have an on-board liquid crystal display (LCD) which is controlled by the microcontroller, the LCD displays the load connected, the state of the load and power consumed by each load. The LCD used is a 16x2 size which enable it to display the load status to the user.

3.10 The design of the web-based system and mobile software application

The plan-driven software development process was used to design this software-based system. The development process of required specification, analysis, and design, which involves incremental delivery.

At each iteration, the following software engineering tasks were carried out:

Required Specification

Analysis and Design

The sitemap of the admin and user shown in Figure 3.38 and Figure 3.39 while the Tables for the design with fields defined and relationship structure of the database design shown in Table 3.3 and Table 3.4.

3.10.1 Required Specification

The system's functional and non-functional needs were laid down at this point. The use case diagrams for the web-based system and the mobile software application were used to model the system's design. To save and retrieve data for presentation to both the utility company and the electrical consumer, it must be able to interface with the database.

3.10.2 Analysis and Design

In order to analyze and design the software, object-oriented techniques were used. This made it possible to model the static components of the software using diagrams created with the

Unified Modelling Language (UML). StarUML was the employed tool for both web-based system and mobile software application. The use case diagram for the base station is shown in Figure 3.41.

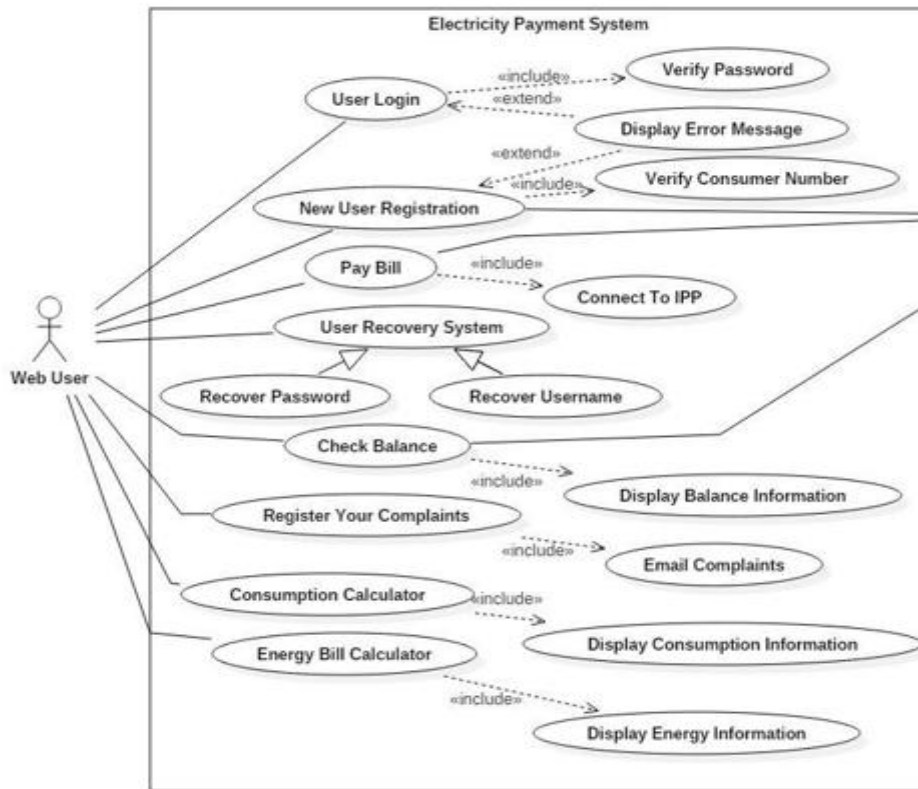


Figure 3.41: Use Case Diagram for the Base Station

3.11 The schema of the database for the base station

The database schema serves as a comprehensive blueprint, providing a logical representation of the entire database structure. It encompasses the data types, primary key (such as meters, meter requests, power consumed), and dependencies between different data entities. Both primary key and foreign key are employed as constraints within the schema. Each relation in the database schema corresponds to a table name, while the attributes are represented by column names. The database schema diagram for the base station can be found in Figure 3.42.

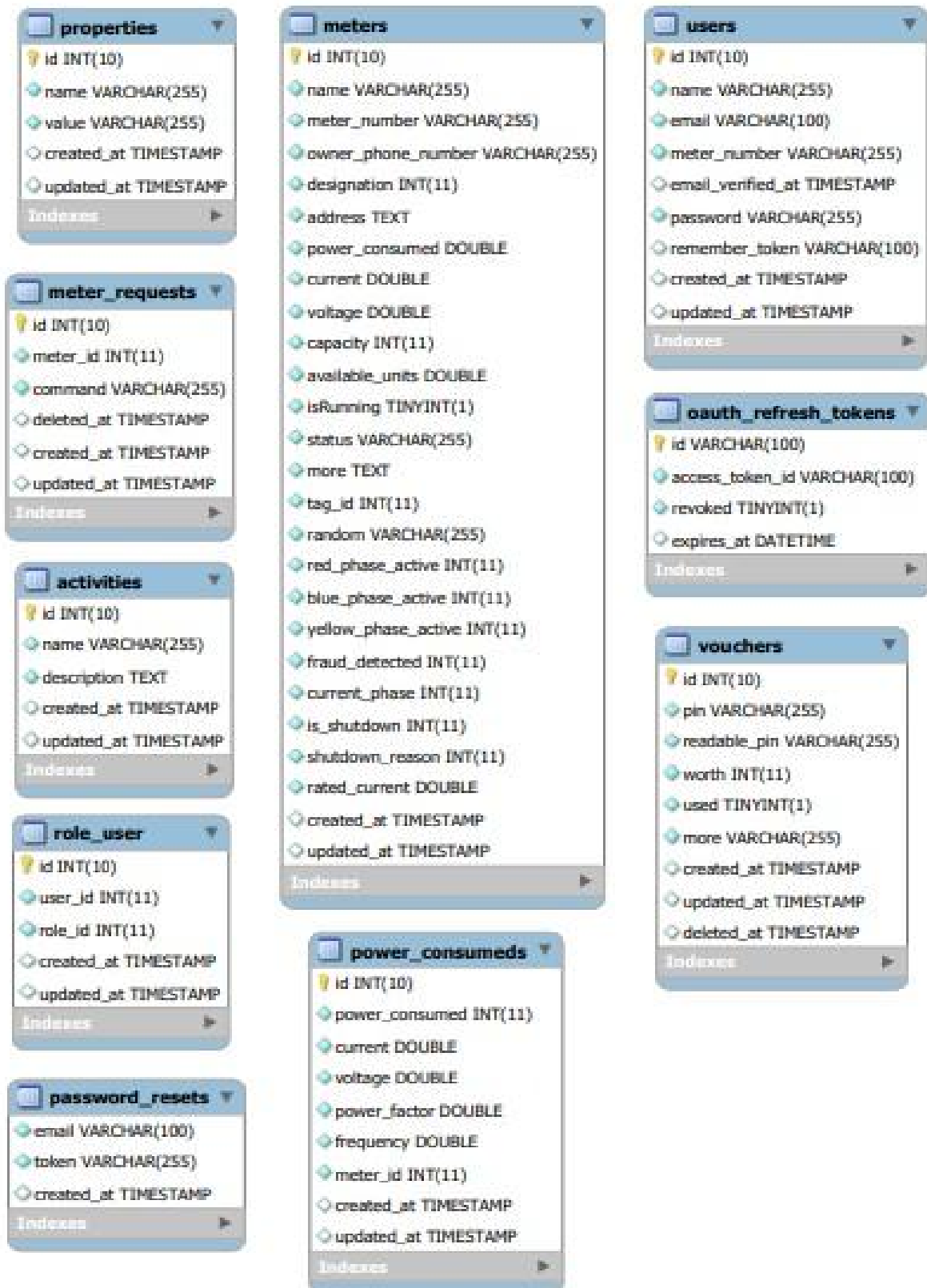


Figure 3.42: Schema diagram of database for the Base Station

3.12 The class diagram of the web-based station

The software for the web-based station's class diagram. The various application entities are represented as shown in Figure 3.43 for classes

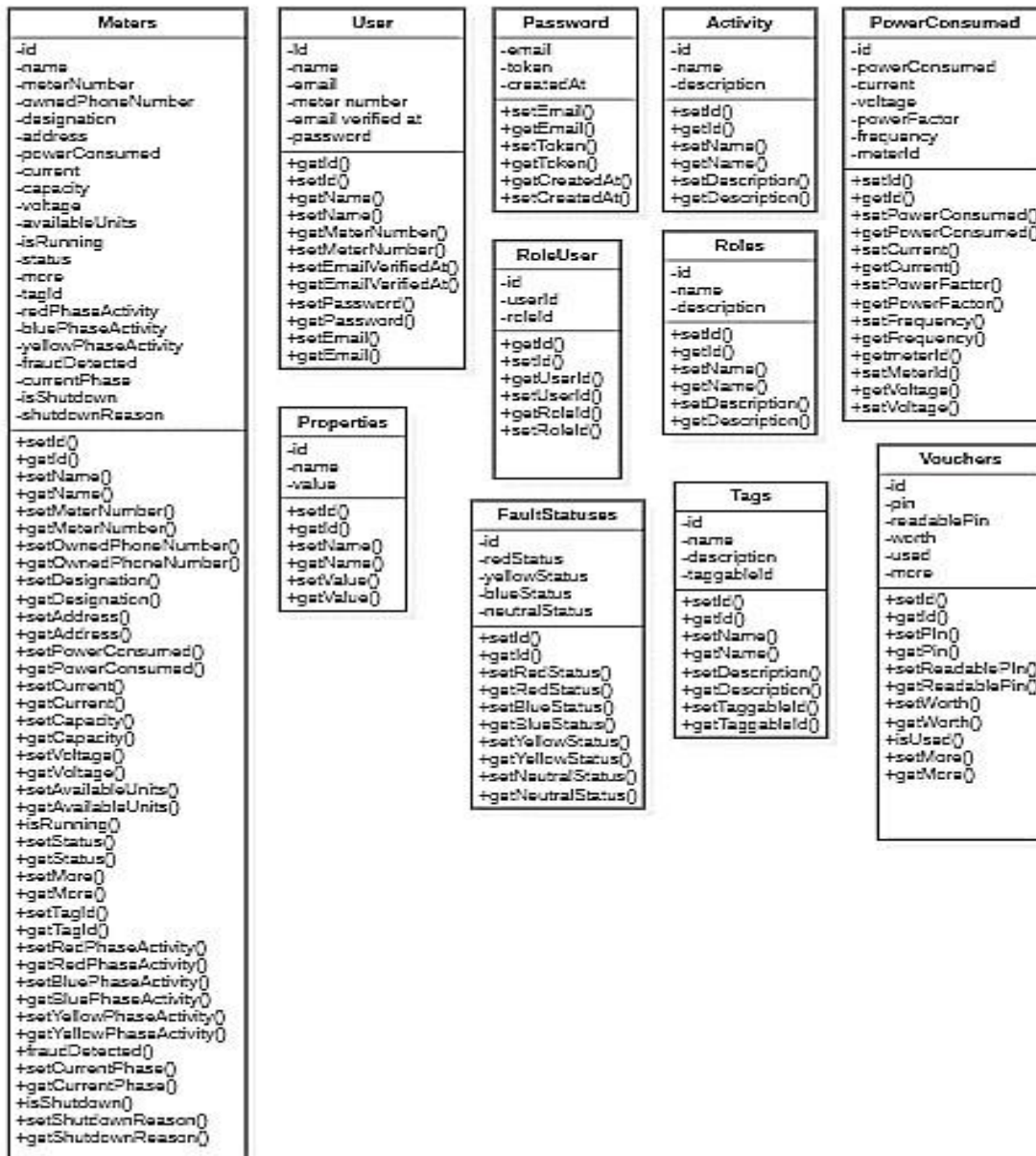


Figure 3.43: The web-based system's Class Diagram

The class diagram of the web-based system provides a visual representation of the classes, their relationships, and the structure of the system. It illustrates the static structure of the system, highlighting the classes, their attributes, methods, and associations. The web-based application software was developed using an object-oriented programming language, entities within the system are represented as classes, which encapsulate related functionality. For instance, the "meter" class facilitates load switching capabilities, allowing control over the activation and deactivation of loads. Essential attributes such as the IP address and current are accessed and modified through dedicated getter and setter routines. The two key classes that stand out in terms of significance are "meter" and "user," each playing crucial roles in addressing various challenges. The class diagram is divided into

two sections: properties and methods. The upper portion corresponds to the class's properties, providing a description of its attributes, while the lower portion represents the methods that define the class's functionalities. Additional important classes include "role," "vouchers," and "fault status." The "role" class is employed to assign different user roles such as staff, user, or admin, as determined by an administrator. The "fault status" class maintains the status of phases and the neutral line, which is essential for displaying data on the User Interface (UI) and recording it in the database for archival purposes. The "meter" class, mentioned earlier, contains comprehensive information related to meters. The "voucher" class stores both used and unused vouchers, along with their respective values. During the database design process, each of these classes and their associated attributes are stored in the database for efficient data management.

3.12.1 Web-based System Database Design

This chapter presents specifics of the software design for the full automated metering, power management, and monitoring system. Source code is in Appendix E, but flow charts are provided. A relational database management system called MySQL was used to build the database. Information is separated into distinct, subject-based tables in the relational database that was established, and when necessary, table relationships are employed to link the tables together.

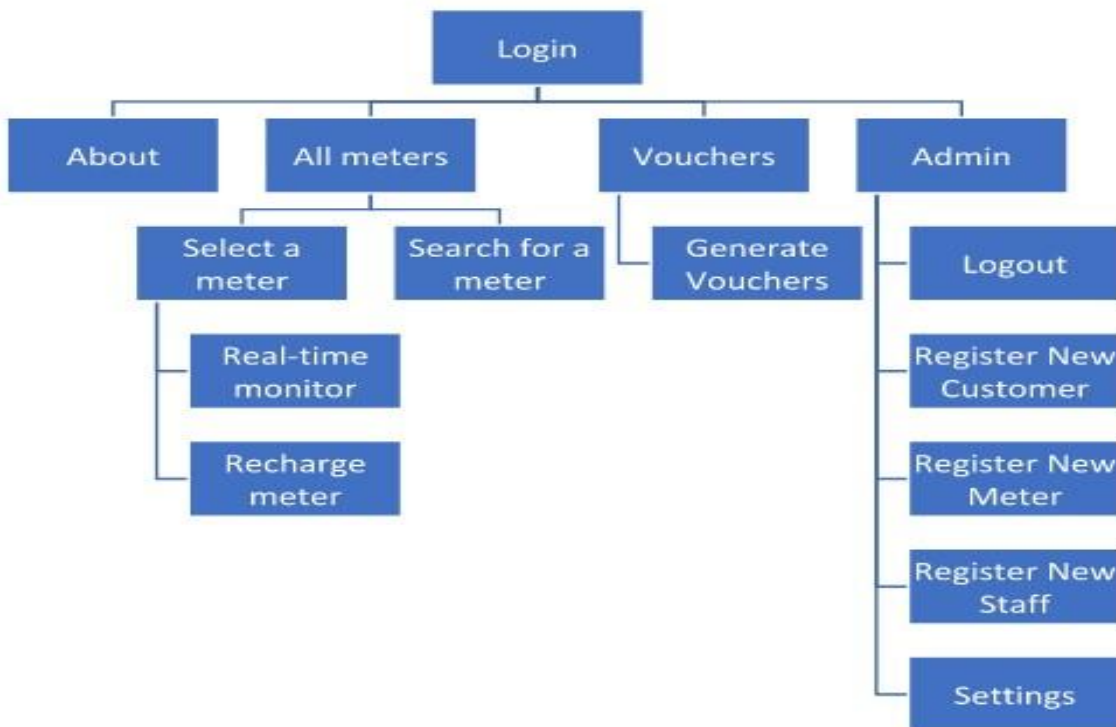


Figure 3.44: Sitemap of Admin for base station

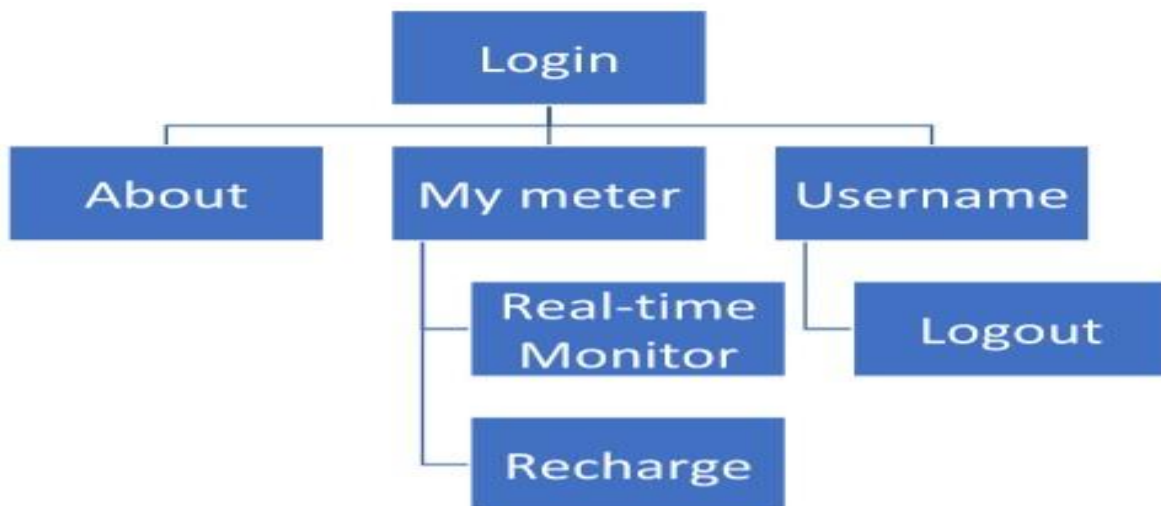


Figure 3.45: Sitemap of User for Base Station

3.12.3 Base station software design

The base station software consists of two parts; web-based application and interface app (windows application connecting the long-range transceiver through USB port).

a. Web based Application design

The web-based application backend is programmed with PHP (Hypertext Preprocessor) using Laravel Framework while the frontend was designed with VueJs JavaScript library (along with HTML/CSS). MySQL database is used to store the state of all the meters, customer details and voucher pins. The details of the database design is shown in the diagram below. The web-based Application processes the data sent through HTTP POST request sent from the interface app. Each HTTP request body contains the state of a given meter with the meter number which is used to identify the meter that has sent the information. After processing the corresponding row in the meter table of the MySQL database is updated to match the present state. New entry is also added to the power_consumed table with the meter_id. When necessary, this will be utilized to determine the meter's power usage.

The frontend of the application consists of different pages which includes Admin specific pages and pages which contain general meter information. The application handles 3 type of users which depends on the value of role_id column in the role_user table. The types include; admin, staff, and customer. Depending on the role assigned to the user who logs into the system, some pages may not be available for privacy and security reasons.

The admin type of user can perform all operation. Admin function includes but not limited to:

- Register new meter

- View and recharge any meter.

- Shutdown any meter.

- Load balancing

Register new customer

Register new Staff.

Register new admin.

Generate, view and delete recharge vouchers.

The staff type of user can perform also, not own a meter. Staff function includes:

Register new meter

View and recharge any meter

Register new customer.

Load balancing

The customer type of user can perform operations related to his/her meter only and can own one meter. Customer function includes:

View details/state of his/her meter.

Recharge meter.

3.12.4 Design objectives for the database design

The design objectives for the database are as follows:

- i. To cut down on redundant data, to organize information into subject-based tables.
- ii. The information the database engine needs to link the data in the tables together to define relationship between records in the tables.
- iii. The user information's accuracy and integrity should be supported by the database design.
- iv. The design must take into account this study software's data processing and reporting requirements.

3.12.5 Purpose of the database

The database purpose is to give users a mechanism to save meter readings, meter information, meter information and related records that are necessary for the proper operation of the design.

3.12.6 Organizing the data

During the research stage of this design, the various categories of data in the database were itemized. Tables were created for each type of data item and related fields were put in a table. The fields were organized so that data is stored only once

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meters table stores all meter details and state. As shown in the diagram below.

power_consumed table stores power consumed by all meters with unique id to identify each meter.

Other tables in the database are used by the framework (Laravel) for authentication (oauth_personal_access_clients, oauth_refresh_token, etc) and for storing extra properties of a meter or user as shown in Table 3.3.

Table 3.3: Tables used for this design and the fields defined.

activities	
id	int(10)
name	varchar(255)
description	text
created_at	timestamp
updated_at	timestamp

oauth_access_tokens	
id	varchar(100)
user_id	int(11)
client_id	int(10)
name	varchar(255)
scopes	text
revoked	tinyint(1)
created_at	timestamp
updated_at	timestamp
expires_at	datetime

oauth_refresh_tokens	
id	varchar(100)
access_token_id	varchar(100)
revoked	tinyint(1)
expires_at	datetime

roles	
id	int(10)
name	varchar(255)
description	text
created_at	timestamp
updated_at	timestamp

vouchers	
id	int(10)
pin	varchar(255)
readable_pin	varchar(255)
worth	int(11)
used	tinyint(1)
more	varchar(255)
created_at	timestamp
updated_at	timestamp
deleted_at	timestamp

meters	
id	int(10)
name	varchar(255)
meter_number	varchar(255)
owner_phone_number	varchar(255)
designation	int(11)
address	text
power_consumed	double
current	double
voltage	double
capacity	int(11)
available_units	double
isRunning	tinyint(1)
status	varchar(255)
more	text
tag_id	int(11)
random	varchar(255)
red_phase_active	int(11)
blue_phase_active	int(11)
yellow_phase_active	int(11)
fraud_detected	int(11)
current_phase	int(11)
is_shutdown	int(11)
shutdown_reason	int(11)
rated_current	double
created_at	timestamp
updated_at	timestamp

oauth_auth_codes	
id	varchar(100)
user_id	int(11)
client_id	int(10)
scopes	text
revoked	tinyint(1)
expires_at	datetime

password_resets	
email	varchar(100)
token	varchar(255)
created_at	timestamp

meter_requests	
id	int(10)
meter_id	int(11)
command	varchar(255)
deleted_at	timestamp
created_at	timestamp
updated_at	timestamp

oauth_clients	
id	int(10)
user_id	int(11)
name	varchar(255)
secret	varchar(100)
redirect	text
personal_access_client	tinyint(1)
password_client	tinyint(1)
revoked	tinyint(1)
created_at	timestamp
updated_at	timestamp

power_consumeds	
id	int(10)
power_consumed	int(11)
current	double
voltage	double
power_factor	double
frequency	double
meter_id	int(11)
created_at	timestamp
updated_at	timestamp

tags	
id	int(10)
name	varchar(255)
description	varchar(255)
taggable_id	int(11)
created_at	timestamp
updated_at	timestamp

migrations	
id	int(10)
migration	varchar(255)
batch	int(11)

oauth_personal_access_clients	
id	int(10)
client_id	int(10)
created_at	timestamp
updated_at	timestamp

properties	
id	int(10)
name	varchar(255)
value	varchar(255)
created_at	timestamp
updated_at	timestamp

users	
id	int(10)
name	varchar(255)
email	varchar(100)
meter_number	varchar(255)
email_verified_at	timestamp
password	varchar(255)
remember_token	varchar(100)
created_at	timestamp
updated_at	timestamp

role_user	
id	int(10)
user_id	int(11)
role_id	int(11)
created_at	timestamp
updated_at	timestamp

The interface app is programmed with C# and WPF (Windows Presentation Foundation) Graphics User Interface (GUI) framework. It interfaces the Long-Range Transceiver (LoRa) in relation to the web application program.

The transceiver is connected to the laptop through USB using a USB-TO-UART converter (CP2102) module. The interface program gets data from the USB port after it has passed through the converter, turns it into a virtual COM port, and then delivers it as an HTTP POST request to the web-based application. The HOST and PATH of the web-based application must be provided in order to locate it. Also, the web-based program directly sends all data to the COM port, which is attached to the transceiver.

3.14 Maintenance of the web-based system

The web-based system's design has been created, tested, and deployed. Thereafter, there will be need to carry out continuous maintenance on the web-based system. This maintenance could be done in the area of its content, software used for the development and hardware's for effective communication. However, in the design of Automated metering power management and monitoring web-based system content maintenance and software update may be needed. Content maintenance is a continual process. To ensure that all live content is pertinent, accurate, and current, content management may involve updating or adding new pages, updating or adding of new meters, or fixing a typo on one page.

3.15 Design and development of the mobile application

The mobile application's development and design are closely related processes. Use-case and class diagram creation occurs during the design phase, while application functionality is built using an Integrated Development Environment (IDE) during the development phase. The IDE used for the development of the mobile application is Android Studio.

3.15.1 Design of the mobile application

The use case diagram for the design of the mobile application is shown in Figure 3.46



Figure 3.46: Use case diagram of the mobile application

Figure 3.46 presents a use case diagram illustrating the user journey within the application. It outlines the different functionalities available to users and the corresponding actions they can perform. The initial step is the login process, where users enter their credentials, including the username and password, to access the mobile app's menu. Once logged in, users can navigate through various menu options located at the bottom of the screen. These options include viewing meter details, managing loads, setting planner time, and making payments. Additionally, there is a settings menu at the top of the screen, allowing users to update their passwords and configure IP addresses for both the meter and home energy planner.

In the "view meter details" section, users can interact using the application, users can transmit commands to the meter. via the provided IP address and retrieve information from the meter.

The "manage load" menu enables users to perform actions such as checking the load status, setting on and off times, overriding timers to automatically turn loads on or off, and utilizing the standby detection and removal feature. The latter helps users reduce energy consumption by identifying plugged-in devices that are not actively in use.

The "set planner time" feature allows users to update the real-time clock on the home energy planner. As for the "on-time" functionality, users can specify the minutes and hours for which the load should turn on and off. The setup process of the mobile App shown in Figure 3.48.

In the "payment" menu, users have the option to pay with a card or via bank transfer. For card payments, users enter their card details and proceed with the payment. In the case of bank transfers, users are presented with account details and the relevant bank information for the transfer process. The corresponding unit amount will be credited into the meter accordingly.

Overall, the use case diagram demonstrates the various actions and capabilities available to users within the application, providing a comprehensive overview of the user journey.

3.15.1 Software Static Structure Modelling

The class diagram of the mobile application shown in Figure 3.48.

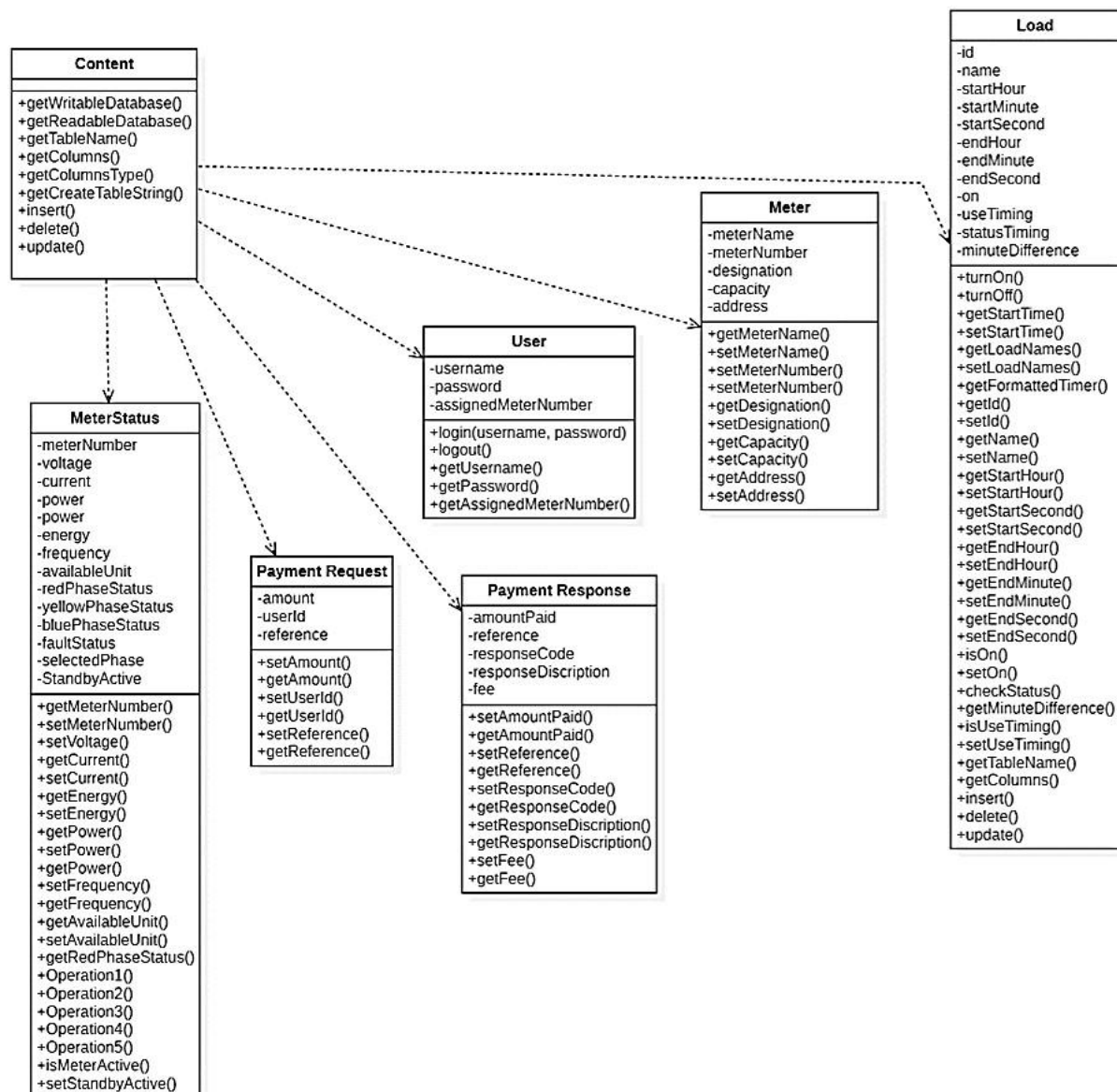


Figure 3.47: The Class diagram of the mobile Application.

The class diagram of the mobile application depicts the structure and relationships among classes present in the system. It presents a graphical illustration of classes, encompassing their attributes, functions, and associations. The application design employs Java, a widely recognized object-oriented programming (OOP) language. The class diagram exhibits the base classes from which other classes inherit. The device facilitates the retrieval of attributes such as meter number, voltage, current, power, and frequency. The associated methods encompass getters and setters for meter status, as well as load time details including start and stop times.

3.15.2 Software development of the mobile App

The Android architecture, a software stack, developed to meet the needs of mobile devices. It comes with the Linux kernel and several C++ libraries that are made available through a variety of procedures and programs. The system comprises of an

Android-based application program (App). Because most mobile phones support the Android Operating System, the Android App was created (OS). Java and the Android Software Development Kit (SDK) were both used in the design and development of the App. This Android software development kit includes complete sets of tools like integrated development Environment (IDE), libraries, sample code, mobile phone emulator with documentation, and debuggers.

3.15.3 Programming of the Mobile App

The Meter Utility is a native Android application, which means it was programmed using the Official Android SDK (Software Development Kit) using the supported programming languages (Java and XML in the Android Studio Integrated Development

Environment (IDE); which is the official IDE for developing android applications. Following the standard design of User Interface for android Application, XML was used to mark-up the user interface, while Java was used to implement the functionality. The application can run on any Android Device with Wi-Fi capability.

The application is designed to communicate with the Home Energy planner (HEP) and the Meter. The HEP and meter will be referred to as device in subsequent sections.

3.15.4 Logical Implementation

The logic of the application was implemented in Java programming language.

The application can connect to the network devices on the wireless Local Area Network (LAN) using their IP address. The application uses the IP address of the Home Energy Planner (HEP) and the meter to establish communication between them. The working principle of the application can be broken down into two different processes, which include; set-up process and interaction process;

3.15.5 Set-up process

During the set-up process the IP of the HEP and meter is inputted into the application and the application persist it in the local storage of the device. This enables the device to retrieve this

information automatically in subsequent run. The application uses this information to connect to the HEP and meter respectively. The information can be modified afterward in the settings screen.

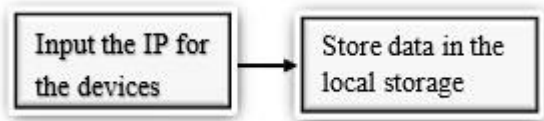


Figure 3.48: Setup Process of the mobile App

3.15.6 Interaction process

When a user performs any action in the application, depending on the action, an HTTP request is sent to the HEP or meter along with the encoded payload. The response from the devices is then prepared and shown on the application's user interface.

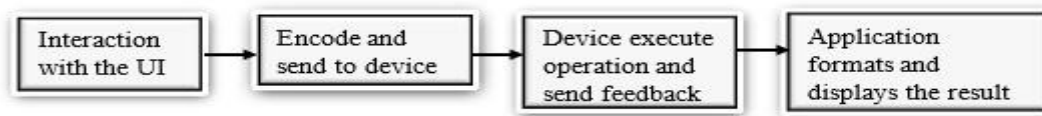


Figure 3.49: Block diagram of the interaction process.

3.15.7 Principle of operation of Mobile App

The mobile App is an android application with Wi-Fi communication Capability. The app offers a Graphic User Interface (GUI) that enables the user to input data and make requests to the Home Energy Planner (HEP) and meter.

The home energy planner and meter are identified by their respective Internet Protocol

(IP) address. To use the, Wi-Fi Access point (hot-spot) of the mobile phone need to be configured with a service set identifier (SSID) and password so that it can be visible to the HEP and meter. The HEP and meter Wi-Fi module is configured to automatically establish connection with the hot-spot of the mobile phone. The HEP and meter are able to acquire a distinct IP address through this process, which the App uses to connect with them.

When the app is loaded, the user is presented with a simple GUI that allows them to set the HEP's time as well as the ON-OFF times for each load that is connected to the HEP. It also provides a page which shows the details of the meter which include voltage, current, power consumed, energy consumed, and status of the distribution phases like the Red, Yellow, blue and the users meter information.

Every exchange of information between the App and the devices (HEP and meter) is encoded as an HTTP GET request to the specific device's IP address.

3.15.8 Overview of the Mobile App

A complete overview of the user's mobile software application, including the home appliance it is controlling, the meter and power distribution network it is monitoring, is shown in Figure 3.50.

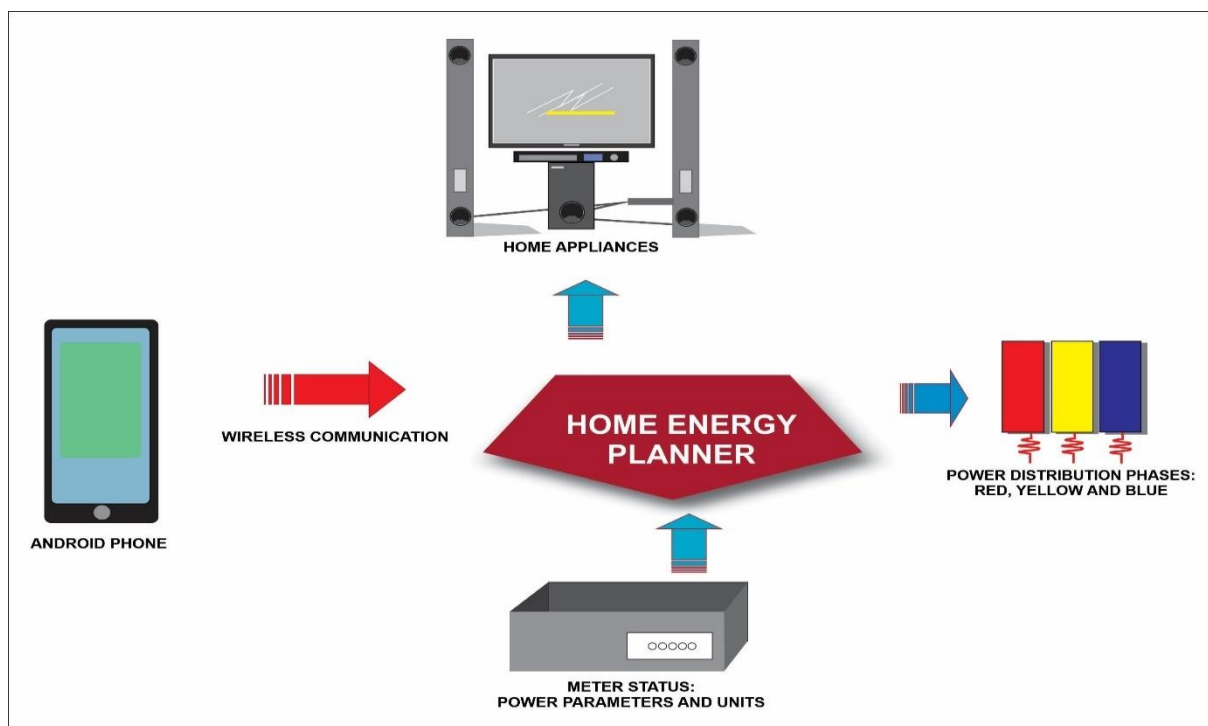


Figure 3.50: Overview of the Mobile App

The mobile app in the image above is a low-cost home automation system for efficient remote control, regulating electricity users' household loads, and keeping an eye on the meter status of the power distribution system. It will alert customers about power outages. The Home energy planner, which can be monitored and controlled from a distance using mobile phones through Wi-Fi, directly connect the sensors, actuators, and relays to the main controller. The control, energy management system, including lights, power outage, heating and cooling systems, and other electrical equipment, are design aspects.

3.16 The Experimental Process

In this section, the experimental activities carried out are discussed.

3.16.1 Material used for the system Evaluation

The following materials were used for the evaluation of the system:

Three designed Rf.-based Automated meters

Three designed home energy planners

An Android phone with designed software application

Digital Multimeter

12 Pieces of Electrical loads as stated in Table 3.5 with the respective serial number and power rating.

Digital Ammeter

Digital Voltmeter

Table 3.5: Electrical loads measured

S/N	Load	Power (W)
1	ADA SMC Ceiling fan	70.00
2	ORL Ceiling fan	70.00
3	Century rechargeable fan	30.00
4	LG Washing machine	320.00
5	Qlink Standing fan	105.00
6	LG LCD TV	100.00
7	LG Express cool freezer	240.00
8	Philip Electric iron	1000.00
9	Villmax LED bulb	12.00
10	Brightmax LED bulb	10.00
11	XG-7202 LED bulb	7.00
12	Jungsram incandescent bulb	100.00

3.16.2 Parameter for Measurement

The following parameters were considered in the measurements.

Power consumed by load (W)

Current drawn by loads (A)

Supply Voltage (V)

Total Energy consumed after a period of time (kWh)

The details are listed in Table 3.6. Other requirements but not measured directly were derived from the measured.

3.16.3 Setup of the Experimental Environment

The experimental laboratory was setup in such a way that it could support the implementation of the power management and monitoring with the web-based system. The laboratory contained three meters, three home energy planners, a mobile App and loads to evaluate the work's process.



Figure 3.51: Setup of the Experimental Laboratory



Figure 3.52: Experimental Testing on the Wireless transceiver carried out in Rural Area of Ugoneki, Edo State, Nigeria.

3.16.4 Method of Analysis of the Experiment Data

The following methods were utilized to examine the survey responses from the respondents as part of the study's statistical data analysis: For data analysis, both Microsoft Excel and the Statistical Package for the Social Sciences (SPSS version 22), as shown in Figures 3.53 and 3.54, were used. The regression analysis was performed using Microsoft Excel. The mean and standard error are the chosen statistics. Probability value (P-value) and t-statistics were the statistical tools used for the regression analysis. The statistical approach was chosen because the acquired data could be used to compare the hypothesis to the data observed. In chapter four, the analyses' results are presented.

PhD Computer Engr coding.sav [DataSet1] - IBM SPSS Statistics Data Editor

File Edit View Data Transform Analyze Direct Marketing Graphs Utilities Add-ons Window Help

1: generator 1.00 Visible: 23 of 23 Variables

	XC	Electricity	Meter	Unit	Loading	customer	satisfied	billing	Giving	tempering	illegal	responsible	residence	house	home	generator
1	4.00	1.00	1.00	2.00	2.00	1.00	2.00	4.00	3.00	3.00	3.00	3.00	4.00	1.00	1.00	1.00
2	3.00	1.00	2.00	2.00	2.00	2.00	3.00	4.00	3.00	4.00	3.00	2.00	4.00	2.00	1.00	2.00
3	3.00	1.00	1.00	2.00	4.00	2.00	4.00	2.00	3.00	3.00	2.00	4.00	4.00	2.00	1.00	2.00
4	3.00	1.00	1.00	2.00	3.00	2.00	3.00	3.00	3.00	2.00	1.00	2.00	2.00	2.00	1.00	2.00
5	4.00	1.00	2.00	2.00	3.00	2.00	3.00	2.00	2.00	3.00	2.00	3.00	2.00	1.00	2.00	1.00
6	3.00	1.00	1.00	2.00	1.00	1.00	2.00	3.00	2.00	3.00	2.00	3.00	2.00	2.00	2.00	2.00
7	4.00	1.00	1.00	2.00	1.00	2.00	3.00	2.00	3.00	3.00	3.00	4.00	4.00	2.00	1.00	1.00
8	4.00	1.00	1.00	2.00	1.00	2.00	2.00	3.00	1.00	4.00	2.00	2.00	3.00	1.00	1.00	2.00
9	4.00	1.00	1.00	2.00	2.00	1.00	2.00	3.00	2.00	3.00	2.00	2.00	2.00	1.00	2.00	1.00
10	3.00	1.00	1.00	2.00	3.00	2.00	1.00	2.00	3.00	2.00	3.00	2.00	2.00	1.00	1.00	2.00
11	3.00	2.00	2.00	2.00	3.00	1.00	4.00	3.00	3.00	4.00	1.00	2.00	1.00	2.00	1.00	2.00
12	3.00	1.00	2.00	2.00	2.00	2.00	3.00	4.00	3.00	4.00	3.00	2.00	4.00	2.00	2.00	2.00
13	3.00	1.00	1.00	2.00	4.00	2.00	4.00	2.00	3.00	3.00	2.00	4.00	4.00	2.00	1.00	2.00
14	3.00	1.00	1.00	2.00	3.00	2.00	3.00	3.00	3.00	2.00	1.00	2.00	2.00	2.00	1.00	1.00
15	4.00	1.00	2.00	2.00	3.00	2.00	3.00	2.00	2.00	3.00	2.00	3.00	2.00	1.00	2.00	2.00
16	3.00	1.00	1.00	2.00	1.00	1.00	2.00	3.00	2.00	3.00	2.00	3.00	2.00	2.00	2.00	1.00
17	4.00	1.00	1.00	2.00	1.00	2.00	3.00	2.00	3.00	3.00	3.00	4.00	4.00	2.00	2.00	2.00
18	4.00	1.00	1.00	2.00	1.00	2.00	2.00	3.00	1.00	4.00	2.00	2.00	3.00	1.00	1.00	1.00
19	4.00	1.00	1.00	2.00	2.00	1.00	2.00	3.00	2.00	3.00	2.00	2.00	2.00	1.00	2.00	2.00
20	3.00	1.00	2.00	2.00	2.00	2.00	3.00	4.00	3.00	4.00	3.00	2.00	4.00	2.00	1.00	2.00
21	3.00	1.00	1.00	2.00	4.00	2.00	4.00	2.00	3.00	3.00	2.00	4.00	4.00	2.00	1.00	2.00
22	3.00	1.00	1.00	2.00	3.00	2.00	3.00	3.00	3.00	2.00	1.00	2.00	2.00	2.00	1.00	2.00
23	4.00	1.00	2.00	2.00	3.00	2.00	3.00	2.00	2.00	3.00	2.00	3.00	2.00	1.00	2.00	1.00

Figure 3.53: Analysis (Data View) of electricity consumer's response on BEDC services

PHD Computer Engr coding.sav [DataSet1] - IBM SPSS Statistics Data Editor

File Edit View Data Transform Analyze Direct Marketing Graphs Utilities Add-ons Window Help

	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
1	BEDC	Numeric	8	2	How many hour...	{1.00, 1-4ho...	None	8	Right	Scale	Input
2	Electricity	Numeric	8	2	Do you know h...	{1.00, Yes}...	None	8	Right	Nominal	Input
3	Meter	Numeric	8	2	Do you have a ...	{1.00, Yes}...	None	8	Right	Nominal	Input
4	Unit	Numeric	8	2	Do you underst...	{1.00, Yes}...	None	8	Right	Nominal	Input
5	Loading	Numeric	8	2	Do you face an...	{1.00, Alwa...	None	8	Right	Nominal	Input
6	customer	Numeric	8	2	Do you think B...	{1.00, Yes}...	None	8	Right	Nominal	Input
7	satisfied	Numeric	8	2	Are you satisfie...	{1.00, very s...	None	8	Right	Nominal	Input
8	billing	Numeric	8	2	Estimated billin...	{1.00, Alwa...	None	8	Right	Nominal	Input
9	Giving	Numeric	8	2	Giving tips to B...	{1.00, Alwa...	None	8	Right	Nominal	Input
10	tempering	Numeric	8	2	Meter temperin...	{1.00, Alwa...	None	8	Right	Nominal	Input
11	illegal	Numeric	8	2	Illegal connecti...	{1.00, Alwa...	None	8	Right	Nominal	Input
12	responsible	Numeric	8	2	What is respon...	{1.00, Corru...	None	8	Right	Nominal	Input
13	residence	Numeric	8	2	What type of a...	{1.00, duple...	None	8	Right	Nominal	Input
14	house	Numeric	8	2	Does everyone ...	{1.00, yes}...	None	8	Right	Nominal	Input
15	home	Numeric	8	2	When does any...	{1.00, less t...	None	8	Right	Nominal	Input
16	generator	Numeric	8	2	Do you use gen...	{1.00, yes}...	None	8	Right	Nominal	Input
17	hours	Numeric	8	2	If yes, how man...	{1.00, 1-3 h...	None	8	Right	Nominal	Input
18	fuel	Numeric	8	2	How much do y...	{1.00, 1-5 th...	None	8	Right	Nominal	Input
19	fault	Numeric	8	2	How long does ...	{1.00, 1-3 w...	None	8	Right	Nominal	Input
20	report	Numeric	8	2	Do the area hav...	{1.00, yes}...	None	8	Right	Nominal	Input
21	purchase	Numeric	8	2	How easy is it t...	{1.00, very e...	None	8	Right	Nominal	Input
22	tempted	Numeric	8	2	Are you tempte...	{1.00, yes}...	None	8	Right	Nominal	Input
23	controlling	Numeric	8	2	Do you desire t...	{1.00, yes}...	None	8	Right	Nominal	Input
24											

Data View Variable View

Figure 3.54: Variable View of Electricity consumer's response on BEDC services

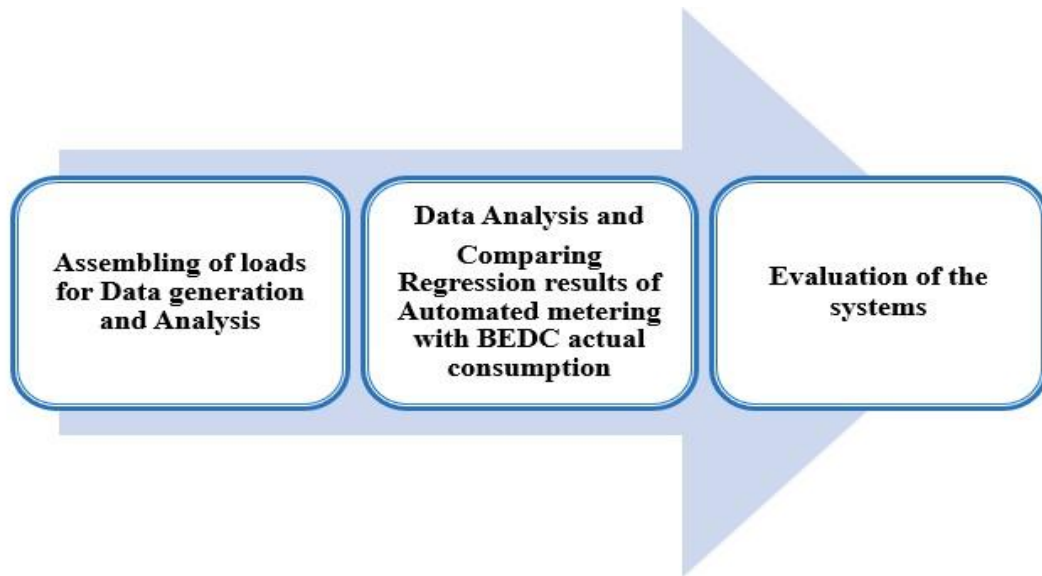


Figure 3.55: Workflow of the evaluation process

To get the reading for the BEDC metering system, the maximum time from the BEDC company due to load shedding is four hours daily. However, the monthly and yearly data within this period is included in this work. After an hour, let the power usage, supply voltage, and current drawn by loads. = P1, V1, I1 After two hours, let the power usage, provided voltage, and current drawn by loads. = P2, V2, I2. After three hours, let the power usage, provided voltage, and current drawn by loads. = P3, V3, I3. After four hours, observe the power usage, provided voltage, and current drawn by loads. = P4, V4, I4.

Table 3.6 Daily Power Consumption with Automated metering system

LOAD	P1 (W)	V1 (V)	I1 (A)	P2 (W)	V2 (V)	I2 (A)	P3 (W)	V3 (V)	I3 (A)	P4 (W)	V4 (V)	I4 (A)
1	55.800	221.500	0.252	57.100	226.200	0.253	57.200	226.200	0.254	57.400	226.300	0.254
2	48.100	225.000	0.256	46.000	222.000	0.236	45.800	223.400	0.235	45.900	223.200	0.236
3	10.800	223.600	0.049	10.600	225.300	0.047	10.500	225.400	0.048	10.400	225.500	0.046
4	84.400	215.200	0.440	94.900	227.400	0.422	171.100	231.000	0.749	102.700	224.200	0.465
5	69.300	215.300	0.327	68.100	213.700	0.324	67.200	215.200	0.318	67.500	214.800	0.319
6	55.200	215.600	0.285	55.100	215.200	0.283	55.200	214.900	0.284	50.100	215.100	0.261
7	178.000	213.200	0.836	176.80	212.600	0.833	177.300	213.400	0.834	175.900	212.200	0.820
8	778.600	210.800	3.695	847.50	220.100	3.850	850.200	221.600	3.841	888.200	224.800	3.951
9	10.700	215.900	0.049	10.700	216.300	0.049	10.720	215.600	0.048	10.730	215.500	0.047
10	7.900	216.500	0.036	7.900	217.000	0.036	7.900	215.900	0.036	7.800	216.100	0.036
11	6.800	215.800	0.032	6.600	215.500	0.031	6.500	215.400	0.031	6.500	215.100	0.031
12	70.800	214.500	0.332	78.300	228.500	0.345	77.500	227.200	0.343	76.900	213.200	0.342

The linear correlation equation used in this work of the form

$$Y = a_0 + b_1x \quad (3.28)$$

The aim is to calculate the total energy consumed, the linear equation for energy consumption derived as follows:

$$E = Pt \quad (3.29)$$

$$Y = a_0 + Ptb_1 \quad (3.30)$$

Since

$$p = iv$$

$$y = a_0 + ivtb_1 \quad (3.31)$$

Here, the mean power usage \bar{P} for the different loads at time t calculated.

This experiment was recorded within an interval of 4 hours respectively.

Therefore, the mean power was calculated to find the mean of the total energy consumed by each load. Using equation (3.29),

$$E = Pt$$

Therefore,

$$\bar{E} = \bar{P}t$$

The linear equation becomes:

$$y = a_0 + \bar{P}tb_1 \quad (3.32)$$

where \bar{E} = mean energy consumed.

Let \bar{P} = mean power

Let \bar{V} = mean voltage

Let \bar{t} = mean time

$$Y = a_0 + \bar{P}\bar{t}b_1 \quad (3.33)$$

Let Ada SMC ceiling fan = Cf

$$\bar{P}_{CF} = \frac{55.80 + 57.10 + 57.20 + 57.40}{4} = \frac{227.50}{4} = 56.88W$$

Let ORL ceiling fan = ORf

$$\bar{P}_{ORF} = \frac{48.10+46.00+45.80+45.90}{4} = \frac{185.80}{4} = 46.45W$$

Let Century rechargeable fan = Rf

$$\bar{P}_{RF} = \frac{10.80+10.60+10.50+10.40}{4} = \frac{42.30}{4} = 10.58W$$

Let LG Washing Machine = WMc

$$\bar{P}_{WMC} = \frac{84.40+94.90+171.1+102.70}{4} = \frac{453.10}{4} = 113.27W$$

Other loads as stated in Table 3.6 for power usage calculated as shown for Ada SMC, ORL ceiling fan, Century Rechargeable fan and washing machine. Table 3.7 depicts the measured energy of Automated metering system Let the measured energy consumption after one hour, two hours, three hours and four hours = E1, E2, E3, E4. The results presented in chapter four

Table 3.7 Energy Consumption of Users Load with Automated metering system

LOAD	E1 (kWh)	E2 (kWh)	E3 (kWh)	E4 (kWh)
1	0.048	0.049	0.058	0.059
2	0.047	0.05	0.052	0.056

3	0.025	0.026	0.027	0.027
4	0.282	0.350	0.423	0.453
5	0.169	0.174	0.183	0.198
6	0.358	0.426	0.476	0.504
7	0.547	0.723	0.902	1.083
8	0.894	0.958	0.982	0.986
9	0.007	0.008	0.009	0.009
10	0.005	0.005	0.006	0.006
11	0.003	0.004	0.0041	0.043
12	0.104	0.105	0.105	0.106

$$\bar{E}_{cf} = \frac{0.048 + 0.049 + 0.058 + 0.059}{4} = \frac{0.214}{4} = 0.054 \text{ kWh}$$

All other loads as stated in Table 3.7 for energy usage are calculated as shown for Ada ceiling fan.

Table 3.8: The mean Energy and Power Consumption with Automated Metering

Measured load	Mean Energy (\bar{E}) (kWh)	Mean Power (\bar{P}) (Watt)
1	0.054	56.880
2	0.051	46.450
3	0.026	10.580
4	0.377	113.270

5	0.181	68.030
6	0.441	53.900
7	0.814	177.150
8	0.955	841.130
9	0.008	10.710
10	0.006	7.880
11	0.003	6.600
12	0.105	75.880

Table 3. 9: Power Consumption of Users Load with Benin Electricity Distribution Company (BEDC) metering system (CONLOG)

Load	P1 (W)	V1 (V)	I1 (A)	P2 (W)	V2 (V)	I2 (A)	P3 (W)	V3 (V)	I3 (A)	P4 (W)	V4 (V)	I4 (A)
1	57.700	221.500	0.272	58.200	226.200	0.278	59.300	226.200	0.281	60.300	226.300	0.29 2
2	58.400	225.000	0.262	58.900	222.000	0.266	59.800	223.400	0.268	60.400	223.200	0.27 2
3	14.600	223.600	0.066	15.600	225.300	0.069	16.100	225.400	0.072	17.200	225.500	0.07 6
4	114.300	215.200	0.620	126.900	227.400	0.720	193.100	231.000	0.840	182.700	224.200	0.82 0
5	82.800	215.300	0.410	88.300	213.700	0.424	93.200	215.200	0.440	96.600	214.800	0.44 9
6	75.300	215.600	0.355	78.600	215.200	0.368	88.100	214.900	0.400	91.300	215.100	0.42 4
7	198.800	213.200	0.958	205.40	212.600	1.020	208.300	213.400	1.036	226.300	212.200	1.06 7
8	889.300	210.800	4.333	918.60	220.100	4.384	937.700	221.600	4.541	959.800	224.800	4.65 1
9	11.100	215.900	0.066	11.300	216.300	0.068	11.620	215.600	0.069	11.740	215.500	0.07 1
10	8.300	216.500	0.052	8.700	217.000	0.058	8.770	215.900	0.061	9.200	216.100	0.06 2
11	7.100	215.800	0.041	7.300	215.500	0.042	7.340	215.400	0.042	7.380	215.100	0.04 4

12	82.600	214.500	0.412	86.700	228.500	0.423	89.800	227.200	0.446	92.500	213.200	0.46 1
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$$\bar{P}_{ORF} = \frac{58.40 + 58.90 + 59.80 + 60.40}{4} = \frac{237.50}{4} = 59.38W$$

All other loads as stated in Table 3.9 for power usage are calculated as shown for ORL ceiling fan.

Table 3.10: Energy Consumption of Users Load with BEDC metering system

LOAD	E1 (kWh)	E2 (kWh)	E3 (kWh)	E4 (kWh)
1	0.098	0.109	0.121	0.128
2	0.097	0.108	0.119	0.1266
3	0.061	0.063	0.068	0.072
4	0.463	0.579	0.698	0.722
5	0.223	0.287	0.387	0.399
6	0.595	0.687	0.716	0.724
7	0.843	0.974	1.101	1.224
8	0.979	1.133	1.312	1.511
9	0.010	0.014	0.018	0.021
10	0.008	0.009	0.016	0.019
11	0.0055	0.007	0.008	0.009
12	0.322	0.412	0.499	0.521

$$\bar{E}_{CF} = \frac{0.098 + 0.109 + 0.121 + 0.128}{4} = \frac{0.456}{4} = 0.114kWh$$

$$\bar{E}_{ORF} = \frac{0.097 + 0.108 + 0.119 + 0.126}{4} = \frac{0.450}{4} = 0.113kWh$$

All other loads as stated in Table 3.10 for energy usage are calculated as shown for Ada SMC and ORL ceiling

Table 3.11: The mean Energy and Power Consumption with BEDC Metering system

Measured load	Mean Energy (\bar{E}) (kWh)	Mean Power (\bar{P}) (Watt)

1	0.114	58.880
2	0.113	59.380
3	0.066	15.880
4	0.616	154.250
5	0.327	90.230
6	0.681	83.330
7	0.814	209.700
8	1.234	926.330
9	0.016	11.440
10	0.013	8.740
11	0.007	7.280
12	0.439	87.900

Table 3.12 Energy consumption of Automated and BEDC metering system

Measured load	Total Energy Consumption of Automated meter (kWh)	Total Energy Consumption of BEDC meter (kWh)
1	0.177	0.261
2	0.166	0.262
3	0.125	0.207
4	0.241	0.384
5	0.190	0.302
6	0.174	0.294
7	0.314	0.456
8	1.067	1.376
9	0.125	0.207
10	0.122	0.198
11	0.120	0.196
12	0.199	0.299

The graphical result is presented in chapter four.

Table 3.13: Monthly and Yearly Power Consumption of Users Loads with Automated metering system

Load	P1 (W)	Monthly	Yearly	Monthly	Yearly	P2(W)	Monthly	Yearly	Monthly	Yearly
1	55.80	1785.600	20478.600	8.064	92.484	57.100	1827.200	20955.700	8.096	92.851
2	48.10	1539.200	1765.700	8.192	93.952	46.000	1472.000	16882.000	7.552	86.612
3	10.80	345.600	3963.600	1.568	17.983	10.600	339.200	3890.200	1.504	17.249
4	84.40	2700.800	30974.800	14.080	161.480	94.900	3036.800	34828.300	13.504	17.249
5	69.30	2217.600	25433.100	10.464	120.009	68.100	2179.200	24992.700	10.368	118.908
6	55.20	1766.400	20258.400	9.120	104.595	55.100	1763.200	20221.700	9.056	103.861
7	178.00	5696.000	65326.000	26.752	306.812	176.800	5657.600	64885.600	36.656	305.711
8	778.00	24915.200	285746.200	118.240	1356.065	847.500	27120.00	311032.500	123.200	1412.95
9	10.70	342.400	3926.900	1.568	17.983	10.700	342.400	3926.900	1.568	17.983
10	7.90	252.800	2899.300	1.152	13.212	7.900	252.800	2899.300	1/152	13.212
11	116.80	217.600	2485.600	1.024	11.744	6.600	211.200	2422.200	0.992	11.377
12	70.80	2265,600	25983.600	10.624	121.844	78.300	2505.600	28736.100	11.040	126.615

Table 3.14: Monthly and Yearly Power Consumption of Users Loads with Automated metering system Continued

Load	P3 (W)	Monthly	Yearly	I3 (A)	Monthly	Yearly	P4 (W)	Monthly	Yearly	I4 (A)	Monthly	Yearly
1	57.200	1830.400	20992.400	0.254	8.128	93.218	57.400	1836.800	21065.800	0.254	8.128	93.218
2	45.800	1465.600	16808.600	0.235	7.520	86.245	45.900	1468.800	16845.300	0.236	7.552	86.612
3	10.500	336.000	3853.500	0.048	1.536	17.616	10.400	332.800	3816.800	0.046	1.472	16.882
4	171.100	5475.200	62793.700	0.749	23.968	274.883	102.700	3286.400	37690.900	0.465	14.88	170.655
5	67.200	2150.400	24662.400	0.318	10.176	116.706	67.500	2160.000	24772.500	0.319	10.208	117.073
6	55.200	1766.400	20258.400	0.284	9.088	104.228	50.100	1603.200	18386.700	0.261	8.352	95.787
7	177.300	5673.600	65069.100	0.834	26.688	306.078	175.900	5628.800	64555.300	0.82	26.24	300.94
8	850.200	27206.400	312023.400	3.841	122.912	1409.647	888.200	28422.400	325969.400	3.951	126.432	1450.017
9	10.720	343.040	3934.240	0.048	1.536	17.616	10.730	343.360	3937.910	0.047	1.504	17.249
10	7.900	252.800	2899.300	0.036	1.152	13.212	7.800	249.600	2862.600	0.036	1.152	13.212
11	6.500	208.000	2385.500	0.031	0.992	11.377	6.500	208.000	2385.500	0.031	0.992	11.377
12	77.500	2480.000	28442.500	0.343	10.976	125.881	76.900	2460.800	28222.300	0.342	10.944	125.514

$$\bar{E}_{cf} = \frac{1.536 + 1.568 + 1.856 + 1.888}{4} = \frac{6.848}{4} = 1.712 \text{ kWh}$$

$$\bar{E}_{ORF} = \frac{1.504 + 1.600 + 1.664 + 1.792}{4} = \frac{6.56}{4} = 1.64 \text{ kWh}$$

Table 3.15: The mean monthly energy and power consumed with Automated metering

Measured Load	Mean Energy (\bar{E}) (kWh)	Mean Power (\bar{P}) (Watt)
1	19.6345	20873.13
2	18.80875	17047.15
3	9.63375	3881.025
4	138.359	41571.93
5	66.427	24965.18
6	161.847	19781.3
7	298.6463	64959
8	350.485	308692.9
9	3.02775	3931.488
10	2.0185	2890.125
11	4.963675	2422.2
12	38.535	27846.13

Table 3.16: The mean yearly energy and power consumption with Automated Metering

Measured load Mean Energy (E) Mean Power (P)

	(kWh)	(Watt)
1	1.712	1820
2	1.64	1486.4
3	0.84	338.4
4	12.064	3624.8
5	5.792	2176.8
6	14.112	1724.8
7	26.04	5664
8	30.56	29616
9	0.264	342.8
10	0.176	252
11	0.4328	211.2
12	3.36	2428

Table 3.17: Monthly and Yearly Power Consumption of Users Load with Benin Electricity Distribution Company (BEDC)

metering system-CONLOG Product

Load	P1(W)	Monthly	Yearly	(I1) (A)	Monthly	Yearly	P2(W)	Monthly	Yearly	I2(A)	Monthly	Yearly
1	57.700	194.100	21349.000	0.272	8.976	100.64	58.200	1920.600	21534.000	0.278	8.096	92.851
2	58.400	1927.200	21608.000	0.262	8.646	96.94	58.900	1943.700	21793.000	0.266	7.552	86.612
3	14.600	481.800	5402.000	0.066	2.178	24,42	15.600	514.800	5772.000	0.069	1.504	17.249
4	114.300	3771.900	42291.000	0.62	20.46	229.4	126.900	4187.700	46953.000	0.72	13.504	154.874
5	82.800	2732.400	30636.000	0.41	13.53	151.7	88.300	2913.900	32671.000	0.424	10.368	118.908
6	75.300	244.900	27861.000	0.355	11.715	131.35	78.600	2593.800	29082.000	0.368	9.056	103.861
7	198.800	6560.400	73556.000	0.958	31.614	354.46	205.400	6778.200	75998.000	1.02	26.656	305.711
8	889.300	293446.900	329041.000	4.333	142.989	1603.21	918.600	30313.800	339882.000	4.384	123.200	1412.95
9	11.100	366.300	4107.000	0.066	2.178	24.42	11.300	372.900	4181.000	0.068	1.568	17.983
10	8.300	273.900	3071.000	0.052	1.716	19.24	8.700	287.100	3219.000	0.058	1.152	13.212
11	7.100	234.300	2627.000	0.041	1.353	15.17	7.300	240.900	2701.000	0.042	0.992	11.377
12	82.600	2725.800	30562.000	0.412	13.596	152.44	86.700	2861.100	32079.000	0.423	11.040	126.615

Table 3.18: Monthly and Yearly Power Consumption of Users Load with Benin Electricity Distribution Company (BEDC) metering system (CONLOG)

Load	P3 (W)	Monthly	Yearly	I3(A)	Monthly	Yearly	P4 (W)	Monthly	Yearly	I4(A)	Monthly	Yearly
1	59.300	1956.900	21941.000	0.281	8.128	93.218	60.300	1989.900	22311	0.292	8.128	93.218
2	59.800	1973.400	22126.000	0.268	7.520	86.245	60.400	1993.200	22348	0.272	7.552	86.612
3	16.100	531.300	5957.000	0.072	1.536	17.616	17.200	567.600	6364	0.076	1.472	16.882
4	193.100	6372.300	71447.000	0.84	23.968	274.883	182.700	6029.100	67599	0.82	14.88	170.655
5	93.200	3075.600	34484.000	0.44	10.176	116.706	96.600	3187.800	35742	0.449	10.208	117.073
6	88.100	2907.300	32597.000	0.4	9.088	104.228	91.300	3012.900	33781	0.424	8.352	95.787
7	208.300	6873.900	77071.000	1.036	26.688	306.078	226.300	7467.900	83731	1.067	26.24	300.94
8	937.700	30944.100	346949.000	4.541	122.912	1409.647	959.800	31673.400	355126	4.651	126.432	1450.017
9	11.620	383.460	4299.400	0.069	1.536	17.616	11.740	387.420	4343.8	0.071	1.504	17.249
10	8.770	289.410	3244.900	0.061	1.152	13.212	9.200	303.600	3404	0.062	1.152	13.212
11	7.340	242.220	2715.800	0.042	0.992	11.377	7.380	243.540	2730.6	0.044	0.992	11.377
12	89.800	2963.400	33226.000	0.446	10.976	125.881	92.500	3052.500	34225	0.461	10.944	125.514

Table 3.19: The mean monthly energy and power consumption with BEDC

Measured load	Mean Energy (\bar{E}) (kWh)	Mean Power (\bar{P}) (Watt)
1	3.762	1942.875
2	3.7125	1959.375
3	2.178	523.875
4	20.3115	5090.25
5	10.7745	2977.425
6	22.4565	2749.725
7	34.1715	6920.1
8	40.71375	30569.55
9	0.51975	377.52
10	0.429	288.5025
11	0.23925	240.24
12	14.4705	2900.7

The results are presented in chapter four.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Summary of Results

This section contains the results of the respondents' questionnaire survey, as well as the graphical analysis of the effectiveness of the existing metering system. However, apart from the wireless transceiver and Excel output tables other tables can be found in Appendix K. It also includes a comparison and findings of the entire system.

Survey Results on a percentage of loads left on.

A total of 324 respondents, or 56.64%, admitted to having unintentionally left their loads on when the utility company restored the power supply. While 248 respondents, or 43.36% of the sample size, indicated that they don't, details of the respondents' survey responses and the apartments are listed in Appendix K. Unintentionally left-on consumer loads include lighting, heating, cooling, ventilation, and entertainment; the percentage of respondents who use each at the appropriate time shown in a table in Appendix K. Nine buildings in all were chosen at random from the 572 respondents. A total of 324 respondents left their loads running, whereas 248 turned off every load before leaving the home

$$\text{Percentage of total respondent} = \frac{\text{number of respondents}}{\text{total number of respondents}} \times 100 \quad (4.1)$$

This represents $\frac{324}{572} \times 100 = 56.648\%$ of the total respondents and

$$\text{Percentage of respondents who left their loads on} = \frac{\text{number of respondents/apartment}}{\text{total number of respondents leaving loads on}} \times 100 \quad (4.2)$$

$\frac{51}{324} \times 100 = 15.74\%$ of respondents living in one room apartment left their loads on.

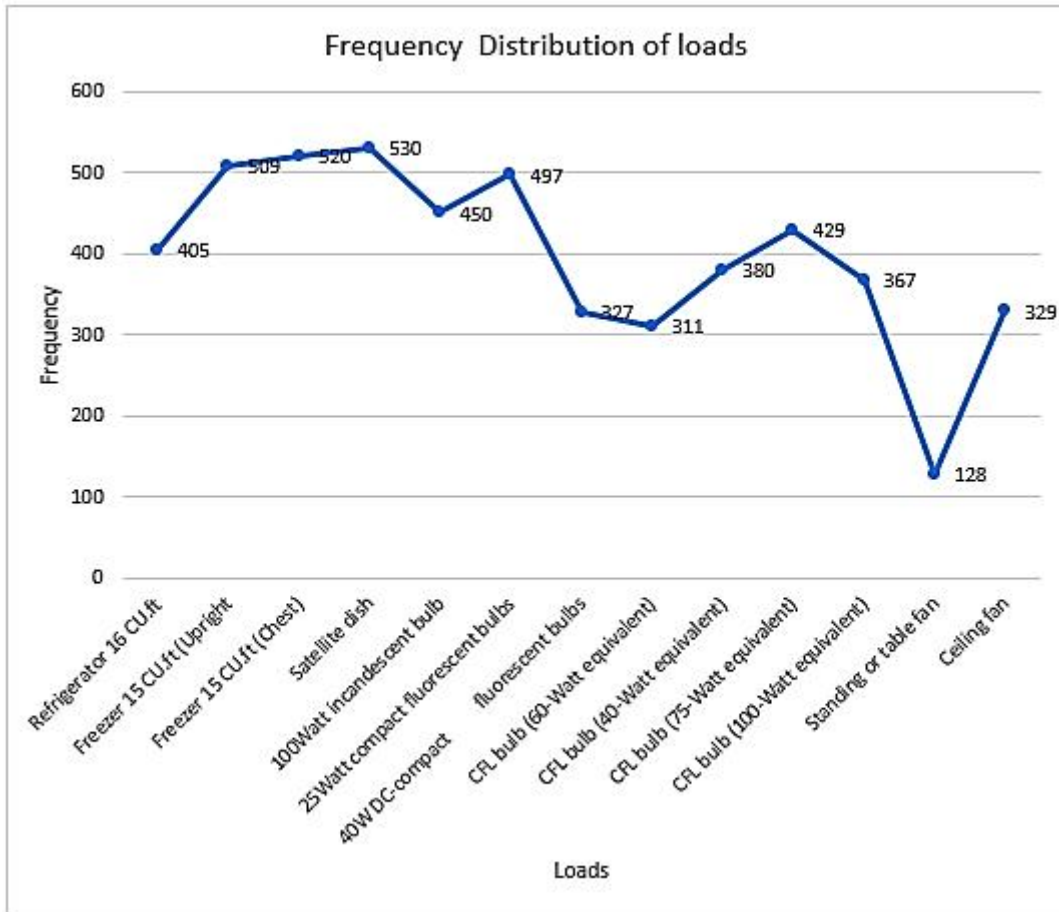


Figure 4.1: Frequency count of loads left on.

According to the displayed graph in Figure 4.1, a significant portion of the loads remains left on. Specifically, the 15 cubic feet (Chest) freezer is left on at a frequency of 520. This is closely followed by a 25-watt compact fluorescent light, left on at a frequency of 497 while standing fans have a frequency of 128.



Figure 4.2: Percentage rationing of loads left on.

Based on the visual representation in Figure 4.2, a substantial portion of the loads remains in an active state. In particular, the 15 cubic feet (Chest) freezer has a high percentage of 92.98, indicating that it is left on most of the time. Following closely is the 25-watt compact fluorescent light, which registers a percentage of 87.19, signifying its frequent operation. In contrast, standing fans exhibit a comparatively lower percentage of 22.46, implying that they are left on to a lesser extent.

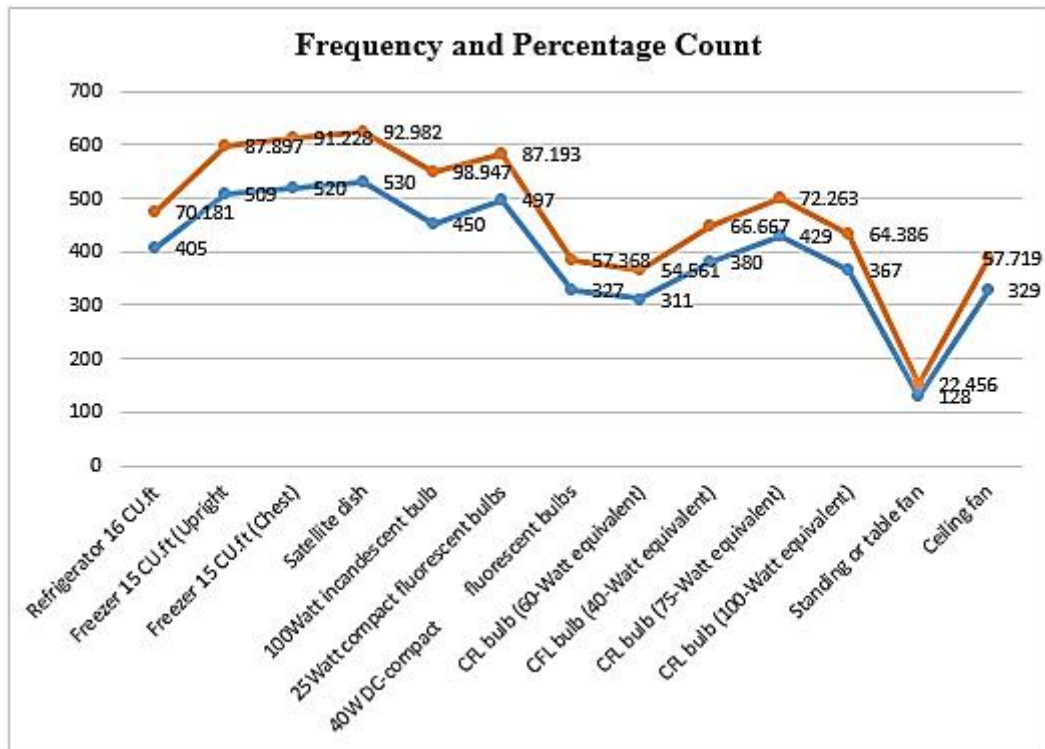


Figure 4.3: Frequency and Percentage count of Loads left on.

Based on the information depicted in Figure 4.3, a significant portion of the loads remains powered on continuously. Notably, the 15 cubic feet (Chest) freezer operates at a frequency of 520, which accounts for 92.98 percent of the observed duration. Subsequently, the 25-watt compact fluorescent light exhibits a frequency of 497, representing 87.19 percent of the total duration. In contrast, the standing fan has a frequency count of 128, which corresponds to a relatively lower percentage of 22.46.

4.1.2 Survey Results on Electricity supply in hours received from utility company

Figure 4.4 presents the results of the questionnaire for the Electricity supply in hours received from the utility company using the formula in equations 4.1 and 4.2. Equations 4.1 and 4.2 in this section's other survey results calculations used the same formula.

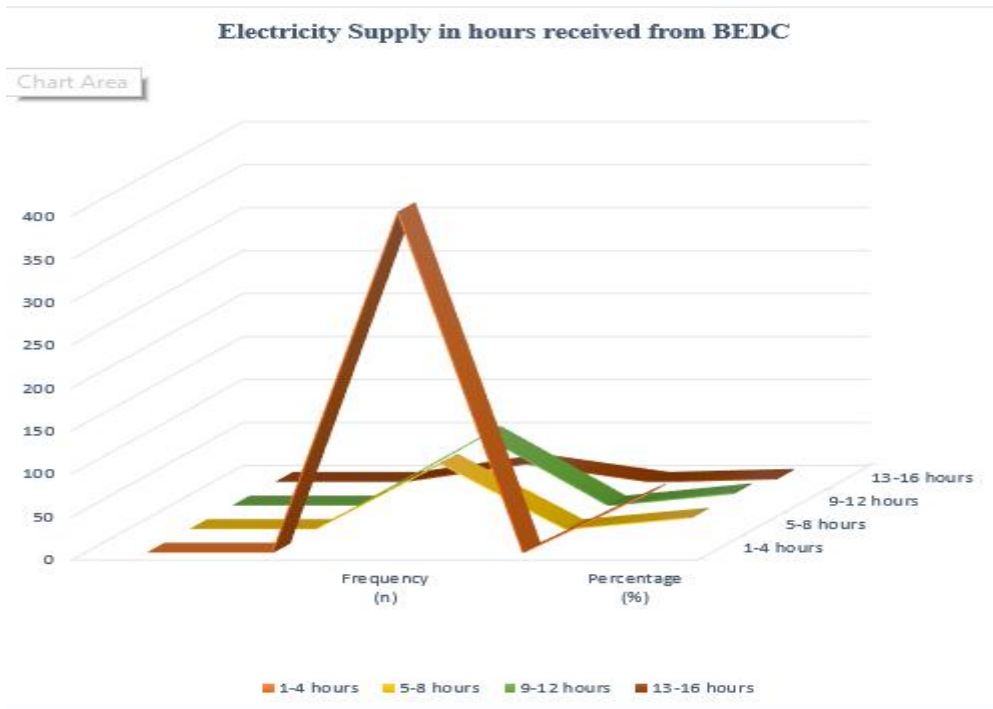


Figure 4.4: Electricity Supply in hours received from BEDC

According to the data presented in Figure 4.4, a considerable number of individuals interviewed report inadequate electricity supply for a significant duration. Specifically, out of the total of 572 respondents, 394 individuals state that they receive electricity power supply for only 1-4 hours daily, accounting for 68.9 percent of the respondents. Additionally, 76 respondents mention receiving electricity supply for 5-8 hours daily, constituting 13.3 percent of the total respondents. In contrast, a smaller percentage of 21 respondents (3.7 percent) claim to receive electricity supply for 13-16 hours daily

4.1.3 Survey results on certain factors contributing to Nigeria's power problem

The questionnaire responses on certain factors contributing to Nigeria's power problem are shown in Figure 4.5.

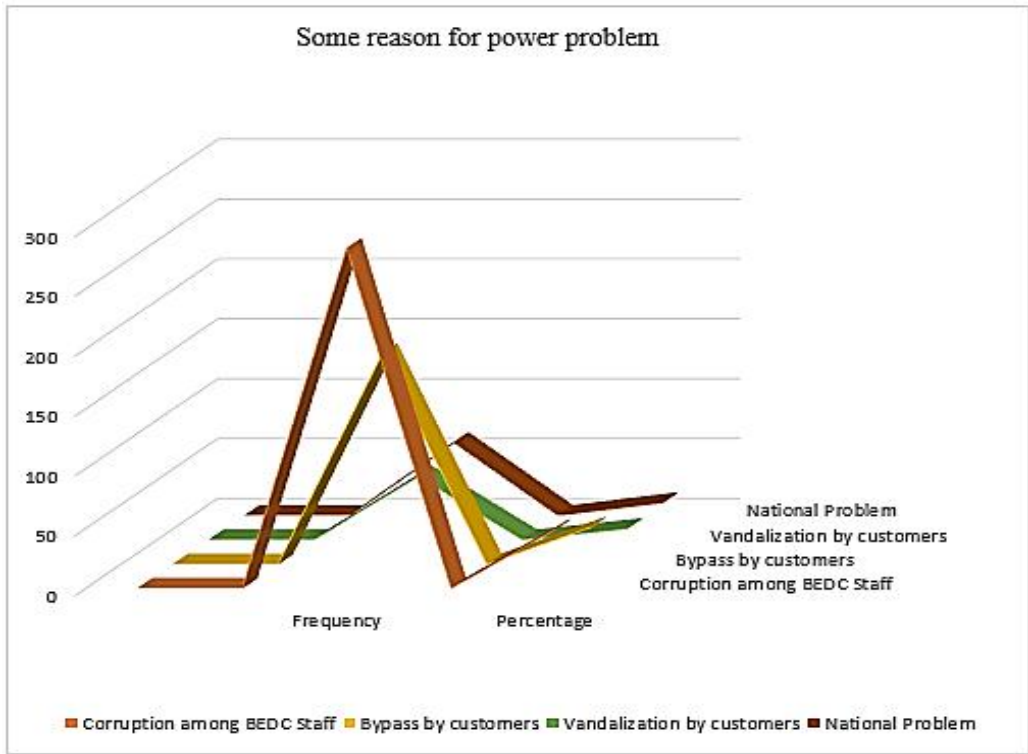


Figure 4.5: Some reason for power problem

Based on the data depicted in Figure 4.5, a significant proportion of individuals surveyed indicate various factors contributing to power supply issues. More specifically, among the 572 respondents, 282 individuals (equivalent to 49.2 percent) cite corruption as the primary cause. Additionally, 176 respondents (30.8 percent) attribute power supply problems to the bypassing actions of electricity consumers. In contrast, a smaller percentage of 53 respondents (9.3 percent) attribute the issues to the vandalization of BEDC facilities.

4.1.4 Survey findings for utility company visits for cable cuts and fallen poles

The survey findings for consumers who always visit the utility company in the event of a fallen pole and cable cut are provided in Figure 4.6.

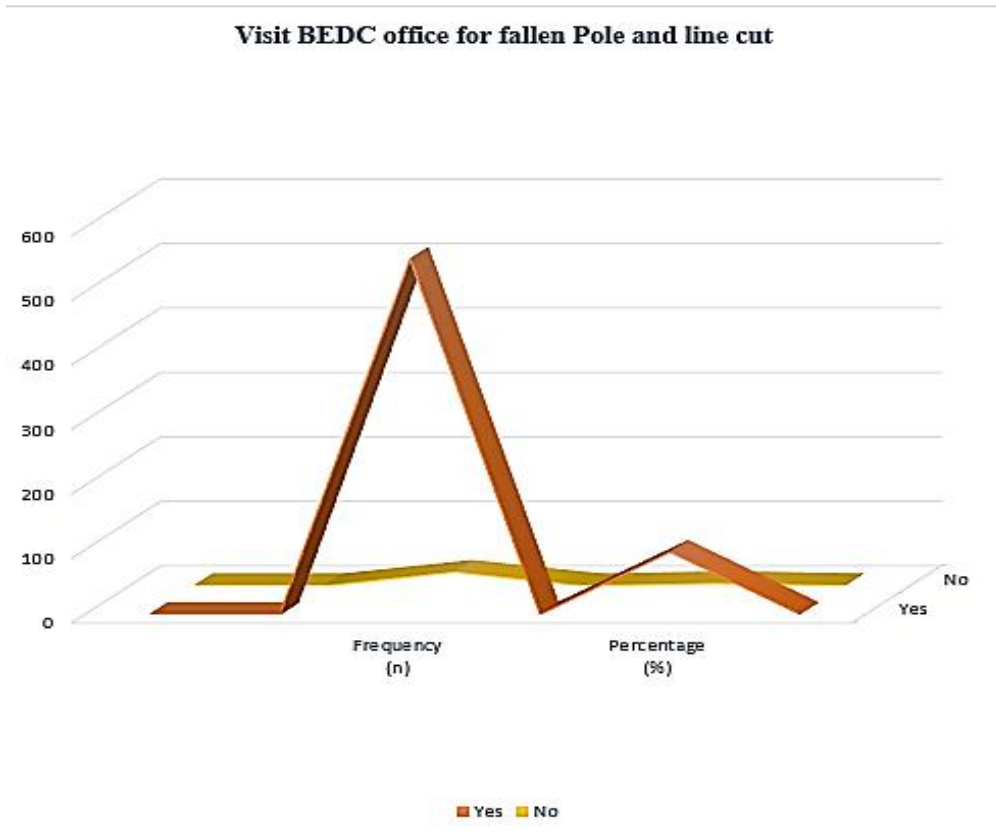


Figure 4.6: Visit Utility office (BEDC) for service wire or line cut

According to the data presented in Figure 4.6, a notable portion of individuals surveyed assert the need to visit the utility office when faced with service wire or line cut issues. Specifically, out of the 572 respondents, 551 individuals (equivalent to 96.3 percent) confirm that they are required to visit the office prior to receiving assistance. In contrast, a smaller percentage of 21 respondents (3.7 percent) answered negatively, indicating that they do not need to visit the office.

4.1.5 Survey results for the amount of time taken to fix fallen poles and cable cuts

The questionnaire findings for the amount of time taken to fix a fallen pole and a line cut are shown in Figure 4.7.

Time to attend to fallen Pole and line cut

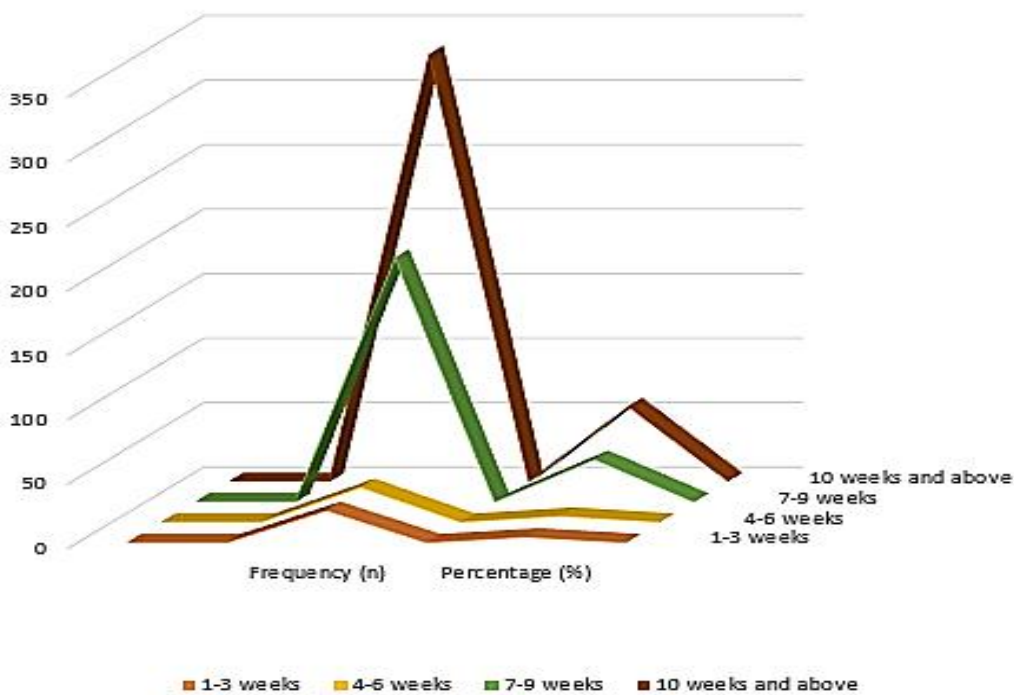


Figure 4.7:

Time to attend to service wire or line cut

According to the data presented in Figure 4.7, a substantial portion of individuals interviewed express the duration it takes to address service wire or line cut concerns. More precisely, out of the 572 respondents, 331 individuals (equivalent to 57.9 percent) state that it takes 10 weeks or longer to resolve the issue. Furthermore, 189 respondents (33.0 percent) report a timeframe of 7-9 weeks. In contrast, a smaller percentage of 25 respondents (4.4 percent) mention a duration of 1-3 weeks.

4.1.6 Findings from a survey of generator users who utilize electricity

The results of the questionnaire for power users who utilizes generators are shown in Figure 4.8.

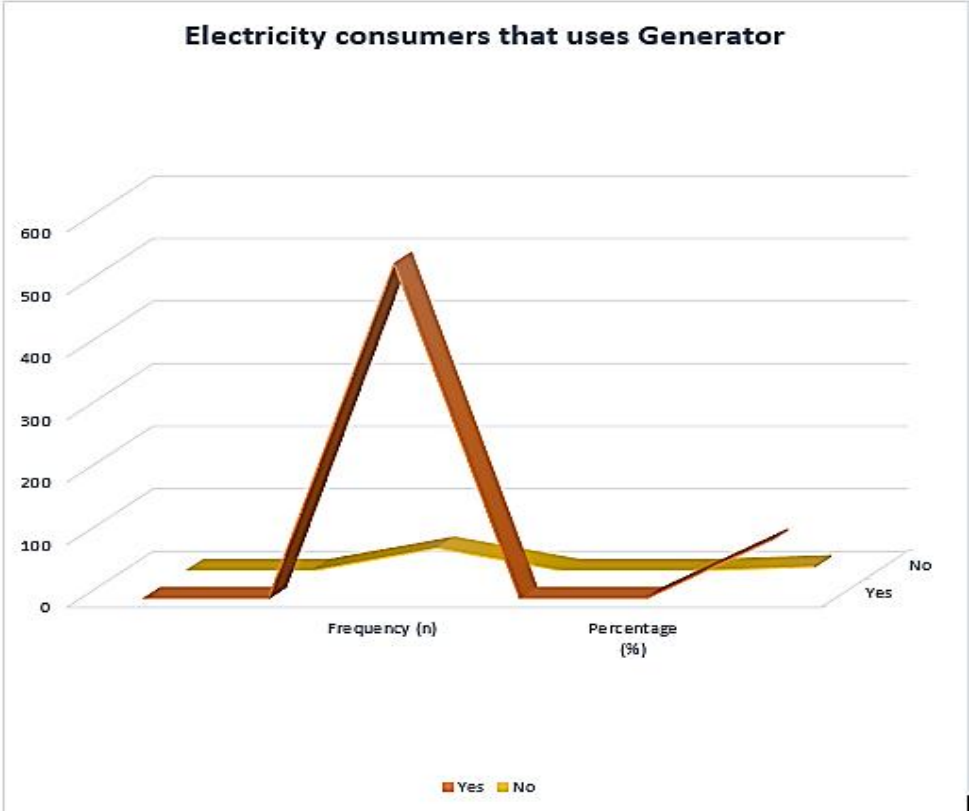


Figure 4.8: Electricity Consumers that uses Generator

Based on the data depicted in Figure 4.9, a significant proportion of individuals surveyed indicate their reliance on generators as electricity consumers. More specifically, out of the 572 respondents, 536 individuals (equivalent to 93.7 percent) confirm that they typically resort to using a generator in the event of a power outage. In contrast, a smaller percentage of 36 respondents (6.3 percent) responded negatively, indicating that they do not utilize a generator.

4.1.7 Survey findings for daily hours that Nigerian customers run generators

The questionnaire findings for daily hours spent running generator are shown in Figure 4.9

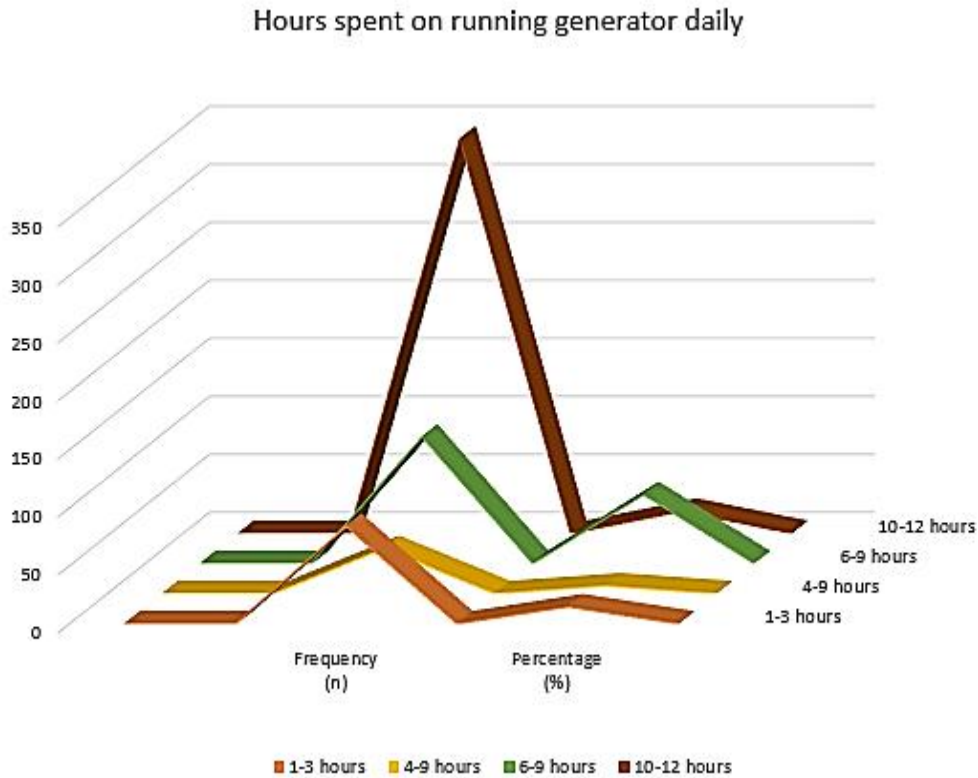


Figure 4.9: Hours spent running generator daily

According to the data presented in Figure 4.9, a notable proportion of individuals surveyed provide insights into the duration they run generators daily during power outages. More precisely, out of the 572 respondents, 340 individuals (equivalent to 59.4 percent) indicate that they typically operate their generators for 10-12 hours each day. Furthermore, 109 respondents (19.1 percent) report running their generators for 6-9 hours daily. In contrast, a smaller percentage of 39 respondents (6.8 percent) mention a duration of 4-6 hours daily.

Results of the survey on the monthly amount (in Naira) spent on fuel

The findings of the questionnaire, which show how much (in Naira) was spent on fuel each month are shown in Figure 4.10

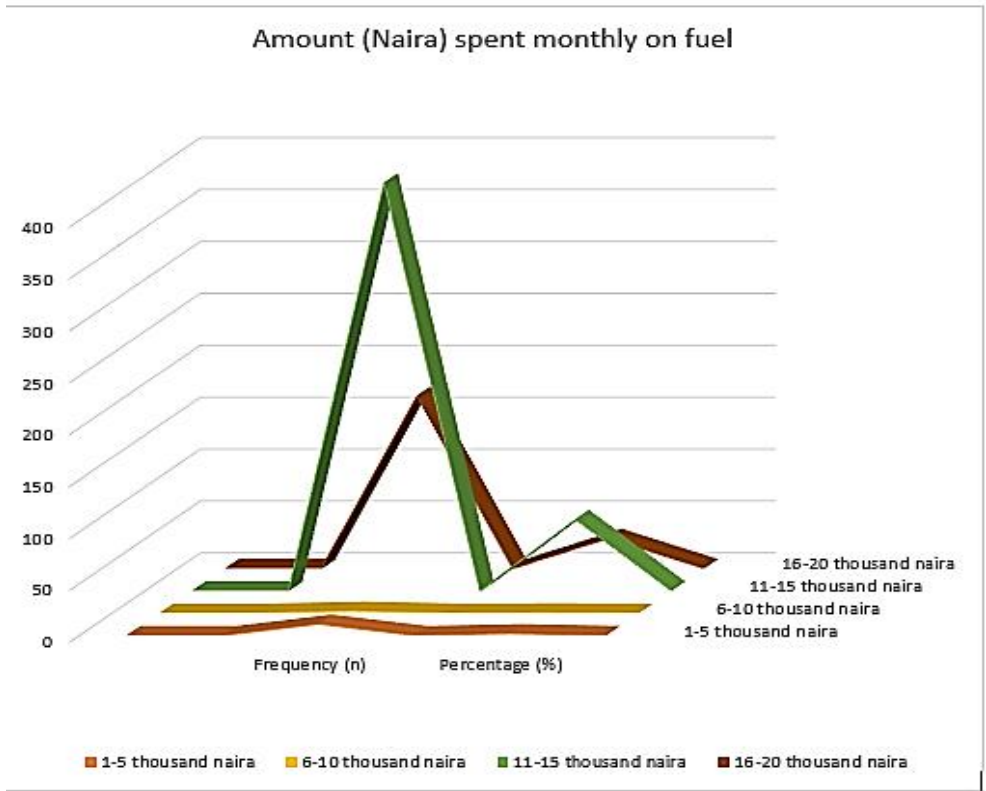


Figure 4.10: Amount (Naira) Spent on Fuel Monthly

Based on the data depicted in Figure 4.10, a significant portion of individuals surveyed share information regarding their monthly expenses in Nigerian naira for operating generators during power outages. More precisely, out of the 572 respondents, 393 individuals (equivalent to 68.7 percent) state that they spend between 11,000 and 15,000 naira per month. Furthermore, 166 respondents (29.1 percent) report monthly expenditures ranging from 6,000 to 9,000 naira. In contrast, a smaller percentage of 2 respondents (0.3 percent) mention spending between 6,000 and 10,000 naira monthly.

4.1.9 Customers value survey findings from a utility firm (BEDC) in Nigeria

The survey findings for a utility company's (BEDC's) consumers' value presented in figure 4.11.

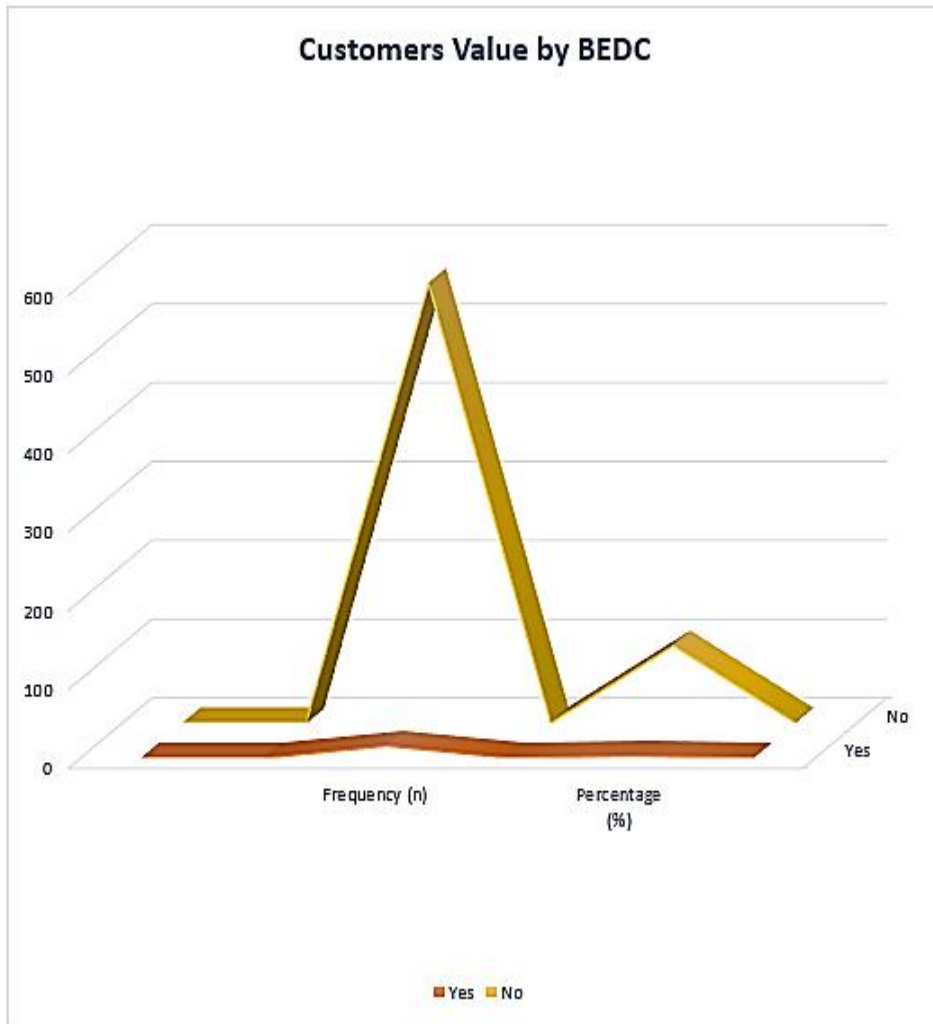


Figure 4.11: Customers value by BEDC

According to the data presented in Figure 4.11, a considerable proportion of individuals surveyed express their perception of being valued as customers by the BEDC Electricity Utility Company in Nigeria. Specifically, out of the 572 respondents, 557 individuals (equivalent to 97.4 percent) affirm that they do not feel valued by the Utility Company. In contrast, a smaller percentage of 15 respondents (2.6 percent) answered positively, indicating that they feel valued by the BEDC Utility Company in Nigeria.

4.1.10 Survey Results on how well power consumers understand how utility company calculate load consumption

Figure 4.12 displays the survey results for Nigerian power consumers' knowledge of utility company calculations based on load consumption.

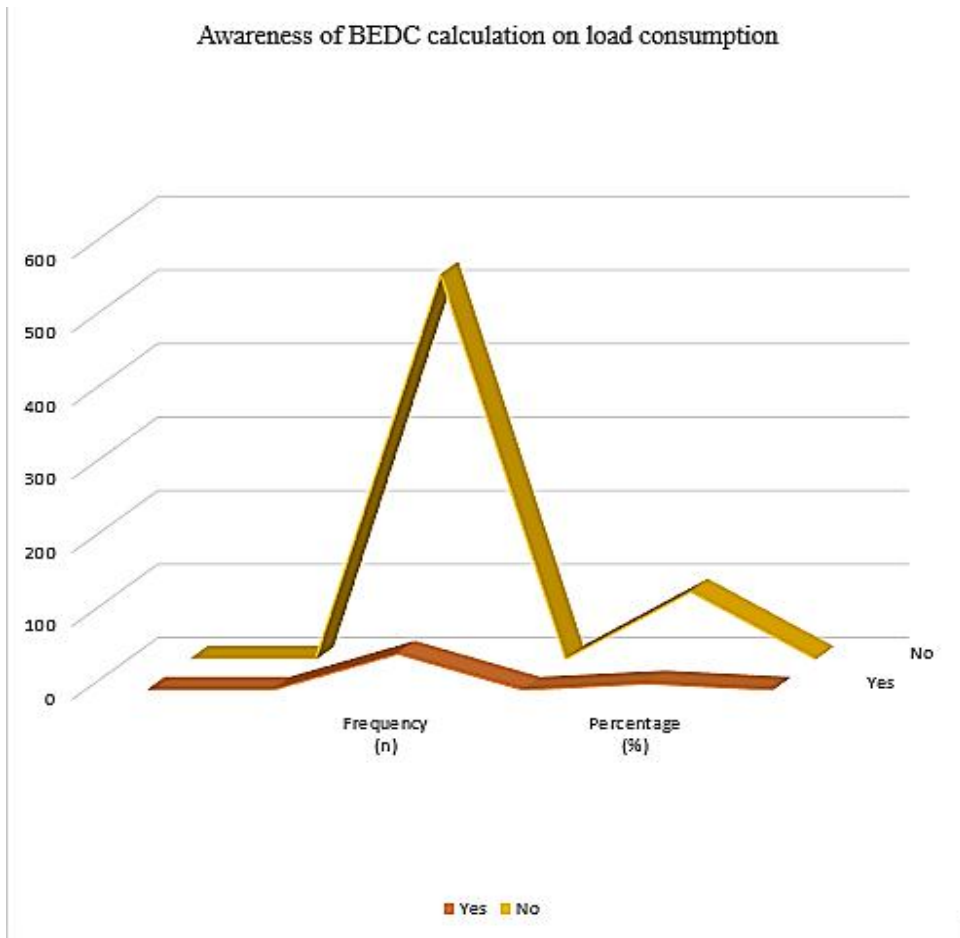


Figure 4.12: Awareness of BEDC Calculation on load consumption

Based on the data depicted in Figure 4.12, a significant segment of the surveyed population indicates their perception regarding the level of awareness among users of existing appliances with regards to load consumption calculation by the BEDC Electricity Utility Company in Nigeria. More specifically, among the 572 respondents, 523 individuals (or 91.4 percent) acknowledge their lack of knowledge regarding the calculation performed by the Utility Company. Conversely, a smaller proportion of 49 respondents (or 8.6 percent) responded affirmatively, indicating their awareness of the load consumption calculation conducted by the BEDC Utility Company in Nigeria.

Survey results for consumers with prepaid meters

The survey results for customers who use prepaid meters are shown in Figure 4.13.

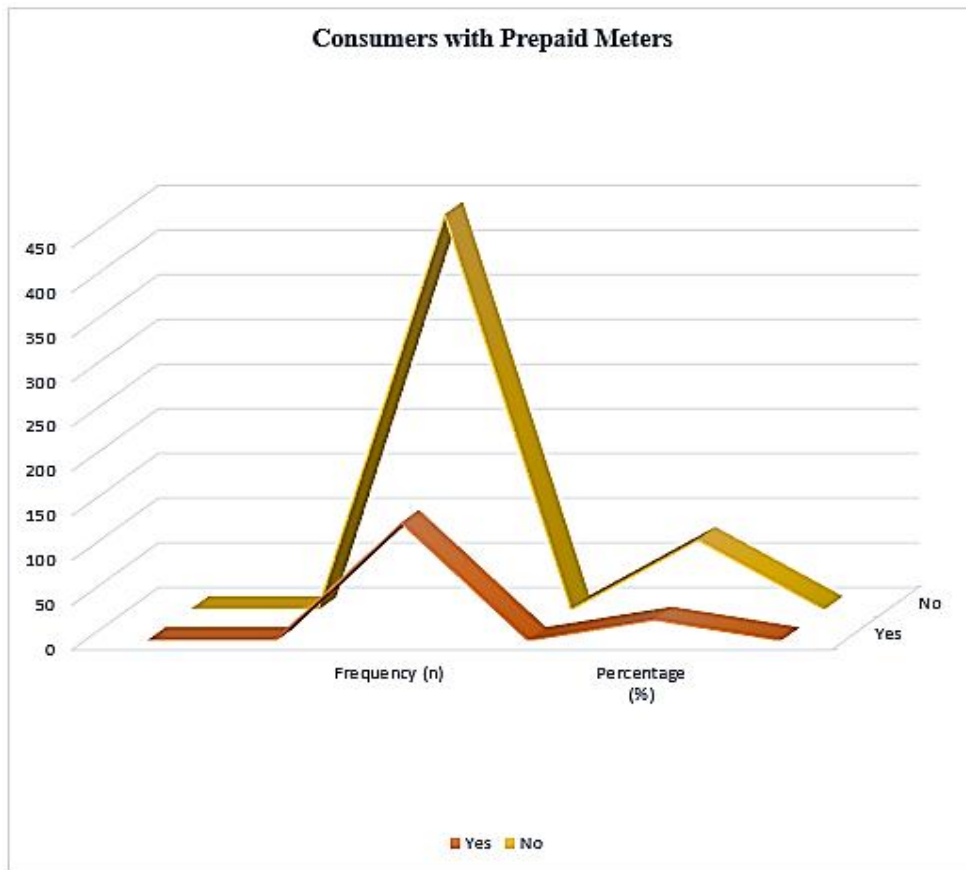


Figure 4.13: Consumers with Prepaid meters

Based on the data depicted in Figure 4.13, a significant segment of the surveyed population indicates the presence of consumers with prepaid meters. More specifically, among the 572 respondents, 441 individuals residing in both rural and urban areas (or 77.1 percent) acknowledge that they do not possess prepaid meters. In contrast, a smaller proportion of 131 respondents (or 22.9 percent) responded affirmatively, indicating that they have prepaid meters in Nigeria.

4.1.12 Results of a survey on prepaid meter unit consumption

Figure 4.14 lists the survey findings for knowledge of prepaid meter unit consumption.

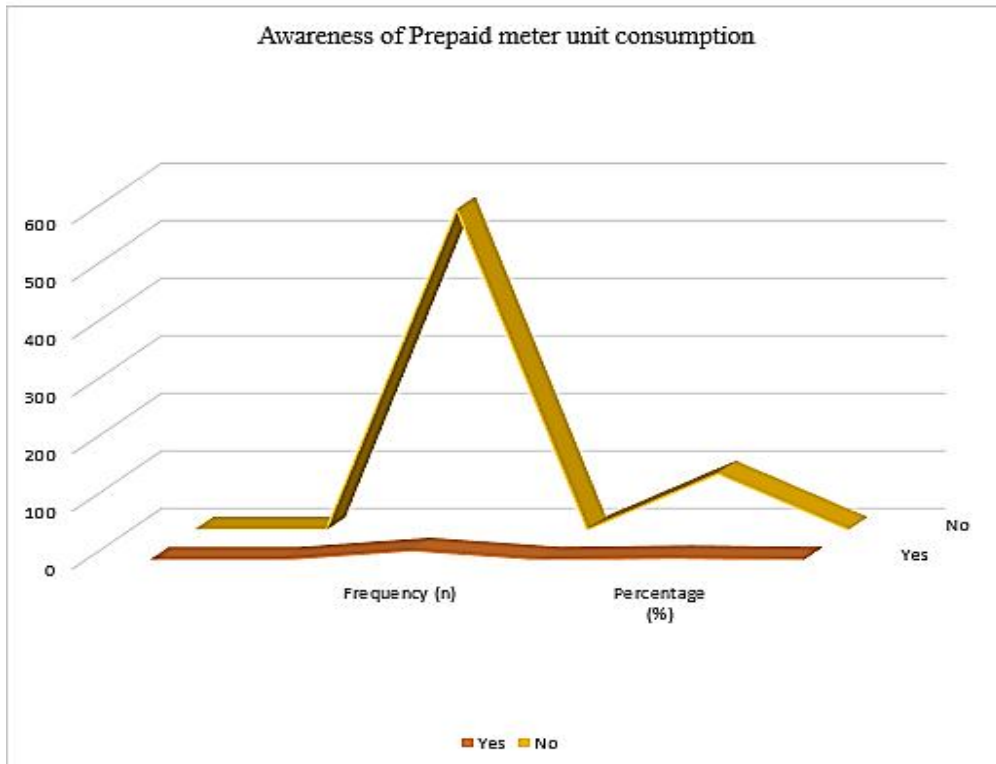


Figure 4.14: Awareness of Prepaid meter Unit consumption

According to the data presented in Figure 4.14, a notable portion of the surveyed population expresses their perception regarding the level of awareness pertaining to prepaid meter unit consumption. Specifically, out of the 572 respondents, 556 individuals (equivalent to 97.2 percent) acknowledge their limited understanding of prepaid meter unit consumption. In contrast, a smaller percentage of 16 respondents (or 2.8 percent) responded positively, indicating their awareness of prepaid meter unit consumption in Nigeria.

4.1.13 Results of the survey on the difficulties of purchasing or loading prepaid meters

Figure 4.15 shows the results of the questionnaire about the difficulties of purchasing or loading prepaid meters.

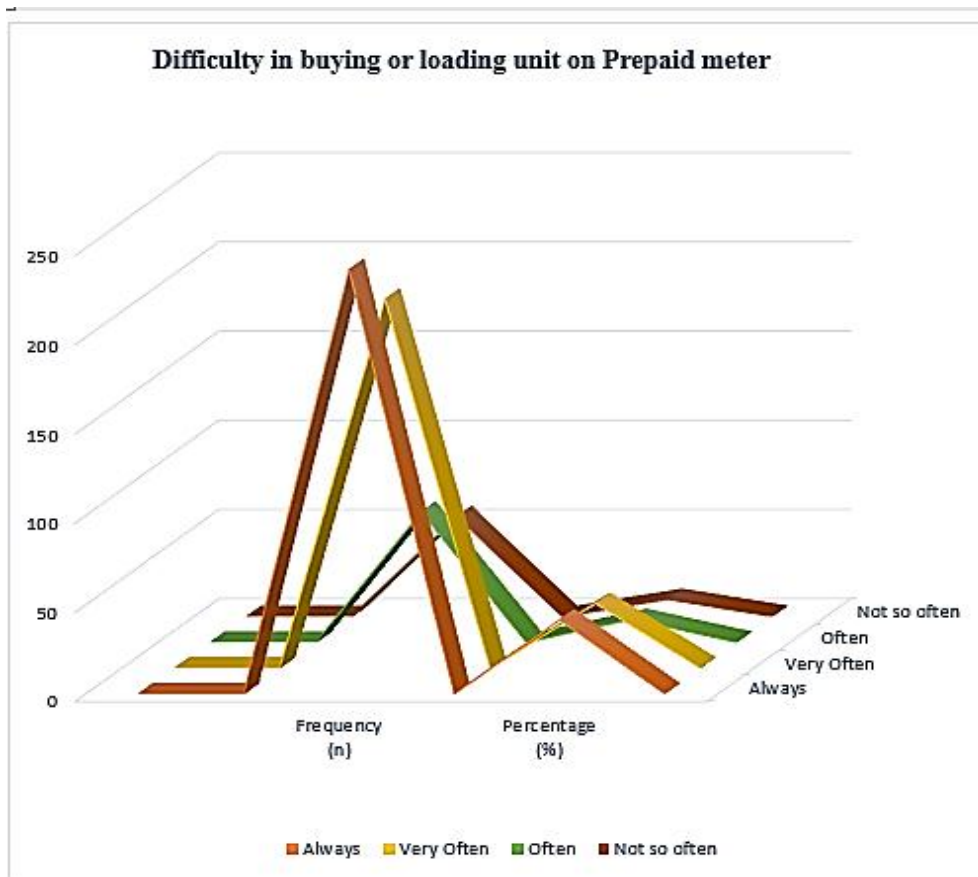


Figure 4.15: Difficulty in buying to loading unit on prepaid meter

According to the data presented in Figure 4.15, a substantial segment of the surveyed population indicates challenges associated with purchasing and loading units on prepaid meters. Specifically, out of the 572 respondents, 236 individuals (or 41.3 percent) consistently express difficulties in buying and loading units on prepaid meters. Additionally, 207 respondents (or 36.2 percent) frequently encounter obstacles when attempting to purchase and load units on prepaid meters. In contrast, a smaller percentage of 56 respondents (or 9.7 percent) report encountering such difficulties less frequently.

Results of the survey on meter tampering

Figure 4.16 displays the results of the survey on meter tampering.

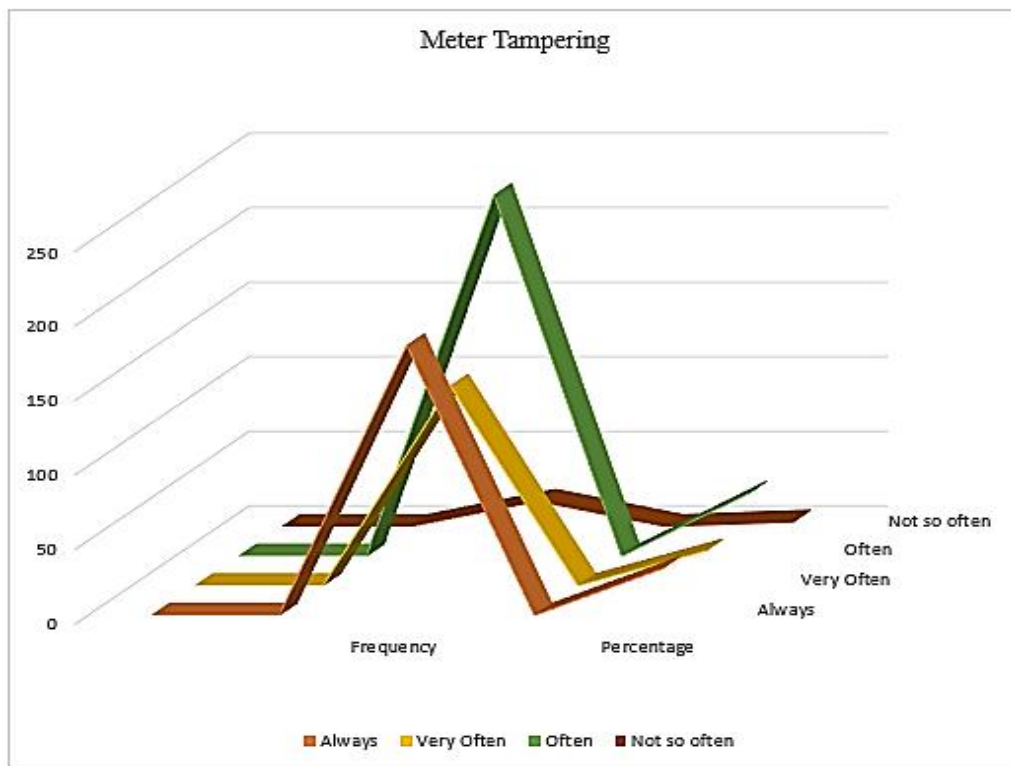


Figure 4.16: Meter Tampering

Based on the data depicted in Figure 4.16, a significant portion of the surveyed population reveals instances of consumer tampering with their prepaid meters. More specifically, out of the 572 respondents, 242 individuals (equivalent to 42.3 percent) frequently report cases where consumers tamper with their prepaid meters. Additionally, 179 respondents (or 31.3 percent) indicate that consumer tampering with prepaid meters occurs very often, particularly in both rural and urban areas. In contrast, a smaller percentage of 17 respondents (or 3.0 percent) state that such incidents happen less frequently.

4.1.15 Results of the survey "Tempted to Bypass"

The survey findings for being tempted to bypass are shown in Figure 4.17.

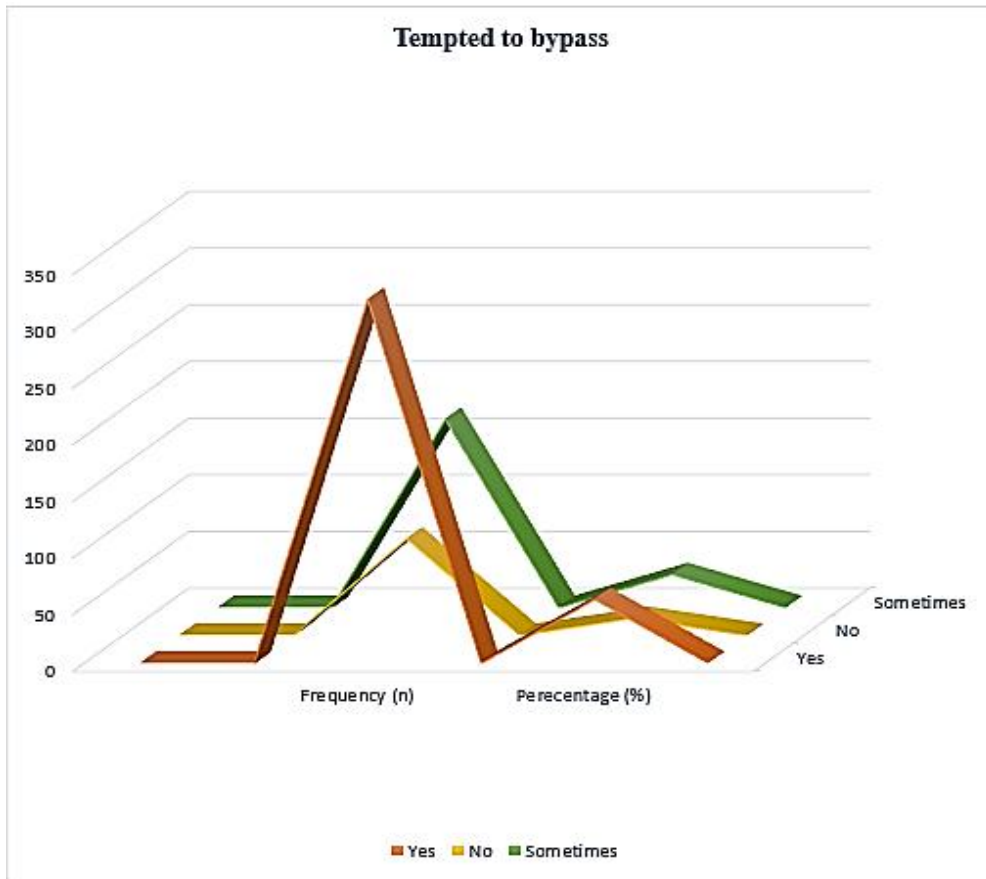


Figure 4.17: Tempted to bypass

Based on the data presented in Figure 4.17, a notable segment of the surveyed population discloses instances of being tempted to bypass their electricity supply after facing difficulties in purchasing meter units. Specifically, out of the 572 respondents, 321 individuals (or 56.1 percent) admit to being tempted to bypass their prepaid meters. Additionally, 166 respondents (or 29.0 percent) indicate occasional temptations to bypass, particularly in urban areas. In contrast, a smaller percentage of 85 respondents (or 14.9 percent) assert that they do not experience any temptation to bypass their prepaid meters.

4.1.16 Consumer satisfaction survey results for BEDC customer service in Nigeria

Figure 4.18 shows the survey results regarding consumers' satisfaction with BEDC customer service.

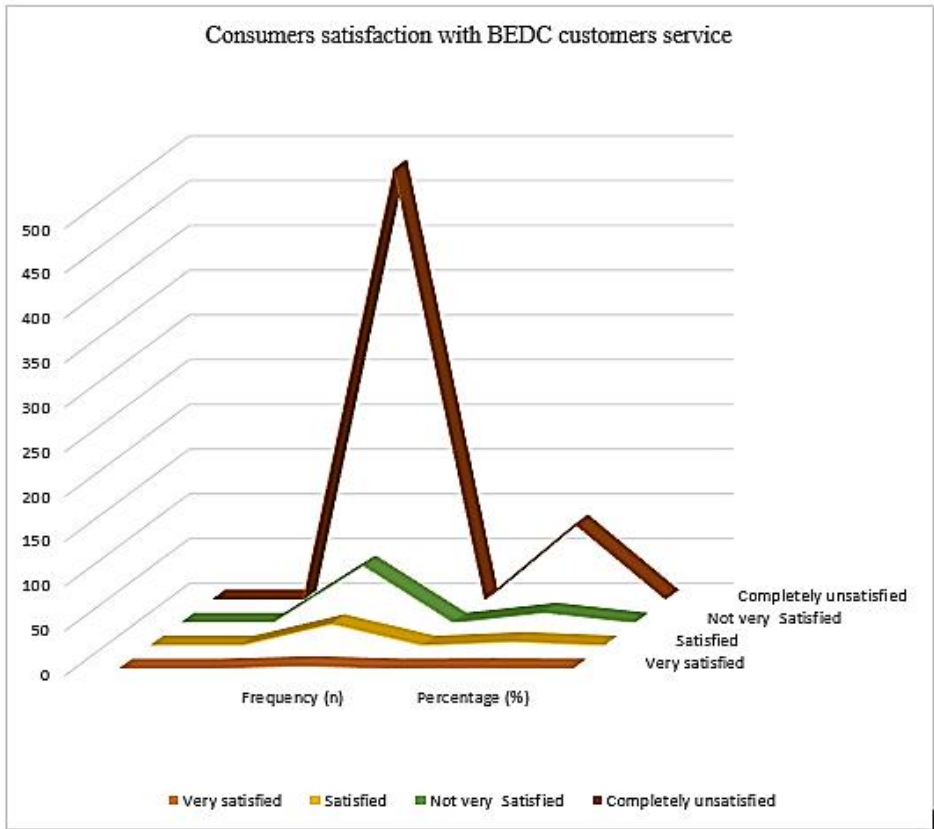


Figure 4.18: Consumers Satisfaction with BEDC customer’s service

According to the data depicted in Figure 4.18, a significant portion of the surveyed population reveals their level of satisfaction with BEDC customer services. Specifically, out of the 572 respondents, 481 individuals (equivalent to 84.1 percent) express complete dissatisfaction with the customer services provided. Additionally, 64 respondents (or 11.2 percent) state that they are not very satisfied, particularly in urban areas. In contrast, a smaller percentage of 3 respondents (or 0.5 percent) indicate being highly satisfied with the customer services.

4.1.17 Survey results for consumers desire to control their consumption of electricity

The survey results regarding the desire to control electricity consumption are shown in Figure 4.19.

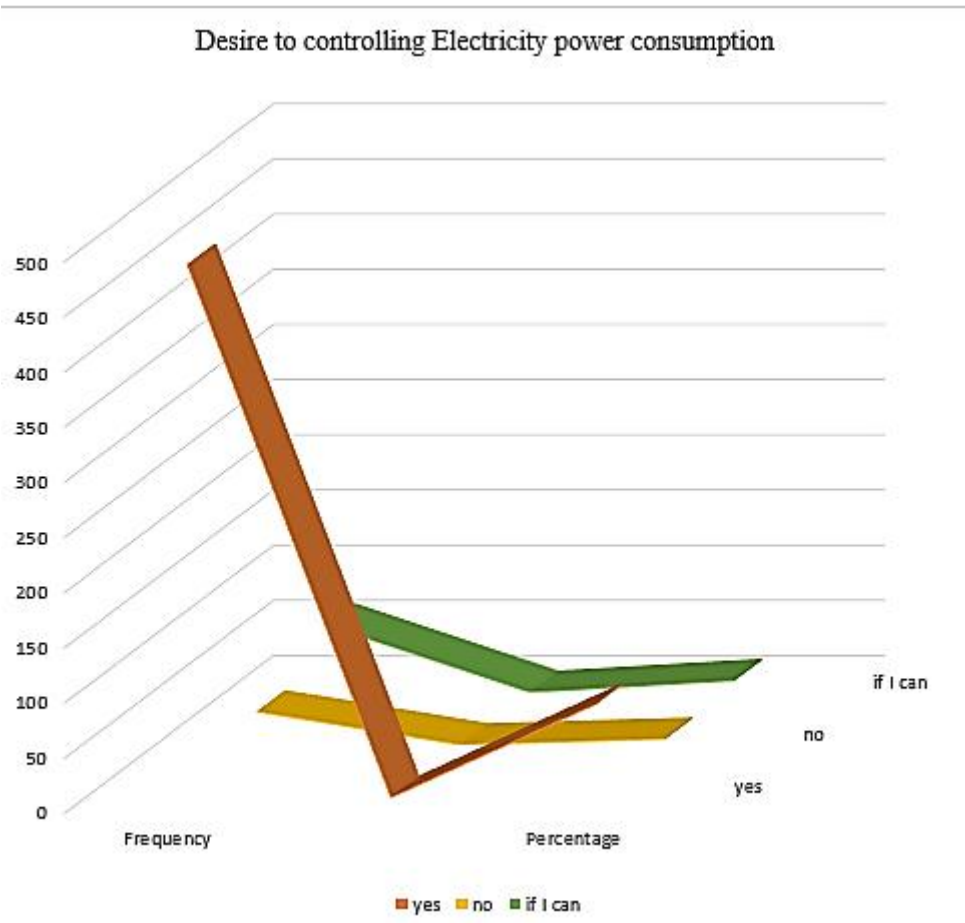


Figure 4.19: Desire to controlling Electricity power consumption

Based on the data presented in Figure 4.19, a notable segment of the surveyed population expresses their inclination towards controlling their electricity power consumption. Specifically, out of the 572 respondents, 481 individuals (or 84.1 percent) affirm their desire to control their electricity power consumption. Additionally, 61 respondents (or 10.7 percent) indicate that if given the opportunity, particularly in urban areas, they would love to have control over their electricity power consumption. In contrast, a smaller percentage of 30 respondents (or 5.2 percent) residing in rural areas express a lack of interest in controlling their electricity power consumption.

Results of the simulation between the web-based system and the MATLAB interface for open-circuit fault detection and reporting.

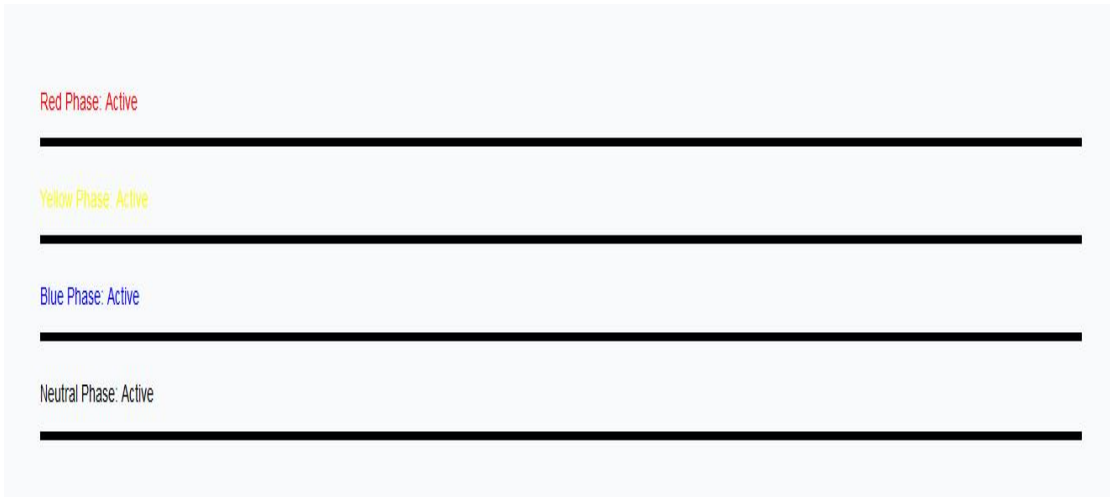


Figure 4.20: Three phase distribution line on the web-based interface

The three-phase distribution lines on the web-based interface are depicted with respect to their status in the screenshot shown in Figure 4.20. They are all clearly active, indicating that no lines have been cut or opened.

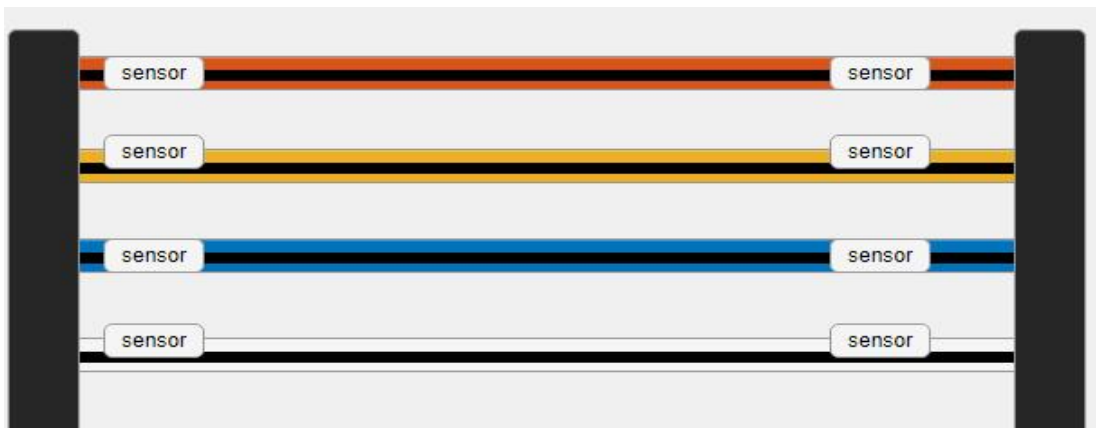


Figure 4.21: Three phase distribution line on MATLAB interface indicating all lines active.

The three-phase distribution lines are depicted on the MATLAB interface with respect to their status in the screenshot shown in Figure 4.21. It is evident that none of the lines are damaged or opened because they are all active.

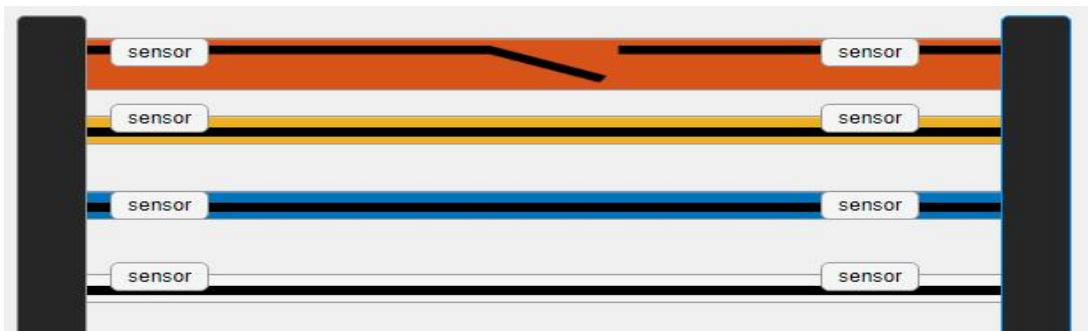


Figure 4.22: Three phase distribution line on MATLAB interface indicating red phase broken

The three-phase distribution on the MATLAB interface is depicted in screenshot form in Figure 4.22, with the red phase opened or cut. In contrast to Figure 4.21, where all the lines are active, it consists of sensors that automatically communicate faults and system status to a web-based system, as illustrated in Figure 4.23.

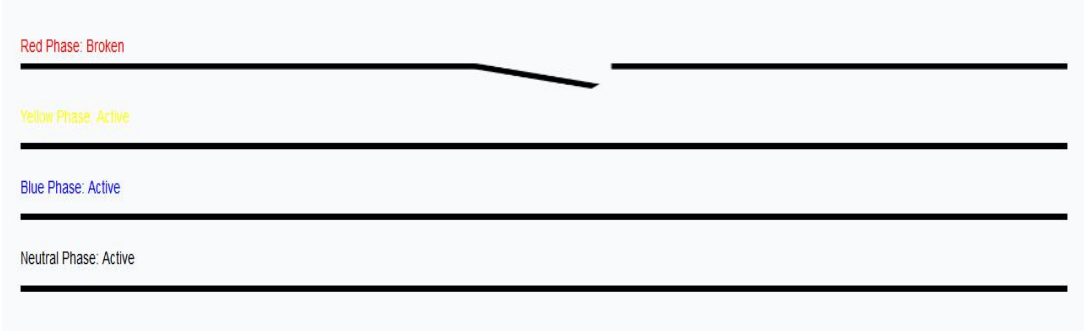


Figure 4.23: Three phase distribution line on the Web-based interface indicating red phase broken

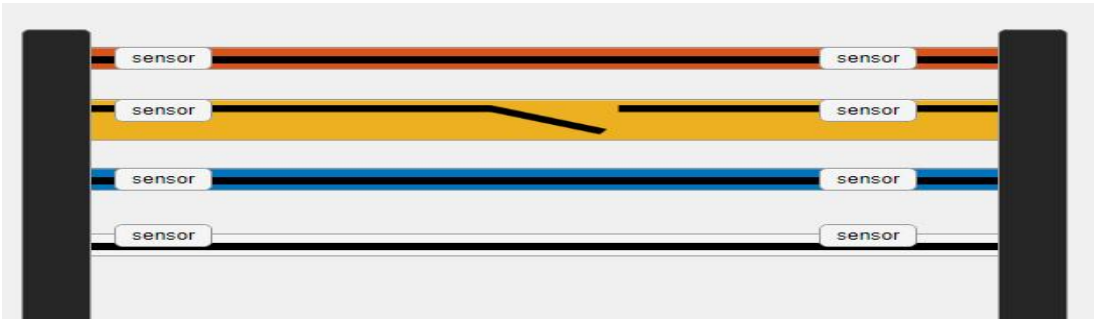


Figure 4.24: Three phase distribution line on MATLAB interface after restoration of red phase indicating yellow phase broken.

The three-phase distribution on the MATLAB interface is depicted in screenshot form in Figure 4.24 with the yellow phase opened or cut. As illustrated in Figure 4.25, which contrasts with Figure 4.22 following the restoration of the red phase presently operational, it is composed of sensors that detect fault and automatically communicate the problem and status to the web-based system.

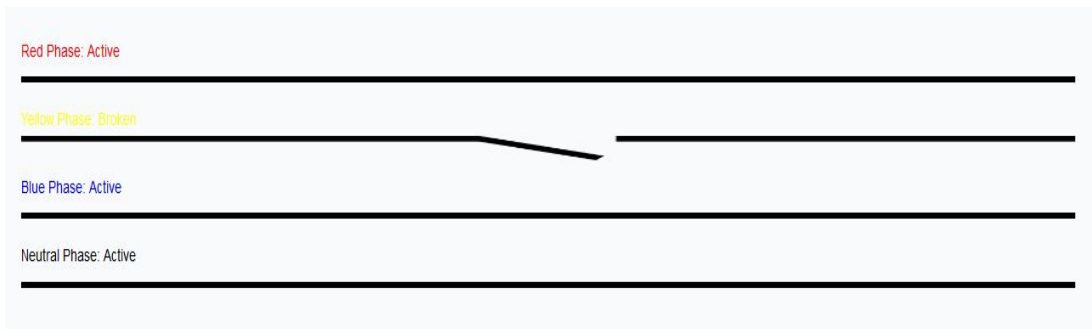


Figure 4.25: Three phase distribution line on web-based interface after restoration of red phase indicating yellow phase opened or cut.



Figure 4.26: Three phase distribution line on MATLAB interface after restoration of broken yellow phase indicating all lines active.

The three-phase distribution on the MATLAB interface is depicted in Figure 4.26's screenshot following the restoration of the yellow phase, which was previously opened or cut. In contrast to Figure 4.25, where the yellow phase was opened or cut, it consists of sensors that detect faults and automatically send the defect and status to the web-based system as seen in Figure 4.27.

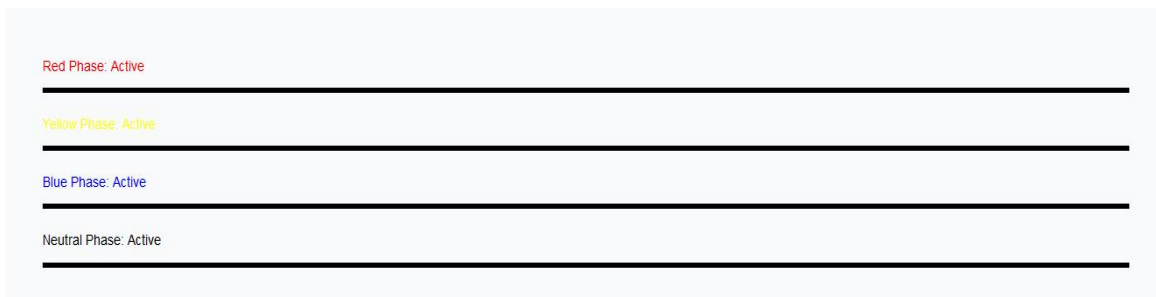


Figure 4.27: Three phase distribution line on Web-based interface after restoration of opened yellow phase indicating all lines active

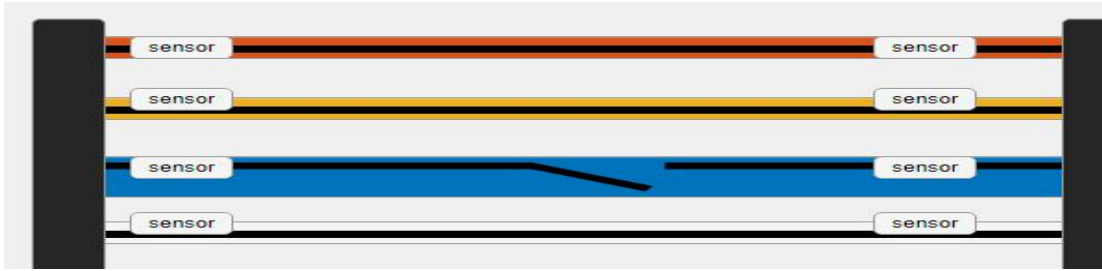


Figure 4.28: Three phase distribution line on MATLAB interface after restoration of opened yellow phase indicating blue phase opened or cut.

Figure 4.28's screenshot displays the three-phase distribution on the MATLAB interface following the restoration of the yellow phase, which had previously been broken or cut together with the blue phase. In contrast to Figure 4.26, where all lines are active, it consists of sensors that detect faults and automatically send the problem and status to the web-based system as seen in Figure 4.29.

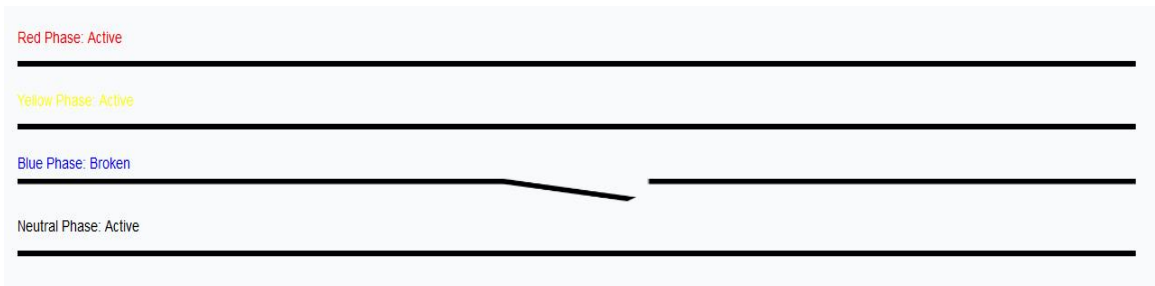


Figure 4.29: Three phase distribution line on web-based interface after restoration of broken yellow phase indicating blue phase opened or cut.

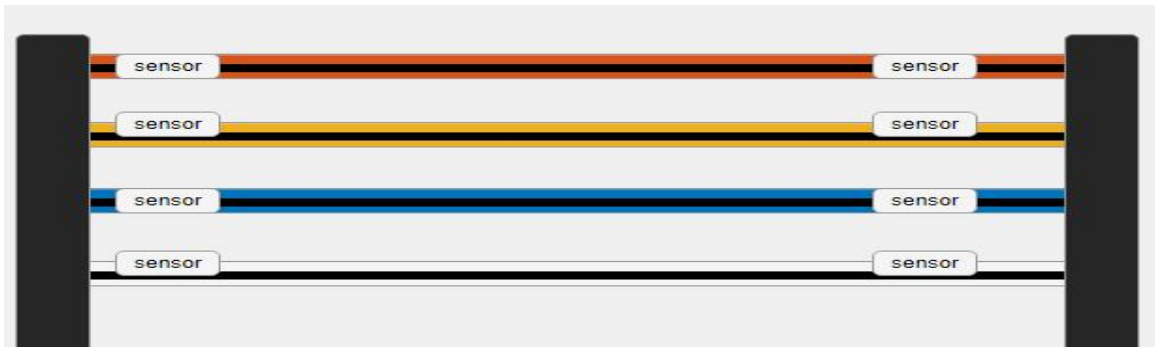


Figure 4.30: Three phase distribution line on MATLAB interface after restoration of opened (cut) blue phase indicating all lines active.

The three-phase distribution on the MATLAB interface is depicted in Figure 4.30's screenshot following the restoration of the blue phase, which was previously opened or cut. In contrast to Figure 4.28, where the blue phase was broken, it consists of sensors that detect faults and automatically communicate the problem and status to the web-based system.

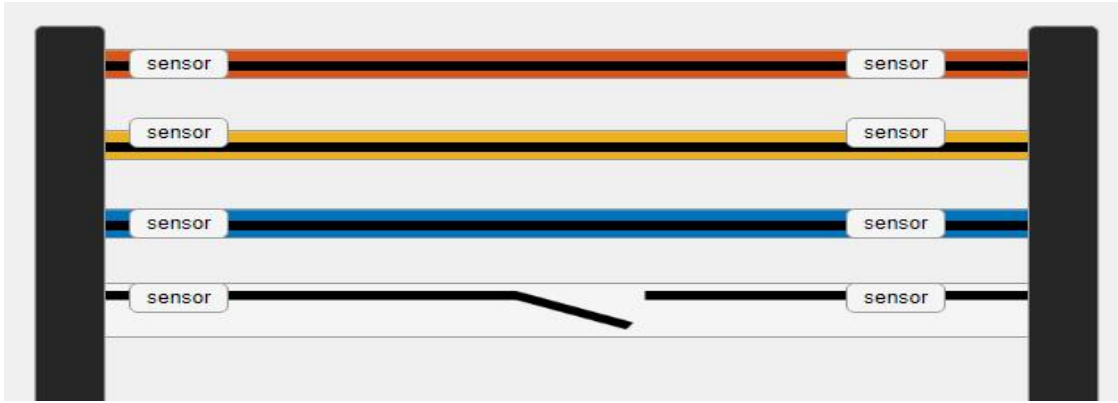


Figure 4.31: Three phase distribution line on MATLAB interface after restoration of broken blue phase indicating Neutral line opened or cut.

The three-phase distribution line on the MATLAB interface may be seen in Figure 4.31's screenshot after the restoration of the blue phase, which was previously broken or cut with the neutral line now broken or cut. In contrast to Figure 4.30, where all lines are active, it consists of sensors that automatically detect faults and transmit them to the web-based system as seen in Figure 4.32.

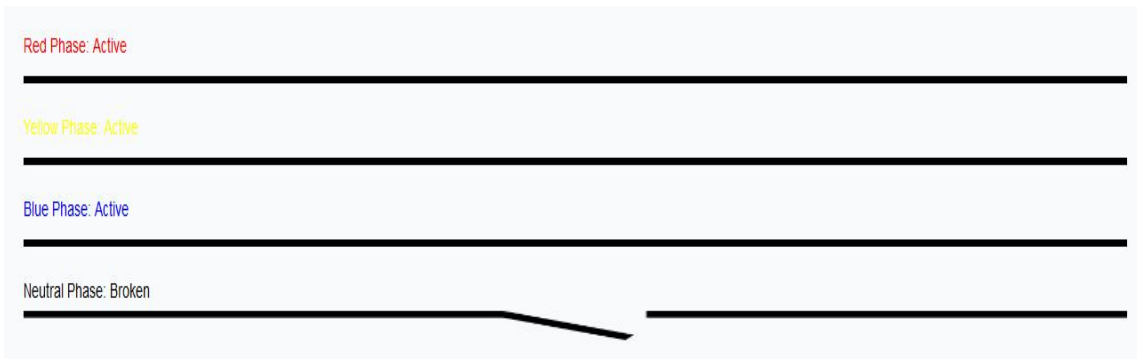


Figure 4.32: Three phase distribution line on web-based interface after restoration of broken yellow phase indicating Neutral line opened or cut

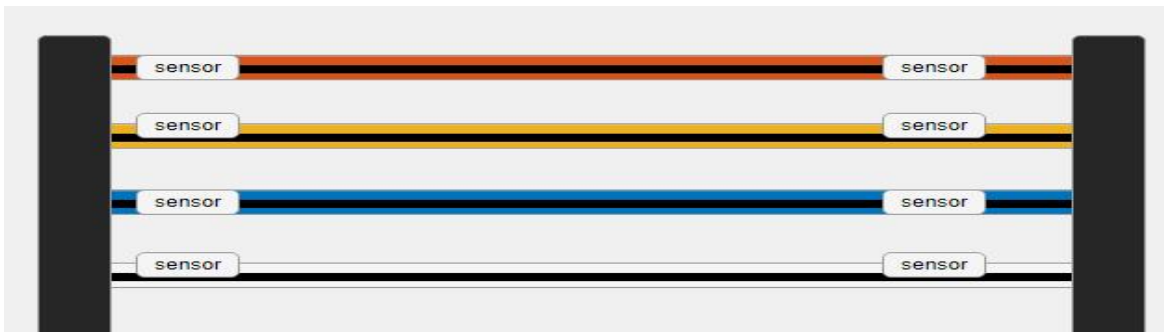


Figure 4.33: Three phase distribution line on MATLAB interface after restoration of broken neutral line indication all lines active.

The three-phase distribution line on the MATLAB interface is visible in Figure 4.33's screenshot after the neutral line, which had previously been cut or broken, has been restored. When compared to Figure 4.31, when the neutral line was broken or opened, it consists of sensors that automatically notify faults and system statuses to the web-based system.

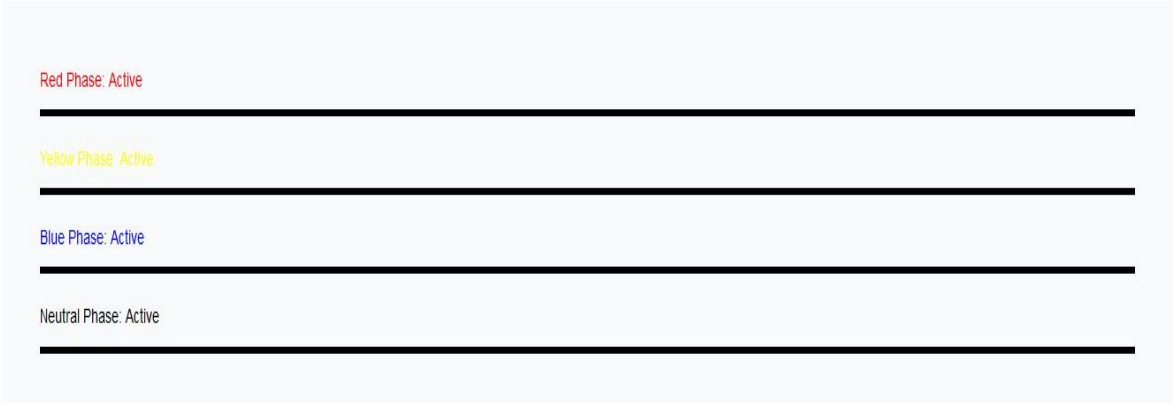


Figure 4.34: Three phase distribution line on the web-based interface after restoration of broken neutral line indicating all lines active.

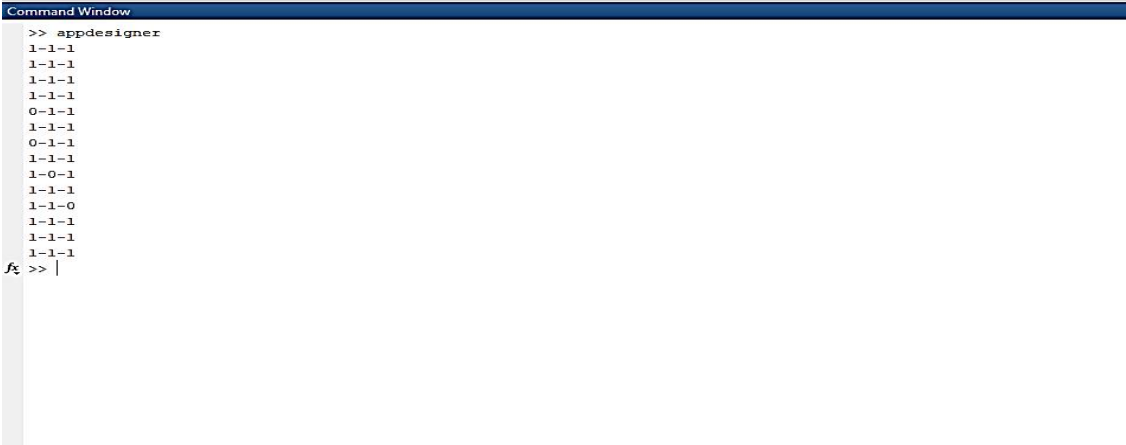


Figure 4.35: Three phase distribution line on MATLAB Command window interface after restoration of opened (cut) neutral line indicating all lines active.

After restoring all lines that were previously opened, the three-phase distribution line is visible on the MATLAB command window interface in Figure 4.35.

Screenshot showing results of Base Station and Mobile App

The homepage of the automated metering, power management, and monitoring system is shown in Figure 4.36. Following the homepage, there are pages for about us, all meters, Recharge (online and manual using 20-digit token), Voucher, Registering New Customers, Registering New Staff, Edit Meter Information and assign capacity to meters by Admin, and Registering New Customers. Phase status, current power consumption, Control Section

(Admin shutdown), load monitoring and Security page (Meter tampering). The screenshot results from the Mobile App for the three meters are depicted in Figures 4.54 through 4.61, indicating meter status, meter number, meter parameter such as available unit, energy and power consumption, voltage, current indication for which phase with available power on the distribution network. The load management section for users and utility company depicted in figures 4.62 through 4.71.



Figure 4.36: The homepage

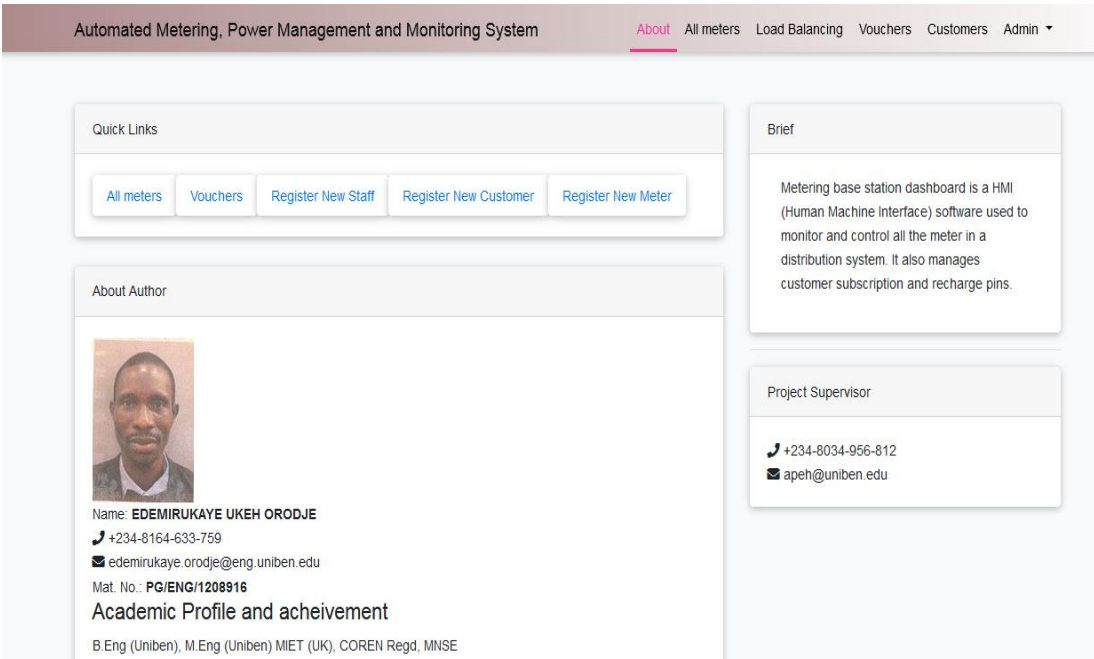


Figure 4.37: About Us

The Figure 4.37 depicts brief description the author, supervisor and the research topic via the menu that includes all meter, load balancing, vouchers, customers and administrative sections.

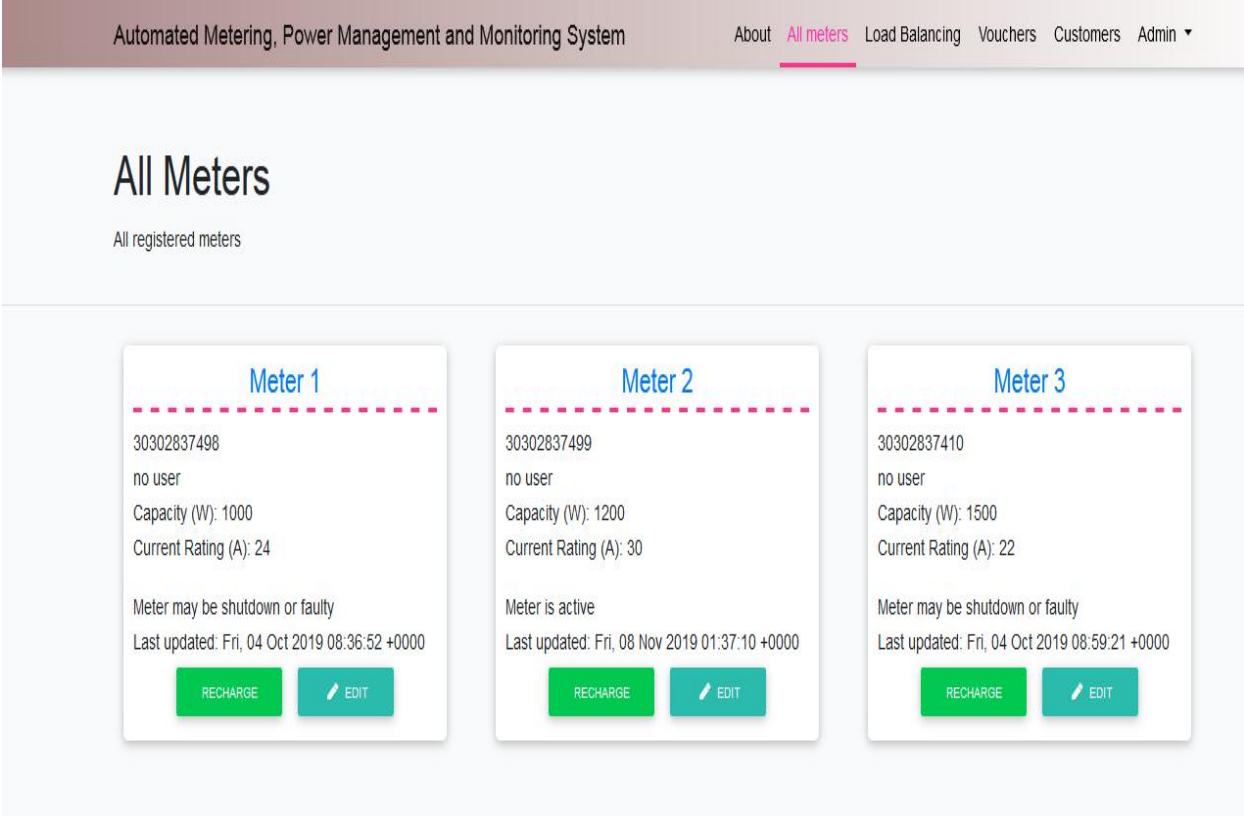


Figure 4.38: All meter page with meter two active

The Figure 4.38 depicts the all-meters page from wireless Automated metering based-station of the utility company showing the meter status and parameter like the load capacity when only meter two active while others are inactive and the menu that includes all meter, load balancing, vouchers, customers and administrative sections.

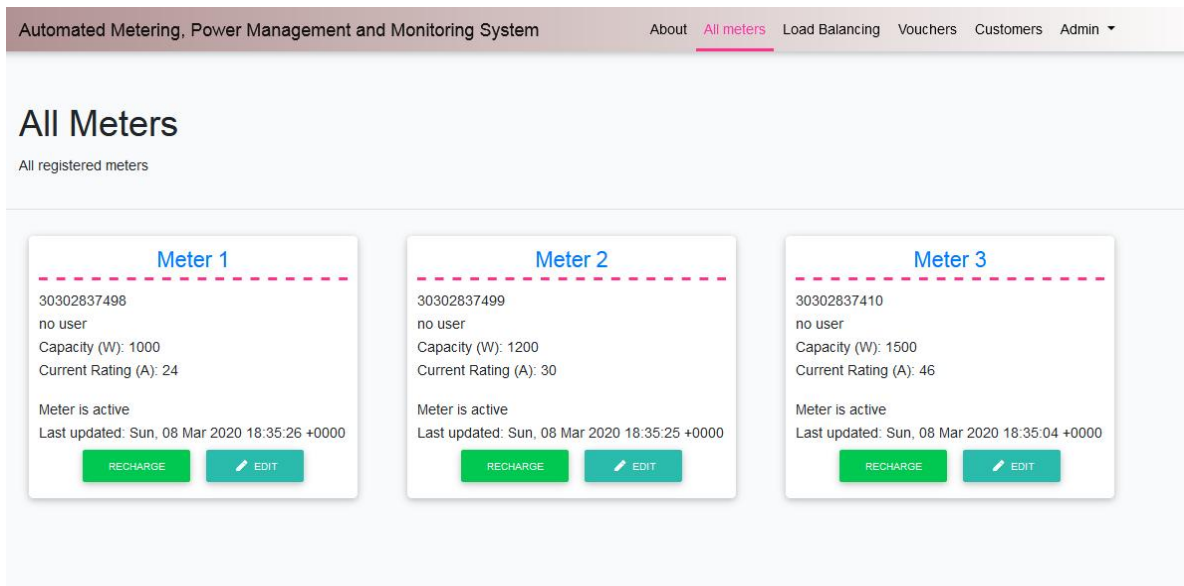


Figure 4.39: All meter Page when all meters are active

When all three meters are active, the figure depicts the all-meter page from the utility company's wireless Automated metering based-station, which shows the meter status and parameters such as load capacity, as well as the menu that includes all meter, load balancing, vouchers, customers, and administrative sections.

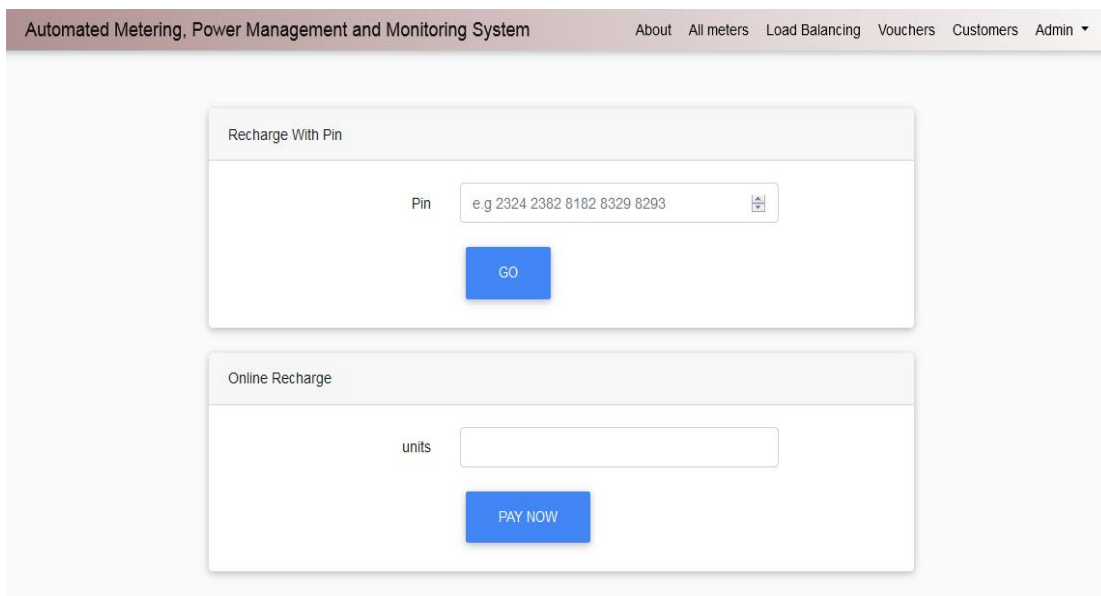


Figure 4.40: Recharge page

The Figure 4.40 depicts the utility company's both manual and automatic Recharge page with 20 digits as token pin for users, the menu that consists about Us, all meter, vouchers, customers and other administrative parts.

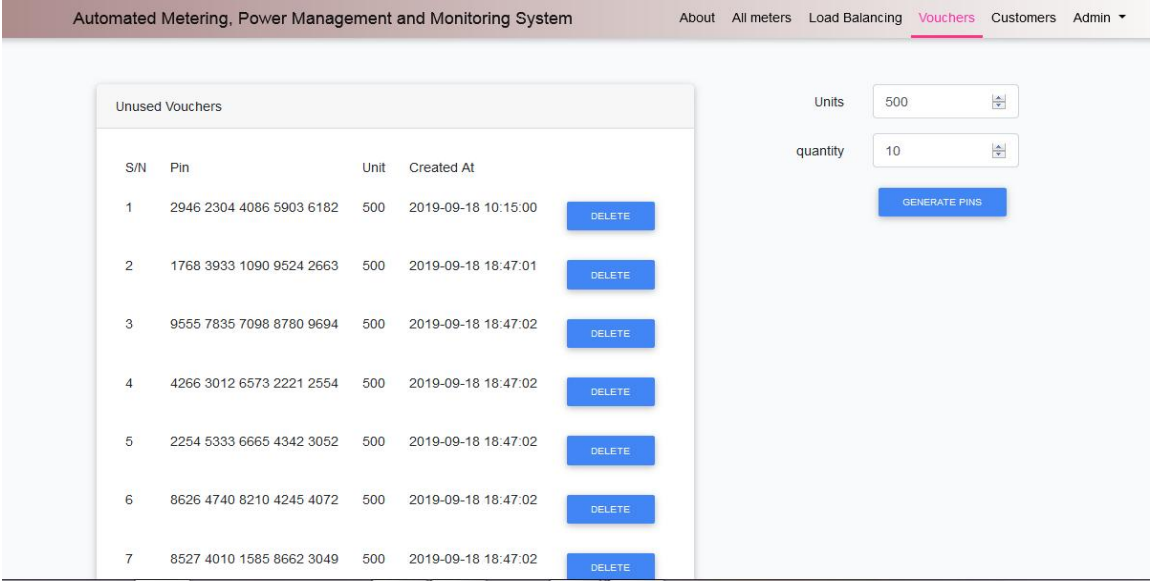


Figure 4.41: vouchers Page

The Figure 4.41 presents the utility company's automatic Vouchers page, which includes the unit and 20 digits as a token pin for users, as well as a menu that includes information about the firm, all meters, consumers, and other administrative sections.

Automated Metering, Power Management and Monitoring System About All meters Load Balancing Vouchers Customers Admin ▾

Register New Customer

Name

E-Mail Address

Address

Phone Number

Meter Number

Password

Confirm Password

Figure 4.42: Registering New Customers page

In addition to a menu with information about the firm, all meters, and other administrative components, the image depicts the utility company's website for new customers, which includes the customer's name, email address, residential address, phone number, and meter number.

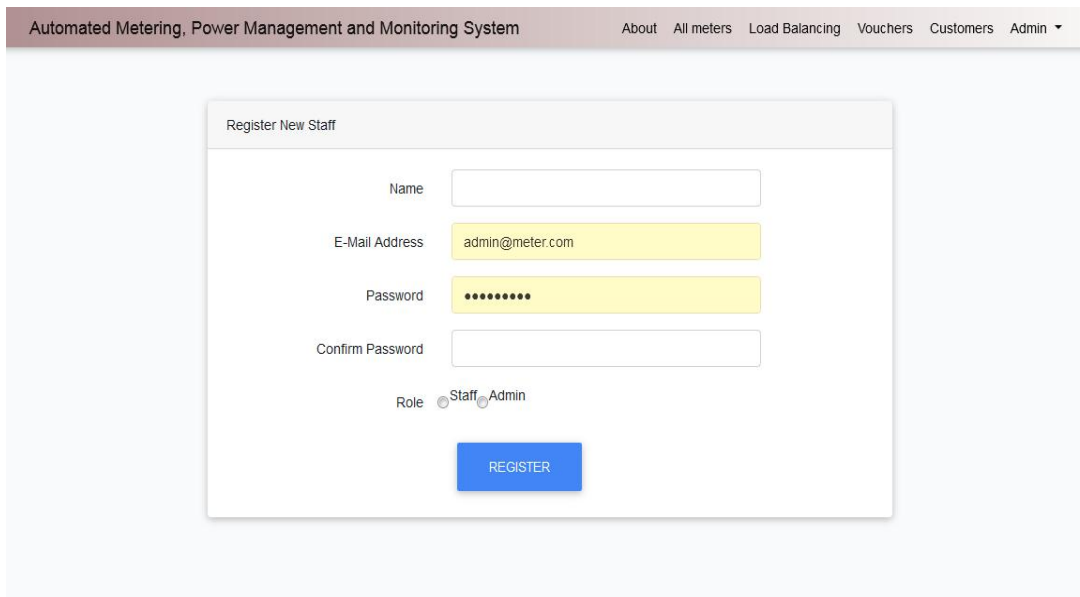


Figure 4.43: Registering New Staff page

The Figure 4.43 shows the utility company business's new staff registration page, which includes a menu with information about the firm, all meters, and other administrative sections, as well as the staff name, email address, password, and role.

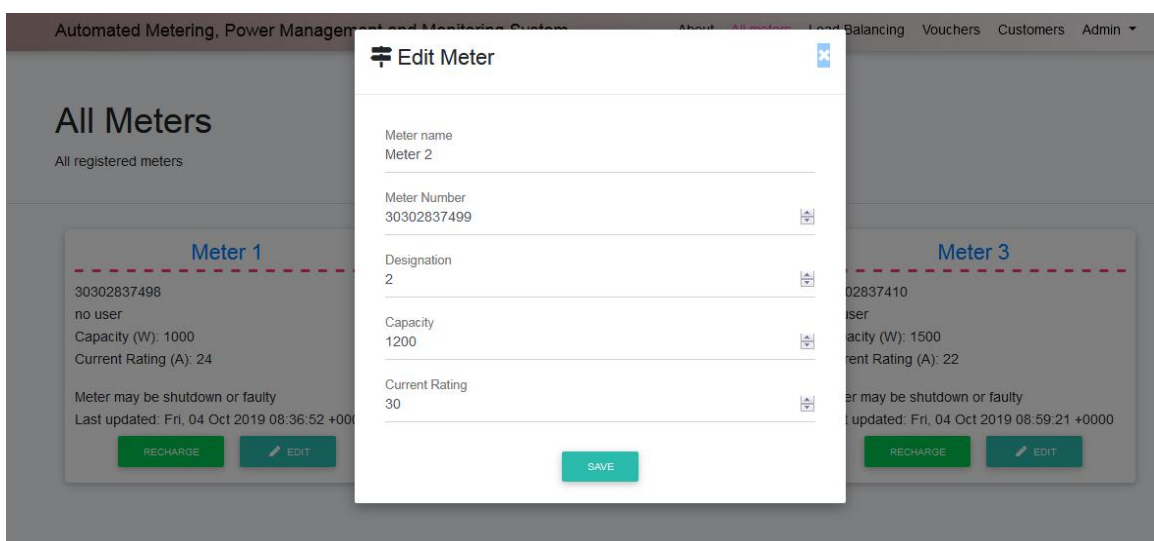


Figure 4.44: Assigning capacity to meter two on Edit meter page by Admin

The Figure 4.44 depicts the utility company's Edit meter information page by Admin via assigning current and power capacity to meter two for power management, safety, accurate, and efficient measurement of consumption and reducing energy costs for consumers.

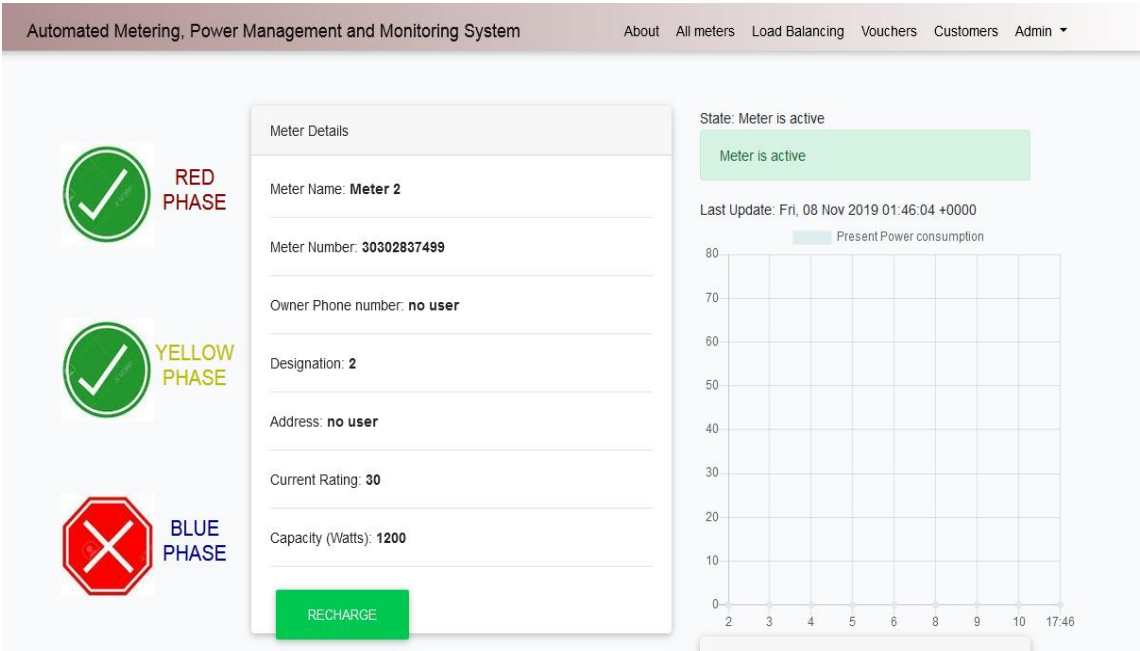


Figure 4.45: Phase status page when blue phase opened (cut)

The Figure 4.45 shows the utility company's power monitoring page when the blue phase is down and others are active of the web-based system for automated fault detection and reporting of the three-phase power distribution system, which includes Red phase, Yellow phase, and Blue Phase, as well as a menu with company information, all meters, vouchers, customers, and administrative sections.

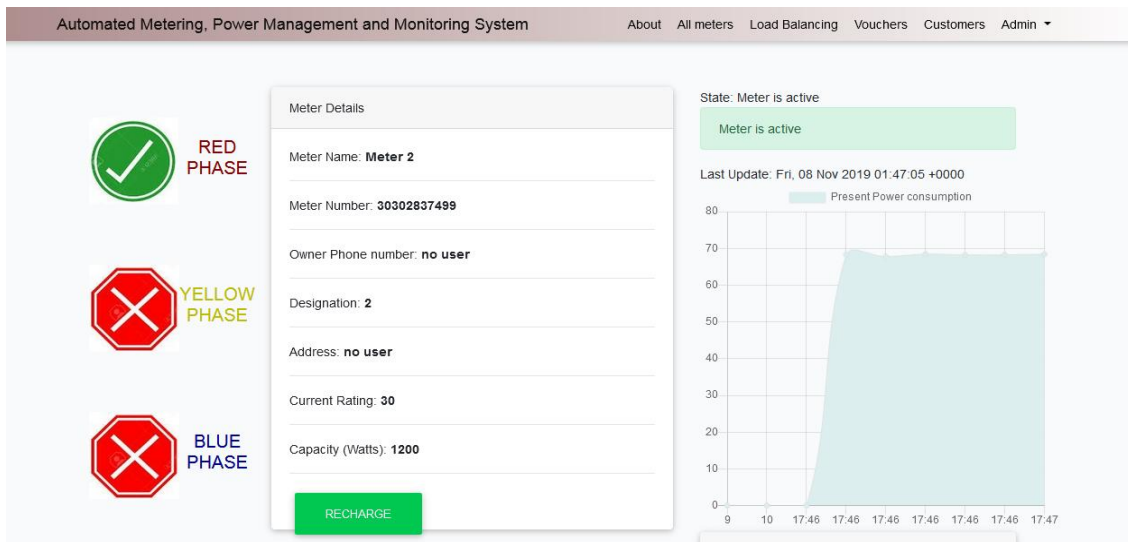


Figure 4.46: Phase status page when yellow and blue phase are opened (cut)

When the yellow and blue phases of the web-based system for automated fault detection and reporting of the three-phase power distribution system, which includes Red phase, Yellow phase, and Blue Phase, are down and only red is active, the Figure 4.46 depicts the utility company's power monitoring page, which includes a menu with company information, all meters, vouchers, customers, and administrative sections.

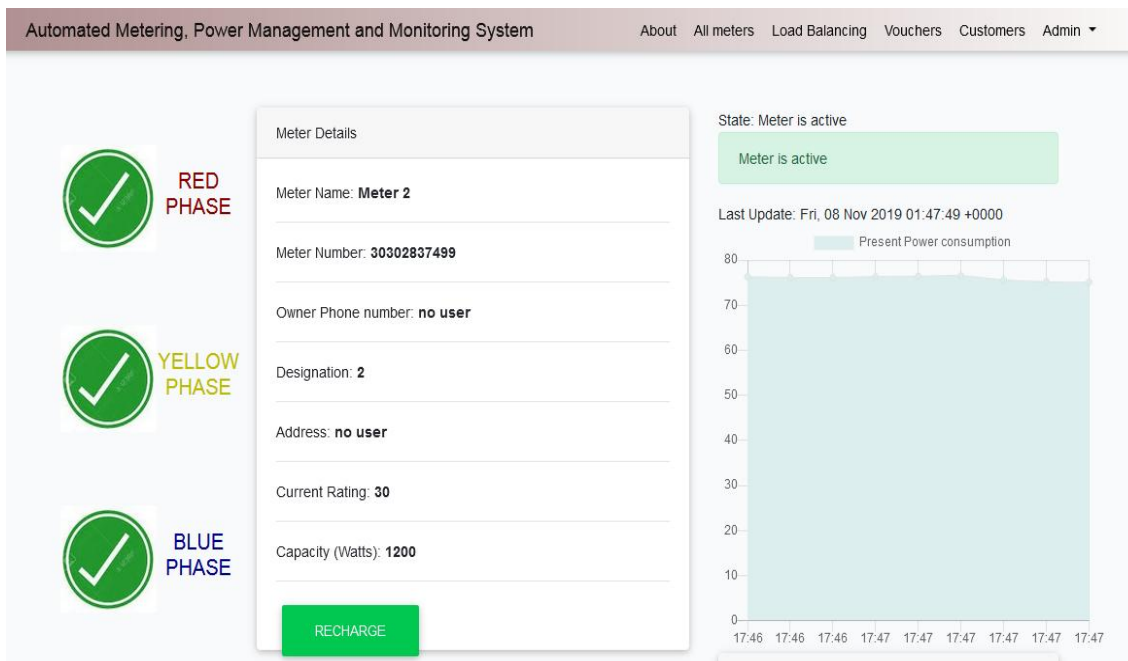


Figure 4.47: Phase status page after restoration of opened phases

The Figure 4.47 depicts the utility company's power monitoring page of a web-based system for automated fault detection and reporting of the three-phase power distribution system, which includes Red phase, Yellow phase, and Blue phase, as well as a menu with company

information, all meters, vouchers, customers, and administrative sections, after the fault has been fixed and the system has been restored.

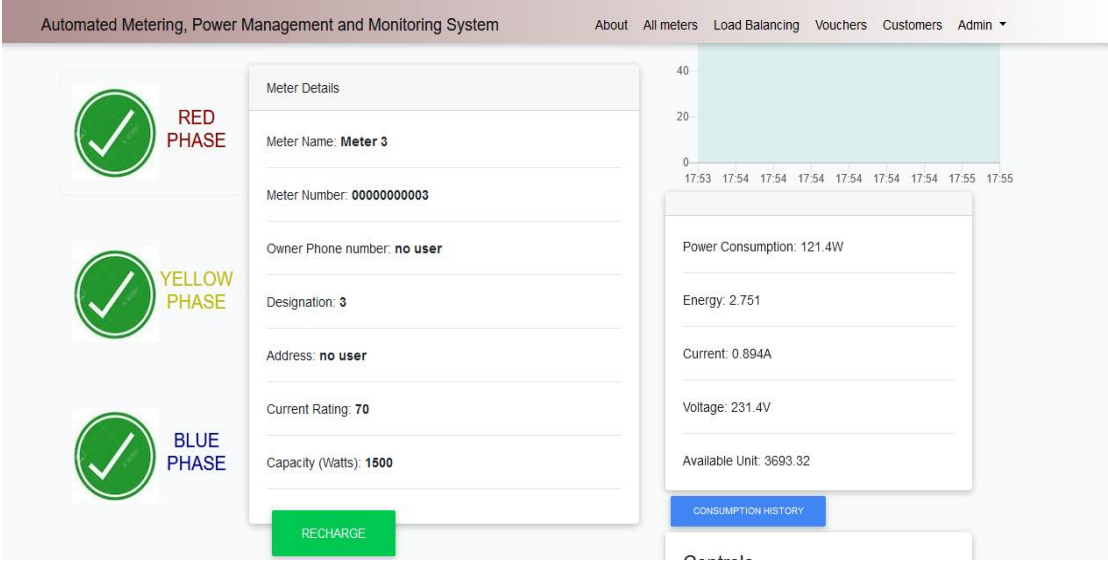


Figure 4.48: Monitoring power consumption and metering parameter

Figure 4.48 illustrates the power monitoring page of the web-based system utilized by the utility company. This page is designed to oversee consumer power consumption and metering parameters under normal operating conditions, following the resolution of any faults and the restoration of the system. The page encompasses the automated fault detection and reporting functionality for the three-phase power distribution system, which includes the Red phase, Yellow phase, and Blue phase. Additionally, the page features a menu that provides access to essential company information, comprehensive meter data, voucher management, customer profiles, and other relevant information.

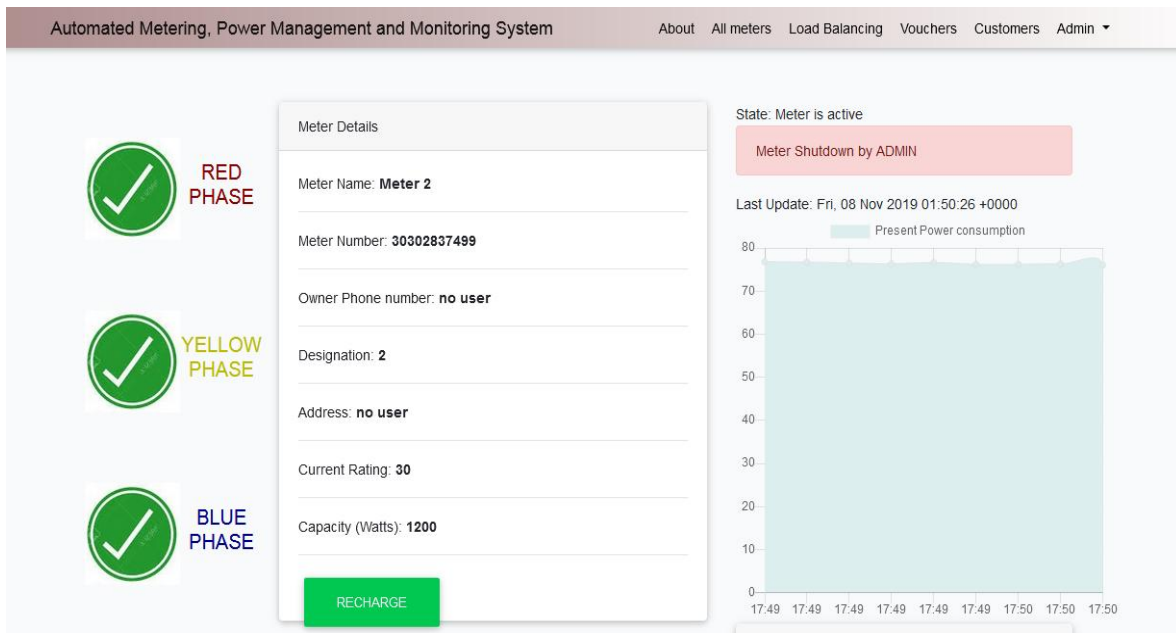


Figure 4.49: Control page displaying meter shut down by Admin

The Figure 4.49 depicts the control of the utility company's power monitoring page, which includes a menu with company information, all meters, vouchers, customers, and other information, as well as a shutdown by Admin of the web-based system due to abnormal conditions on the part of the consumers as a result of overload.

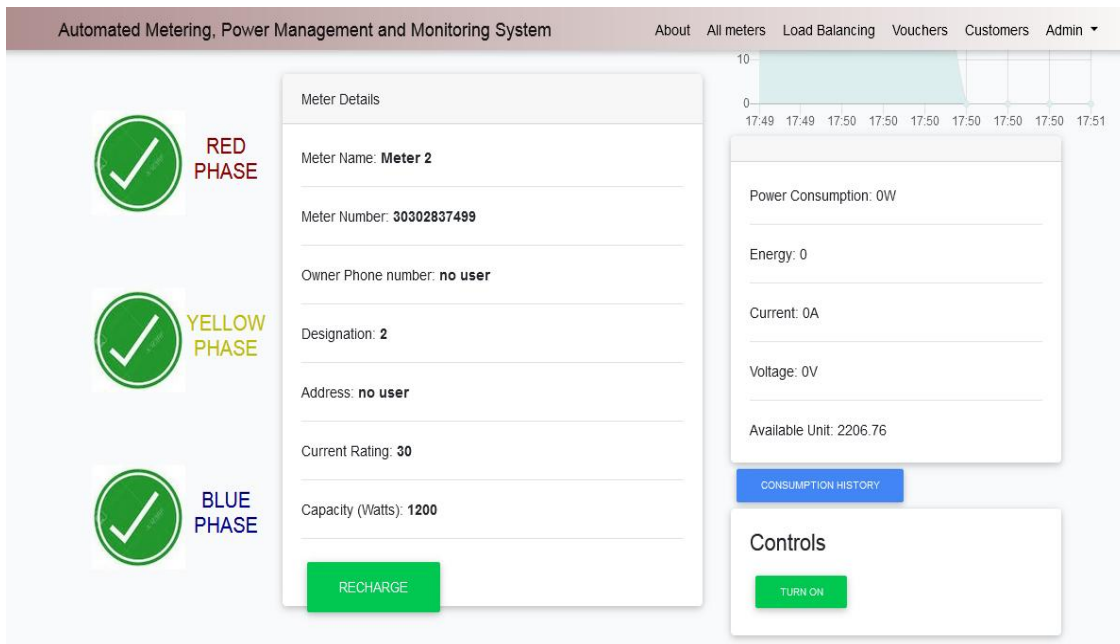


Figure 4.50: Control page displaying meter parameter during shut down by Admin

The Control page, which includes a menu with company information, all meters, vouchers, customers, and other information, illustrates the meter parameter during shut down by Admin of the utility company's power monitoring as a result of overload by consumer.

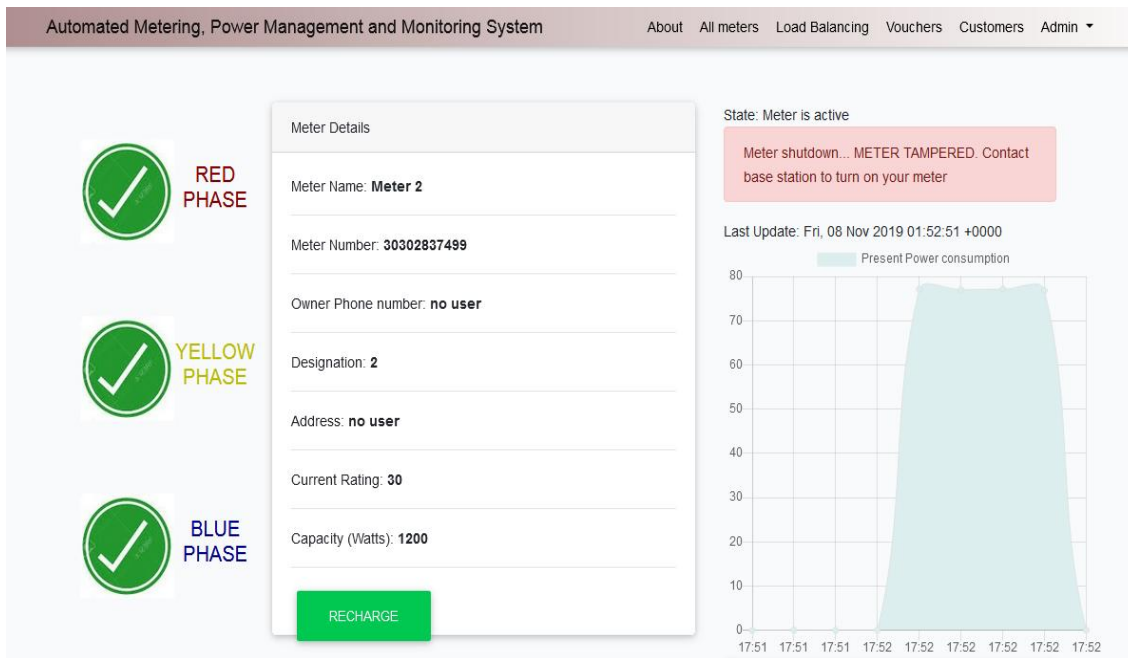


Figure 4.51: Security page displaying meter tampering contact base station

The Figure 4.51 depicts the control and security of the utility company's power monitoring page, as well as a menu with corporate information, all meters, vouchers, customers, and other information, when the meter is being tampered as a result shutdown by the admin of the web-based system.

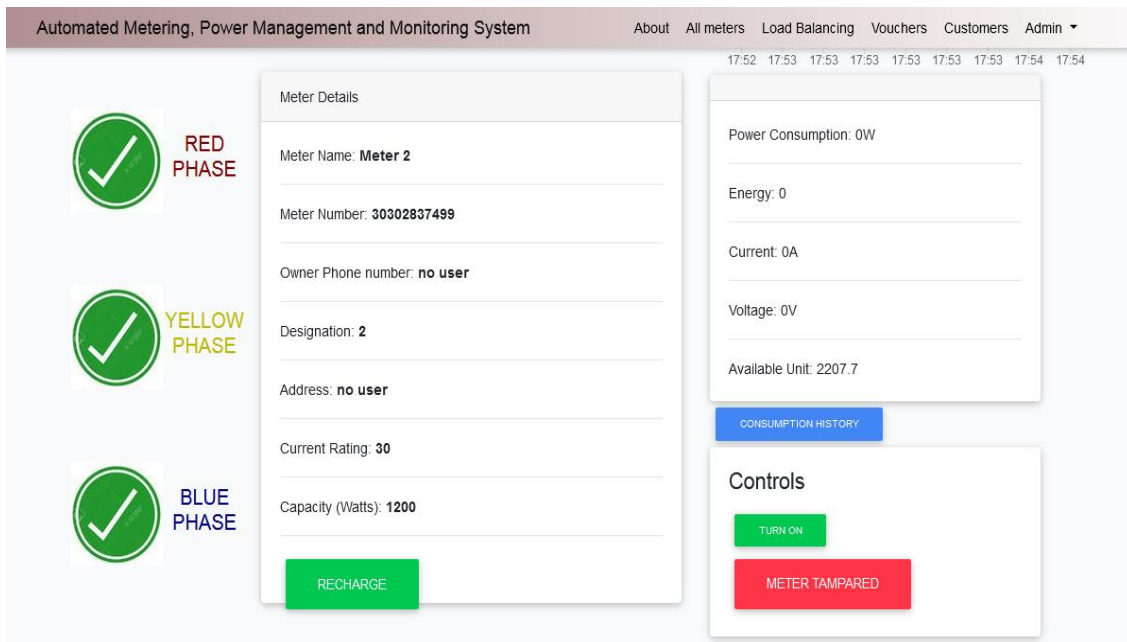


Figure 4.52: Security page displaying meter tampering

After a consumer tampered with the utility company's power meter, on the web-based website under abnormal conditions, the figure illustrates the meter parameter during Admin shut down.

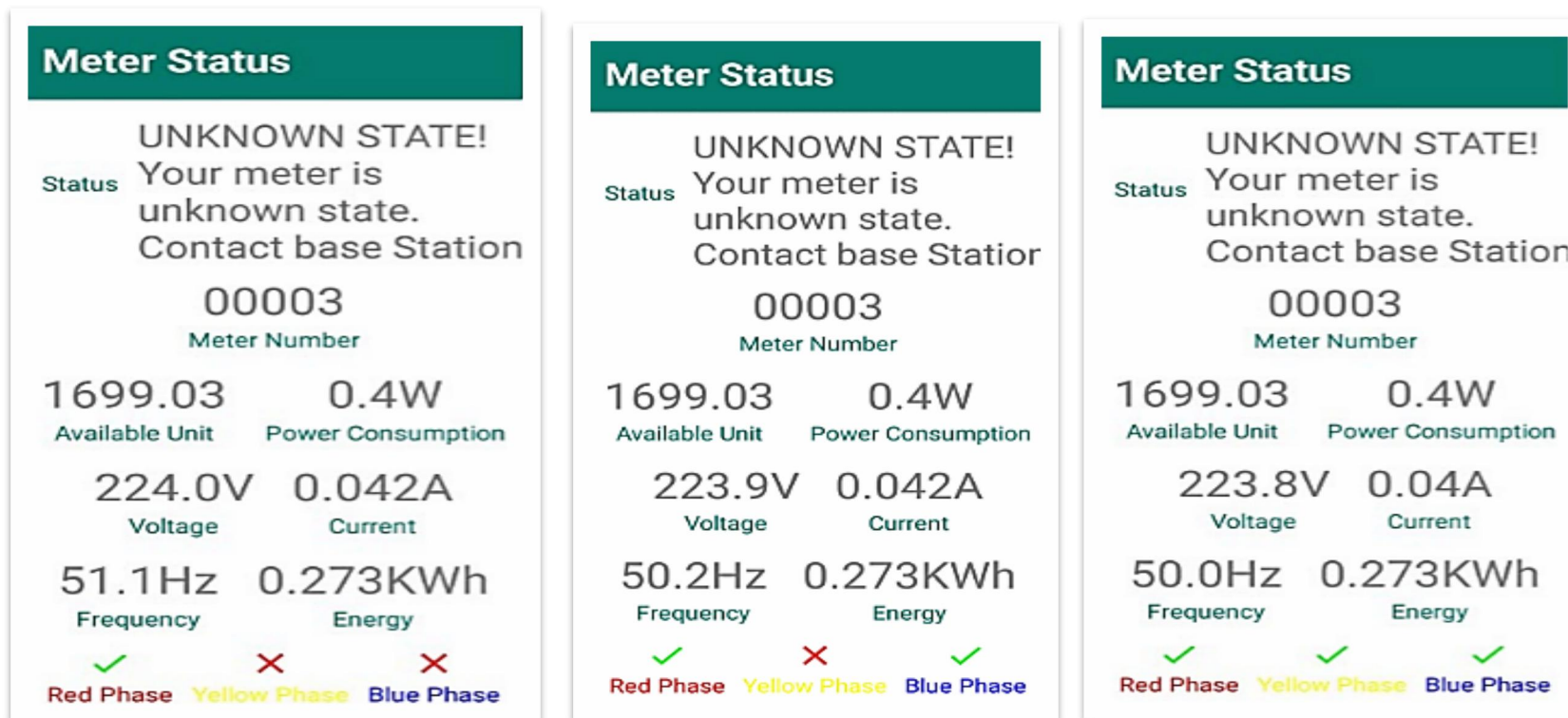


Figure 4.53: Information of meter three on the Mobile App

Figure 4.53 demonstrates the efficient monitoring of open-circuit faults on the three-phase power distribution system by the mobile app. Moreover, it offers essential meter parameters for consumers, similar to those in the case of meter three. The figure shows the status of the system when two phases (yellow and blue) were opened, followed by the yellow phase being opened due to a fault. However, after the fault was fixed, all phases were restored. This same scenario applies to meters one and two as well.

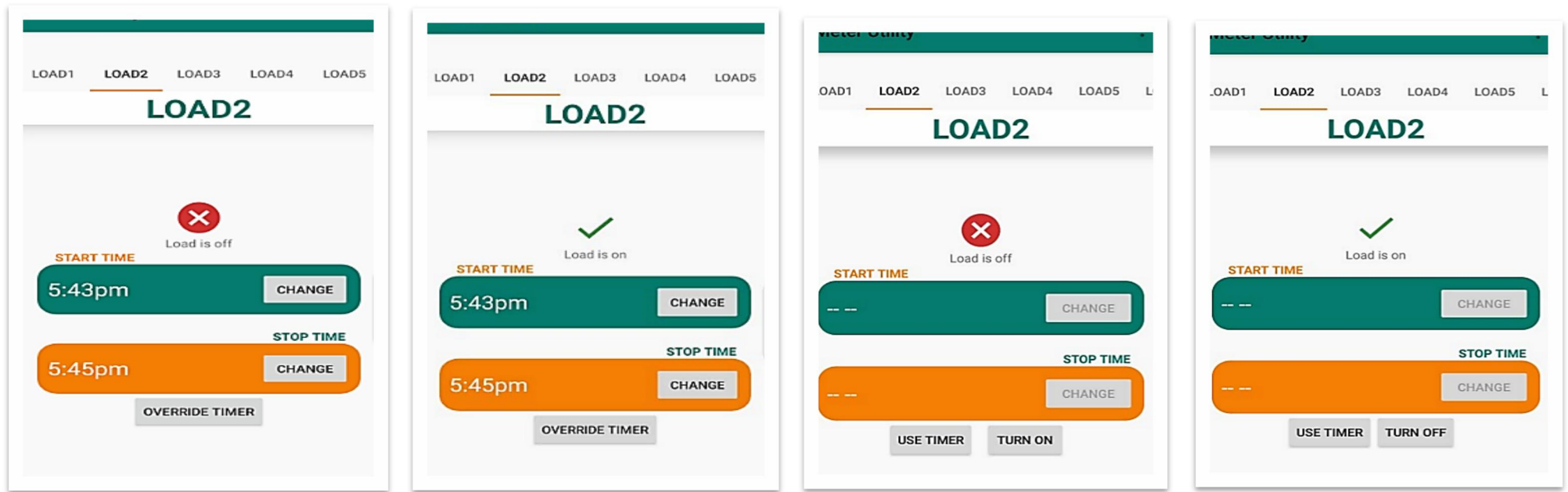


Figure 4.54: Mobile App's load management interface for load two, covering both the timer and override timer sections.

Figure 4.54 illustrates the load management feature of the Meter Utility Mobile Software App. It displays the timer and override timer sections for load two when it was turned off. By utilizing the timer feature, users can schedule load two to activate at 5:45 p.m., having been clocked at 5:43 p.m. On the other hand, the override timer function enables load two to be switched on alongside all other consumer appliances and loads, irrespective of their programmed activation times. This convenient software empowers customers to automatically control their loads, promoting efficiency, reducing waste, and leading to cost savings. The Mobile App's capacity to handle up to one thousand and twenty-four (1024) loads ensures adaptability to increasing residential demands. The same principles apply to load one, three, four, five, and six within the Mobile App.

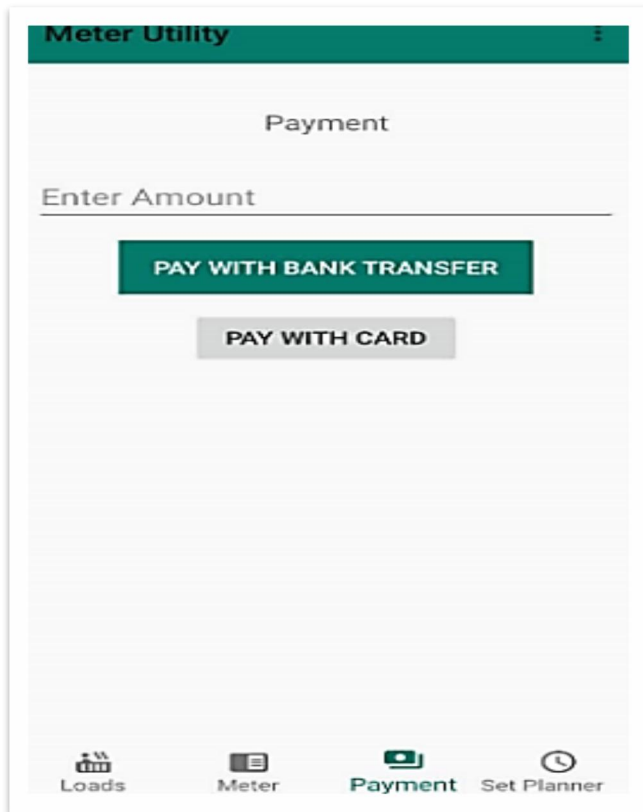


Figure 4.55: The payment page on the Mobile App

Figure 4.55 depicts the payment feature of the mobile app for electricity consumption, allowing consumers to conveniently and effortlessly pay for their electricity usage without the need to visit a physical payment outlet. This streamlined process ensures a faster, easier, and more convenient payment experience for customers, especially when it's seamlessly integrated with banks after registration.

Summary of Results of Data analysis and Evaluation

This section presents the data analysis results of 12 different loads observed for analysis and the evaluation results obtained during the experimentation of the selected loads.

In the analysis of Automated and BEDC metering systems, it is necessary to ascertain the values of the two coefficients, the intercept a_0 and the constant b_1 for the energy. To ascertain the total energy consumed by each load, it is necessary to test for the dependent variable x (Power) and independent y (Energy) variables' significance. From the Excel output, 12 data set were used for the regression analysis. The output result at 95% confidence level of the data analysis stated in Table 4.1.

Table 4.1: The Excel output of the Data analysis for Automated metering system

Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$a_0 =$ 0.112941621	0.0691732	1.63273666 7	0.133574052	-0.041185875	0.2670 691	-0.04119	0.267069
$b_1 =$ 0.001134318	0.000272947	4.15582200 1	0.001961741	0.000526155	0.0017 425	0.000526	0.001742

From table 4.1,

The intercept $a_0 = 0.112941621$

The x-variable $b_1 = 0.001134318$

The T-stat = $\frac{Coefficient}{Std Error} = 4.156$

With the T-Stat of 4.156, (P=.002), since the P-value is much less than 5% which is only .2%, it is accepted. This indicates the acceptance of the Alternate hypothesis (HA) and rejection of the null hypothesis (Ho).

From the Excel output, the P-value of .002<0.050 is .2% < 5%, which means variables X and Y can be considered statistically significant.

Table 4.2: The Excel output of the Data analysis for BEDC metering system

Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$a_0 =$ 0.186490779	0.077805899	2.396871985	0.037515609	0.013128433	0.359853124	0.013128433	0.359853124
$b_1 =$ 0.001285274	0.000275636	4.662945332	0.000890313	0.000671119	0.001899428	0.000671119	0.001899428

Table 4.3: The Excel output of the Monthly Data analysis for Automated metering system

Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$a_0 = 3.649848$	2.207488	1.653394	0.129256	-1.26874	8.568438	-1.26874	8.568438
$b_1 = 0.001132$	0.000272	4.159112	0.001951	0.000526	0.001739	0.000526	0.001739

The T-stat = 4.161

Table 4.4: The Excel output of the yearly Data analysis for Automated metering system

Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$a_0 = -41.8592$	25.31713	1.653394	0.129256	-14.5509	98.26929	-14.5509	98.26929
$b_1 = 0.001132$	0.000272	4.159111	0.001951	0.000526	0.001739	0.000526	0.001739

The T-stat = 4.161

With the T-Stat of 4.161, ($P = .002$), since the P-value is much less than 5% which is only .2%. it is accepted,

From the Excel output, the P-value of $0.0019 < 0.050$ that is $0.19\% < 5\%$ means X and Y can be considered statistically significant. This same consideration applies to BEDC metering system as well

Table 4.5: The Excel output of the Monthly Data analysis for BEDC metering system

Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$a_0 = 6.658298$	3.010917	2.211385	0.05144	-0.05044	13.36704	-0.05044	13.36704
$b_1 = 0.001306$	0.000323	4.040453	0.00236	0.000586	0.002026	0.000586	0.002026

The T-stat = 2.211

Table 4.6: The Excel output of the Yearly Data analysis for BEDC metering system

Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
$a_0 = 81.38355$	36.54378	2.227015	0.052954	-1.28422	164.0513	-1.28422	164.0513
$b_1 = 0.001285$	0.000336	3.827629	0.004042	0.000525	0.002044	0.000525	0.002044

The T-stat = 2.227

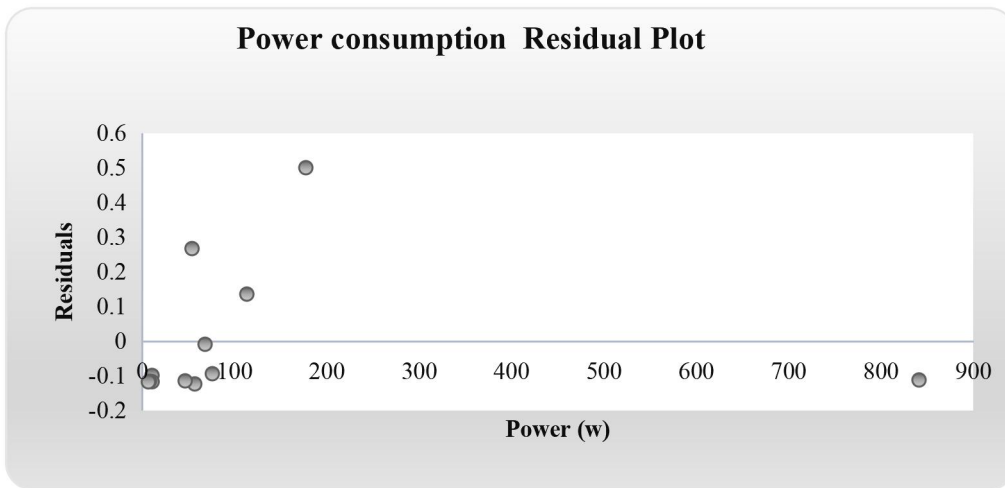


Figure 4.56 Plot of daily residual power consumption of BEDC metering system

Figure 4.56 shows the difference between the actual power consumption of BEDC metering system and the predicted power consumption. This shows there is not much significant variation between the actual and predicted daily power consumption.

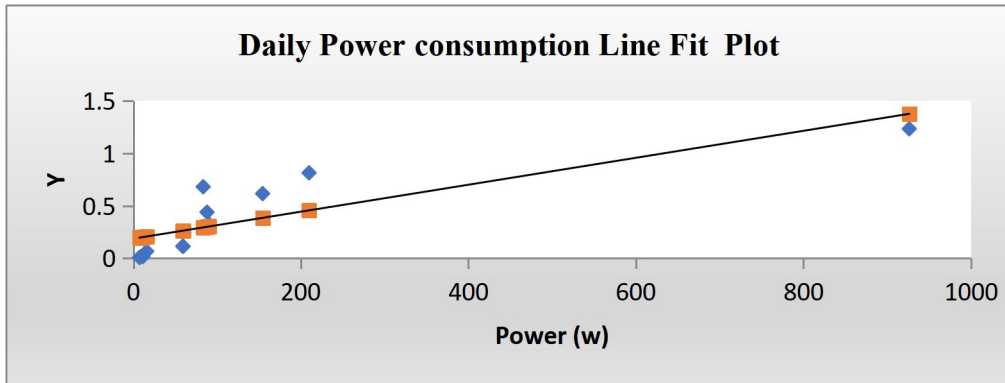


Figure 4.57 The fit Plot of daily power consumption of BEDC meter

Figure 4.57 shows the trend in power consumption in a day. It shows the power consumption progress linearly with the loads.

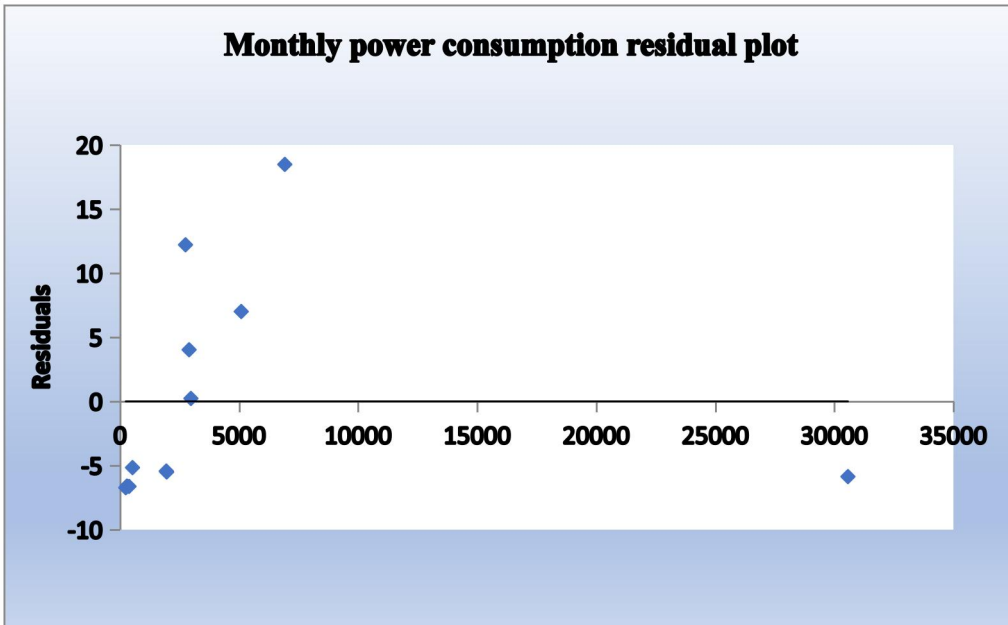


Figure 4.58 Plot of Monthly residual power consumption of BEDC metering system

The discrepancy between the BEDC metering system's actual and expected power consumptions is depicted in Figure 4.58. This demonstrates that the real and anticipated monthly power consumption do not differ noticeably.

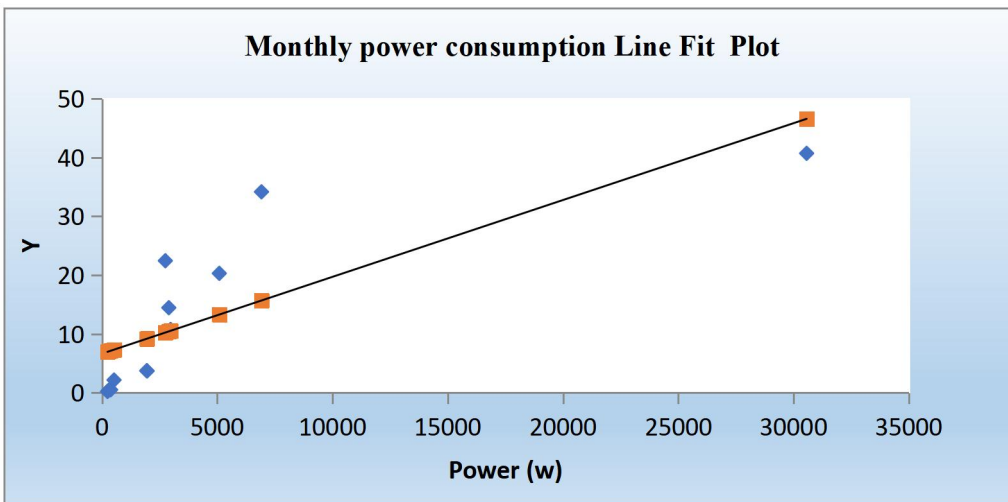


Figure 4.59 The fit Plot of Monthly power consumption of BEDC meter

The monthly trend in power use is depicted in Figure 4.59. It demonstrates how power usage increases linearly as loads increase.

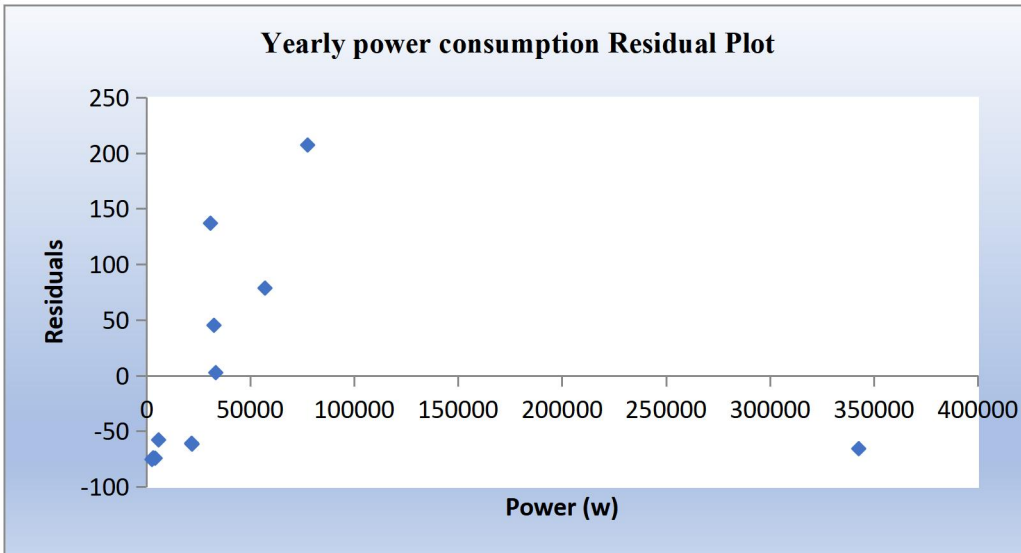


Figure 4.60 Yearly Plot of residual versus power consumption of BEDC metering system

The discrepancy between the BEDC metering system's actual and expected power consumptions is depicted in Figure 4.60. This demonstrates that the difference between the expected and actual annual power consumption is not particularly substantial. demonstrates that the difference between the expected and actual annual power consumption is not particularly substantial.

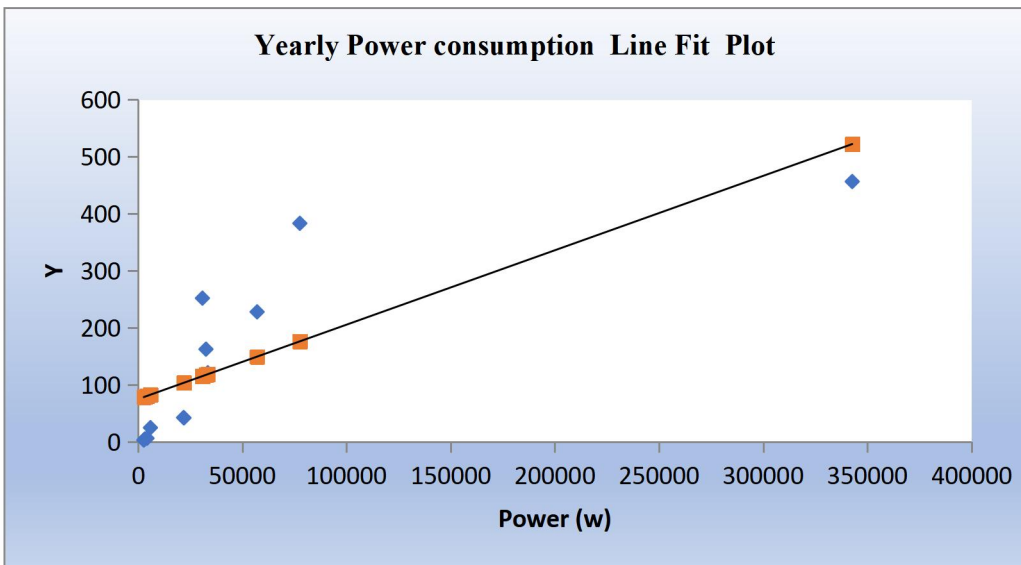


Figure 4.61 The fit Plot of yearly power consumption of BEDC meter

The annual trend in power usage is depicted in Figure 4.61. It demonstrates how power usage progresses linearly as loads increase.

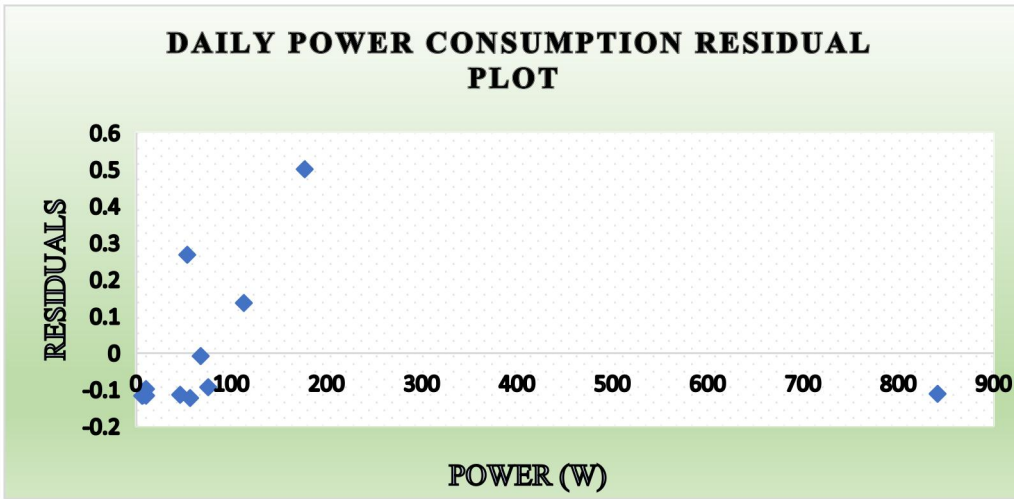


Figure 4.62 Daily Plot of residual power consumption of Automated metering system

The discrepancy between the Automated Metering System's actual and expected power usage is depicted in Figure 4.62. This demonstrates that there is not much difference between the daily power consumption that is projected and what actually occurs.

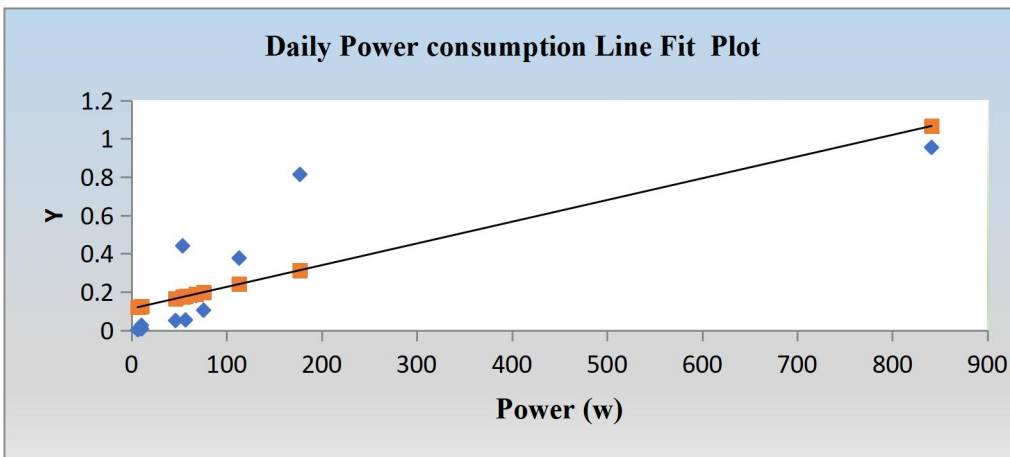


Figure 4.63: The fit Plot of power consumption of Automated metering system

The automated metering system's daily power consumption pattern is depicted in Figure 4.63. It demonstrates how power usage increases closely linearly as loads increase compares to BEDC metering system.

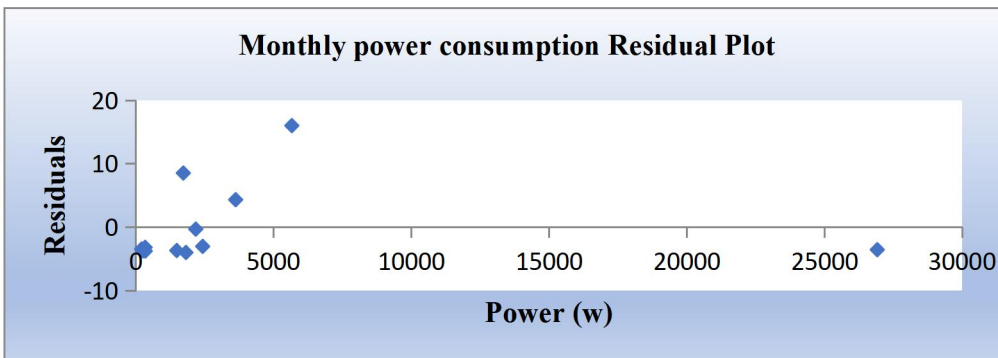


Figure 4.64: Plot of Monthly residual power consumption of Automated metering system

Figure 4.64 shows the difference between the Automated metering system's actual and anticipated power consumptions. This shows that there is no discernible difference between the actual and projected monthly power use.

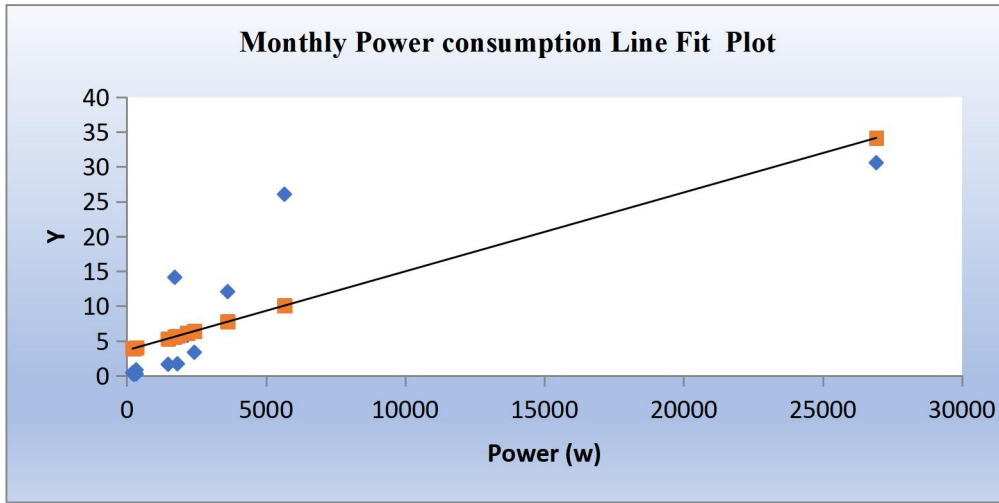


Figure 4.65: The Monthly fit Plot of power consumption of Automated metering system

The automated metering system's power usage pattern over the course of a month is depicted in Figure 4.65. It demonstrates how power usage increases linearly as loads increase.

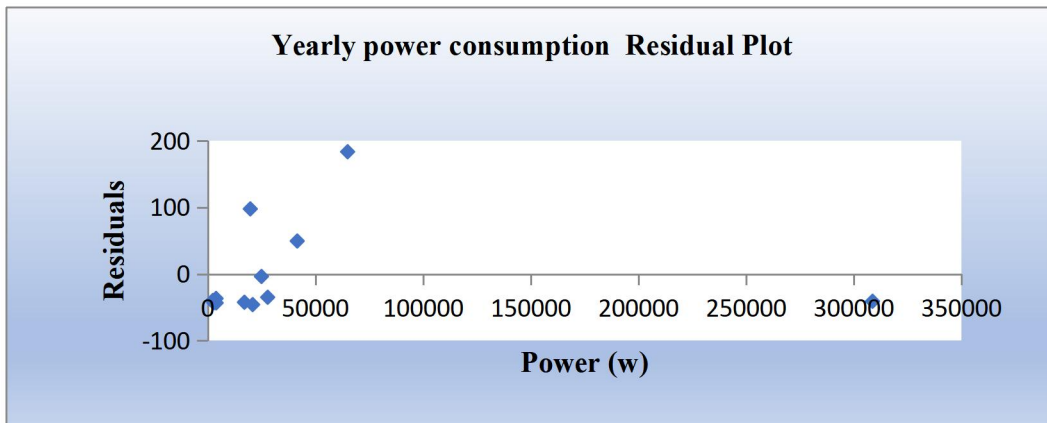


Figure 4.66: Plot of yearly residual versus power consumption of Automated metering system

The discrepancy between the Automated Metering System's actual and expected power usage is depicted in Figure 4.66. This demonstrates that there isn't much of a difference between annual expected and actual power use.

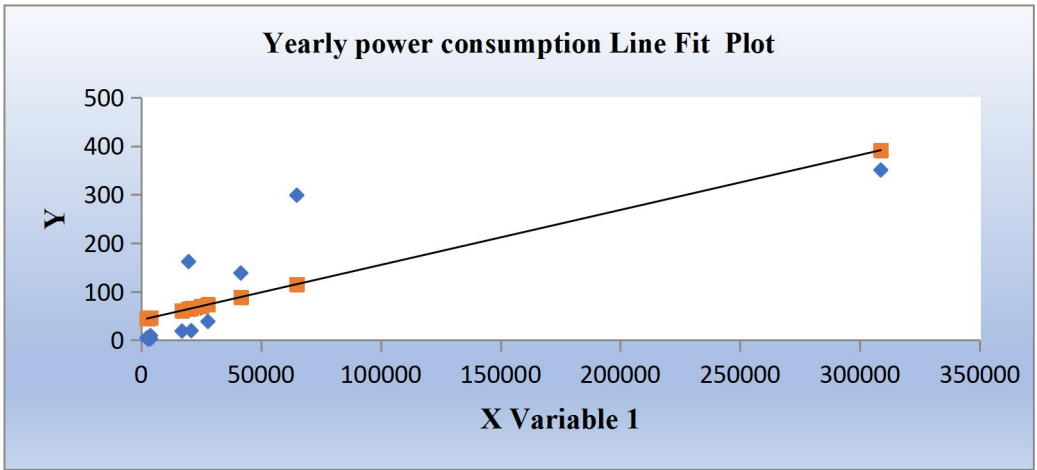


Figure 4.67: Plot of yearly power consumption line fit of Automated metering system.

In Figure 4.67, it depicts how, when compared to BEDC metering system, power usage of automated metering system grows closely linearly as loads increase over the course of a year.

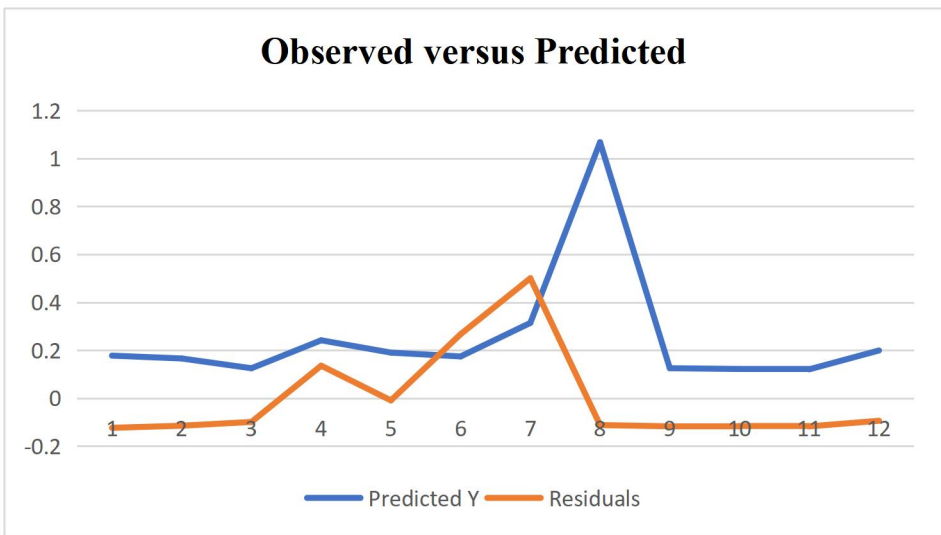


Figure 4.68 Plot of observed against Predicted values of Automated metering system

The predicted plot displays the results of the experiment with an automated metering system, whereas the observed plot displays the actual data points received from the twelve loads. Since the points are near the fitted line and have a small confidence interval, which indicates a close relationship, this demonstrates that the observed and predicted are well-fit. This is seen in Figure 4.68.

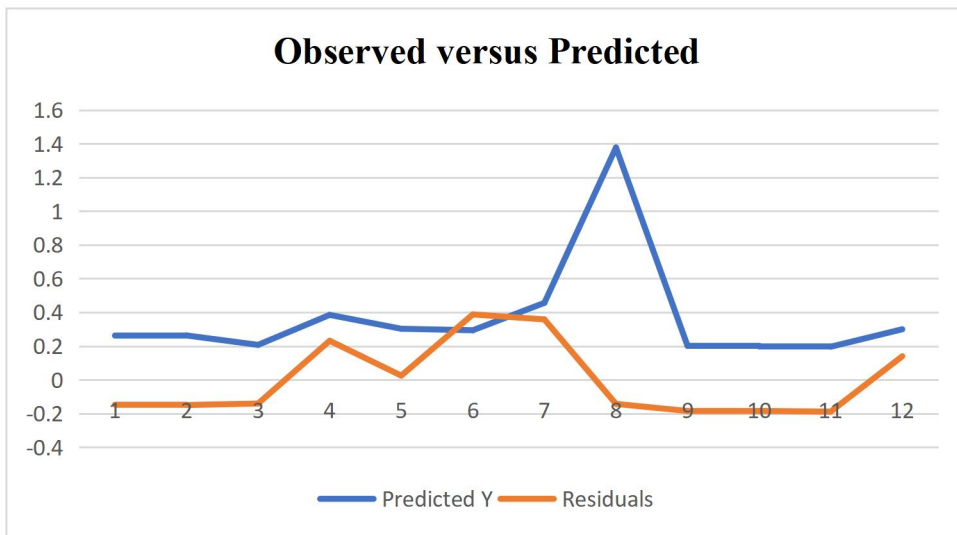


Figure 4.69: Plot of Observed against Predicted values of BEDC metering system

Figures 4.68 and 4.69 for both Automated metering system and BEDC metering system show a plot of the predicted values using the linear regression data against the 12 observed loads from the experimental. These figures demonstrate the close fit between the value predicted using the data and the observed loads from the experiment.

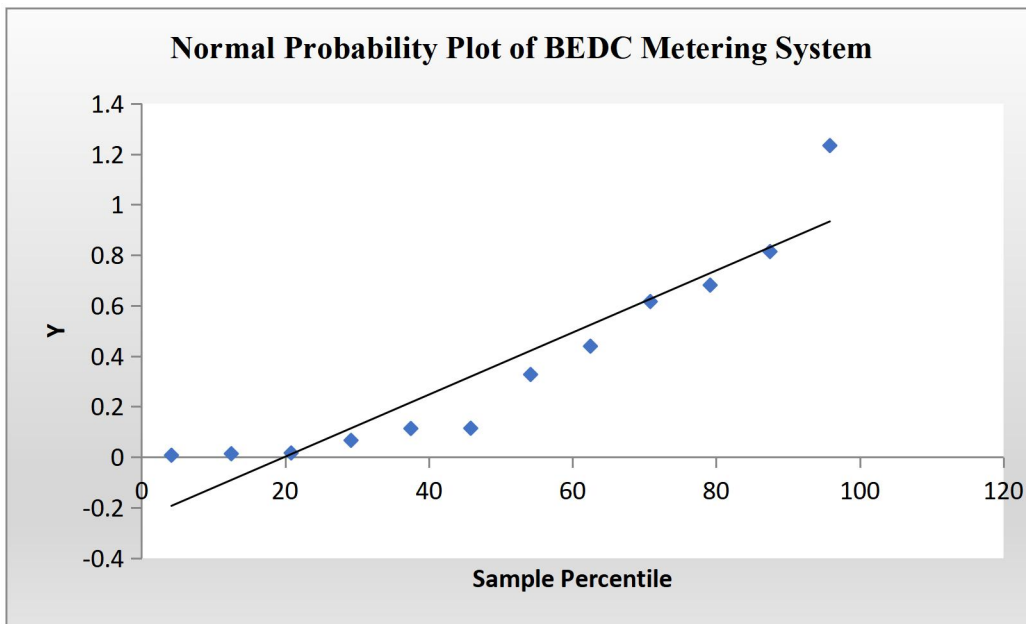


Figure 4.70: A Normal probability plot of BEDC metering system

The results in Figures 4.70 shows that the 12 data observed from which the samples were drawn were normally distributed for BEDC metering system.

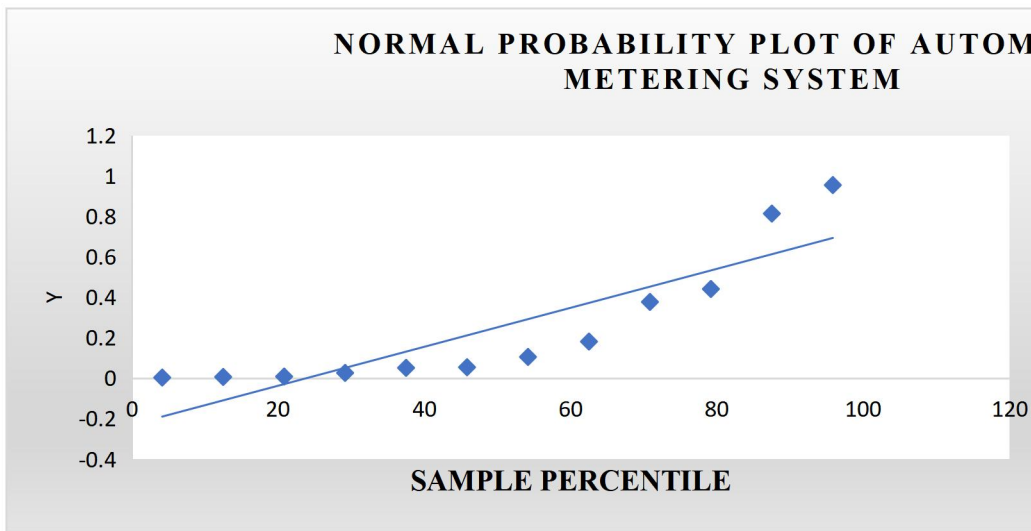


Figure 4.71: A Normal probability plot of Automated metering system

The results in Figures 4.71 shows that the 12 data observed from which the samples were drawn were normally distributed for Automated metering system.

Results of comparison of the metering Systems

Figure 4.72 shows the results of comparison of Automated metering system and BEDC metering system.

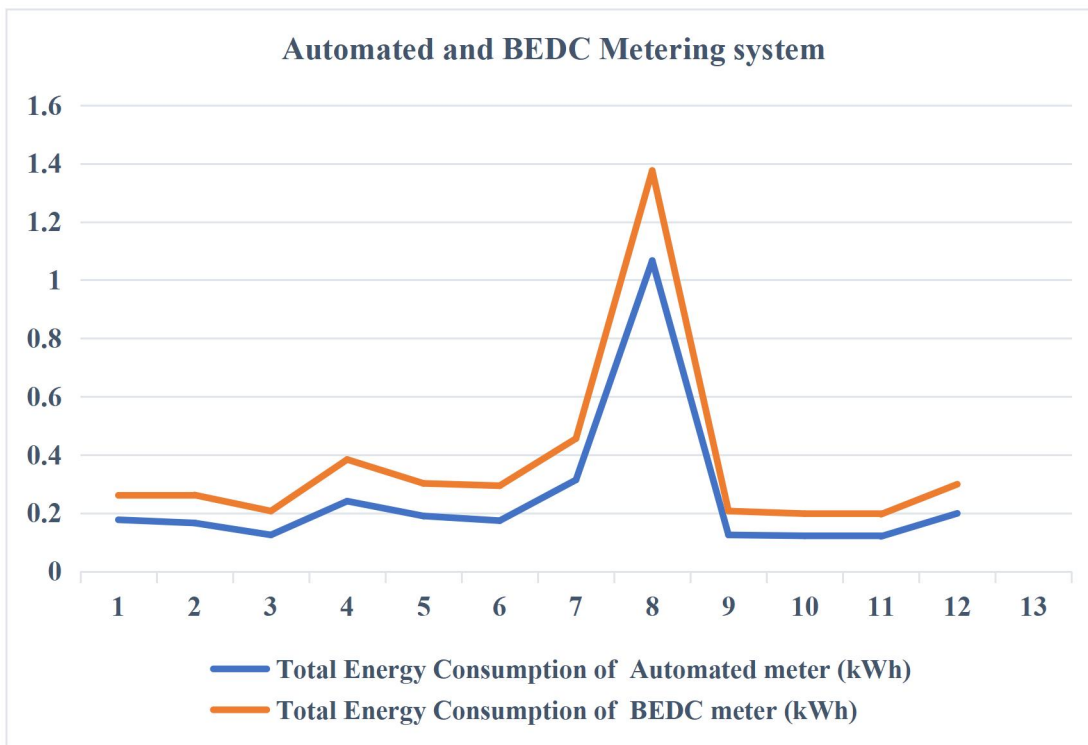


Figure 4.72: Results of comparison of the metering system

Meter with Automated metering system.

The total amount of energy consumed by the BEDC and automated metering systems was calculated through measurement. When determining the total energy used by each load, data from measured power usage and regression analysis of Excel output demonstrate that BEDC Metering System consumes more energy than Automated Metering System. As a result, an automated metering system should be appropriate for effective power management and monitoring of electrical loads. Figure 4.72 compares the user load power consumption data from the Automated metering system and the BDEC metering system graphically.

Results of tests conducted on Wireless transceivers in both urban and rural areas.

The test experiment was carried out in both a rural and an urban area, with data from the test results being used to cover several kilometres in both settings, demonstrating the reliability of the device. Appendix J offers a picture of the experiment, Tables 4.7 presents the location and distance travelled (in kilometres’).

Tables 4.7: Wireless transceiver's position and range (in kilometres) for both rural and urban settings.

Meter Position	Base Station Position	Signal Status	Distance Covered (km)
Oluku	UBTH	HIGH	1
Oluku	Uwasota	HIGH	1.5
Ugoneki	Lighthouse	HIGH	7
Ugoneki	Abudu Secretariat	HIGH	8
Uybe	Benin-Agbor bypass	HIGH	4
Ugoneki	Benin-Agbor bypass	LOW	10
Uybe	Agbor	LOW	17
Ugoneki	Abudu town	LOW	16

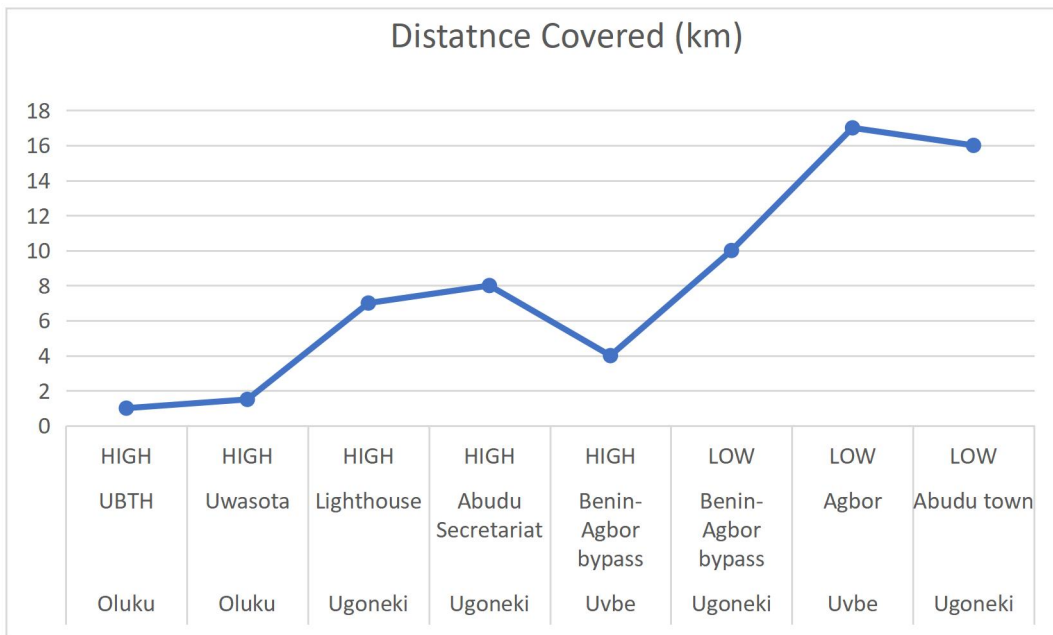


Figure 4.73: Test results on Wireless transceiver for both urban and rural area

4.7 Discussion

This study designed an integrated system to address the monitoring, managing, and control issues faced by Nigerian power utility companies and consumers due to the limitations of the existing prepaid meter. The system combines an automated meter, a web-based system, a home energy planner, and a mobile software application. The inability of the current electricity distribution company's website to accurately measure power distribution and consumption creates challenges for both the company and consumers. To overcome this limitation, the web-based system incorporates automated open-circuit fault detection and reporting, which monitors the service wire of the three-phase power distribution lines.

In Nigeria, most energy consumers are unaware of their monthly electricity consumption, making it difficult for them to have control and monitor their power usage, affecting the operation of their appliances. The lack of remote monitoring and control leads consumers to leave appliances on even when not in use. To address this issue, a mobile software application called "meter utility" was designed to automate the detection and reporting of open-circuit faults in the three-phase power distribution network. The application works with both the prepaid meter and the home energy planner, allowing control of loads, retrieval of meter parameters, monitoring of load consumption, tracking power availability, and detecting outages on the service wire.

The automated metering system was developed using an Atmega328p microcontroller, which selects the available phase voltage across phases based on data from three phase sensors. It activates a relay to regulate the phase output voltage according to the chosen phase voltage. The Home Energy Planner (HEP) activates the load if voltage is present in any of the three phases. By incorporating a LoRa RF wireless transceiver and additional software for fault detection, reporting, and monitoring, the system differentiates itself from previous approaches that focused on GSM prepaid systems and protective relays such as Geno et al (Geno et al., 2021).

The Home Energy Planner utilizes an Arduino Nano microcontroller and communicates with the meter utility app on an Android phone. It uses an ESP8266 and a Wi-Fi network to regulate loads based on instructions

from the wireless device. The system includes a Real-Time Clock (RTC) connected to the microcontroller, allowing users to schedule load activation and deactivation at specific times. This research work distinguishes itself from previous studies that focused on Bluetooth-based home automation and RFID-tagging of elderly people such as Nisar et al.'s al (Nisar et al., 2019). The objective is to enable effective power management and monitoring by utility companies and simplify residential load automation and consumption control for consumers.

During the evaluation of the metering system, twelve loads were measured for various parameters such as voltage, current, power, and energy consumption. Regression analysis was performed, and the results showed a statistically significant linear relationship between the BEDC meter and the Automated Metering System. The automated metering system consumed less energy (3.02 kWh) compared to the BEDC meter currently in use in Nigeria (4.442 kWh).

The study concludes that the power management problem in Nigeria can be addressed by implementing the Automated Metering System along with the Home Energy Planner and meter utility software application. The research output can be applied in residential homes and small offices but may not be suitable for large-scale industries. The recommendation is to extend similar research to industrial and other large-scale power consumers in developing nations like Nigeria.

The power management problem in Nigeria can be resolved with the use Automated Metering System with the help of the Home Energy Planner and meter utility software application which provides solution to the research questions and the objectives.

The research output can be applied in residential homes, small offices with exception of large-scale industries. Hence, it is recommended that similar work like this research be extended to industrial and other large scale power consumers in developing nations like Nigeria.

4.8 Findings

The summary of the findings of this research are:

97.2% of the respondents who are users of the existing metering system lack awareness of electricity power unit consumed daily. while 84.1% express strong desire to have knowledge and control over their daily power consumption to mitigate the estimated billing method employed by utility company.

96.3% of respondents visit the utility company to report open-circuit faults on distribution lines; this may take days to resolve as a result of delay in detection.

By analyzing the energy value of 2.751 kWh, power consumption of 121.4W, current of 0.0094, and voltage of 231.4V in relation to consumer consumption, it becomes evident that the utility company can accurately determine the load consumption of consumers via AMPMS novel web-based system where consumers can monitor the same via meter utility mobile App.

A notable discovery is that within a four-hour timeframe, the existing prepaid meter consumed 4.442 kWh, while the automated metering system consumed a significantly lower amount of 3.02 kWh. This comparison demonstrates that automated meters consume less energy than the currently utilized meters in Nigeria.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This thesis has examined the current metering system's effectiveness in managing load consumption, addressing power management issues, and monitoring energy usage across various prepaid meters used by different consumers. Additionally, it has designed a comprehensive system for detecting and reporting open-circuit faults.

The study has developed an automated meter that allows for real-time energy usage comparisons among power consumers and facilitates efficient load monitoring through a centralized wireless-based system. Over a four-hour period, twelve (12) electrical loads were monitored, revealing a significant difference in energy consumption between the conventional prepaid meter, which consumed 4.442 kWh of energy, and the automated metering system, which consumed only 3.02 kWh of energy. This comparison highlights the energy-saving potential of automated meters when compared to the current meters in use in Nigeria.

With the assistance of the Home Energy Planner and a mobile software application, end-users will have the capability to create personalized schedules for automatic appliance activation and deactivation, thereby reducing unnecessary power wastage. The implemented system aims to eliminate instances of underpayment, overpayment, and absolute evasion of electricity bills, while also effectively preventing electricity theft. These measures are expected to enhance the overall economic viability of the power distribution system.

Recommendation

This research did not consider the possibility of expanding the AMPMS system to cater to Industrial and Large-scale Power Consumers. Future research should commence with a thorough evaluation of the power management and monitoring requirements specific to industrial and large-scale power consumers in developing nations. This entails gaining insights into the distinctive challenges and needs these consumers encounter in effectively managing their power usage. Furthermore, regarding the "Meter Utility" mobile app, it is advisable to consider hosting it on the Google Play Store. Additional research in this area should also be contemplated.

5.3 Contribution to Knowledge

The research has made the following specific contributions to knowledge:

In Nigeria, a system has been developed using an innovative wireless protocol to facilitate efficient management and monitoring of electricity consumption by consumers and the three-phase power distribution network during open-circuit faults.

A novel integrated system for management, control, and monitoring of consumption has been devised for consumers.

To enhance payment efficiency, a tokenless mobile recharge payment system has been developed. Utility companies have incorporated features to recharge energy meters in the event of customer mobile phone loss.

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www.datasheetarchive.com

www.arduino.cc

www.texasinstrument.com

www.Arduinodatasheet.com

www.venturesafrica.com/nigerias-power

www.Alibaba.com

www.aliexpress.com/store

www.semtech.com

www.atmel.com

APPENDICES

APPENDIX A: SAMPLE OF THE QUESTIONNAIRE ADMINISTERED

UNIVERSITY OF BENIN FACULTY OF ENGINEERING

DEPARTMENT OF COMPUTER ENGINEERING

QUESTIONNAIRE

Please, kindly tick the appropriate answer or write where necessary

NOTE: The purpose of this questionnaire is to generate data for research purpose only.

AGE: 30 AND BELOW [], 31-50 [], 51-65 [], ABOVE 65 []

LOCATION: [] BENIN CITY []

GENDER: MALE [], FEMALE []

LEVEL OF EDUCATION: PRIMARY [] SECONDARY [] COLLEGE OF EDUCATION []
POLYTECHNIC [] UNIVERSITY []

Q1. How many hours of Electrical power supply do you enjoy from BEDC daily? Please tick (Per day in hours) [1 - 4], [5 - 8], [9 - 12], [13 - 16] [17 and above] Q2. Do you have a prepaid meter in your apartment?

YES [] NO []

Q3. Do you know how your electricity bill is calculated?

YES [] NO []

Q4. Do you understand how much of electric power your apartment consumes daily?

YES [] NO []

Q5. Do you face difficulty in buying and loading units on your prepaid meters? YES [] NO [] Q6. If Q5 is YES, Please tick, Always [], Very often [], Often [], Not so often [].

Q7. Do you think BEDC treats you like a valued customer?

YES [] NO []

Q8. How satisfied are you with BEDC customer's service? Please tick,

Very satisfied [], Satisfied [], Not very satisfied [], Completely unsatisfied []

Q9. Can you please rate the occurrences of the following acts around or in your area?

i. Estimated billing system

Please tick, Always [], Very often [], Often [], Not so often [], Not all [] ii. Giving bribe to BEDC official to avoid paying for Electricity consumed

Please tick, Always [], Very often [], Often [], Not so often [], Not all []

iii. Meter tampering by consumer.

Please tick, Always [], Very often [], Often [], Not so often [], Not all []

iv. Illegal connection/by-pass by BEDC consumers

Please tick, Always [], Very often [], Often [], Not so often [], Not all []

Q10. What do you think is most responsible for the problems with power supply in your area?

Please Tick:

i. Corruption in BEDC and their Staff [] ii. Illegal connection/by-pass by BEDC customers [] iii. Vandalization of BEDC facilities [] iv. National problems []

v. Load shedding [] vi. Others []

Q11. What type of apartment do you occupy? [Please tick]

a. Duplex []

In (a) above how many rooms are in your duplex 4. [], 5. [], 6 [], 7. [], others [] b. Four Bedroom flat []

Three Bedroom flat []

Two Bedroom flat

Self-contain (Room and Parlour) []

Self-contain (one room) []

Room and Parlour []

Boys quarters (BQ) []

One room []

Q12. Please tick the appliances and other loads you use in your apartment?

S/N	Appliances	Tick here	Specify number(s)
1	Central Air conditioner		
2	Window/Split Air conditioner		
3	Electric cooker/oven		

4	Hair dryer		
5	Washing machine		
6	Hot Plate		
7	Clothes pressing Iron		
8	Toaster		
9	Microwave oven		
10	Vacuum Cleaner		
11	Water heater		
12	Portable Heater (Boiling Ring)		
13	Electric kettle		
14	Blender		
15	LCD monitor		
16	Desktop computer		
17	Laptop computer		
18	Standing or table fan		
19	Ceiling fan		
20	Satellite dish		
21	Cable box (Dstv, Startime, and Gotv)		
22	Electric shaver/clipper		
23	Standard TV		
24	Plasma TV		
25	LCD TV		
26	25 inches Color TV		
27	12 inches Black and white TV		
28	Stereo		

Q19. If Q18 is yes tick type: Diesel [], Petrol [],

Q20. If yes, how many hours do you run it daily? Please tick (Per day in hours) [1 - 3], [4 - 6], [6 - 9],
[10 - 12]

Q21. How much do you spend on fuel monthly -----?

Q22. When a fault like a fallen pole or wire cut on the service line occurs in your area, how long does it take it is attended to it? Please tick (Per week) [1 - 3], [4 - 6], [7 - 9], [10weeks and above]

Q23. Does the area have to report a case of wire cut to utility company like BEDC before it is attended to? Yes [] No []

Q24. Are you tempted to bypass your meter when you face difficulty in recharging your meter? Yes []
No [] Sometime []

Q25. Do you desire to control how much you spend on electricity bills by monitoring your power consumption? Yes [], No [], If I can []

APPENDIX B: Code for the metering system.

```
#include <stdio.h>
```

```
#define REG_VOLTAGE 0x0000
```

```
#define REG_CURRENT_L 0x0001
```

```
#define REG_CURRENT_H 0x0002
```

```
#define REG_POWER_L 0x0003
```

```
#define REG_POWER_H 0x0004
```

```
#define REG_ENERGY_L 0x0005
```

```
#define REG_ENERGY_H 0x0006
```

More information on the meter code is available at:

<https://github.com/auptsoft/meter>

APPENDIX C: Code for the home energy Planner.

```
#include <Wire.h>
```

```
LiquidCrystal lcd16By2(rs, en, d4, d5, d6, d7);
```

More information on the home energy planner code is available at:

https://github.com/auptsoft/meter_app

APPENDIX D: Code for mobile App.

```
    android:icon="@drawable/ic_chrome_reader_mode_black_24dp"
}    android:label="@string/app_name"
    android:roundIcon="@drawable/ic_chrome_reader_mode_black_24dp"    android:supportsRtl="true"

    <action android:name="android.intent.action.MAIN"    />

    <category android:name="android.intent.category.LAUNCHER" />

</intent-filter>

</activity>

<activity android:name="com.app.auptsoft.meterutililty.LoadEditActivity"    android:label="Edit
Loads" android:theme="@style/AppThemeWithActionBar" />

<activity android:name="com.app.auptsoft.meterutililty.AddLoadActivity"    android:label="Add New
Load" android:theme="@style/Dialogtheme" />

</manifest>
```

More information on the mobile App code is available at:

https://github.com/auptsoft/meter_app

APPENDIX E: Code for Database System

```
$factory->define(App\User::class, function (Faker $faker) {
    return [
        'name' => $faker->name,
        'email' => $faker->unique()-
        >safeEmail,
        'email_verified_at' => now(),
```

?php use

Illuminate\Support\Facades\Schema; use

Illuminate\Database\Schema\Blueprint;

APPENDIX F: Code for simulation of Open-Circuit FDR design.

```
classdef app1 < matlab.apps.AppBase
    % Properties that correspond to app components
    properties (Access = public)
        UIFigure matlab.ui.Figure
    end

    % App initialization and construction
    methods (Access = private)

        % Create UIFigure and components
        function createComponents(app)

            % Create UIFigure
            app.UIFigure = uifigure;
            app.UIFigure.Position = [100 100 640 480];
            app.UIFigure.Name = 'UI Figure';
        end
    end

    methods (Access = public)

        % Construct app
        function app = app1

            % Create and configure components
            createComponents(app)
        end
    end
end
```

APPENDIX G: Data from MATLAB simulation of open-circuit FDR design

S/N	TIME (sec)	RED PHASE	YELLOW	BLUE PHASE
1	0	1	1	1
2	5	1	1	1
3	10	1	1	0
4	15	0	1	1
5	20	1	1	1
6	25	1	1	1
7	30	1	1	1
8	35	1	1	1
9	40	1	1	1



10	45	1	0	1
11	50	1	1	1
12	55	1	1	1
13	60	1	1	1
14	65	1	1	1
15	70	1	0	0
16	75	1	1	1
17	80	1	0	1
18	85	1	1	0
19	90	1	0	1
20	95	1	0	1
21	100	1	1	1
22	105	1	1	1
23	110	1	1	1
24	115	1	0	1
25	120	1	1	1
26	125	1	1	1
27	130	1	1	1
28	135	1	0	1
29	140	1	1	1

APPENDIX H: Data from Web-based interface of open-circuit FDR

S/N	TIME (sec)	RED PHASE	YELLOW	BLUE PHASE
1	0	1	1	1
2	5	1	1	1
3	10	1	1	0
4	15	0	1	1
5	20	1	1	1
6	25	1	1	1
7	30	1	1	1
8	35	1	1	1
9	40	1	1	1
10	45	1	0	1
11	50	1	1	1
12	55	1	1	1
13	60	1	1	1
14	65	1	1	1
15	70	1	0	0
16	75	1	1	1
17	80	1	0	1
18	85	1	1	0
19	90	1	0	1
20	95	1	0	1
21	100	1	1	1

22	105	1	1	1
23	110	1	1	1
24	115	1	0	1
25	120	1	1	1
26	125	1	1	1
27	130	1	1	1
28	135	1	0	1
29	140	1	1	1
30	145	1	1	1

APPENDIX I: Datasheet for SX1278 Wireless transceiver

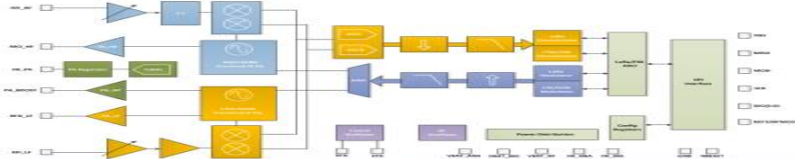



SX1276/77/78/79

WIRELESS, SENSING & TIMING

DATASHEET

SX1276/77/78/79 - 137 MHz to 1020 MHz Low Power Long Range Transceiver



GENERAL DESCRIPTION

The SX1276/77/78/79 transceivers feature the LoRa™ long range spread spectrum modem that provides ultra-long range spread spectrum communication and high interference immunity whilst minimising current consumption.

Using Semtech's patented LoRa™ modulation technique SX1276/77/78/79 can achieve a sensitivity of over -148dBm using a low cost crystal and bill of materials. The high sensitivity combined with the integrated +20 dBm power amplifier yields industry leading link budget making it optimal for any application requiring range or robustness. LoRa™ also provides significant advantages in both blocking and selectivity over conventional modulation techniques, solving the traditional design compromise between range, interference immunity and energy consumption.

These devices also support high performance (G)FSK modes for systems including WMBus, IEEE802.15.4g. The SX1276/77/78/79 deliver exceptional phase noise, selectivity, receiver linearity and IIP3 for significantly lower current consumption than competing devices.

ORDERING INFORMATION

Part Number	Delivery	MOQ / Multiple
SX1276IMLTRT	T&R	3000 pieces
SX1277IMLTRT	T&R	3000 pieces
SX1278IMLTRT	T&R	3000 pieces
SX1279IMLTRT	T&R	3000 pieces

• QFN 28 Package - Operating Range [-40;+85°C]
 • Pb-free, Halogen free, RoHS/WEEE compliant product

KEY PRODUCT FEATURES

- LoRa™ Modem
- 168 dB maximum link budget
- +20 dBm - 100 mW constant RF output vs. V supply
- +14 dBm high efficiency PA
- Programmable bit rate up to 300 kbps
- High sensitivity: down to -148 dBm
- Bullet-proof front end: IIP3 = -11 dBm
- Excellent blocking immunity
- Low RX current of 9.9 mA, 200 nA register retention
- Fully integrated synthesizer with a resolution of 61 Hz
- FSK, GFSK, MSK, GMSK, LoRa™ and OOK modulation
- Built-in bit synchronizer for clock recovery
- Preamble detection
- 127 dB Dynamic Range RSSI
- Automatic RF Sense and CAD with ultra-fast AFC
- Packet engine up to 256 bytes with CRC
- Built-in temperature sensor and low battery indicator

APPLICATIONS

- Automated Meter Reading.
- Home and Building Automation.
- Wireless Alarm and Security Systems.
- Industrial Monitoring and Control
- Long range Irrigation Systems

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APPENDIX J: Testing for wireless transceiver in rural and urban Area.



APPENDIX K: Survey Results Tables

Consumer loads left on

Decision	Number of Respondents	Percentage	Cumulative Percentage
YES	324	56.64	56.64
NO	248	43.36	100.0
TOTAL	572	100.0	

Consumer apartments and percentage of respondents that left loads on.

S/N	Residential Apartment	Count (Respondents who left loads on)	Cumulative Count	Cumulative Percentage (%)
1	One room	51	51	15.74
2	One room Self-contain	49	100	30.86
3	Room and Parlour	54	154	47.53
4	Room and Parlour self-contain	33	187	57.71
5	Two-bedroom flat	66	253	78.08
6	Three-bedroom flat	22	275	84.87
7	Four-bedroom flat	20	295	91.04

The frequency and percentage of device left on

Some reason for power problem

Electricity Consumers Response	Frequency (n)	Percentage (%)
Corruption in BEDC and their Staff	282	49.2
By-pass	176	30.8
Vandalization of BEDC facilities	53	9.3
National Problem	61	10.7
Total	572	100

Visit Utility office (BEDC) for service wire cut

Electricity Consumers Response	Frequency (n)	Percentage (%)
Yes	551	96.3
No	21	3.7
Total	572	100

Time to attend to service wire cut

Electricity Consumers Response	Frequency (N)	Percentage (%)
1-3 Weeks	25	4.4
4-6 Weeks	27	4.7
7-9 Weeks	189	33.0
10 weeks and above	331	57.9
Total	572	100

Electricity Consumers that use Generator

Electricity Consumers Response	Frequency (n)	Percentage (%)
Yes	536	93.7
No	36	6.3
Total	572	100

Hours spent running generator daily

Electricity Consumers Response	Frequency (n)	Percentage (%)
1-3 hours	84	14.7
4-6 hours	39	6.8
6-9 hours	109	19.1
10-12 hours	340	59.4
Total	572	100

Amount (Naira) Spent on Fuel Monthly

Electricity Consumers Response	Frequency (n)	Percentage (%)
1-5 Thousand	11	1.9
6-10 Thousand	2	0.3
11-15 Thousand	393	68.7
16-20 Thousand	166	29.1
Total	572	100

Customers value by a Utility company (BEDC) in Nigeria

Electricity Consumers Response	Frequency (n)	Percentage (%)
Yes	15	2.6
No	557	97.4
Total	572	100

Awareness of Utility Company Calculation on load consumption

Electricity Consumers Response	Frequency (n)	Percentage (%)
Yes	49	8.6
No	523	91.4
Total	572	100

Consumers with Prepaid meters

Electricity Consumers Response	Frequency (n)	Percentage (%)
Yes	131	22.9
No	441	77.1
Total	572	100

Awareness of Prepaid meter Unit consumption

Electricity Consumers Response	Frequency (n)	Percentage (%)
Yes	16	2.8
No	556	97.2
Total	572	100

Difficulty in buying or loading prepaid meter

Electricity Consumers Response	Frequency (n)	Percentage (%)
Always	236	41.3
Very Often	207	36.2
Often	73	12.8
Not so often	56	9.7
Total	572	100

Meter Tampering

Tempted to bypass

Electricity Consumers Response	Frequency (n)	Percentage (%)
Yes	321	56.1
No	85	14.9
Sometimes	166	29.0
Total	572	100

Consumers Satisfaction with BEDC customer's service

Electricity Consumers Response	Frequency (n)	Percentage (%)
Very satisfied	3	0.5
Satisfied	24	4.2
Not very satisfied	64	11.2
Completely unsatisfied	481	84.1
Total	572	100

Desire to controlling Electricity power consumption

Electricity Consumers Response	Frequency (n)	Percentage (%)
Yes	481	84.1
No	30	5.2
If I can	61	10.7
Total	572	100

APPENDIX L: Meta-Analysis Table

A summary of related works done on automated metering power management and monitoring system.

S/N	Author(s)	Title	Method	Aim	Result	Gap
(1)	Katie et al (2006)	The database and analysis platform for electricity tariffs.	This work uses the group, blocks, Utility and tariff levels to construct an organized data and allow multiple conditions to be applied to the same inputs. The group structure separates charges according to rate type, season, and if appropriate the aspect of service the customer is being charged for	It was aimed to develop a database and analysis platform for electricity tariff.	A block defines a limited range of input data values over which a given rate applies. A group always consists of a contiguous set of blocks that span the full range from zero to infinity.	The work was based on simulation
(2).	Odior et al (2010)	Some operations of electric power supply system in Benin City area of Nigeria	The method used was to take average number of operating transformers in various substations and their percentage loadings were also studied. They include such actions that are taken during emergency outages, planned or pre- arranged outages as well as load shedding	It was aimed to improve on the operations of electric power supply system in Benin City area of Nigeria.	The first consists of those arising from policy actions which are deliberate in nature and they are usually taken to safeguard the equipment. They include such actions that are taken during emergency outages the other class includes those arising from forces external to the system, and they include over- current,	Rural areas were affected and only technical losses were considered. However, it was also based on simulation

					earth fault, high peak	
(3)	ZHANG et al (2012)	The designed Monitoring System based on PLC and Configuration Software on a power distribution network.	The system uses PLC to collect various intelligent instruments on site and electrical parameters of devices. Uploaded to the monitoring system by the switch through the serial server. The configuration design uses Fame View monitoring configuration software to achieve real-time display and status display for field equipment through configuration images.	It was aimed to design Monitoring System based on PLC and Configuration Software on a power distribution network.	The reports, database, curves, and other systems can also be integrated so as to help query historical data	The debugging and running experiments show that the system is characterized fail operation not stable and safety not guaranteed
(4)	Apeh and Mokogwu (2013)	Development of home power management system.	The method used was that a PIC16F887 Microcontroller was programmed to provide 24 hour real-time timing power consumption management according to user timing parameters made available to the programmed Code.	It was aimed at the design and development of a prototype Power Management System for home which will enhance energy user behavior for achieving energy consumption efficiency	The home power management system developed produced outputs that exhibited good correlation with input supply. The output for ports 1, 2, 3, 4 and 5 were respectively 187V, 185V, 184V, 185V and 183V which is satisfactory.	The implication of this work is less damage to sensitive equipment and using Power on a need-to-use basis.

(5)	Georgievs ki et al (2013)	Optimizing Energy Costs for Offices Connected to the Smart Grid	It showed an average economic savings of about 35% by presenting an approach based on measuring consumption on individual devices as well as measuring the production on generating units	To Optimize Energy Costs for Offices Connected to the Smart Grid	End users where able to determine requirements which lead to policies for each device and energy contracts were closed for short-term time interval.	It was limited to smart grid.
(6)	Nguyen et al, (2013)	Energy intelligent Buildings based on User Activity	summarize and compare several studies on building energy and comfort management (BECM) systems,	To design and implement an Energy intelligent Buildings based on User Activity	simulation results show up to 58% savings on energy for lighting and 10-40% for HVAC system	It was based on simulation and limited to certain loads
(7)	Fabiano et al (2015)	Monitoring in Industrial Systems Using Wireless Sensor Network.	With the use of intelligent Sensors Modules (ISMs) and the Remote Data Acquisition Units (RDAUs). They were able to transmitting data to the Supervisory Controller (SCs)	The aim is to Monitor Industrial Systems Using Wireless Sensor Network with the use of intelligent Sensors Modules (ISMs) and the Remote Data Acquisition Units (RDAUs).	Results show that the sensor node is able to transmit without any packet Losses up to a distance of 80 m, regardless of the antenna orientation.	The transmitter not properly battery powered and affected results.

(8)	Apeh and Olaye (2015).	Design and Construction of a 5KVA power inverter with real time automated power Consumption Management System.	The method used is to divide the system into two subsystems namely power inverter and the control/Timing subsystem. User preferences for power consumption profiles are entered using a keypad of 16-key encoder to take the output of a 16-key switch and encode it onto only four outputs using a truth table.	The aim is to presents the design effort to improve on power management of an inverter and the developed system automatically manages power consumption by turning ON or turning OFF corresponding connected loads.	The system was tested, working perfectly and met the objective of the design with four regulated and two unregulated which was found to have an efficiency of 89%.	It was not suitable for load higher than 5kVA.
(9)	Brenda Shaffer et al (2017)	The Application of Energy Data for Intelligence Analysis.	The use of Energy's input of foreign states, The total energy supply and electricity level of electrification and average price of electricity and the percentage of households for which this price is accessible, energy intensity Rate.	The aim is to provide analysts in intelligence or other government agencies a guide to understanding how energy data can be applied to others in the world.	The diagrams of sources of Poland and Vietnam also show the great diversity of electricity, which led to different foreign.	The data collected not suitable for developing nation

(10)	Hasan et al (2018)	Design of wireless smart metering system.	The methods used wireless communication system based on MSP430 and ESP430 Microcontrollers (MCU) and ZigBee wireless transceiver .The designed system realizes the functions of wireless transmission and communication between the smart meter and the central computer at a distance of 10m	The main aim of the concept is to design of wireless smart metering system which could be used for some residence.	Wireless smart metering in the residential environment to enable power data acquisition for status monitoring and control decisions.	The drawback is short distance on the wireless transmission, which will require smart grid system and lack of Standby detection system.
(11)	Lu et al (2019)	Reducing household electricity usage	The method used was to employ a physical model to examine the underlying mechanism of energy flow and as result predict building energy consumption.	The main aim of the concept was to minimize waste of energy consumption for some residence.	It shows a reduction of energy consumption under various weather condition	The data for the prediction was not valid and not applicable for all buildings

APPENDIX M: Publication

Edemirukaye Ukeh Orodje and Apeh Simon T. (2018)

“Towards design and evaluation of an automated metering, power management and monitoring system” International Conference Proceedings of the 13th iSTEAMS Conference, Accra, Ghana.

12(1), 189-202.

Edemirukaye Ukeh Orodje and Apeh Simon T. (2018)

“Evaluation of an automated metering with flexible management and monitoring system” Advances in Multidisciplinary Research Journal (AIMS). 6(4), 11-34.

Edemirukaye Ukeh Orodje and Apeh Simon T. (2018)

“Evaluation and Implementation of an advanced integrated metering system with interactive capability” International Conference Proceedings on “Urbanization and sustainable development in Africa” Caleb University. 12(2) 227-234.

Edemirukaye Ukeh Orodje and Apeh Simon T (2021)

Automated control of fixed loads and remote sockets: design and evaluation “Open Access Research Journal of Engineering and Technology” 01(02), 049-058

APPENDIX N: Design Calculation of Automated Metering and Home energy Planner

Automated Metering:

Transformer:

$$V_{rms} = 12v$$

$$I_{rms} = 1500mA$$

$$V_{Peak} = V_{rms} \times \sqrt{2}$$

$$= 12 \times \sqrt{2}$$

$$V_{peak} = 16.97v$$

$$I_{peak} = I_{rms} \times \sqrt{2}$$

$$= 1500mA \times \sqrt{2}$$

$$= 2,121.32mA$$

The load resistance RL is given by:

$$RL = \frac{V_{peak}}{I_{peak}}$$

$$RL = \frac{16.97}{2121.32} = 7.9998$$

$$RL \cong 8.00\Omega.$$

Rectification:

Voltage after rectification Vdc given by:

$$V_{dc} = \frac{2V_{peak} - 2v_d}{\pi}$$

where V_d is the bridge rectifier's voltage drop across the two diodes a positive half cycle?
($V_d = 0.7$)

$$V_{dc} = \frac{2 \times 16.97 - (2 \times 0.7)}{\pi}$$

$$V_{dc} = 10.8 - 1.4 = 9.4v$$

The current after rectification I_{dc} is given by:

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{9.4}{8.00} = 1.175A$$

Choice of capacitors:

C1 is chosen as the output capacitor because it has a very low reactance to the ripple frequency.