CLOUD BASED POWER FAILURE SENSING AND MANAGEMENT MODEL FOR THE ELECTRICITY GRID IN DEVELOPING COUNTRIES – A CASE OF ZAMBIA

BY
SINKALA, JANET NANYANGWE

A dissertation submitted to the University of Zambia in partial fulfilment of the requirement of the Degree of Masters of Engineering in Information and Communication Technology

THE UNIVERSITY OF ZAMBIA

LUSAKA

2020

COPYRIGHT DECLARATION

DECLARATION

I, Janet Nanyangwe Sinkala hereby declare that the work presented in this dissertation is my own, and that to the best of my knowledge, it has not been previously produced or submitted before for a degree, diploma or other qualification at this university or any other institution for academic purposes, and that all sources of information have been duly acknowledged.

SIGNED:

……………………………………………………………………………………………

JANET NANYANGWE SINKALA

Author

This project is submitted for examination and registration with my competent approval as the Supervisor for JANET NANYANGWE SINKALA

SIGNED:……………………………………………………………………………………

Dr. JACKSON PHIRI

Supervisor

Date: ……………………………………………….

CERTIFICATE OF APPROVAL

This dissertation by JANET NANYANGWE SINKALA has been approved as fulfilling the requirements or partial fulfilment of the requirements for the award of the Degree of Masters of Engineering in Information and Communication Technology by the University of Zambia.

Examiner 1

Name………………………………………………………………………………………….

Signature……………………………………………………………………………………

Date………………………………………………………………………………………….

Examiner 2:

Name………………………………………………………………………………………….

Signature……………………………………………………………………………………

Date………………………………………………………………………………………….

Examiner 3:

Name………………………………………………………………………………………….

Signature…………………………………………………………………………………….

Date…………………………………………………………………………………………..

Board of Examiners

Chairperson…………………………………………………………………………………

Signature: ……………………………………………………………………………………..

Date:…………………………………………………………………………………………

ABSTRACT

In Zambia part of the electric grid is not monitored, this means that there are no sensors in the electric grid to enable grid status information to be sent to the power utility. Without these sensors the power utility finds it difficult to determine when there is a power failure in the distribution electric grid, especially if the power failure occurs in the Low Voltage level. Usually power failure management relies on humans. The customer with a telephone is the one whose call initiates the dispatch of a field crew to attend to power failures. However, this system of addressing power outages is not very effective and usually results in long durations of system interruptions which have a negative impact on the social economic activities of the country. This study proposes a cloud based power failure sensing system to enable automatic power failure sensing and reporting as well as monitoring of the low voltage power network. A baseline study was conducted to determine the challenges faced by both ZESCO (Service provider) and the electricity clients in the current power failure reporting management model. The results from the baseline study indicate that challenges are being faced by electricity clients when it comes to reporting power failures. These include failure to get through to the customer call centre due to busy lines, unanswered calls, failed calls and network failure. Challenges faced by the electricity service provider are the inability to attend to all the customers through the call centre as customer calls are rejected due to limited Call Centre system resources, difficulties in determining the power failure location and poor response to power failures reported. To address these challenges the proposed cloud based power failure sensor prototype made use of a Voltage sensor circuit, Arduino Microcontroller board, SIM7600E 4G/GPRS/GSM/GPS module, cloud architecture, Web Application and Google Map API. This research proves that automating the distribution network is necessary as the results from the proposed model show reduction in dependency on customer trouble calls, improved power failure reporting time, automatic update of power failure location information, power utility visibility of the grid and quick response to power failures resulting in reduced outage durations. The results of this research were successfully published in the International Journal of Advanced Computer Science and Applications (IJACSA) Journal Volume 11 Issue 2 February 2020.

Key words – Cloud Technology, power failure sensing, low voltage network, electric grid, cloud architecture.

DEDICATION

This piece of work is dedicated to God above all else.

To my husband Simon Sinkala, ever so supportive. To my three children Joshua Sinkala, Taizya Nambela and Timothy Sinkala

ACKNOWLEDGEMENT

I give praise and thanks to God for giving me good health, understanding and many other blessings during the course of my study. I am extremely grateful to my mother, Ms. Christine Chituta Sinyangwe for her patience, love and encouragement throughout the duration of my studies. I am also extremely grateful to Dr. Phiri who helped enormously and guided me with his knowledge and experience throughout my research to completion. I would like to thank the Ministry of Higher Education for awarding me a scholarship needed to complete this research. Thanks to ZESCO for opening their doors to me to enable the successful completion of my research. Many thanks to my husband Simon and my children for the encouragement and support they gave me throughout my studies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

ABREVIATION	DESCRIPTION
AC	Alternating Current
ADC	Analog to Digital Converter
API	Application Programming Interface
ARPANET	Advanced Research Projects Agency Network
ASP	Active Server Pages
AT	ATtention
AVR	Automatic Voltage Regulator
AWS	Amazon Web Services
BS	Base Station
CAIDI	Customer Average Interruption Duration Index
CDMA	Code Division Multiple Access
COM1	Communication 1
CPU	Central Processing Unit
CSS	Cascading Style Sheets
DC	Direct Current
DOD	Depth Of Discharge
EDGE	Enhanced Data rates for GSM Evolution
EVDO	Evolution-Data Optimized
FAN	Field Area Network
FDMA	Frequency Division Multiple Access
FRA	Food Reserve Agency
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile communications
GUI	Graphical User Interface
HLR	Home Location Register
HSPA	High Speed Packet Access
HSPDA	High-Speed Downlink Packet Access
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
I/O	Input/Output
IaaS	Infrastructure as a Service
IBM	International Business Machines
IC	Integrated Circuit
ID	Identification
IDE	Integrated Development Environment

IMEI	International Mobile Equipment Identity
IoT	Internet of Things
IT	Information Technology
IIS	Internet Information Service
LAN	Local Area Network
LAS-CDMA,	Large Area Synchronized Code Division Multiple Access
LED	Light Emitting Diode
LCD	Liquid Crystal Display
LMDS	Local Multipoint Distribution Service
LTE	Long Term Evolution
LTE-FDD	Long Term Evolution Frequency Division Duplex
LTE-TDD	Long Term Evolution Time Division Duplex
MC-CDMA,	Multi-carrier code-division multiple access
ME	Mobile Equipment
MIMO	Multiple Input Multiple Output
MOSFET	Metal–Oxide–Semiconductor Field-Effect Transistor
MPPT	Maximum Power Point Tracking
MS	Mobile Station
MSC	Mobile Switching Center
NAN	Neighbourhood Area Network
NIST	National Institute of Standards and Technology
NOOBS	New Out Of the Box Software
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OOD	Object Oriented Development
OOSD	Object-Oriented System Development
OOSDLC	Object-Oriented System Development Life Cycle
OOSDM	Object-Oriented Systems Development Methodology
OSX	Operating System X
PaaS	Platform as a Service
PCB	Printed Circuit Board
PDA	Personal Device Assistance
PIC	Programmable Interface Controllers
PIR	Passive Infrared
PSTN	Public Switched Telephone Network
PV	PhotoVoltaic
RAM	Random Access Memory
RFID	Radio-frequency identification
RNC	Radio Network Controller
RTC	Real-Time Clock
RTU	Remote Terminal Unit

SaaS	Software as a Service
SCADA	Supervisory Control Data Aquisition
SAIDI	System Average Interruption Duration Index
SANS	SysAdmin, Audit, Network and Security
SD	Secure Digital
SGSN	Serving GPRS Support Node
SMS	Short Message Service
SPSS	Statistical Package for Social Sciences
SQL	Structured Query Language
SRS	Simple Random Sampling
TDMA	Time Division Multiple Access
UART	Universal Asynchronous Receiver Transmitter
UML	Unified Modeling Language
UMTS	Universal Mobile Telecommunication System
USB	Universal Serial Bus
UWB,	Ultra-Wide Band
VLR	Visitors Location Register
VLSI	Very Large Scale Integrated Circuits
VPN	Virtual Private Network
WAN	Wide Area Network
WBAN	Wireless Body Area Networks
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Networks
WMAN	Wireless Metropolitan Area Networks
WPAN	Wireless Personal Area Networks
WWAN	Wireless Wide Area Networks
ZAF	Zambia Air Force
ZESCO	Zambia Electricity Supply Corporation

CHAPTER ONE
INTRODUCTION

1.1 Introduction

In this chapter the research study is introduced. The introduction to the research and background to the study are covered. The problem statement, aim of the study, objectives, and research questions are also given. This is then followed by the significance of the study, scope of research and ethical considerations. Finally, the organization of the dissertation and a summary of the chapter are presented.

1.2 Introduction to the Research

Electrical power systems are extremely huge and complex networks which are integrated for economic benefits, increased reliability and operational advantages. A power system is mainly made up three subsystems being generation, transmission and distribution [1].

The electric power distribution grid is the final stage in the delivery of electric power as it carries electricity from the transmission system to individual consumers. Distribution substations connect to the transmission system and lower the transmission voltage to medium voltage ranging between 0.4 kV and 35 kV with the use of transformers [2]. Primary distribution lines carry this medium voltage power to distribution transformers located near the customer's premises. Distribution transformers again lower the voltage to the utilization voltage used by lighting, industrial equipment or household appliances. Often several customers are supplied from one transformer through secondary distribution lines which are at 0.4kV. Commercial and residential customers are connected to the secondary distribution lines through service drops. Customers demanding a much larger amount of power may be connected directly to the primary distribution level or the sub-transmission level [3].

Huge parts of the electric grid especially the distribution network are not monitored in most developing countries including Zambia. This entails that the utility is not aware of the condition of the distribution network. Due to this, power failure durations are usually long and have a negative impact on the social economic activities of the country.

Traditionally, distribution systems have included very little smart sensor mechanism with almost all communications performed by humans. Introduction of automation in the power failure management of the distribution grid reduce dependency on customer trouble calls and leads to operator visibility of the grid, reduction of outage duration, crew and dispatcher efficiency savings and reduction in costs related to restoration and trouble call centre.

There are several sensing methods and techniques which can be used in the distribution electric grid. The need to maintain CAIDI and SAIDI indices within the allowed performance and prevent customer inconvenience has driven the distribution utilities to introduce innovative ways of managing their networks more efficiently and effectively by using sensor-based technologies.

Some of the key applications where sensor based technologies are being used by the utilities for improving operations, revenues and energy efficiency are:

1. Asset management system – In asset management tiny wireless RFID (Radio Frequency Identification) tags are placed on a network asset such as distribution transformer or smart meters. These RFID devices communicate with the intelligent asset management system, which helps the utilities in asset planning, deployment, tracking and optimization [4].

2. Transformer monitoring system – Sensors on transformers are used in on-line monitoring of transformer parameters such as Surface temperature, Winding temperature, Transformer oil level and Oil temperature. This information can be utilized to take proactive action in fault prevention, thus increasing the reliability of distribution network.

For monitoring winding and oil temperatures temperature sensors are used to detect changes in temperature of the oil and the windings. Once these changes in the temperature are detected and are above a predefined thresh hold a signal is sent to operate cooling fans, set an alarm , operate breakers to offload the transformer and send signals through the communication network to the operations centre for monitoring and further analysis [5].

3. Fault management and service restoration – In fault management fault passage current sensors on Low voltage distribution systems can measure the current flow in real time and help in the early

detection of overloading, short circuit or earth fault [4]. A high accuracy current sensor monitors the phase current flowing and when that current level exceeds a user-selectable threshold (as a result of a phase-to-phase or phase-to-ground fault) the fault is detected by use of a customized programed microprocessor which gives an output indication through a mechanical flag indicator and LED indicators. These sensors are connected to the communication network through a communication module to send the fault information to the operations centre [6].

4. Real time network analysis - Supervisory Control and Data Acquisition (SCADA) at the substation get regular data from remote sensors via Remote Terminal Units (RTUs) in real time, which is analyzed to know the state of the networks. These remote terminal units consist of central processing units, communication modules and input/output modules to collect information from substation equipment through sensors [7]. In the substation sensors such as current and voltage instrument transformers to capture current and voltage from an electricity line, auxiliary contact on the breakers and isolators for status indication and temperature sensors on the transformers act as input to the RTUs. These RTUs in turn relay the information through the communication network to operation centers. Sensor-based technologies helps in network fault prevention, optimization and planning by making predictive analysis possible [8].

5. Power quality monitoring - The power quality of an electrical distribution network is affected by power line disturbance such as wave shape faults, overloading, capacitor switching transients, impulse transients or harmonic distortions. In monitoring power quality each sensor unit measures and records harmonic and inter-harmonic frequencies present on the main electricity supply at specific locations [4]. Voltage and current sensors of a power line capture the voltage and current and feed the information to a microprocessor which is programmed to extracts power quality information such as harmonics and over voltage. This information is in turn fed into an analytic software module which does analytical modeling for power quality and stores information into a database.The recorded data is then periodically transmitted through a wireless or wired communications network to a centralized database, where the information can be analyzed and stored.

6. Peak load management - Intelligent electronic appliances fitted with sensors can communicate with the electric grid in real time to switch off or defer operation to cheaper off-peak hours, thus helping in energy balancing during peak loads. For load management smart meter sensors measure

the energy consumption of consumers and transmit that information to the operations centre through communication networks [4]. Using these smart meter sensors the power utility can control the energy consumption by turning off customer devices such as air cons and geysers. Apart from installation of sensors in the home, energy consumption sensors can be installed on electricity lines to measure energy delivered to customers on each line. These sensors sense the energy consumed and relay that information to the power utility through a communication network. Based on the energy measured the power utility can send a signal to cut off power by opening the circuit breaker of the lines [9].

7. Automated demand response - Automated demand response refers to a smart grid device or application interacting with customers to influence their consumption of electricity or their load demand during select time periods. This signals customers to decide to lower their consumption or shed electricity during peak periods, and shift their demand to off-peak periods to save energy costs [4]. Demand response relies on an advanced metering infrastructure (AMI), i.e., a two-way communication infrastructure between a utility's enterprise network and its smart meters, whose purpose, besides automatic meter reading, is providing up-to-date tariff information to customers. An AMI infrastructure consists of a Neighborhood Area Network, where nodes called collectors collect meter data from downstream smart meter sensors and forward the data upstream toward the backhaul network to the operation centers for monitoring and analysis [9].

The distribution network is an important element of the total electrical supply scheme as it is the interface between the transmission system and the customers. It has been reported that 80% of the outages that occur at customer premises are due to failures in distribution networks [10]. To mitigate the customer interruption costs due to power failures, distribution systems need a distribution automation system for power failure detection [11] [12]. Automation of the power failure management system is critical for detecting a power failure and its location to enable rapid restoration of supply. Location of the geographical position of the power failure is important to keep the stability of the power system after fault detection. In [11] it is pointed out that the reduced number of customers interrupted and the associated customer minutes of interruptions are the primary major benefits of automated power failure sensing systems.

The electricity industry faces constant power failures, which require an effective and modern way of power failure fault management. This study is an attempt to develop a power failure sensing and management model for electricity clients in Zambia. This model will be cloud based.

1.3 Background to the study

The Zambia electricity grid is a system of electric transmission lines linking generators to loads and comprises substations and transmission lines at 330 kV, 220 kV, 132 kV, 88kV, 66 kV, 11kV, 33kV and 0.4kV voltage levels. It is built on a robust back bone of 330kV from the southern part of the country through Lusaka and Central provinces to the Copperbelt [13].

This electricity grid is mostly operated by Zambia Electricity Supply Corporation (ZESCO). ZESCO Limited is a vertically integrated electricity utility, which generates, transmits, distributes and supplies electricity in Zambia. ZESCO's mission is making it easy for people to live a better life. In order to make it easy for people to live a better life it is necessary that reliable electricity is provided to the customer.

Due to favorable economic development, the demand for electricity in Zambia has been increasing at average annual rates of 3-4 percent. The Zambian government has projected an increase in the rural electrification rate from the current 2 percent to 50 percent by the year 2050, while urban electrification rate has been projected to increase from 48 to 90 percent by 2030 [14]. On 27th July 2019 ZESCO connected the one millionth customer to the national grid [15]. The corporation has witnessed growth of about 400 % between 2000 and 2019, with the customer base increasing from 200,000 in the year 2000, to about 900,000 in the year 2018 and consequently 1,000,000 customers in 2019 [15]. An increase in the customer base for the Zambian electricity industry comes with an increase in electricity grid network and subsequently increase in power outages.

In spite of the increase in economic development and electric grid network, availability and reliability of electricity supply is a major concern. The country has vast natural resources vital for electricity generation such as the conventional fossil fuels coal and renewables like large hydropower and strong solar radiation yet the country experiences frequent and prolonged power outages. With Zambia being part of the sub Saharan African countries which have a total duration of outages averaging approximately 800 hours a year [16], it is important that reliable and efficient automatic power failure sensing systems are put in place to reduce on outage durations as well as ensure customer satisfaction. This will ensure reliable and efficient electricity supply.

Power failure remote sensing is necessary for acquisition of data from anywhere without the need for physical visits. It relies on sensory objects to sense and collect data from remote in real time and relay that information to a central place.
It is important that reliable and efficient electricity supply is provided through remote sensing technology to ensure security and reliability of the electrical energy infrastructure.

1.4 Problem Statement

In Zambia, part of the electric grid is not monitored [17]. This makes it difficult for the service provider to determine when there is a power failure or no electricity supply in the distribution electric grid, especially if the power failure occurs in the 0.4kV voltage level. Electricity Clients usually have to call and inform the utility's customer service to report a power failure. The utility usually becomes aware of the power failure only when the customer reports it as they are unable to monitor the low voltage level. However, this system of addressing power outages is not very effective and usually results in long durations of system interruptions as the customer usually experiences challenges when reporting power failure to the power utility resulting in the utility not knowing about the power failure for some time. Such prolonged power failure outages usually have a negative impact on businesses as it leads to loss of business revenue for electricity clients running businesses dependent on electricity. Further, it is an inconvenience for customers using electricity for daily household activities. For critical institutions like hospitals and clinics, this can be catastrophic as it may result in loss of lives.

Some utilities and agencies have surveyed the power outage causes in power systems and it is reported that about 80% of the power failure outages are caused by the faults in the distribution system [18]

This study will attempt to address and improve on power failure reporting management through sensing and cloud based technologies applied in the distribution system. The research study further seeks to propose a means of automatic power failure sensing whereby power failure notification and location is automatically sent to the power utility without the need for the customer to call the customer service center to report the power failure.

1.5 Aim of Study

The aim of the study is to design and develop a cloud based power failure sensing system to enable automatic reporting of power failure to the power utility as well as enable monitoring of the low voltage power network in Zambia**.**

1.6 Research Objectives

This research was guided by the following objectives

i) To assess the challenges faced by both ZESCO (Service Provider) and the Electricity clients in the current power failure reporting management model.
ii) To develop a model based on cloud and sensing technology for power failure reporting management based on the current business model for ZESCO.
iii) To develop a prototype for sensing and reporting power failure based on the model developed in the second objective.

1.7 Research Questions

This research was guided by the following research questions

i) What are the major challenges faced by ZESCO and electricity clients in the current power failure reporting management model?
ii) How can we develop a power failure reporting management model based on sensing and cloud technologies for the electricity grid in Zambia?
iii) How can we develop a prototype for sensing and reporting power failure based on the model developed in the second objective?

1.8 Significance of the Study

i) The future grid is a smart grid. A grid with sensors, computers, automation, and new technologies and equipment working together is what will make up the smart grid. Sensors in the electric grid make up the future of the smart electric grid. The Zambian grid is not a smart grid, this entails that research needs to be conducted on how to make this grid smart. This research attempts to do that by proposing the use of a cloud based sensing system in the distribution network. The development of an automated power failure reporting management model will help ZESCO management to ensure that power failures are attended to and resolved quickly, thereby ensuring reduction in duration of power outages and hence lead to reduced economic losses, lost productivity, and customer inconvenience.

ii) Power sensors in the distribution electric grid will enable the power utility visibility and situational awareness of the electric grid which would assist in operations and maintenance of the electric grid to ensure reliability and stability of the grid. The data from the sensors would assist in performing system diagnostics to support faster and accurate response and could be used as inputs to algorithms to assist in electric grid decision making.

iii) The study has contributed to the academic body of knowledge and has formed a basis for more detailed research work on the same or similar research topic in the future. The findings of this study have been published in the International Journal of Advanced Computer Science and Applications (IJACSA), volume. 11, issue 2, pages 392-405, 2020.

1.9 Scope of the Study

The scope of the study will be limited to the ZESCO power failure management model for the Low Voltage distribution electricity network (0.4kV). The study conducted will concentrate on electricity clients in Lusaka district townships.

1.10 Ethical Considerations

Participants will be treated with respect and consent will be obtained from them before they participate in the study. Participants will have the right to understand what the researcher is doing and the researcher will share the findings with them for their reactions among others.

1.11 Organization of the Dissertation

This dissertation is organized into five chapters. Chapter 1 is the Introduction to the Research. In this chapter, a brief overview and background of the work in this dissertation is given. Then the problem statement, aims, objectives, research questions, significance of the study and ethical consideration is presented. This chapter concludes by giving an outline of the dissertation.

Chapter 2 looks at the background theory and related works. In this chapter, Firstly, a review of the power failure management is conducted and the current status of the Zambian distribution electricity network is given. This is followed by an extensive review of cloud computing and Power sensing components stating the characteristics of these technologies and suitability for use in this research. This is then followed by a brief review of Cellular communication technologies and software development approaches. Lastly, this chapter closes by looking at related works to cloud and Sensing technology.

The research methodology is given in Chapter 3. In this chapter, the materials and methods used to conduct the baseline study and implement the system are presented. In Chapter 4, the research findings and discussion of the baseline study and the system implementation are presented. Finally, in Chapter 5 the recommendations and conclusions are given.

1.12 Summary

In this chapter, the basic introduction of the work in this dissertation was given. The electricity distribution process was described together with the application of sensors in the electric grid. The need for an automated power failure sensing and reporting system was also discussed. The problem statement, aim, objectives and research questions were then outlined. Finally the significance of study, scope of study, ethical considerations were given and the chapter was closed with the outline of the dissertation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this chapter, the literature and the works related to this research study are reviewed. The literature review was conducted to find out what is known about the subject matter. The literature review covers technologies thematic and related to this research. Firstly, a review of the power failure management and current status of the distribution grid is conducted followed by an extensive review of cloud computing, sensing components stating the characteristics of these technologies and suitability for use in this research. This is then followed by a brief review of cellular communication technologies and software development approaches. Lastly, this chapter closes by looking at works related to cloud and sensing technology.

2.2 Power Failure Management in the Distribution Grid

Huge parts of the electric grid especially the distribution network are not monitored in most developing countries including Zambia. This entails that the utility is not aware of the condition of the distribution network unless informed by the customer or substation superintendents. Due to this, power failure durations are usually long and have a negative impact on the social economic activities of the country. In [19] it is indicated that Power supply in most African countries is unreliable with the World Bank enterprise surveys indicating that most African enterprises experience frequent outages. Long power failure duration results in economic losses, lost productivity, and customer inconvenience [11]. Approximately, 90% of these outages and disturbances are in the distribution network therefore much attention should be given to improving the power system in the distribution network [20]

Traditionally, distribution systems have included very little smart sensor mechanism with almost all communications performed by humans. With little or no sensors in the distribution grid, power failure management relies on humans. The customer with a telephone is the one whose call initiates the dispatch of a field crew to restore power. Operations consists of manual equipment switching, and manual collection of load, energy consumption and abnormal event data [21]. The power failure management systems consist of trouble call centers, computer networks, manual utility procedures to identify, diagnose and locate power failure faults, provide feedback to affected customers, dispatch repair crews, restore supply, maintain historical records of the outage, and calculate statistical indices on electrical outages [22]. In this system trouble calls from customers being the primary source of outage notification is the least reliable method because sometimes customers may not be aware of the power outage and may not call resulting in long outage durations [23]. According to [20] customers report only one third of outages in the first hour of outages. Further, customers would not respond instantly to the outages, not bothering to make the call if the outage happens during the night time [20] . Lack of smart sensors in the distribution network results in grid operators' poor visibility of the grid and a lack of situational awareness [24] which leads to long durations of power outages raising the utility's System Average Interruption Duration Index (SAIDI) and Customer Average Interruption Duration Index (CAIDI).

Introduction of automation in the power failure management of the distribution grid reduce dependency on customer trouble calls and leads to operator visibility of the grid, reduction of outage duration, crew and dispatcher efficiency savings and reduction in costs related to restoration and trouble call centre [22]. Messages from smart sensors in the distribution grid can be used as input to the fault diagnosis and fault location algorithms and enable them operate efficiently and effectively [22]. With these input messages outage and restoration notifications are instantly sent to the utility [23]. These notification would provide wide-area grid awareness, integrating real time sensor data, provide rapid information about blackouts as well as insights into system operation for utilities [24]. Additionally automation of the distribution grid would enable sensing of system overloads, provide rerouting of power to prevent or minimize a potential outage, support faster and accurate response, enabling rapid diagnosis and improved decision support [24]. The messages from the smart sensors requires a communication network for transmitting of data to the grid operators and data centre for analysis of the data. The application of sensing and cloud computing technologies enables automatic detection of data from the distribution network and ability for the utility to view, analyze and store this data in data centers.

2.3 Current Distribution Electric Grid Status in Zambia

In Zambia the distribution network consists of voltage levels 33kV, 11kV and 0.4kV. The 0.4kV voltage level is where customers are connected to the electric grid [13]. In Zambia the entire 0.4kV electric grid is not monitored. Monitoring of the distribution electric grid usually ends at 11kV voltage level. Monitoring of the 33-11kV is through the Supervisory Control and Data Acquisition system consisting of remote unit sensors installed in the substations. Monitoring of this voltage level is limited to monitoring of only the outgoing feeders from the substations. The monitored parameters are status of the equipment in the substation and power measurements. This monitoring is made possible through the use of Remote Terminal Units (RTUs) which collect status of equipment such as breaker and isolator status and measurements such as voltage and current [7]. The information collected by the RTUs is transmitted to operation centers for monitoring and analysis. Most of the 33-11kV electric grid network consists of power lines branching off from the main electricity lines coming from the substations. The power line branches are where pole mounted transformers are installed to step down the voltage to 0.4kV voltage level and supply the customer through service cable drops.

There are no sensors installed on the power lines branching from the main electricity lines and on the 0.4kV power lines. This entails that the power utility has no visibility or situation awareness of this part of the electric grid. When a fault occurs in this part of the electric grid the power utility is not aware until it is reported by the customer. Usually customer calls, sms or physical report is what initiates the dispatch of personnel to attend to the fault.

Installation of sensors in this part of the distribution electric grid is needed to enable visibility and situational awareness of the grid. Smart sensors installed either at the customer premises or directly onto the distribution line will enable the monitoring of this electric grid. These sensors would enable monitoring of the various faults associated with the distribution electric grid such as power failure, low voltage, short circuit faults resulting from line-to line fault, double line-to-ground fault, single line-to-ground fault and three phase fault, open circuit faults and transformer faults [25].

2.4 Cloud Computing

2.4.1 Definition

Defining cloud computing depends on the expert talked to, cloud computing can be defined from various perspectives but a major and generally accepted definition of Cloud Computing comes from the National Institute of Standards and Technology (NIST). The NIST definition essentially says that: "*Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction"* [26].

The cloud is defined as a network or internet, which is present at a remote location. Cloud computing can provide services over a public or private WAN, LAN or VPN Network [27]. Cloud computing enables network access to a shared pool of networks, servers, storage, applications, and services [28]. In cloud computing users use the internet to access software running on hardware in a data center without knowledge of, expertise with, or control over the technology infrastructure that supports them [29].

2.4.2 Cloud Computing Technology

Cloud computing technology is based on the computing platform of the internet. This allows the user to be able to access the resources as long as they have access to the internet. Cloud computing refers to both the applications delivered as services over the Internet and the hardware and systems software in the data centers that provide those services [30]. The computing hardware resources can be shared, providing data storage services for different users and a platform for running different applications [31] [32]. Depending on the cloud deployment model the user of cloud services never has to buy or upgrade computing hardware and software and does not need to worry about disaster recovery therefore significantly simplifying business continuity planning [32]. Cloud computing technologies have four deployment models namely private, public, community and hybrid deployments [33] [34] [35]. These deployment models define the purpose of the cloud and the nature of how the cloud is located [33]. Cloud computing offers many services such as

CPU, memory, storage, web services, multimedia, custom software, operating system and virtual machines through service models namely Infrastructure as a service,(IaaS), Software as a service(SaaS) and platform as a service (PaaS) [36] [37] [38]. These deployment and service models enables cloud computing to offer high reliability, high efficiency, scalability, large storage capacity and low cost which enables it to be used in many applications such as agriculture sensing, distributed data collection and sensing, Remote Tracking and Monitoring, Animal Behaviors, Environmental Condition Monitoring, Building Surveillance and Security, Healthcare Monitoring, Smart Meter Readings, Aviation and Aerospace Safety [39].

2.4.3 Cloud Computing Architecture

According to [29] cloud computing architecture refers to the software and hardware systems involved in the delivery of cloud computing services. The architecture consists of deployment and delivery models. Figure 2.1 below shows the cloud computing architecture.

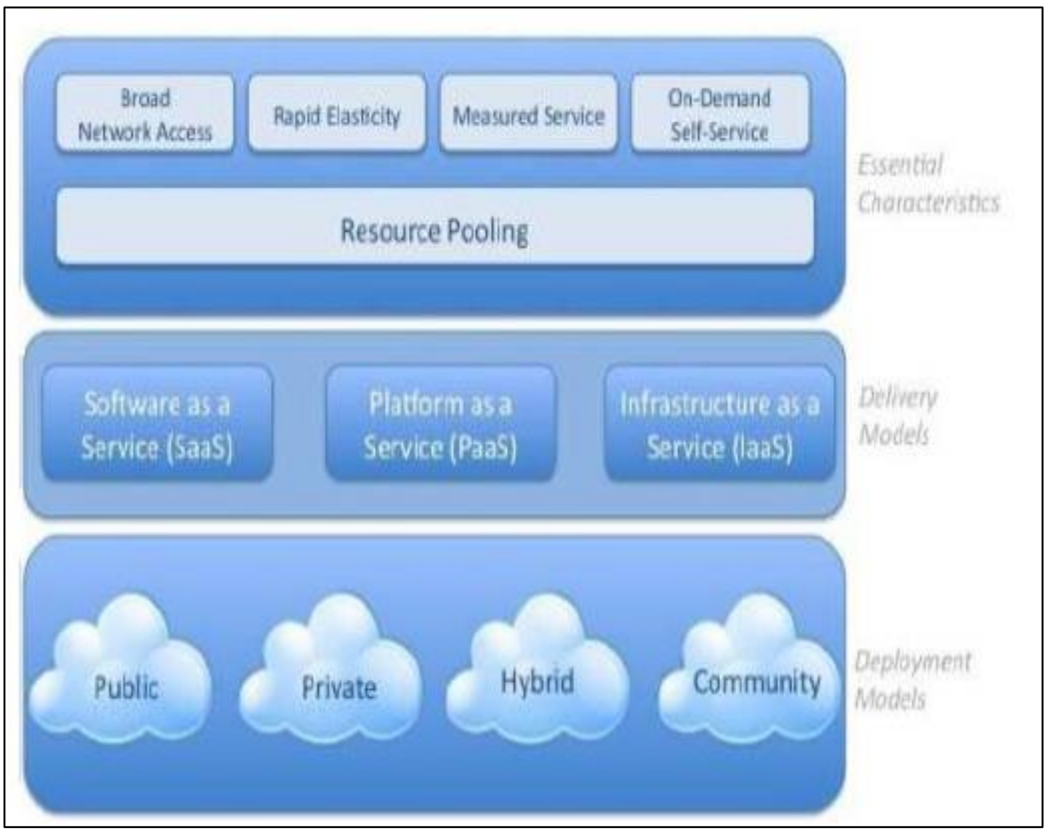


Figure 2.1 Cloud Computing Architecture [40]

2.4.3.1 Deployment Models

A deployment model defines the purpose of the cloud and the nature of how the cloud is located [33]. Cloud computing has the following deployment models

a) Private Cloud

This is a cloud architecture which is designed to be used exclusively by a single organization [26] [34]. A private cloud can be built and managed by the organization's own IT specialists, by a cloud provider or by third party such as an outsourcing firm [41]. Data centre setup, installation and maintenance costs are borne by the organization which returns complete control of the cloud services to ensure reliability and security [35]. Private clouds maybe on or off premises and can only be accessed within the organization it has been designed for. The organization for which the cloud is designed owns the cloud infrastructure and controls how the applications are deployed [35]. Private cloud offers the advantages of higher security, privacy and more control but comes with disadvantages of more restriction and high cost [27].

b) Public Cloud

Public clouds are clouds which are run by third parties with applications of various customers running on the clouds servers, storage systems and networks [41]. An organization selling cloud services owns the cloud and makes it available to the general public. It is sold on demand though it can be free to use. In instances where the service is sold the customer usually pays for the CPU, storage, or bandwidth they consume [42]. Leading public cloud providers include Amazon Web Services (AWS), Microsoft Azure, IBM SoftLayer, and Google Compute Engine [42]. Public cloud comes with the advantage of low cost, reliability and high scalability but also has disadvantages such as low security and being less customizable [27].

c) Hybrid Cloud

A hybrid cloud is a combination of multiple cloud architectures which interoperate through some standardization and protocols [38] [28].In hybrid cloud, public and private cloud architectures interoperate with non-critical processing and information being stored on the public cloud and critical information and storage being done on the private cloud [28]. Hybrid cloud offers the advantages of being scalable, secure and flexible. The disadvantage associated with hybrid cloud is network complexity [27].

d) Community Cloud

A community cloud is a cloud architecture which is shared by a group of organizations with common goals and similar projects [28]. The organizations in a community cloud share common concerns such as their mission, policies, security and regulatory compliance needs [38]. The cloud computing services are hosted by a data centre of a third party enterprise or one of the organizations part of the cloud community. Community cloud provides advantages of low cost because of shared infrastructure but has disadvantages of low security [27].

2.4.3.2 Service Models

The cloud computing services can be delivered by using three service models which control at what level the resources are offered and dictate organization control over the computing resources and applications [36]. These service models are Infrastructure as a service (IaaS), Platform as a service (PaaS) and Software as a Service (SaaS).

In Infrastructure as a service model the client does not need to provide the infrastructure. The cloud computing services are provided in form of hardware, network and storage devices as on demand service [37]. It allows users to deploy and run operating systems and applications allowing the provision of CPU Cycles, storage capacity, network infrastructure and servers automatically through a web based management console [1]. It is applied where demand on infrastructure is constantly changing and for new organizations without capital to invest in infrastructure [26] .

In Software as a service model cloud provider owned applications running on the platform and infrastructure are provided for the client. The provider installs, manages and maintains the applications [43] and the customer’s responsibility is to enter and manage its data and user interactions and do not need to be aware of the infrastructure or platform on which the application is running [38]. SaaS is scalable, accessible worldwide and users do not have to concern themselves with updates, hardware installation, license payments, middleware configurations, system administrations for subscribers and thus software installation, configuration, and customization is accelerated for them [36]. SaaS is applied in areas where applications have a significant need for web or mobile access, were software is to be used for a short term and were software demand spikes significantly [26].

Platform as a service model offers the client the platform for execution and development of applications. Servers, operating system and network connectivity are provided by the service provider and are not managed by the customer [1].The development environment is determined by the cloud provider and the client has control over installation and management of the applications being deployed and application environment settings of the platform [40] [38].

2.4.4 Advantages and Disadvantages of Cloud Computing

Advantages

Cloud computing is said to offer the following advantages most of which enable it to be applied in remote sensing.

i) Flexibility

There is no limitations in the resources that can be used nor the medium through which cloud services can be accessed and used. The cloud computing services can be accessed anywhere at any time making them suitable for use in remote monitoring [44] [26].

ii) Low Cost

Companies using cloud computing services save on hardware as they utilize the resources of the cloud hosting companies for storage of data and applications [44]. There is also a saving in the software updates, management costs, and data storage costs as this is done by the hosting company [44]. Providing hardware and software based on the requirements of the users results in cost savings [1]. The customer only pays for the infrastructure that is being used and is not responsible for the entire infrastructure that may be in place thus saving on cost [45].

iii) Speed and Scales

There is no need to procure and setup hardware and software as these are already setup and provided by the cloud services provider [44]. Cloud computing offers rapid deployment model of applications and the user can easily increase or decrease applications used according to their requirements [44].

iv) Easier Management of Data and Information

Data is centrally located and well organized making it easier to manage and all transactions are recorded making it easier to track employee activities [45]. Whilst resources are managed more effectively and efficiently by having the applications request and relinquish only what they need [45] [46].

v) Device Diversity

Cloud computing services can be accessed anywhere on any device as long as there is access to the internet [1].

vi) Increased Storage Capacity

The cloud resources offered can store more data than our personal computers saving users from having to spend on increasing the memory capacity of computers [1] [26].

vii) Easy to Learn and Understand

Cloud computing services are easy to learn and understand since they are based on technology which users are mostly familiar with such as internet, Gmail and Google [46].

viii) Automatic Updating

Updating of software on cloud computing is automatic, saving companies time and effort to update multiple servers [46] [26].

ix) Customize Setting

Customization of business applications in cloud computing makes businesses more competitive [46].

Disadvantages

i) Dependency

The users of cloud computing are too dependent on the cloud service provider as all the data is stored by the provider [46].

ii) Risk

There is a risk of losing information stored on the cloud as the user has no control on the operation of the cloud resources [46].

iii) Requires a Constant Internet Connection

Cloud computing relies on an internet connection making it dependent on the reliability of the internet connection. When internet connection is offline so are the users and the cloud computing resources offered, resulting in the user not being able to access the data stored on the cloud. [46].

iv) Security

Determining and maintaining the security of data stored on the cloud is difficult since it is handled and stored on third parties' resources which are usually shared amongst a number of users [26].

v) Migration Issue

Usually migration from one cloud services provider to another becomes an issue since it involves transfer of huge amounts of data [26].

2.4.5 Characteristics of Cloud Computing

The basic cloud architecture consists of two main parts. The front end and back end offering services that can be used in sensing and remote monitoring.

2.4.5.1 Cloud Computing Front-End

This is the client part and consists of interfaces and applications required to access cloud computing resources through devices such as desktop computers, mobile phones, tablets, laptops, smart phones and workstations [44]. The clients request for services from the service provider choosing their service in real time and customizing them according to their requirements [1]. The front end clients are also referred to as the cloud consumers as they utilize cloud services. The clients can be categorized into three and these are

i) Mobile Clients – these are clients who are always on the move and consists of devices such as smart phones, PDAs, iPad, tablets [1].

ii) Thin Clients – these are clients without their own hard disk but have enough capacity to access cloud computing resources [1].
iii) Thick Clients – these are clients with their own processors and hard disk to access cloud computing resources [1].

The client end enables the monitoring of sensed parameters from remote sources such as measurements in electricity grid, status of equipment, food storage management, inventory management and condition monitoring [47] [48] [49]

2.4.5.2 Cloud Computing Back-End

The backend of cloud computing offers huge storage services for information collected to be stored on remote servers, and then be accessed via the internet [44]. It consists of servers, huge data storage, security, deployment models, service and cloud infrastructure that create the cloud of computing services and is usually referred to as the cloud service provider end [44]. The backend is where the service provider have their information and communication infrastructure consisting of virtualized application and storage servers connected to each other in a network. The backend server may be geographically separated to enable the service provider to serve client anywhere in the world with high speeds [1].

2.4.6 Cloud Computing and the Electric Grid

The data obtained from an automated electric grid includes real-time online measurement and status data, equipment condition, basic information, test data, operating data, defect data, inspection records and other information [50]. The amount of data is huge and requires large storage capacity and reliability. The automation of the grid also requires the use of different third party applications which requires sharing of information with consumers [51]. The various applications used in electric grid automation requires time-varying computational needs, reliable data storage, ease of access and availability [52]. Cloud computing provides the services required for this data management such as computing and storage services, scalability, security, ease of sharing data, access of data through the internet and cost effectiveness [53].

2.5 Sensor Technology

2.5.1 Introduction

Sensors and sensor systems provide safety, security, and surveillance, besides ensuring that our environment is monitored. Sensors are an interface between the physical world and the world of electrical devices used in many equipment and applications to detect and monitor change [54]. Microprocessor enabled products which need electrical input voltages in order to receive instructions and information provides an opportunity for the use of sensors in a wide variety of products. By use of a wide range of sensing techniques sensors are able to measure chemical, biological, and physical quantities [55]. The action of sensing creates an output signal, via a transduction process, that must be processed and transmitted in some manner in order for a person or another device to do something useful with it [56]. Sensors having the capability to acquire, process, and output measurements over a data bus in a single package are referred to as smart sensors. Radio communications, sampling, remote manageability, and enclosure features can enhance the capabilities of these smart sensors to deliver smart sensor systems [57]. In smart sensor systems signal conditioning, data processing, transmission, storage, and display of the sensor measurement is provided by a combination of hardware and software. According to [55] a sensor with a microcontroller, a wired/wireless interface, and memory is called a sensor platform. Sensor platforms are able to detect physical quantities such as pressure, movement, temperature, heat and light enabling applications in electrical grid monitoring, cars, machines, aerospace, medicine, manufacturing and robotics.

2.5.2 Definition of Sensors

Sensing technology consists of transducers called sensors and actuators. Transducers are devices that converts a signal from one physical form to a corresponding signal having a different physical form. A sensor is usually referred to as an input transducer and an actuator as an output transducer [58]. According to [54] a sensor is a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument. Figure 2.2 shows sensor input and output.

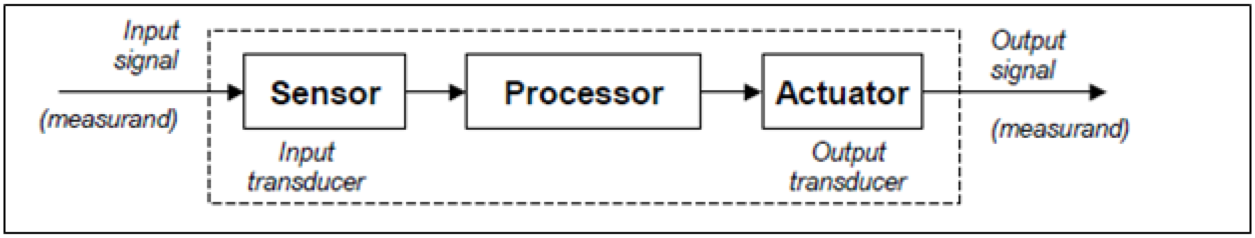


Figure 2.2 Sensor Input and Output [58]

2.5.3 Sensor Platforms

Sensor Platforms are platforms with a microcontroller, a wired/wireless interface, and memory. They are able to interface with external sensors and have an interface for programming the microcontroller to perform a specific function [55]. Radio communications, sampling, remote manageability, and enclosure features on smart sensor platforms enables them to deliver smart sensor systems [55]. Smart Sensor systems integrate signal processors, and intelligence capabilities in a single chip [59]. They incorporate sensing and transduction functions with an analog interface circuit, a microcontroller with an integrated analog-to-digital converter (ADC), and an input/output (I/O) bus interface in a single integrated package [57]. [55] Further mentions that physically or wirelessly connecting sensor hardware and actuators to the sensor platform's sensor interface (digital or analog) makes the platforms useful for prototyping. Many sensor platforms exist but the most common sensor platforms are Arduino, Shimmer, and smartphones.

2.5.4 Microcontrollers

More and more advanced semiconductor devices and equipment's have been built with very high intensity and density because of the increased development of Very Large Scale Integrated Circuits (VLSI) in recent years. Millions of MOSFETs integrated in a very small semiconductor chip to generate multifunction processors make up Microprocessors [60]. A microprocessor is a VLSI device that can be programmed to perform specific functions or tasks [60]. One of the most popular and important microprocessors is the Central Processing Unit, or CPU, which is the center of a computer and used to process and coordinate all operations on a computer. By combining microprocessors with a memory unit, and I/O ports into a single semiconductor chip a microcontroller system can be built [60]. Figure 2.3 shows the structure of a microcontroller system.

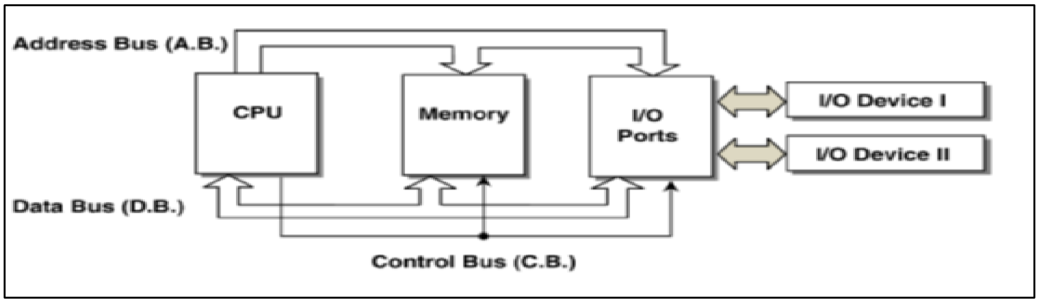


Figure 2.3 Basic Structure and Configuration of a Microcontroller System [60]

A microcontroller is an integrated circuit consisting of a Processor, Memories, Peripherals, Inputs and outputs.

2.5.5 Microcontroller Development Boards

A Microcontroller development board is a printed circuit board (PCB) with circuitry and hardware designed to enable testing with a certain microcontroller board's features [61]. Microcontroller development boards are used in the largest phase of product design and manufacturing cycle called the design and prototyping phase [62]. Microcontroller development boards are used in the design and prototyping phase to save time. The Development boards are combined with a processor, memory, chipset and on-board peripherals like Liquid Crystal Display, Keypad, Universal Serial Bus, serial port, Analogue to Digital Converters, RTC, Motor Driver ICs, SD card slot, Ethernet, etc. with debugging features [61]. In development boards all of the hardware and circuitry are already assembled making experimentation and general prototyping much easier and preventing doing of repetitive tasks [62]

2.5.5.1 Types of Microcontroller Development Boards

The two commonly used development boards are Arduino and Raspberry Pi. This study will focus on Arduino because it is the microcontroller used to develop the prototype.

a) Arduino

The arduino microcontroller board is usually used in prototyping**.** It is described in [63] as being the simplest and most powerful open source platform for electronics and prototyping based on Atmel AVR processor hardware and software [63]. Arduino is based on a simple input/output (I/O) board and a development environment that implements the Processing language [64]. Arduino is composed of two major parts: the Arduino board and the Arduino IDE.

i) Arduino Board

The Arduino board consists of a simple input/output board combined with a processor, memory, chipset and on-board peripherals like Liquid Crystal Display, Keypad, Universal Serial Bus, serial port, Analogue to Digital Converters, RTC, Motor Driver Integrated Circuits, SD card slot, Ethernet, etc. [61] [64].

ii) Arduino IDE

The Arduino Integrated Development Environment is a special program which can run on a computer. It uses a simple language modelled after the processing language to allow for code to be programmed for the Arduino board microcontroller [64]. The IDE translates the code into C language and then using the compiler this code is translated into a form which can be processed by the microcontroller [64].

Advantages of Using Arduino

The use of the Arduino development board has risen in popularity because of its many advantages such as

i) Inexpensive - compared to other microcontroller platforms, Arduino boards are relatively inexpensive. The hardware used is cheap and replacements do not cost much. [63] [64]
ii) Ability to run on Cross-platforms - The Arduino Software (IDE) can be installed and run on various operating systems such as Windows, Macintosh OSX, and Linux operating systems. Most microcontroller systems are limited to Windows [63].
iii) Simple and clear IDE software environment - The Arduino Software (IDE) is easy-to-use for beginners and enough for advanced users to take advantage of as well. Programming is via a USB port making it easy since most modern computers have USB ports. [64]

iv) Open source and extensible software - The Arduino software is open source and can be extended by experienced programmers. The language can be expanded through C++ libraries. [63]

v) Open source and extensible hardware - The plans of the Arduino boards are issued under a Creative Commons license making it possible for experienced circuit designers to extend and improve it [63].

2.5.6 Sensor Platforms and the Electric Grid

The interconnected nature of the electric grid demands that grid variables and assets are monitored at all levels. Sensor platforms provide that monitoring needed. Sensors in the electric grid are needed to measure a wide range of physical parameters [65]. These physical parameters which need to be sensed in the electric grid include Voltage, current, power, power factor, frequency and harmonics. The sensors detect and measure power flow, voltage level, and power quality from the generation, transmission and distribution systems [66]. The electric grid employs a multilayer of sensors including electrical, mechanical, chemical, potential and current transformers [66]. Sensors in the distribution network are usually sparse and in most networks entirely absent. [67] Suggests that the use of smart line sensors are options that can be used for distribution grid power state monitoring. In [65] they mention that information received from sensors can assist in grid planning involving planning the generation, transmission and distribution, grid operations which involves real-time monitoring of electrical equipment to ensure stability and reliability and then finally in events analysis to prevent disturbances and outages. Additionally sensors in the electric grid can be used to determine the state of power, faults, devices, outages, topology and power quality [67].

2.6 Cellular Wireless Communication

2.6.1 Introduction

Wireless communication involves the transfer of information between points that are not connected by an electrical conductor [68]. Most wireless technologies use radio waves whose distances can be a few meters or thousands and millions of kilometres [68].

Wireless networks can be classified according to the communication signal range and application, into wireless wide area networks (WWANs) , wireless metropolitan area networks (WMANs) , wireless local area networks (WLANs), wireless personal area networks (WPANs), and wireless body area networks (WBANs) [69] [70]. Table 2.1 shows the basic characteristics of wireless networks

Table 2.1 Basic Characteristics of Wireless Networks [69]

Classification	Communication range	Examples	Current major applications
WWAN	> 10 km	GSM, UMTS	Mobile Internet access
WMAN	<10 km	IEEE 802.16	Broadband Internet access
WLAN	< 100 m	IEEE 802.11a/b/g/n	Internet access, file sharing
WPAN	< 10 m	IEEE 802.15 TG1	File sharing, headset
WBAN	<1 m	IEEE 802.15 TG6	Body senor network

Wireless wide area networks are also referred to as cellular networks. Wireless Wide Area Networks use licensed frequencies and extend beyond 50 kilometers [70]. Through multiple satellite systems or antenna sites looked after by the service provider, cellular networks can be maintained over large areas. There are mainly two available WWAN technologies: Cellular networks and Satellites [70]. This literature review will focus on cellular networks.

2.6.2 Cellular Networks

The cellular network technologies, 4G and forthcoming 5G wireless services are a rapidly growing industry and have increased an organization's ability to reach customers regardless of their locations. Cellular technologies have evolved over the years beginning with first generation (1G) cellular systems, through second generation (2G) and third generation (3G) systems, and then fourth generation (4G) systems. With the fifth generation systems being currently developed [71]. The first generation is no longer in use so this research will concentrate on the 2nd, 3rd, 4th and 5th generations of cellular networks.

2.6.2.1 Evolution of Cellular Systems

Cellular systems started with 1st generation which is no longer used as it offered limited services.

The 2nd generation systems based on digital, supporting voice and low speed data were discovered in the late 1990s [72]. They use TDMA (time division multiple access) and CDMA (code division multiple access) which enables it to offer higher spectrum efficiency, better data services, and more advanced roaming than 1G systems [73]. Its main aim was to use the bandwidth of 30 to 200 kHz with data rate of 64kbps to deliver services like Text, Pictures, SMS, e-mails etc. [74]. With downloading being an issue and browsing speed low, users were not satisfied with the data rates which lead to 2.5G and 2.75G being introduced [74]. 2.5G and 2.75G provided users with more browsing speed and allowed downloading of mp3 songs by increasing data rates to 144kpbs and 180kbps respectively. 2.5G and 2.75G were referred to as GPRS (General Packet Radio Service) and EDGE (Enhanced Data rates for GSM Evolution) cellular technologies [75]. The basic disadvantages of 2nd generation cellular systems include having no support for higher data rates, weak digital signal and inability to handle complex data.

2.6.2.2 Third Generation Cellular Systems

Third generation cellular systems were developed to meet the growing demand in network capacity, high speed data transfer, multimedia applications supporting greater voice and data capacity and high data transmission at low-cost with backward compatibility with 2G and 2.5G systems [71]. It uses packet switching technique and Wide Band Wireless Network which provide global access and more clarity. It is called UMTS (Universal Mobile Telecommunication System) in Europe and CDMA2000 in America [76]. 3G systems have a bandwidth of 15-20MHz for high speed internet and provide speed of around 125kbps to 2Mbps for faster downloading, thus enabling clear and continuous voice and video calling [74] . According to [77] [76] the basic disadvantages of 3G are high cost of upgrading, high power consumption and only 3G compatible handsets can be used.

2.6.2.3 Fourth Generation Cellular Systems

As the data requirements increased, the downlink and uplink throughput rates were improved by employing higher modulation techniques. This resulted in the introduction of the IP based fourth Generation mobile system in the late 2000s [78]. 4G is also called LTE (Long Term Evolution) and has been developed to be able to inter-operate with the other cellular systems [78]. 4G technology provides high speed, high quality, low latency, high capacity, security and low cost services for voice and data services, multimedia and internet over IP [76]. LTE is able to provide download rates of about 100 Mbps for multi-antenna (2x2) systems and upload rates of about 50Mbps by using Orthogonal Frequency Division Multiple Access (OFDMA) [78]. 4G also uses MIMO (Multiple Input Multiple output) technology to enable signal quality and channel capacity enhancement by transmitting different signals on multiple antennas [71].

2.6.2.4 Fifth Generation Cellular Systems

The fifth generation mobile and wireless communication network will be supported by LAS-CDMA, OFDM, MC-CDMA, UWB, Network-LMDS and IPv6 [79]. Growth in video traffic, shortage of spectrum, need to minimize energy requirements of web devices and network infrastructure and the desire for higher data rates propelled the development of 5G systems [79]. The major difference between 4G and 5G is that 5G provides higher speeds, lower battery consumption, better coverage, higher number of supported devices, lower infrastructure costs, higher versatility and higher reliability of communications. Table 2.2 shows a comparison of the 5 generations of cellular systems

Table 2.2 Cellular Technologies Comparison [79]

Generation	1G	2G	2.5G	3G	3.5G	4G	5G
Start	1970-1980	1990-2000	2001-2004	2004-2005	2006-2010	2011-Now	Soon (2020)
Data Bandwidth	2 Kbps	64 Kbps	144 Kbps	2 Mbps	More than 2 Mbps	1 Gbps	more than 1 Gbps
Technology	Analog Cellular	Digital Cellular	GPRS, EDGE, CDMA	CDMA 2000 (1xRT, EVDO) UMTS, EDGE	EDGE. Wi-Fi	WiMax LTE Wi-Fi	wwww
Service	Voice	Digital Voice, SMS,Higher Capacity Packet Size Data	SMS, MMS	Integrated High Quality Audio, Video & Data	Integrated High Quality Audio, Video & Data	Dynamic Information access, Wearable Devices	Dynamic Information access, Wearable Devices with AI Capabilities
Multiplexing	FDMA	TDMA, CDMA	CDMA	CDMA	CDMA	CDMA	CDMA
Switching	Circuit	Circuit, Packet	Packet	Packet	All Packet	All Packet	All Packet
Core Network	PSTN	PSTN	PSTN	Packet N/W	Internet	Internet	Internet
Handoff	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal & Vertical	Horizontal & Vertical

2.6.2.5 Architecture of a Cellular Network

The architecture of a cellular network consists of a radio access subsystem, network subsystem and management subsystem [80] as shown in figure 2.4

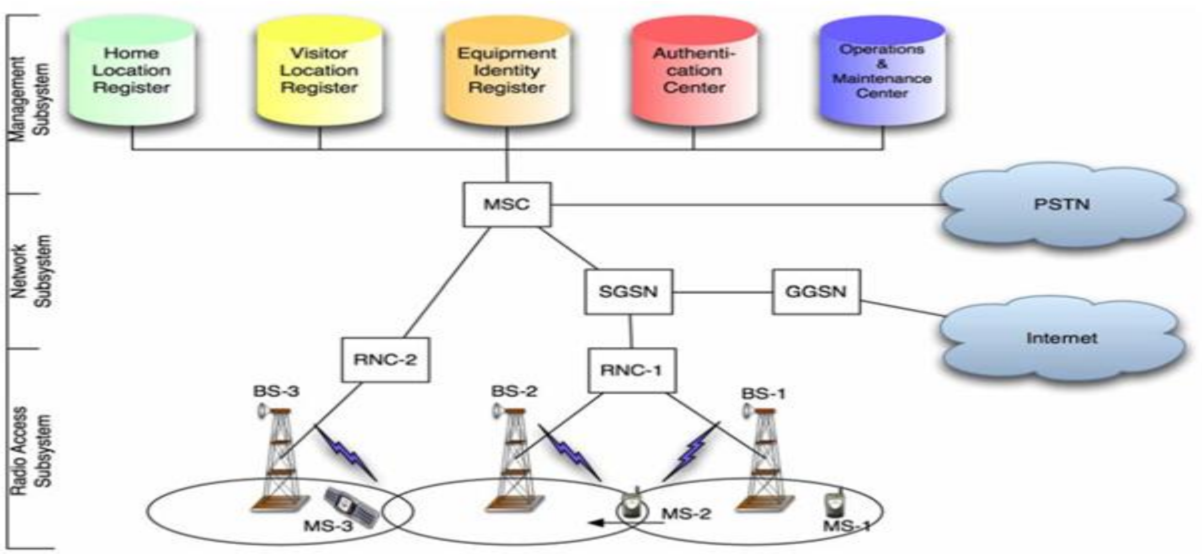


Figure 2.4 Generic Cellular Network Architecture [80]

The radio access subsystem consists of the following equipment

i) Mobile station (MS), also called user equipment is the device whose position is to be determined. It consists of a transceiver, an antenna, and control circuitry [80] [81]. The MS is used to make and receive voice calls and for data download or upload.

ii) Base stations (BSs – also called Node Bs) are fixed transmitters that are points of access to the rest of the network. They consist of several transmitters, receivers and antennas which handle full duplex communications [81]. An MS communicates with a BS during idle periods for signaling purposes, for voice calls or for data transmission [80].

iii) Radio network controllers (RNCs) also known as base station controller (BSC) Control the Base station and manage the radio resources of each BS and MS such as frequency channels, time slots, spread spectrum codes and transmit powers [80].

The network subsystem consists of

i) The mobile switching center (MSC) and GPRS1 support nodes (SGSN and GGSNs): These carry voice and data traffic and handle routing of calls and data packets [80]. The mobile switching center (MSC), the GPRS1 support nodes (SGSN and GGSNs) and gateway are responsible for handling voice and data. They perform the task of mobility management, where they keep track of the cell or group of cells where a MS is located and handle routing of calls or packets when an MS moves from one cell to another [82]. They connect to the public switched telephone network (PSTN) and the Internet.

The management subsystem consists of several databases used for keeping track of the entities in the network that are currently serving the MS. They handle security issues, accounting and other operations [80]. These databases include

ii) Operations and Maintenance Centre database – the operations and maintenance centre database is used for ensuring a backup of the system is available for restoration in case of loss of other databases [82].

iii) Home Location Register database - The home location register (HLR) is a centralized database in charge of the management of mobile subscribers. It maintains subscriber profiles for all subscribers authorized to use the network, stores information about any active IP addresses assigned to an MS as well as subscription and location information [82].

iv) Authentication Center database – Stores confidential data for each subscriber used for authentication and encryption. It stores a secret authentication key for each registered subscriber and implements the security algorithms [82].

v) Equipment Identity Register database - is a database whose main function is to maintain a list of IMEIs for all known GSM MEs. This list is used to recognize whether an MS that attempts to register to the network is using equipment that is obsolete, stolen, or nonfunctional and allow the network to deny or limit services to such devices [82].

vi) Visitor Location Register database - (VLR) is a database containing temporary information for the subscribers who have roamed into the geographic area it serves [82].

2.6.3 Cellular Communication and the Electric Grid

Communication networks are important in the electric grid. These communication networks are needed to transmit data from the sensors in the electric grid to centralized data centers for analysis. Among the key parameters which are necessary for communication networks in electric grids are bandwidth and latency [83]. Normally bandwidth of 64kbps to 50Mbps and low latency are required for real time function and analytics which require sensed data to be delivered within a strict time constraint [67]. Communication networks in the modern grid consists of customer premises network, last mile networks (Neighborhood area network NAN, and Field area network FAN) and Back haul network (Wide Area Network WAN) for connection to the utility control and operations centre [21]. Cellular communication technology is used in the NAN and WAN networks to transmit data from several smart sensors to the power utility [84] [83]. 3G and 4G Cellular networks are used because of the high data rates provided covering distances of over 100km. The major advantages offered by the use of cellular technologies in the electric grid are high bandwidth, low latency, wide area of deployment on already existing infrastructure, high data transfer rates and security algorithms [85].

2.7 Software Development Methodologies

2.7.1 Introduction

Software development is a branch of Software Engineering which deals with the study and Application of engineering processes to the design, development, and maintenance of software [86]. Software development consists of many methodologies which provide a framework for planning, executing, and managing the process of developing software systems [86] [87]. Many software development methodologies exist, including Waterfall, Prototype, Agile development, Iterative, V-Model, Scrum and Cleanroom with Waterfall, Agile development and Prototype being the most commonly used [86]. The choice of software development method used usually depends on the organization, project, and team characteristics, as well as market and operational forces [86].

2.7.2 Waterfall

The waterfall model also known as linear sequential model describes the process model organized in a linear way consisting of – requirements analysis, design, implementation, testing, operations and maintenance [88]. Each step is completed independently, and the next stage cannot begin without successful completion of the one that precedes it [89]. The waterfall model includes requirement analysis where requirements are gathered from different sources and then used to form a design. In the implementation and testing stage the designed module is subjected to different implementation standards and tested to remove errors so as to build the actual software as proposed. After the implementation and testing stage the software operation and maintenance is carried out [88]. The waterfall method is suitable for small system projects where requirements are clearly defined by the project owner and the project manager [90]. The waterfall model was originally used for hardware development and so can be used for both hardware and software development [91]. Figure 2.5 shows the waterfall model.

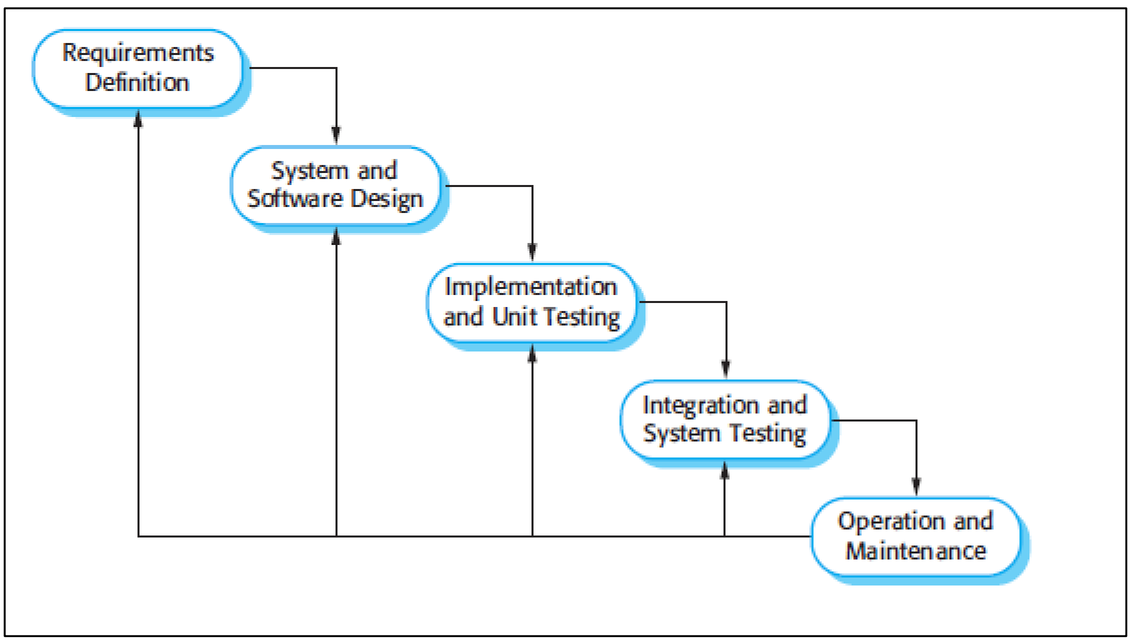


Figure 2.5 Waterfall Model *[88]*

2.7.3 Prototype Model

The prototype model involves creating an incomplete version of a software program being developed. It is used to enable the user understand how it will interact with the actual system thereby enabling them understand the requirements better [87]. Prototyping process is used in complicated and large systems for which there is no manual process or existing system to help determine the requirements and for new innovations and software projects which have not been developed before [87] [90]. In prototyping a prototype is created to perform a specific function, tested to check the results and from the comments arising from the results, the planning stage is done to meet the requirements [90]. Limitation of cost by understanding the problem before binding enough resources is the basic goal of prototyping [92]. This method is suitable for large scale projects where it is almost impossible to properly define exhaustive requirements before any actual coding is performed. Prototyping methodology is also suitable for unique or innovative projects where no previous examples exist [93]. Figure 2.6 shows the stages in prototype model.

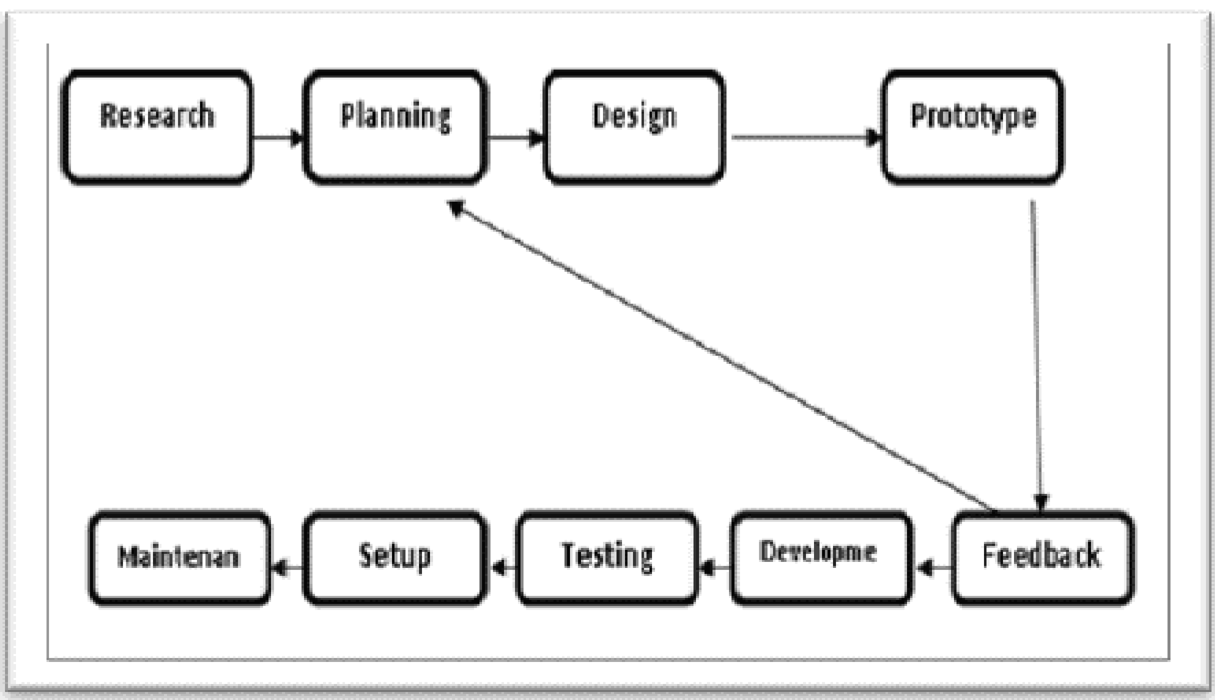


Figure 2.6 Prototype Model *[90]*

2.7.4 Unified Modelling Language (UML)

Models in software development allow engineers to reduce the complexity of the software systems. They are the means for the developer to reason about the requirements, communicating with stakeholders and documenting the system to ease the development task [94]. UML (Unified Modeling Language) is the modelling language usually used in software development and it involves use of use-case diagrams, class diagram, sequence diagrams, activity diagram, state-chart diagrams etc. [95]. UML diagrams are classified into fourteen diagrams on the basis of two category levels:

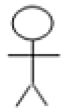
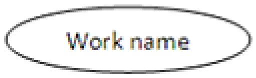
a) structural level; shows how different components of the system are related to each other on different levels of abstraction and these include class diagrams, object diagrams, package diagrams, composite diagrams, deployment diagrams and profile diagrams [96] [97].

b) Behavioral level; shows dynamic behavior of objects including temporal changes in objects, and their interactions with each other and these include use case diagrams, state machine diagrams, activity diagrams, sequence diagrams, communication diagrams, interaction overview diagrams and timing diagrams [96] [97].

2.7.4.1 Use Case Diagrams

In the Unified Modeling Language (UML), a use case diagram is a sub class of behavioral diagrams. A use case diagram is one of the object oriented diagrams. It shows how a system interacts with the external entities [98]. The Use case diagram is used to identify the primary elements and processes that form the system. Primary elements are called "actors" and the processes are called "use cases". Use case diagrams show which actors interact with each use case [99]. Use cases represent what the customer wants the system to do i.e. the customer's requirements of the system and is applied during the entire analysis and design process [100]. Use cases and actors are connected by associations. Table 2.3 below shows the elements and symbols used in use case diagrams.

Table 2.3 Elements and Symbols used in Use Case Diagrams *[99]*

Element	Name	Meaning
	Actor	External user of the system
	Use case	Work carried out in the system/ functionality expected by user
	connecter	Connection between user and use cases

2.7.4.2 Sequence Diagrams

Sequence diagrams are used for modeling interactions between objects. It describes the interactions between objects to fulfill a specific task [100]. A sequence diagram describes the order in which method calls are executed and when they terminate [101]. They describe the flow of messages, events and actions between objects. They also show concurrent processes, activations and time sequences that are not easily depicted in other diagrams [102] .They are used for requirements analysis as well as for test definition or after implementation.

A sequence diagram consists of

i) Participant (actor): indicates an object or entity that acts in the diagram. The diagram starts with an unattached "found message" arrow

ii) message: indicates communication between participant objects

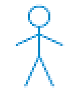
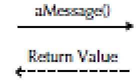
iii) the axes in a sequence diagram: consists of

Horizontal: indicating which object/participant is acting

Vertical: indicating time [102].

iv) Object lifelines; are used in the sequence diagram to represent the existence of the object during a scenario.

Table 2.4 Elements and Symbols used in Sequence Diagrams *[103]*

Term and Definition	Symbol
An actor: ■ Is a person or system that derives benefit from and is external to the system. ■ Participates in a sequence by sending and/or receiving messages. ■ Is placed across the top of the diagram. ■ Is depicted either as a stick figure (default) or, if a nonhuman actor is involved, as a rectangle with <<actor>> in it (alternative).	 anActor <<actor>> Actor/Role
An object: ■ Participates in a sequence by sending and/or receiving messages. ■ Is placed across the top of the diagram.	anObject : aClass
A lifeline: ■ Denotes the life of an object during a sequence. ■ Contains an X at the point at which the class no longer interacts.	
An execution occurrence: ■ Is a long narrow rectangle placed atop a lifeline. ■ Denotes when an object is sending or receiving messages.	
A message: ■ Conveys information from one object to another one. ■ A operation call is labeled with the message being sent and a solid arrow, whereas a return is labeled with the value being returned and shown as a dashed arrow.	 aMessage() Return Value

2.8 Related Works

Related work carried out includes research in the use of sensors to sense various parameters including substation and transformer measurements, street lighting and condition monitoring of equipment. Cloud computing services are used for monitoring of sensed parameters.

Researchers in [104] propose a GSM cloud based street light control and fault detection system. They use a Wi-Fi module for sending faulty light alert messages to the cloud so that information can be captured anytime and anywhere and a GSM module is used to send an alert SMS to a mobile phone. Arduino microcontroller is used to sense and control the streetlights. A light dependent resistor is used to detect whether it is light or dark and is used to switch the lights on and off as well as determine which light is faulty. The study in [47] propose and develop an IoT based prototype model using the APC220 transceiver, GSM, GPRS, RFID, PIR, arduino microcontroller and cloud storage to curb theft of grain at storage points of the food reserve agency. PIR sensors are used to sense motion and send a logical signal to the microcontroller which together with the GSM/GPRS wireless module and RFID is used to send alerts to the cloud and track bags of grain. They concluded that once this technology is adopted, theft will be reduced and grain management in the FRA satellite depots will improve. However there was no provision for locating the satellite depots in their prototype. The researchers in [48] conducted a base line study on the challenges faced by ZAF in inventory management of spares and discovered that the major challenge was due to the manual inventory management which resulted into incorrect inventory reporting and pilferage of items. To address these challenges they propose a web based inventory management system using cloud architecture and barcode technology. The prototype application developed consists of the backend and the frontend components and users are created and managed by the system administrator in order to keep track of their activities. A barcode reader is incorporated to scan the barcode on the items. The barcode scan captures the barcode as well as other details on the scanned item which are then saved to the database. The developed prototype proved to be faster, efficient and more reliable than the manual and paper based system. The researchers however did not provide means of alerting ZAF in the case of spares being pilfered in the form of an alert on a cloud platform or an SMS to mobile phone. In [105] a localized data processing and decision-making framework for IoT enabled environment is proposed. It consists of a master unit, which efficiently manages local sensor networks in Smart Homes. This master unit collects data from the network of sensors installed in different locations within and around the house and transfers the information to the cloud. The master unit is able to determine the dependencies among the sensors whose output data can be predicted using data from other sensors. This minimizes redundancy in usage and power consumption and approximate decisions can be made in case of failure of some of the sensors. They conclude that this proposed framework can result in power consumption and bandwidth saving as certain sensors are powered-on only when the predicted output and last sensed output is above a predefined value. The researchers however concentrated on how power and bandwidth consumption can be saved by learning the dependencies of the sensors and not on how to actualize the use of these sensors in sending alerts to a cloud platform or a mobile phone. [106] Proposes a prototype based on remote sensor network including cloud and internet of things to aid the Food Reserve Agency in analytics, timely action and real-time reporting from all its food depots spread-out throughout Zambia. A baseline study was conducted which identified the challenges FRA had, such as manual report generation, no connectivity to remote warehouses, inability to track stock on demand, theft and spoilage of stock due to lack of environmental monitoring. The proposed prototype was made up of Raspberry Pi microcontroller, temperature and humidity sensors, motion sensors, GPS sensor, ZigBee transceivers and Wi-Fi access. Through these devices they are able to monitor temperature, humidity, location and motion through the cloud application. They concluded that modern warehousing relying on components such as sensors provide better grain storage, management, transparency of operations and hence lead to cost effective grain marketing which leads to better national food security. However the researchers concentrated on alert messages using Wi-Fi which covers distances of about 100metres and did not look at how GPRS or 4G can be used for the same purpose. The researchers in [107] use GSM technology for detection and monitoring of transmission power line faults. The system is able to send an SMS to the utility and the utility has the ability to set current limits to the system. A PIC microcontroller is used to sense the current, voltage and frequency of the system. The PIC microcontroller is able to detect short circuit limits by comparing the current sensed and the preset limit. When the preset limit is crossed the microcontroller sends a signal for tripping the system and an SMS alert is sent via the GSM network. Bidirectional communication was achieved making the setting of the short circuit current limit possible from a mobile phone. The researchers however did not look at how cloud application can further assist in monitoring the transmission line parameters nor did they explore the sending of alerts together with the location of the fault. The study in [49] presents a green data center air conditioning system with environment monitoring, air conditioning, communication, ventilation, and temperature control, while a cloud platform provides data storage, big data analysis and prediction, and up-layer application. Temperature and humidity sensor nodes are used for environment monitoring while Zigbee is used as mode of communicating the sensor information to the cloud platform. This in turn ensures modeling and analysis in the cloud, forecasting air conditioner running condition, as well as providing guidance for air-conditioning maintenance and care. The researchers used zigbee which has short transmission ranges and did not consider the use of Wi-Fi or cellular communication to provide longer distance coverage.

[108] [109] Propose a GSM based system for transmission and distribution fault detection. A microcontroller is used for sensing the voltage, current and frequency. This is then reported to a mobile phone and presented on a computer through serial RS232 communication. The researchers

however do not explore the use of cloud technology through the use of cellular communication nor do they explore the benefits of the use of location maps to indicate the location of faults detected. The researchers in [110] [111] propose the use of GSM technology to monitor substation parameters such as over voltage, under voltage, over current and send this information over to the operator mobile for further action. An SMS through GSM technology is used to send the change in status of the parameters to the operators and operators can send an SMS to read the parameters of the substation. They use a PIC microcontroller for sensing the substation parameters. The researchers however do not explore the use of cloud technology through the use of GPRS or 4G technology which offer higher speeds nor do they explore the benefits of the use of location maps for sending the location of faults detected. [112] Uses the combined GSM, SMS and ATMEGA16 microcontroller system to monitor transformer parameters such as oil level, temperature and load current. [113] Goes further to connect the microcontroller to a computer using RS232 to enable monitoring of the transformer condition. However the researchers did not explore the use of cloud services in monitoring the substation parameters.

From the proposed and implemented projects reviewed from literature, it has been observed that there is substantial potential to be tapped from the use of sensing and cloud technology in power systems and other sectors. It can also be noted that there exist a number of research gaps in the sense that there were no experiments or projects which made use of cloud and sensor technology as applied in three phase power failure management and monitoring enabling alert, location and measurement information to be transferred to both the mobile phone and cloud services for storage and for location on location maps.

This research attempts to develop a cloud based sensing device which will be installed on the 0.4kV distribution electricity lines for the purpose of detecting power failures and relaying this information to the cloud platform and mobile of field personnel. The location of the power failure will also be transmitted to the cloud platform and mobile phone enabling the power utility determine the location of the power failure. Further from the platform it will be possible to determine the duration of the power failure. This research will demonstrate how necessary this device is for the power utility.

2.9 Summary

In this chapter a comprehensive overview of the background theory on power failure management, current distribution status, cloud computing and sensing components was carried out. This was followed by a brief review of cellular communication technologies and software development approaches. Lastly, this chapter closed by looking at some examples of the related works to the application of sensing and cloud technology. From the proposed and implemented projects reviewed from literature, it was observed that there is substantial potential to be tapped from the use of sensing and cloud technology in power systems and other sectors and that there exist a number of research gaps in sensing and cloud technology which need to be explored.

CHAPTER THREE
METHODOLOGY

3.1 Introduction

In this chapter, the materials and methods used to conduct this study are presented. First and foremost, the methodology that was used to conduct the baseline study is presented. This is then followed by the methodology that was used to design the models and implement the prototype.

3.2 Baseline Study

The purpose of the baseline study was to establish the challenges faced by ZESCO (the service provider) and the electricity Clients in the current power failure reporting management model. This study employed exploratory and survey research designs. Exploratory Research Design is a research design described as the problem-finding phase of research where the researcher focusses on the scope of study [114]. The purpose of an exploratory research is the formulation of a problem. The major consideration of exploratory research is the discovery of ideas and theories that have not been completely explored [115]. Survey research is defined as "*the collection of information from a sample of individuals through their responses to questions*" [116]. This type of research allows for a variety of methods to recruit participants, collect data, and utilize various methods of instrumentation. Survey research can use quantitative research strategies using questionnaires with numerically rated items, qualitative research strategies using open-ended questions, or both strategies i.e., mixed methods [117]. Further, Survey Research Design is described as a type of research, which is used to give an overview assessing opinions, trends, beliefs and feelings of selected groups of individuals [95]. Exploratory and survey research was used to assess the challenges faced by both the electricity clients and ZESCO (the service provider) in reporting and addressing power failure respectively as they would be able to give the best insight into the challenges faced by ZESCO and the electricity clients .

3.2.1 Study Population

The population target for this study was employees from Zambia Electricity Supply Corporation who work in the customer service department as well as 383 electricity clients in Lusaka district.

3.2.2 Sampling Technique

The study selected electricity clients in Lusaka district and ZESCO employees in customer service department specifically call centre and faults centre. A Purposive Sampling method was employed in the selection of experts, as the interest was to target those with knowledge of the current power failure management model. However, in selecting, the electricity clients, a multistage cluster sampling method was employed in which eight (8) clusters (Townships) namely Matero, Kalingalinga, Makeni, Emmasdale, Chilenje, Kaunda Square, Garden and Chawama were selected using simple random sampling. Simple Random Sampling (SRS) is a sampling method in which the sample is selected unit by unit, with equal and independent chance of selection for each unit at each draw [118]. This method was selected because it is easy to conduct and each element has an equal chance of selection giving a true representation of the population. Following that selection, convenience sampling was then applied in which households were selected for questionnaire distribution. Convenience sampling provided an easy way of identifying the households to target for the research. Krejcie and Morgan sample selection technique guided the sample size for this study, which follows a curve of relational values between population and corresponding sample values at assumed standard error of 0.05. A sample size of Three hundred and eighty three (383) respondents was used in this study.

3.2.3 Calculation of Sample Size

Krejcie and Morgan sample selection technique guided the sample size for this study. In Krejcie and Morgan sample selection technique the following formula is used to determine sample size

$$S = \frac{X^2 NP(1-P)}{d^2(N-1) + X^2 P(1-P)}$$ Where [119]

S = required sample size

X^2 = 3.841 (the table value of chi-square for one degree of freedom at 95% confidence level)

N = the population size

P = the population proportion (assumed to be 0.50 since this would provide the maximum sample size)

d = the degree of accuracy expressed as a proportion (0.05)

In the study, the population size of electricity clients in Lusaka district was determined to be approximately 386,080 as at 31st June 2019. Based on Krejcie and Morgan's formula for determining sample size, for a given population of 386,080, a sample size of Three hundred and eighty three (383) would be needed to represent a cross section of the population as the calculation below shows.

$$S = \frac{(3.841 \times 386{,}080 \times 0.5) \times (1 - 0.5)}{0.5^2 \times (386{,}080 - 1) + (3.841 \times 0.5) \times (1 - 0.5)}$$

$$S = \frac{370{,}733.32}{968.89} \approx 383$$

3.2.4 Sample Size for each Township

ZESCO in Lusaka district is divided into four regions namely central, eastern, southern and western. Each of these regions is made up of townships. In this study two townships were selected from each region by simple random sampling.

The sample size for each township was calculated based on the overall population of electricity clients in Lusaka district and the number of electricity customers in each ZESCO region where the townships are based. Below is the method used to calculate the sample size for the townships in each region.

a) **Central Region**

In the central region the townships Makeni and Garden were selected through simple random sampling.

The population of electricity customers in the central region was captured as 65,872 as at 31st July 2019. Based on this population, the overall population from all four regions and the overall sample size, the sample size for the central region was calculated as follows

$$\frac{(\text{Population for central region})}{(\text{Overall population for all regions})} \times \text{overall sample size}$$

$$\left(\frac{65{,}872}{386{,}080}\right) \times 383 \approx 65$$

The Sixty five (65) was then divided into two and allocated to Makeni and Garden townships. In this case Makeni sample size was Thirty Two (32) and Garden sample size was Thirty Three (33).

b) **Eastern Region**

In the Eastern region the townships Kaunda square and Kalingalinga were selected through simple random sampling.
The population of electricity customers in the eastern region was captured as 94,251 as at 31st July 2019. Based on this population, the overall population from all four regions and the overall sample size, the sample size for the eastern region was calculated as follows

$$\frac{(\text{Population for Eastern region})}{(\text{Overall population for all regions})} \times \text{overall sample size}$$

$$\left(\frac{94{,}251}{386{,}080}\right) \times 383 \approx 94$$

The Ninety four (94) was then divided into two and allocated to Kaunda square and Kalingalinga townships. In this case Kaunda square sample size was forty seven (47) and Kalingalinga sample size was also forty seven (47).

c) **Southern Region**

In the southern region the townships Chilenje and Chawama were selected through simple random sampling.

The population of electricity customers in the southern region was captured as 119,901 as at 31st July 2019. Based on this population, the overall population from all four regions and the overall sample size, the sample size for the Southern region was calculated as follows

$$\frac{(\text{Population for Southern region})}{(\text{Overall population for all regions})} \times \text{overall sample size}$$

$$\left(\frac{119{,}901}{386{,}080}\right) \times 383 \approx 119$$

The hundred and nineteen (119) was then divided into two and allocated to Chilenje and Chawama townships. In this case Chilenje sample size was sixty (60) and Chawama sample size was fifty nine (59).

d) **Western Region**

In the Western region the townships Matero and Emmasdale were selected through simple random sampling.

The population of electricity customers in the western region was captured as 106,056 as at 31st July 2019. Based on this population, the overall population from all four regions and the overall sample size, the sample size for the Western region was calculated as follows

$$\frac{(\text{Population for Western region})}{(\text{Overall population for all regions})} \times \text{overall sample size}$$

$$\left(\frac{106{,}056}{386{,}080}\right) \times 383 \approx 105$$

The hundred and five (105) was then divided into two and allocated to Matero and Emmasdale townships. In this case Matero sample size was fifty-two (52) and Emmasdale sample size was fifty three (53).

3.2.5 Data Collection Sources

This research involved collecting information from both primary and secondary data sources. Secondary data sources included review of published reports on the subject such as books, essential Journals, conference papers, published academic papers and system documentation. Primary data sources on the other hand included questionnaire interviews with the electricity service provider (ZESCO) personnel and electricity clients in Lusaka District. Questions in these data collection tools contained both open and close-ended questions. This enabled the study extract both qualitative and quantitative responses.

Data collection was carried out over a period of Six weeks starting from the third week of August to the last week of September, 2019. During data collection, the researcher distributed the self-administered questionnaires to the respondents at all the target locations in Lusaka district in the first and second weeks. The researcher then gave the respondents sufficient time which was spread out into a few days to answer the questionnaires. The researcher collected all the answered questionnaires in the third, fourth and fifth weeks of the data collection period. Where the researcher noticed that the respondent was having difficulties in comprehending the questions in the questionnaire, one to one administration of questionnaires was conducted where the researcher explained what each question implied. In the sixth week, the researcher conducted unstructured interviews with key supervisors in charge of ZESCO customer call centre and faults centre. Qualitative and quantitative data was collected in these interviews.

3.2.6 Data Processing and Analysis

Data was analyzed by use of descriptive analysis through a computer based software called IBM Statistical Package for Social Sciences (SPSS).

3.2.7 Ethical Consideration

All the respondents who answered the questionnaires were not required to reveal their identities by writing their names or any information that would give away their identities on the questionnaires. Thus, the respondents were assured of confidentiality and non-persecution arising from their responses.

3.2.8 Limitations of the Baseline Study

The ideal situation would have been to collect data from all the electricity clients in all the provinces of Zambia. This was hindered by time, logistics and financial limitations.

3.2.9 Presentation of Findings

The data was summarized and presented in form of tables and figures such as pie charts and bar charts to facilitate understanding.

3.3 System Automation

The system requirements specification and model design phase of the research study employed the use of qualitative data which was collected through interviews with Call Centre and faults centre supervisors as well as call centre and faults centre operation documentation that were supplied by ZESCO. The interviews with the Call Centre and Faults centre supervisors provided a perspective of the current business processes ZESCO uses in its Power Failure reporting operations. The Call Centre and faults centre supervisor interviews and the documentation also provided the qualitative data needed to specify requirements for the system, design models and finally, develop the system prototype. The methodology that was used for the analysis, design and development of the software system is the Object-Oriented Systems Development Methodology (OOSDM). Using OOSDM it is easier to produce and understand designs as the real world functioning of the system is directly mapped into the system designed. This research study utilized some of the diagrammatic representations that are present in the Unified Modeling language such as use case and sequence diagrams to show the behavior of objects and their interactions with each other. The Water fall model System Development methodology was used for the entire prototype development in this research study. Waterfall method was used because it is simple and easy to use and manage and provides clear defined set of steps to follow during system design making it possible to predict the budget, timeline and scope of the design.

3.3.1 System Development

The prototype development followed a Systems Development methodology based on the waterfall model. The waterfall model consists of a set of steps or phases in which each phase uses the results of the previous one. The waterfall system development methodology consists of the phases (1) Requirements analysis, (2) Design, (3) implementation of hardware and software, (4) Testing, (5) Operations and Maintenance [88]. However because of time and financial constraints the following phases were used in the development of the prototype for this research

(1) Requirements analysis, (2) Design, (3) Implementation of hardware and software, (4) Testing

3.3.2 Requirements Analysis

In this stage the need for a new product is first recognized and general specifications are defined. The requirements describe what the system should do, the services that it provides and the constraints on its operation. The requirements were derived from the baseline study conducted through interviews and questionnaires administered to call centre and faults centre supervisors as well as electricity clients in Lusaka district. These requirements reflect the needs of electricity clients and ZESCO (service provider) for a cloud based power failure sensing management system.

System requirements can be categorized into functional and non-functional requirements. Functional requirements are statements of services the system should provide and non-functional requirements defines the performance attribute of a system such as scalability, capacity, availability, reliability, recoverability and data integrity [88]. The System Requirements Specification therefore, provides a complete description of all the functionalities and specifications for the proposed Cloud Based Power Failure Sensing management model.

a) Functional Requirements

Table 3.1 details the functional requirements required for the application processes.

Table 3.1 Functional Requirements - Application Processes

FR1	Users with the relevant access rights shall have the ability to view all the information about the faults. (Such users may include a Call centre agent, faults coordinator, field personnel, engineer and manager)
FR2	Users with the relevant access rights shall have the ability to view all the affected areas. (Such users may include a Call centre agent, faults coordinator, field personnel, engineer and manager)
FR3	Users with the relevant access rights shall have the ability to indicate power failure problem, update materials required, Generate order number for material and assign power failure faults. (Such users may include Faults coordinator, field personnel and engineer).
FR4	Users shall be able to generate reports
FR5	The system shall be able to update location and duration of the power failure fault. This shall be achieved by use of the 4G/GPRS/GSM/GPS module which will update this information on the cloud platform and mobile phone.

Table 3.2 details the system's information and data flows.

Table 3.2 Functional Requirements - System Information and Data Flows

FR1	The system shall consist of a microcontroller based device installed on a distribution power line to sense power failures.
FR2	The system shall receive data from the Arduino microcontroller through the 4G/GPRS/GSM/GPS cellular Module
FR3	The system shall sense power failure and generate power failure notification on the cloud platform and mobile phone of field personnel
FR4	The system shall send location of the power failure to the cloud and mobile phone accessed through google maps
FR5	The system shall capture history of any power failure events
FR6	The system shall display on the cloud platform the status of the three phases and voltage values for the three phases
FR7	The system shall display the date, time and status of the power failure for each phase

Table 3.3 details the hardware performance requirements the system shall abide by.

Table 3.3 Functional Requirements - Hardware Performance Requirements

FR1	Arduino Mega microcontroller board with Artmega2560 microprocessor for processing signals from the sensor is to be used
FR2	4G/GPRS/GSM/GPS Module for wireless transmission of information to the mobile phone shall be used
FR3	The 4G/GPRS/GSM/GPS module antenna shall be long range.
FR4	An electronic circuit shall be used for stepping down the 230V AC to 12 V AC and then rectified to 12V DC.
FR5	All hardware shall run on standard power (230V).
FR6	The system shall be able to sense loss of power supply in any of the three phases in an electricity distribution line
FR7	The system power shall be powered by one of the phases of the electricity line
FR8	Upon loss of supply from all three phases the system shall be supplied by a battery charged by a solar panel
FR9	A solar battery charge controller shall control the charging of the battery by the solar panel

b) Non- Functional Requirements

Table 3.4 details the software performance requirements the system shall abide by.

Table 3.4 Non-Functional Requirements - Software Performance Requirements

NFR1	Operating system, message passing and middleware, and programming language(s) used shall follow industry standards and be commonly available and widely used.
NFR2	The system shall monitor performance of the power sensing functionality
NFR3	The system shall be user-friendly and intuitive. Context sensitive help screens, prompts and meaningful error messages shall be provided.

Table 3.5 details the systems' availability and reliability requirements specifications.

Table 3.5 Non-Functional Requirements - Reliability and Availability

NFR1	The hardware part of the system shall be able to perform indefinitely without complete loss of service, except in the event of total failure of primary and backup power.
NFR2	The hardware part of the system shall be able to perform even after loss of supply from all three phases.

c) Proposed System Architecture Reflecting the Requirements

The diagrammatic representation of the system architecture of the proposed cloud based automatic Power Failure Reporting model for ZESCO is shown in Figure 3.1.

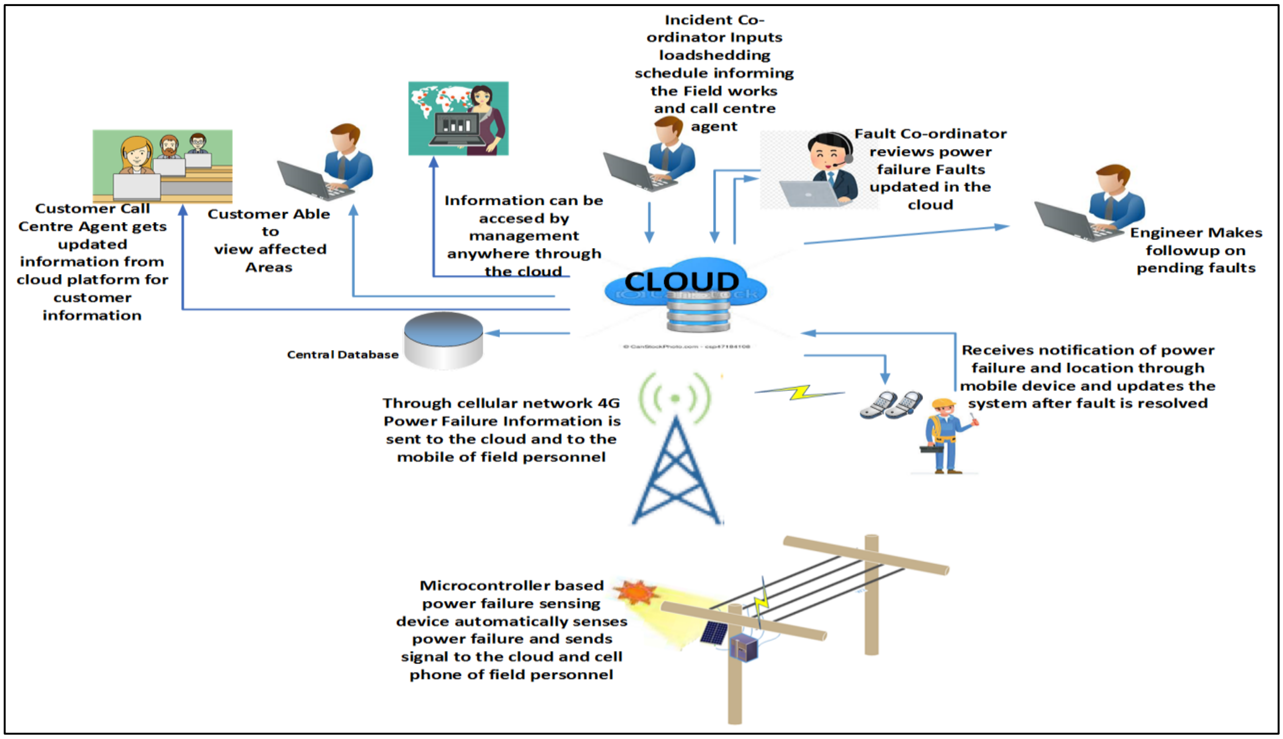


Figure 3.1 Proposed Cloud Based Power Failure Reporting Model for ZESCO

The proposed model for power failure reporting is based on sensing and cloud technology. Sensing plays a key role in the acquisition of data about and from everything without needing physical field visits. Sensing coupled with cloud services enables distributed sensory data collection, global resource and data sharing, remote and real-time data access [39]. The proposed model consists of an electronic device made from Voltage sensor circuit, Arduino microcontroller, 4G/GPRS/GSM/GPS module, solar charge controller, solar charged battery and web Cloud services. The Arduino microcontroller will sense the loss of supply in the power line and transmit the loss of supply indication and location of the power failure to customer call centre through the cloud platform and to the mobile phones of field personnel. Arduino was used because of its low cost, ease of programing, large support community, open source nature, scalability and easy to use hardware and software [63] [120].

3.3.3 System Modeling and Design

To design the system models for the power Failure sensing web application for the cloud platform an Object-Oriented Design (OOD) based on use cases, sequence diagram, entity relationship diagrams, block diagrams and flow charts was used. Models are essential in system development because they provide a representation or simplification of reality. They provide blueprints that can be followed in the development of the system.

a) Use Case Diagram

The Use Case diagram describes the proposed functionality of the new system. Use case diagrams are used for visualizing the functional requirements of a system that will translate into design choices and development priorities [121]. Use case diagrams model the functionality of a system using actors and use cases. Use cases identify and describe system processes from the perspective of users. Each use case is initiated by users or external systems called actors [121]. Table 3.6 shows the actors and description of each actor in the power failure sensing system web application for the cloud platform.

Table 3.6 Description of Actors in the Web Application Use Case Diagram

Actor	Description
Power Failure Sensing system	Power failure sensing system consists of the microcontroller based 4G/GPRS/GSM/GPS electronic device which is responsible for detecting loss of supply and transmitting an alert to the mobile phone and web application
Call Centre Agent	Call Centre agent is the personnel who is able to view power failure faults and inform customers.
Faults Co-ordinator	A faults co-ordinator is personnel in charge of coordinating faults by assigning power failure faults to field personnel
Engineer	An Engineer is personnel in charge of making follow-ups on pending power failure faults and reassigning faults to field personnel
Field Personnel	A field personnel is personnel in charge of investigating and resolving power failure faults
Manager	The manager is in top management and is concerned with generating reports to track system performance.
Customer	A customer is an electricity client who would be interested in knowing which areas are affected by a particular power failure

Figure 3.2 is a diagrammatic representation of the actors and the respective Use Cases for each actor for the power failure sensing web application.

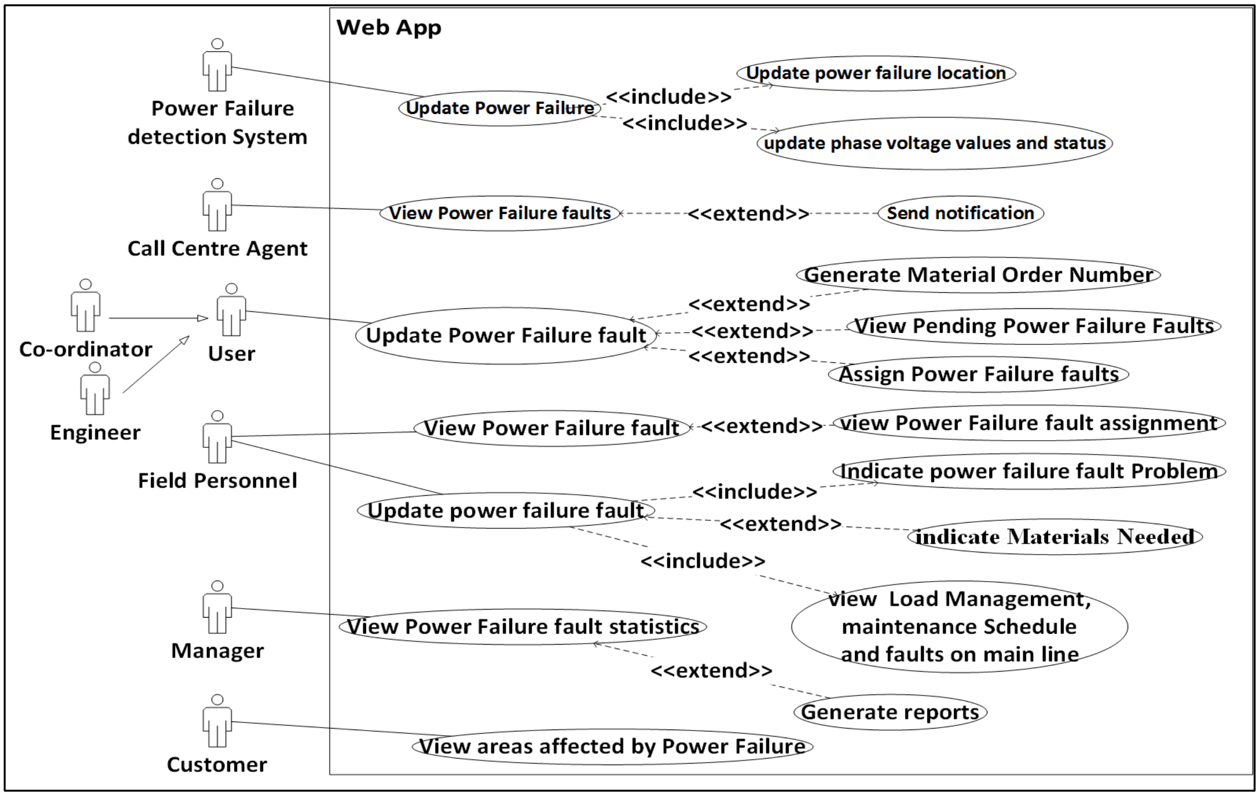


Figure 3.2 Use Case Diagram for Cloud Platform Web Application

The system consists of seven actors as shown in figure 3.2 above.

i) The power failure detection system has use cases of update power failure location and phase voltage values and phases as it is able to detect loss of power supply and update power failure status, voltage values on the web application.

ii) Call Centre agent has use cases of view power failure faults and send notifications as they are able to view power failure faults and send customers notifications to update the customers on the power failure situation

iii) The Faults Coordinator and Engineer are able to generate materials order number to be used by field personnel to draw materials from stores, view pending power faults to assess reasons for delay in resolving the power failure, assign power failure faults to field personnel.

iv) Field personnel are able to view power failure faults to determine power failure assignments, indicate the problem that caused the power failure and the material needed to resolve the fault. They are also able to view maintenance schedules, faults on main line and load management to be able to distinguish the power failure faults which they are meant to attend to.

v) Manager is associated with the use cases view power failure faults statistics and generate reports as they are able to view power failure statistics and subsequently generate reports to determine the performance as well as extract power failure information from the system.

vi) Customer is associated with the use cases view areas affected by power failure as they are able to view the areas affected by the power failure and check whether the power failure problem has been resolved or not.

b) Sequence Diagram

In the object-oriented approach, the flow of information is achieved through sending messages either to and from actors or back and forth between internal objects. This flow of information into and out of a system is described by a system sequence diagram [122]. A system sequence diagram shows the sequence of messages between an external actor and the system. They illustrate the objects that participate in a use case and the messages that pass between them over time [103].

Below are the sequence diagrams used in the design of the prototype cloud platform web application depicting the sequence of message flows in various scenarios.

Figure 3.3 shows the sequence diagram for the actors faults coordinator, engineer, field personnel and manager represented by the user. The flow of information is from the user who logs in through the user interface such as a web browser. The login request messages are sent from the user interface to the web server and eventually to the database for authentication and a successfully return message is sent back to the user through the user interface upon successful authentication. The sequence diagram also shows the flow of messages for viewing faults, updating faults problem, indicate materials needed, generate materials number, viewing load schedules and

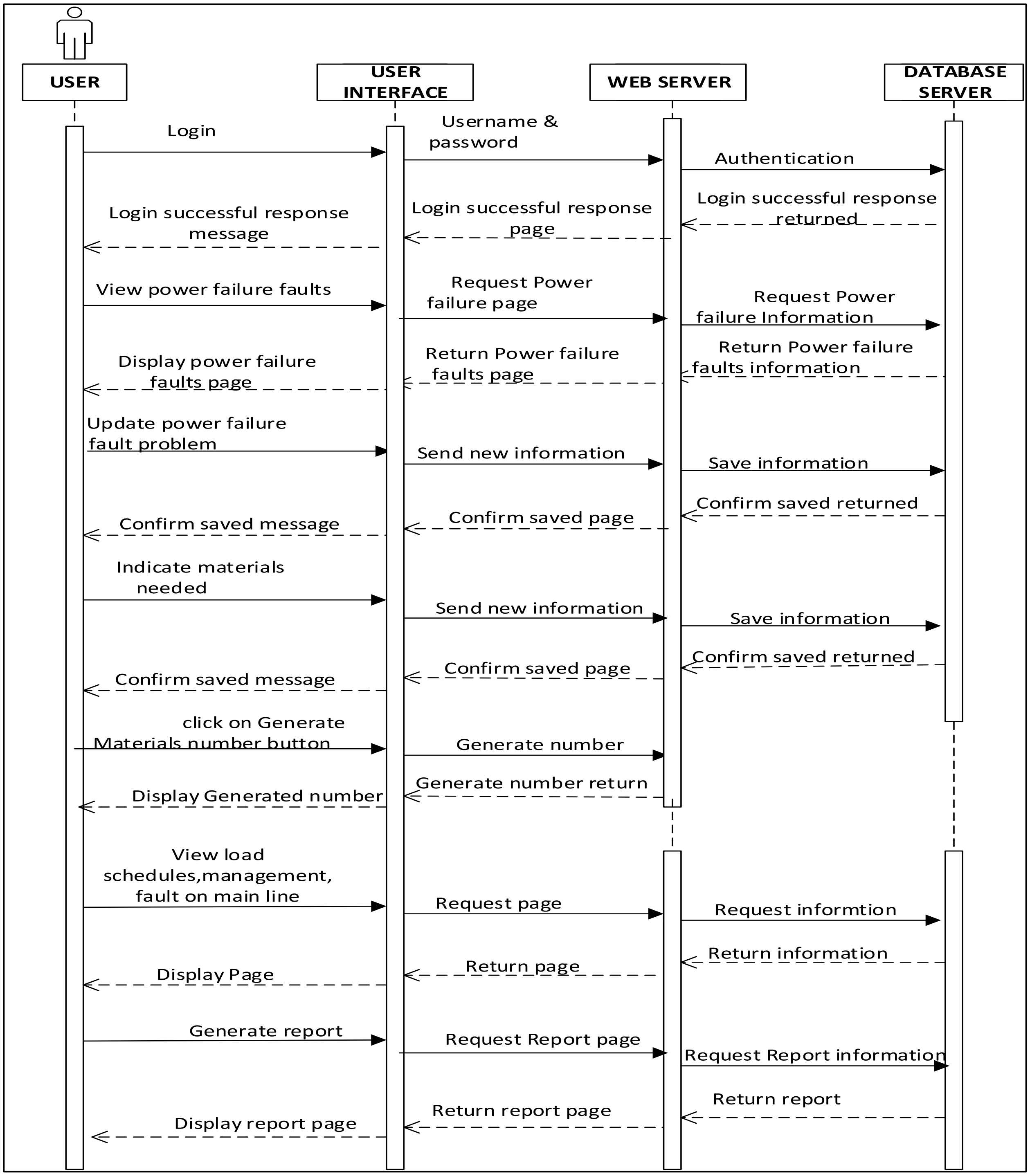


Figure 3.3 Sequence Diagram Representing Use Cases Generated by the Actors Faults Coordinator, Engineer, Field Personnel and Manager

generating reports. All the message flows are from the user through the user interface to the web server and then database and also shows the return messages.

Figure 3.4 below shows the sequence diagram for the customer through the user interface, web server and database. The flow of information is from the user who logs in through the user interface such as a web browser. The login request messages are sent from the user interface to the web server and eventually to the database for authentication and a successfully return message is sent back to the user through the user interface upon successful authentication. The customer is able to view areas affected by the faults by sending messages through the user interface to the web server were a particular webpage is stored and then through to the database were the data is stored. This is then followed by the return messages from the database, webserver and through user interface enabling the customer to view the areas affected by the fault.

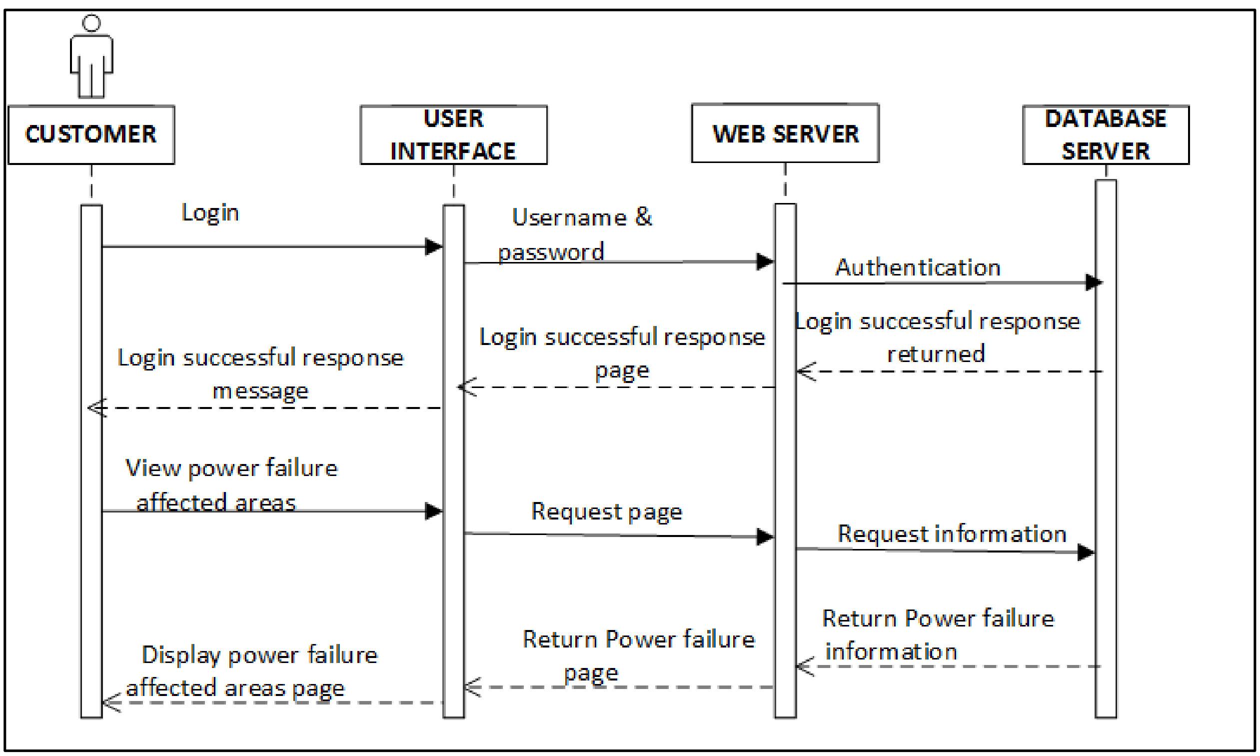


Figure 3.4 Sequence Diagram Representing the Use Case Generated by the Customer

Figure 3.5 shows the sequence diagram for the call centre agent who similarly logs into the system through the user interface by entering the user name and password this information is passed on to the web server and eventually to the database server for authentication. After successful authentication message is sent back to the call centre agent. The call centre agent is then able to view faults and send notifications through the notification modules

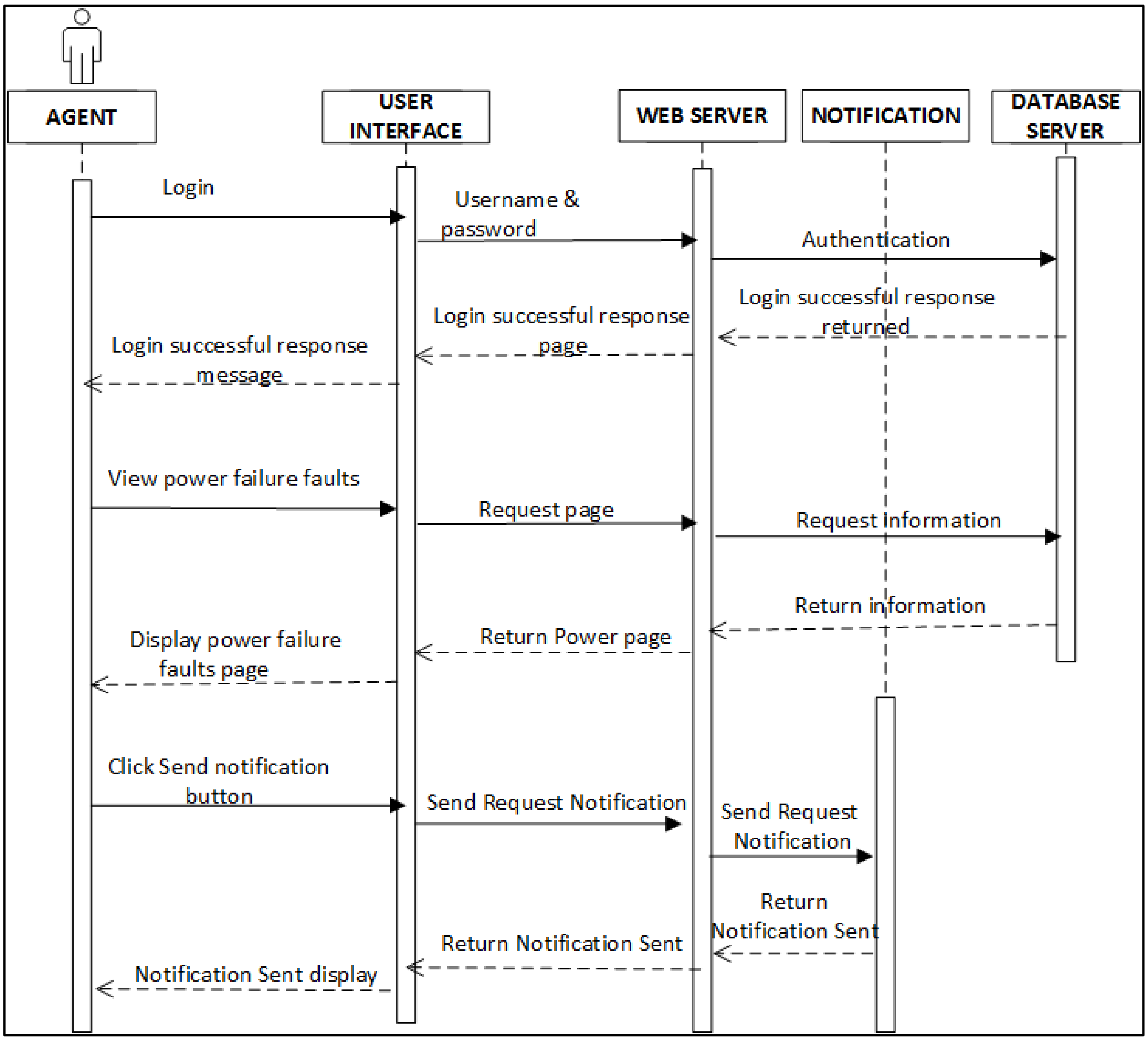


Figure 3.5 Sequence Diagram Representing the Use Case Generated by the Call Centre Agent

Figure 3.6 below shows the sequence diagram for the power failure sensing system. The sensing system interfaces to the web server and database through the middle ware software which facilitates the communication, update and storage of information in the database.

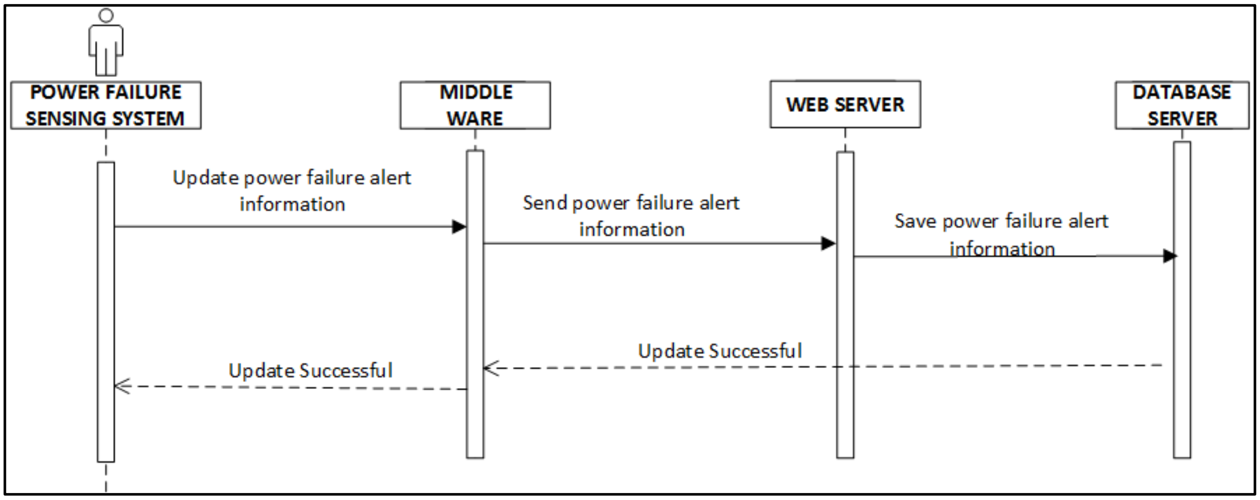


Figure 3.6 Sequence Diagram Representing the Use Case Generated by the Power Failure Sensing System

c) Entity Relationship Diagram

For the prototype cloud application database Entity-Relationship (ER) modeling was used. ER modelling is a top-down approach to database design that begins by identifying important data called entities and relationships between the data that must be represented in the model [123]. The ER model describes data as entities, relationships, and attributes with entities being defined as a thing, a person, a place, an object, an event, or a concept in the real world or in the user environment with an independent existence about which the organization wishes to maintain data [123] [124]. How the entities are associated is referred to as a relationship between the entities. Each entity has attributes which are the particular properties that describe it [123]. The diagram below shows the entity relationship model for the prototype cloud application database. It depicts the different entities, their attributes and the relationships between the entities.

.

d) **Relational Database Schema**

The table below represents the structure of the database which is referred to as the database schema

Table 3.7 Relational Database Schema for Cloud Platform Database

Distribution directorate (Directorate_ID, Directorate_Name)
Call Centre (Centre_ID, Centre_Name, Directorate_ID)
Call Centre Agent (Agent_ID, Agent_Name, Phone_NO, Centre_ID)
Customer Notification (Notification_ID, Notification_Name, Notification_Time, Notification_Date, Agent_ID)
Divisions (Division_ID, Division_Name, Directorate_ID)
Regions (Region_ID, Region_Name, Division_ID)
Engineer (Engineer_ID, Engineer_Name, Phone_NO, Region_ID)
Townships (Township_ID, Township_Name,)
Customers (Customer_ID, Customer_Name, Customer_Phone, Customer_email, Customer_NRC, Township_ID)
Zones (Zone_ID, Zone_Name, Township_ID)
Faults Centre (FCentre_ID, FCentre_Name, Phone_NO, Zone_ID)
Field Personnel (Personnel_ID, Personnel_Name, Phone_NO, Zone_ID)
Materials Needed (Materials_ID, Material_Name, M_Date, M_Time, Personnel_ID)
Faults Problem (Problem_ID, Fault_Name, Fault_Date, Fault_Time, Fault_Type, Personnel_ID)
Fault Co-ordinator (Coordinator_ID, Coordinator_Name, Coordinator_Phone, FCentre_ID)
Faults (Fault_ID, Fault_Name, Fault_Assignment, Fault_AssingmentDate, Fault_AssignmentTime, Coordinator_ID)
Materials Number (Materials_ID, materials_Name, Coordinator_ID)
Electronic Device (Device_ID, Device_Name)
Power Failure (Phase_ID, Status, Time,Phase_name,Date,Location)

e) Block Diagram of the Prototype

Block diagrams were also used to simplify the design of the prototype. Below is the block diagram of the proposed prototype.

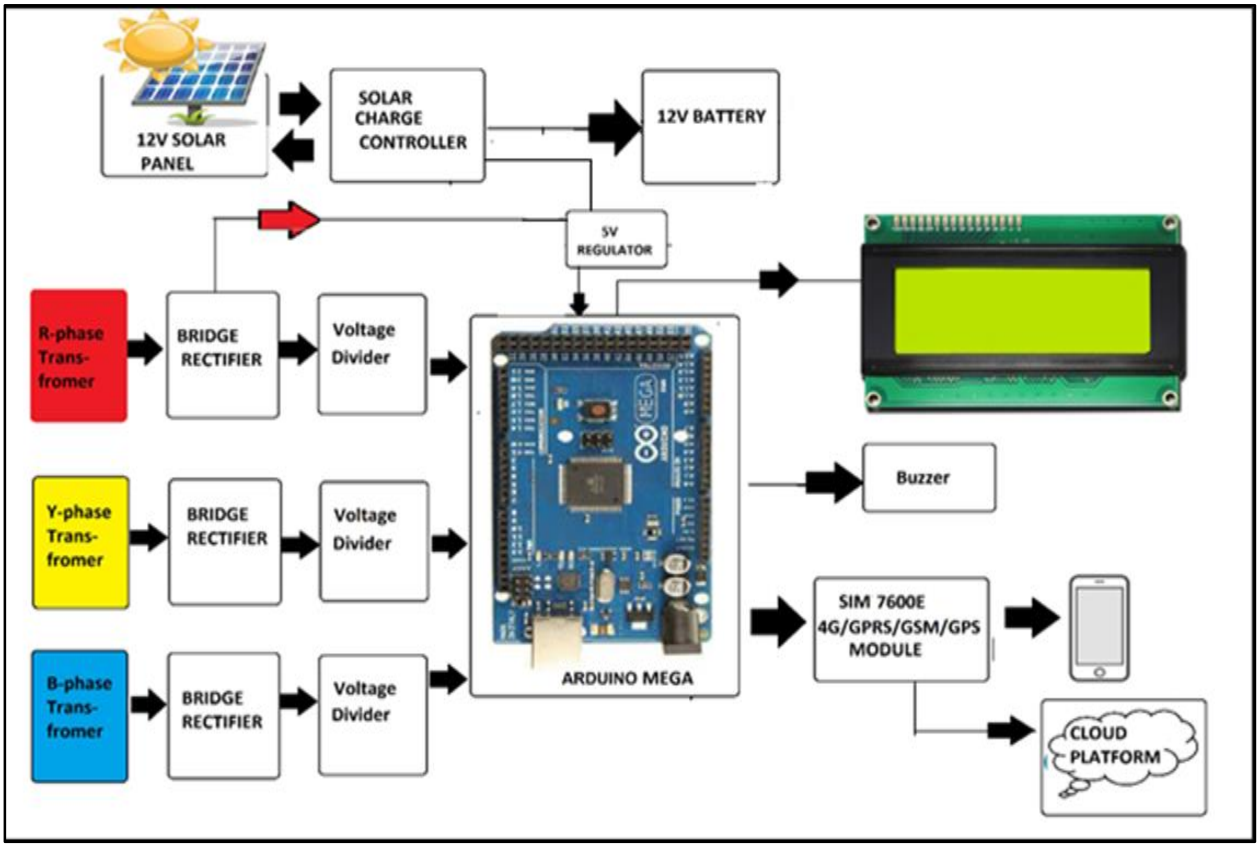


Figure 3.7 Block Diagram of the Arduino Microcontroller Based Power Sensing Device

The block diagram shows the proposed prototype which consists of an electronic device made from Voltage sensor circuit, Arduino Microcontroller board, 4G/GPRS/GSM/GPS module, battery charge controller module and Web Cloud services using cloud architecture, Web Application, Google Map API.

f) Flow Chart of the Prototype Power Failure Sensing Functionality

A flow chart was used to design the power failure sensing functionality of the prototype as shown in Figure 3.8.

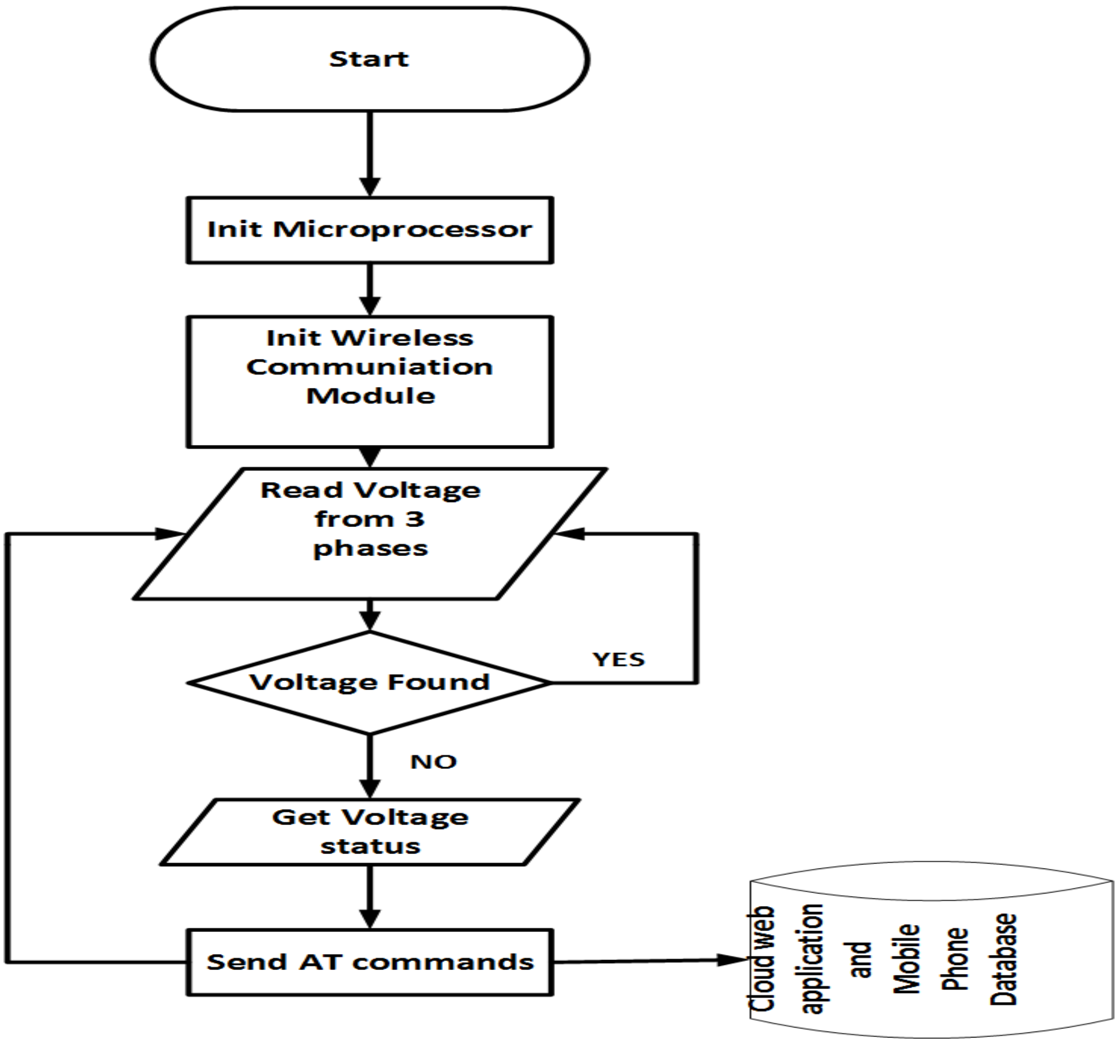


Figure 3.8 Flow Chart of Arduino Power failure Sensing Functionality

g) Electronic Device Design

The prototype consists of an electronic component part which was designed according to the requirements in the requirements stage. According to the requirements there is need to step down a voltage of 230 V to 12 V and use it as input to a 740mA load of the electronic device circuit. For this requirement a transformer rated at 12V and above 740mA, 8.88W is needed

i. So the transformer rating found were 230V to 12 V , 2A transformer because it is readily available and was easy to procure

ii. The bridge rectifier used should be one which will be able to handle the voltage and current of 12 V and 740mA respectively so we chose a bridge rectifier of 35V voltage with 2A current rating. This was chosen because these bridge rectifiers are readily available and were easy to procure

iii. The capacitance across the bridge rectifier was calculated as follow

The output after the rectification is not a proper DC, it is an oscillating output and has a very high ripple factor. To remove the pulsating output a Capacitor is used. The Capacitor charges till the waveform goes to its peak and discharge into the Load circuit when the waveform goes low. So when the output is going low, the capacitor maintains the proper voltage supply into the Load circuit, hence creating the DC voltage. The value of the filter capacitor was calculated as follows.

$$C = \frac{\mathrm{I}}{2fv} \qquad [125]$$

C = capacitance to be calculated

I = Max load current (740mA)

f = Supply Frequency (50Hz),

v = Peak to peak ripple voltage

The voltage on the secondary side of the transformer is 12Vrms so the peak voltage is 12Vrms x 1.414 = 16.97V

Now 1.1V will be dropped on the diode bridge rectifier when forward biased for the half wave.

So 16.97V – 1.1V = 15.87V

So if we take the peak to peak ripple voltage as being 10% of the peak voltage as recommended in [126] [127] then we have 0.1 x 15.87 = 1.587

So Vpp = 1.587V

So now $C = \frac{\mathrm{I}}{2fv}$

$C = \frac{740\mathrm{mA}}{2 \times 50 \times 1.587} = 4662.9\mathrm{uF} \approx 4700\mathrm{uF}$ as this value is readily available

iv. Voltage divider circuit

The voltage divider circuit was used to provide the 1.5V input voltage for the arduino analogue inputs for power failure detection. For the voltage divider circuit the following procedure was used to determine the values of the resistors (R8, R122, R30, R31, R32, R33). Since the circuits are similar the same procedure was used to determine the circuit values

a) The voltage which is to be measured was determined. The input voltage for the arduino analogue inputs should be between 0- 5V, so 1.5 V was chosen to allow for voltages which go beyond 230V.

b) A suitable and standard value for resistor R1 (Representing resistors R8, R30, R32 in main circuit board shown in appendix F) in kilo-ohm range was decided upon.

c) Using formula

$$V_{out} = V_{in}\left(\frac{R2}{R2+R1}\right) \quad [128]$$

Where

Vout = Voltage output = 1.5V,

Vin = Voltage input = 12V,

R2 = Resistor R2 is calculated (Representing resistors R122, R31, R33 in the main circuit board shown in appendix F)

R1 = Resistor R1 (Representing resistors R8, R30, R32 in the main circuit board shown in appendix F)

d) If the value of R2 is not (or close to) a standard value, the value of R1 is changed and the above steps are repeated.

e) In this instance 68 kΩ was chosen as it is a standard value. This was arrived at after a number of iterations which allowed us to get a standard value of R2. A resistor in the kilo-ohm range was used

f) Using formula

$$V_{out} = V_{in}\left(\frac{R2}{R2+R1}\right) \quad [128]$$

Where Vout = 1.5V, Vin = 12V and R1 = 68k then

$$1.5 = 12\left(\frac{R2}{68000+R2}\right)$$

$$R2 = \frac{8500}{0.875} = 9{,}714 \approx 10\text{k}\Omega$$

R2 was calculated to be 10kΩ.

v. Power Supply Circuit

The power supply circuit is made up of the LM2596 regulator which was used because of its high current capacity. The regulator inputs 12 V voltage and outputs 5V and keeps the voltage constant. The power supply is provided by the three phases and the battery. When there is loss of supply on all the phases the solar panel and battery provides the power supply. Appendix F shows the circuit diagram of the prototype main circuit.

3.3.4 Prototype Implementation

This stage involved coding of the software as well as setting up the hardware components. To develop the prototype the following materials were used

The software used in prototype implementation was

i) Arduino IDE for programing the arduino microcontroller board
ii) HTML
iii) CSS
iv) Java Script
v) Microsoft SQL database
vi) Google API
vii) ASP.net
viii) Proteus simulation software
ix) Microsoft Visual Studio

Hardware used was

i) Arduino Microcontroller Development board
ii) SIM7600E 4G/GPRS/GSM/GPS Module
iii) Electronic components
iv) 12 Volts battery
v) LCD display
vi) Laptop for accessing cloud services
vii) Mobile phone for receiving power failure notification
viii) Solar charge controller module

ix) Solar panel

The prototype implementation consisted of two parts, the hardware and software implementations

a) Hardware Implementation

The prototype hardware consisted of the voltage sensor circuit, Arduino microcontroller board, 4G/GPRS/GSM/GPS cellular communication module, solar charge controller and power supply circuit. The device realized from this hardware implementation is to be installed on the 0.4kV distribution electric line as shown in the proposed model in Figure 3.1. These are the distribution lines to which the customer premises are connected through a service line.

i. Voltage Sensor Circuit

The voltage sensor circuit consists of three 230/12V Voltage transformers stepping down the voltage from 230V AC to 12V AC. A diode bridge rectifier rectifies the 12V AC to DC and a voltage divider circuit ensures input of approximately 1.5V DC to the Arduino board analogue inputs. Loss of power in any of the phases results in the loss of the voltage input to the Arduino, the embedded program in the Arduino detects the loss of supply and sends alert messages to the cloud platform and predefined mobile phone number. The Arduino embedded program also reads and displays voltage values of the three phases on the cloud platform.

The voltage sensor circuit consisted of various electronic components which were integrated together on a printed circuit board. A printed circuit board was used to ensure ease of integrating and testing the circuit.

ii. Arduino Microcontroller Board

The Arduino microcontroller board is an Open Source electronic prototyping platform based on flexible easy to use hardware and software. It consists of a circuit board, which can be programmed and a ready-made software called Arduino Integrated Development Environment, which is used to write and upload the computer code to the physical board. Arduino boards are able to read analog or digital input signals from different sensors and turn it into an output. The board functions can be controlled by sending a set of instructions to the microcontroller on the board via Arduino IDE [27]. The Arduino Mega was used in this research because it provides more code memory and

RAM. It is an 8-bit board with 54 digital pins, 16 analog inputs, and 4 serial ports. The analogue inputs are used on the Arduino for power failure detection. These analogue inputs are able to measure voltages from 0 to 5V and in this research approximately 1.5V was applied to the Arduino analogue inputs for voltage detection. The analogue inputs have a 10 bit analogue to digital converter that maps the input voltage into integer values between 0 and 1023. The voltages detected are converted from analogue to digital and read by the embedded program to determine loss of supply. The Arduino was implemented to communicate with the SIM7600E module through the Universal asynchronous receiver transmitter (UART) transmit and receive pins which is able to receive AT commands at a baud rate of 9600bps. Using AT commands to the SIM7600E 4G/GPRS/GSM/GPS module, power failure alert is sent to the mobile phone and cloud based platform.

iii. SIM7600E 4G/GPS Module

The SIM7600E is Multi-Band LTE-TDD/LTE-FDD/HSPA+ and GSM/GPRS/EDGE module which supports uplink and downlink data rates of 5Mbps and 10Mbps respectively. It is designed for applications that need low latency, medium throughput data communication, security and flexibility such as metering, telematics, asset tracking, remote monitoring and E-health. This module was used because it offers better data upload speeds making them suitable for use in application of electrical network monitoring which requires almost real time data updates.

iv. Battery Charge Controller

The electronic device consists of a battery which supplies power to the device in case of loss of power from all the three phases. This battery is being charged by the solar panel through the Maximum Power Point Tracking (MPPT) battery charge controller. A charge controller or charge regulator is a voltage regulator that keeps the battery from overcharging. It regulates the voltage and current coming from the solar panels going to the battery. The "12 volt" panels used in this study put out about 16 to 20 volts, so regulation is needed to protect the battery from damage due to overvoltage. The solar charge controller is used to manage the power going into the battery bank from the solar panel (photovoltaic module). It ensures that the battery is not overcharged during the day, and that the power doesn't run backwards to the solar panels overnight and drain the batteries.

In this study a Maximum Power Point Tracking (MPPT) solar charge controller was used because it increases the solar panel's effectiveness by 30% and extracts maximum power from the photovoltaic (PV) module by forcing the module to operate at a voltage close to maximum power point to draw maximum available power. Maximum Power Point Tracking is an algorithm that is used in charge controllers for extracting maximum available power from the solar panel module under certain conditions. The voltage at which the PV module can produce maximum power is called "maximum power point" or peak power voltage. The controller checks the output of the PV module, compares it to the battery voltage then determines the best power that the PV module can produce to charge the battery and converts it to the best voltage to get maximum current into the battery. It is a DC to DC converter which operates by taking DC input from the PV module, changing it to AC and converting it back to a different DC voltage and current to exactly match the PV module to the battery. A solar panel of rating 60W and 24Ah battery was determined to be able to provide power to the device for a period of 16hours. The calculations were as follows

When there is no power supply from all three phases, the device will be powered by the battery. If we assume average of 8 hours of sunlight per day then the device will be powered by the battery for a period of 16 hours per day.

Run time required = 16 hours

Power consumption of device $\approx$ 9W

Consumption per day = 9W x16hours = 144Wh

Determining Battery Rating

Divide this value by the supply voltage = 144/12 = 12Ah rating of the battery can be used

With the aim of leaving 50% in the battery we get 24Ah battery rating this is because each battery has a Depth of Discharge (DOD) rate to prevent them to be damaged.

Determining Solar Panel Rating

Required Load in Watts

P-Total= (24 x 9W) = 216 Wh.

This is our daily load in watthours we need to be powered up by solar panels

If we assume to have an average of 8 hours complete sunshine per day. The solar rating will be

P-Hourly = 216Whour / 8Hrs = 27W

So solar rating of 27 Watts is required

If we take the battery charging into consideration we get

Battery consumption in watthour = 24Ah X 12 = 288Wh

Taking into consideration the number of hours of sunshine per day

Solar Panel Rating in Watts = 288watthour/8 = 36Watts

So total panel rating will be 27+ 36 = 63 Watts $\approx$ 60 Watts

v. Power Supply Circuit

Power supply for the prototype is provided by the three phase supply and if there is loss of three phase supply the device reverts to being supplied by solar panel and the battery being charged by the solar panel. Regulator LM2596 is used for maintaining the 5V DC supply voltage to the prototype circuit.

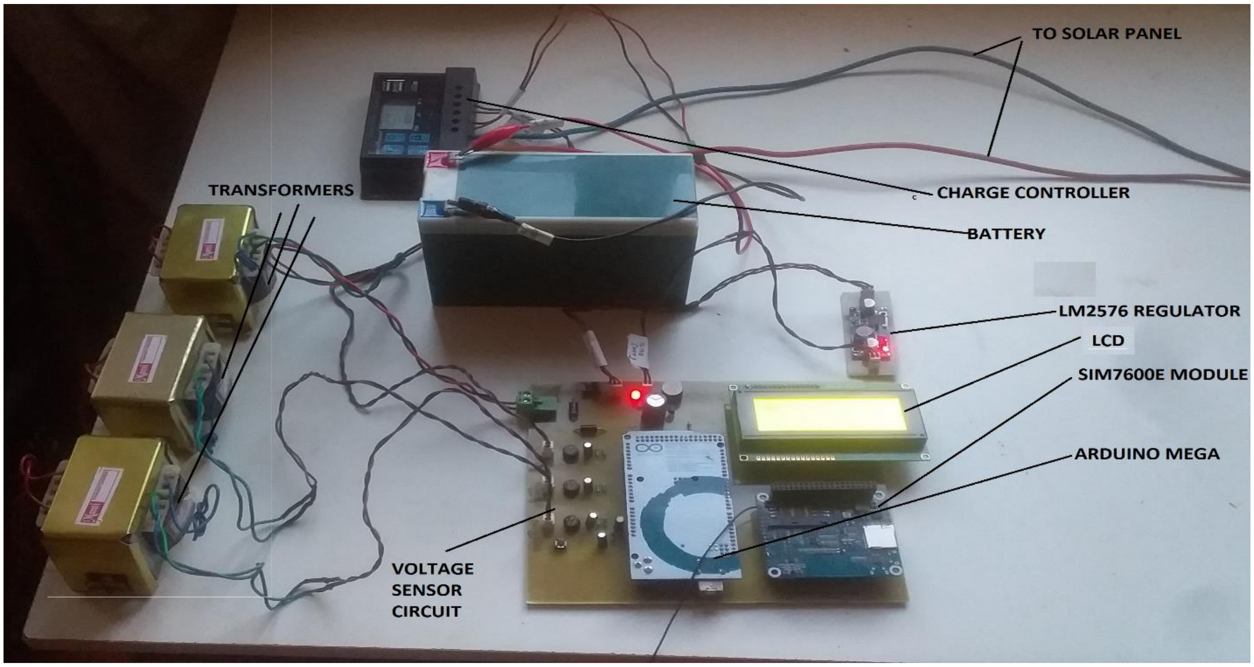


Figure 3.9 Hardware Setup

b) Software Implementation

Software implementation involved coding of the Arduino microcontroller and web application coding.

i) Code Programming

The methodology which was used for code programming was the object oriented programming based on the functionality flow charts, requirements analysis, use case and sequence diagram models designed in section 3.3.2 and 3.3.3.

Object oriented programming was used because it makes it easy to maintain and modify existing code as new objects can be created with small differences to existing ones. The programming languages used in this study were embedded C language for Arduino and ASP.net for the cloud platform web application, which are both object oriented programming languages. The software used for programming the Arduino was the Integrated Development Environment and Microsoft visual studio was used for programming the web application. The figures below show the steps which were used for programming the Arduino and the web application.

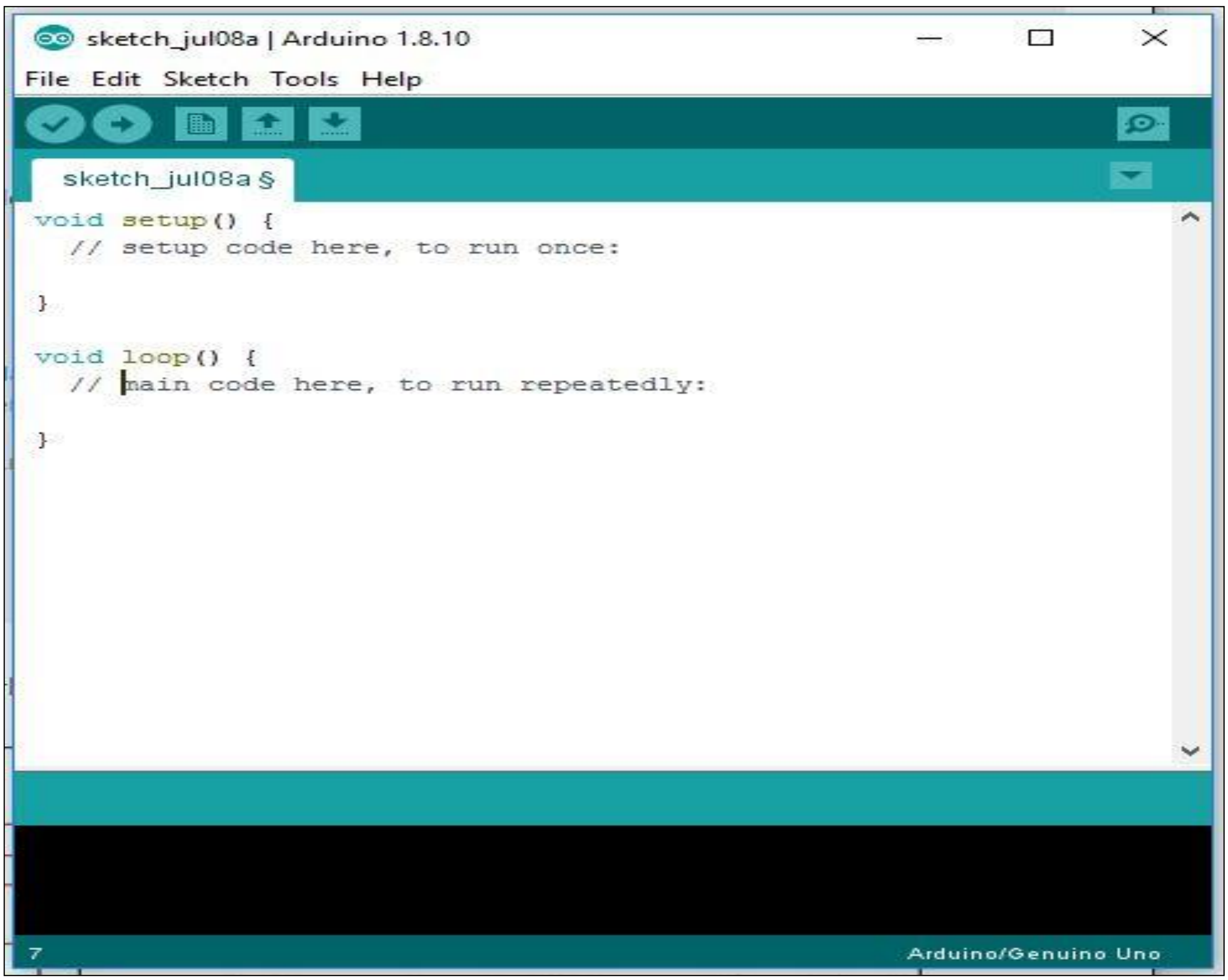
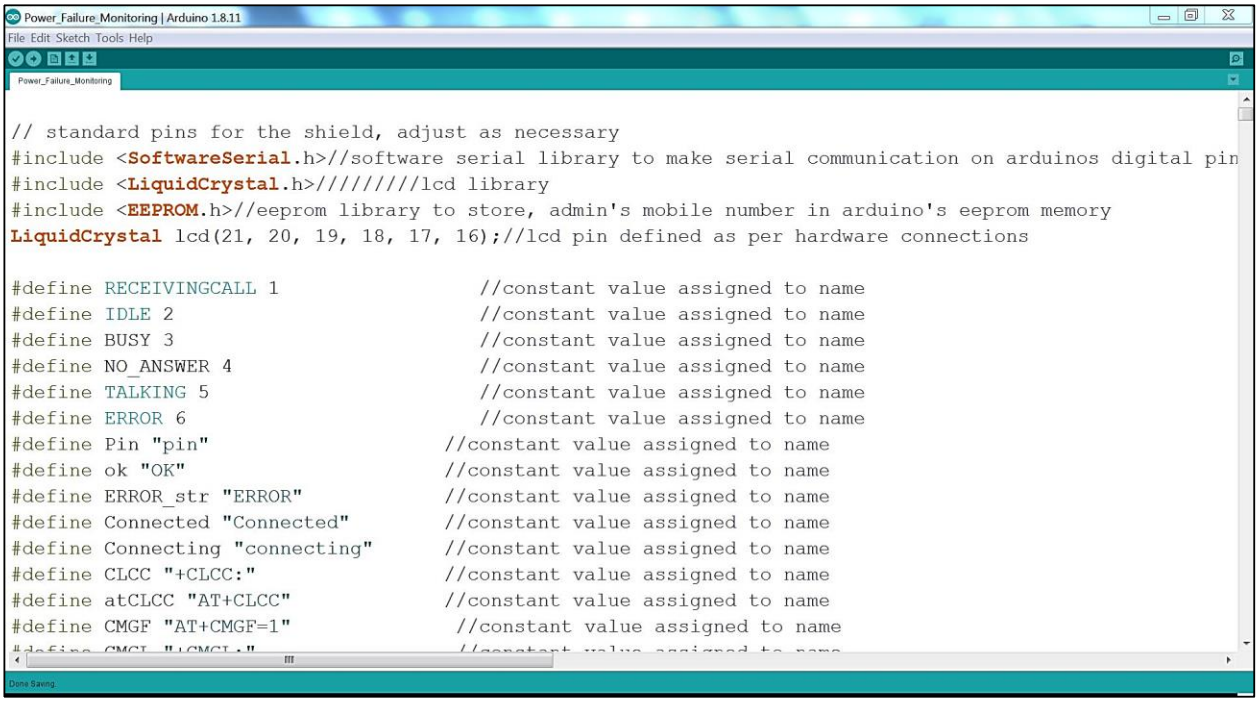


Figure 3.10 Arduino IDE Software Window showing the two Sections of the Arduino Code

Figure 3.10 above shows a snap shot of the Arduino IDE and the program sections used in the programming. The first section is called the setup and is where the code variables are initialized and the second section is called the loop and this is where the program which is to run continuously is defined.




```
// standard pins for the shield, adjust as necessary
#include <SoftwareSerial.h>//software serial library to make serial communication on arduinos digital pin
#include <LiquidCrystal.h>/////////lcd library
#include <EEPROM.h>//eeprom library to store, admin's mobile number in arduino's eeprom memory
LiquidCrystal lcd(21, 20, 19, 18, 17, 16);//lcd pin defined as per hardware connections

#define RECEIVINGCALL 1                  //constant value assigned to name
#define IDLE 2                           //constant value assigned to name
#define BUSY 3                           //constant value assigned to name
#define NO_ANSWER 4                      //constant value assigned to name
#define TALKING 5                        //constant value assigned to name
#define ERROR 6                          //constant value assigned to name
#define Pin "pin"                     //constant value assigned to name
#define ok "OK"                       //constant value assigned to name
#define ERROR_str "ERROR"             //constant value assigned to name
#define Connected "Connected"         //constant value assigned to name
#define Connecting "connecting"       //constant value assigned to name
#define CLCC "+CLCC:"                 //constant value assigned to name
#define atCLCC "AT+CLCC"              //constant value assigned to name
#define CMGF "AT+CMGF=1"               //constant value assigned to name
```

Figure 3.11 Arduino Prototype Code in the IDE

Figure 3.11 above shows part of the Arduino prototype code in the IDE which was used in this research to realize the power failure sensing functionality

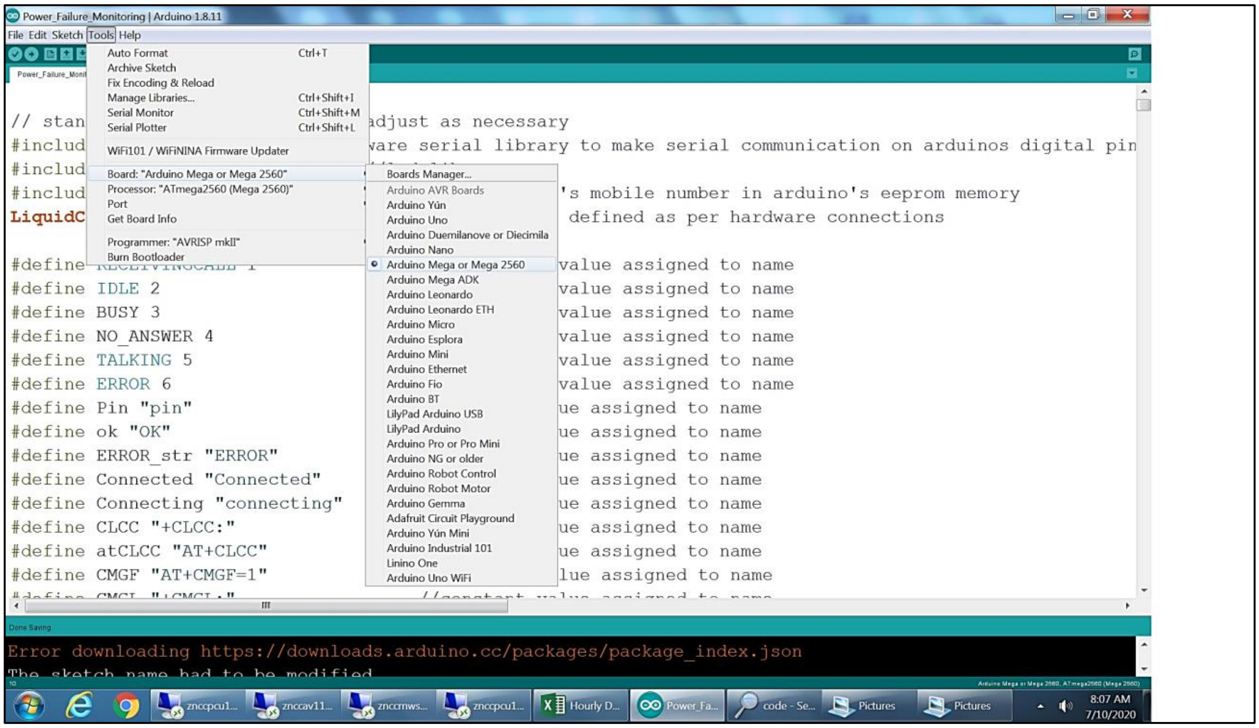


Figure 3.12 Selection of Arduino Mega Microcontroller

Figure 3.12 shows the selection of Arduino Mega microcontroller as this was used in the research. There are several types of Arduino microcontrollers and in this research Arduino Mega microcontroller was used as it has more memory for storing and running the code. The microcontroller is selected in preparation for loading the code into the microcontroller.

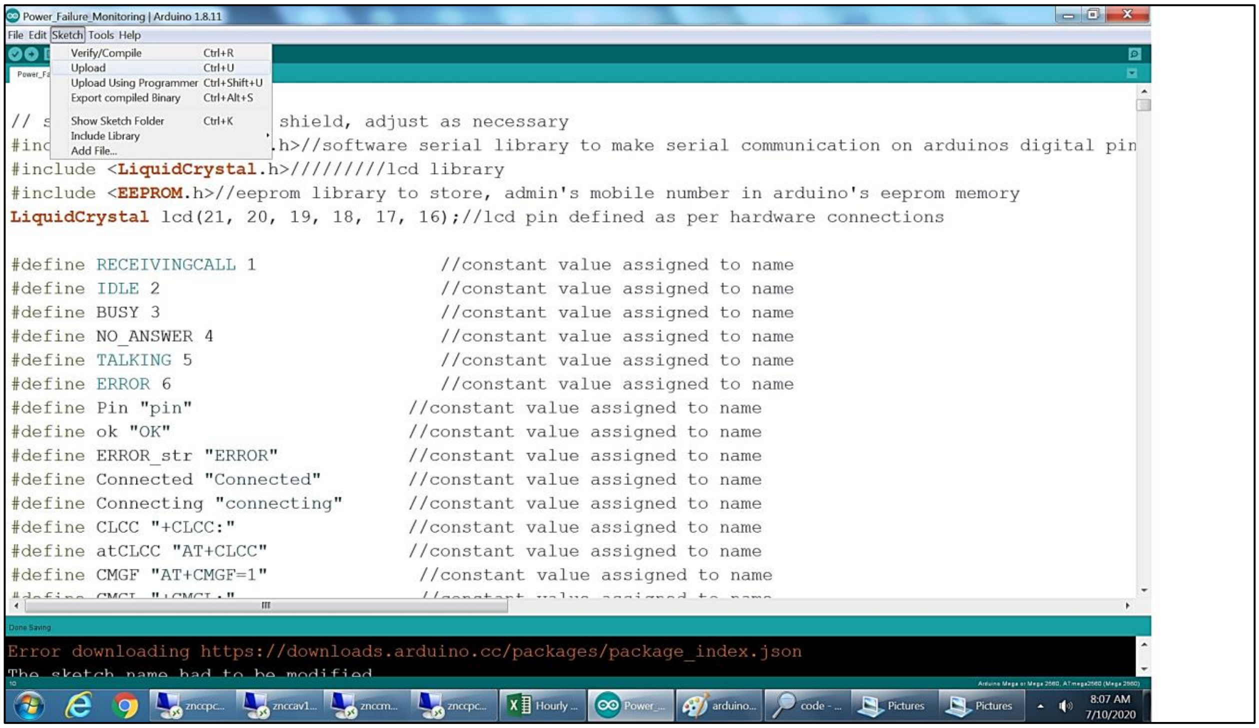


Figure 3.13 Loading of the Code into the Arduino Microcontroller

Figure 3.13 shows the loading of the code into the Arduino Microcontroller. The code is first converted into a form the microcontroller will be able to interpret before it is loaded into the microcontroller.

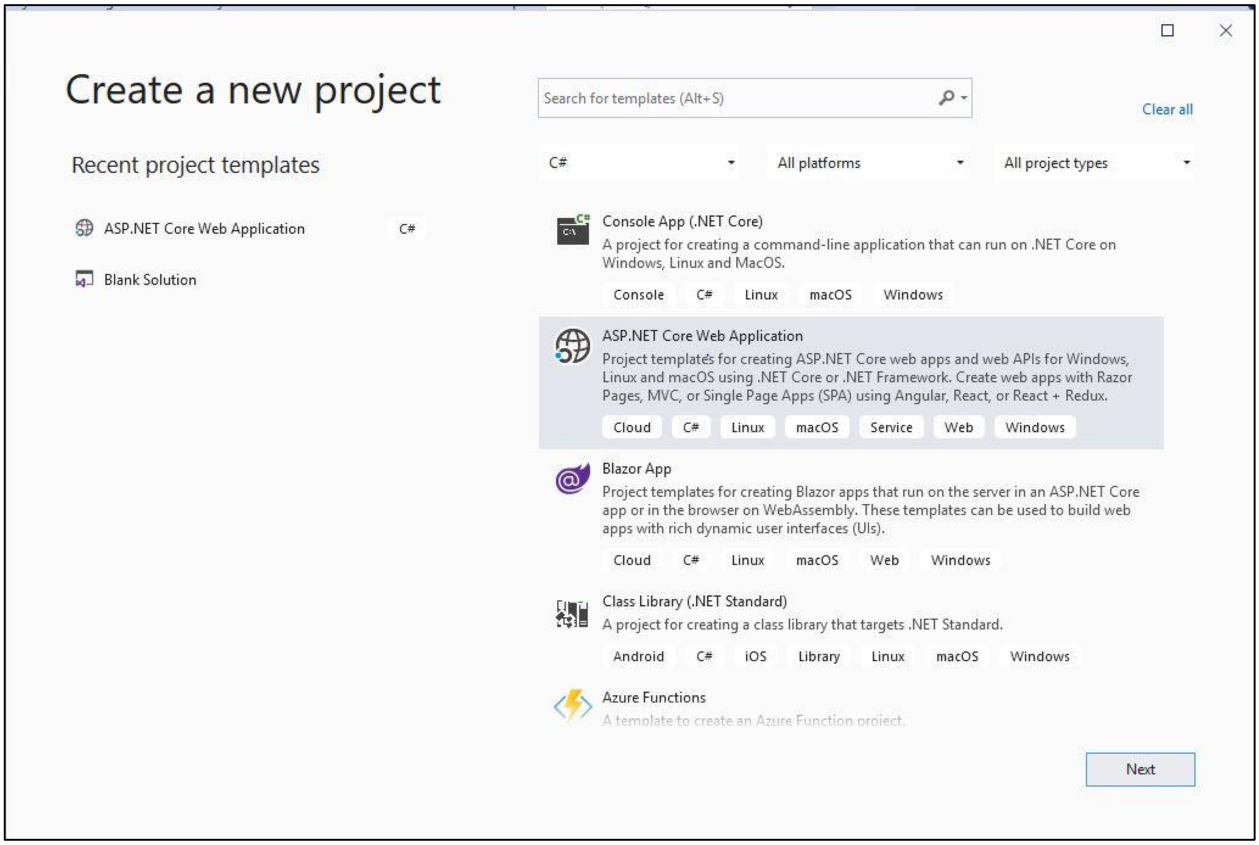


Figure 3.14 Snapshot of the Microsoft Visual Studio to Create the Web Application

Figure 3.14 shows a snapshot of the first step in the creation of the web application using ASP.net in Microsoft Visual Studio. ASP.net core web application option is chosen.

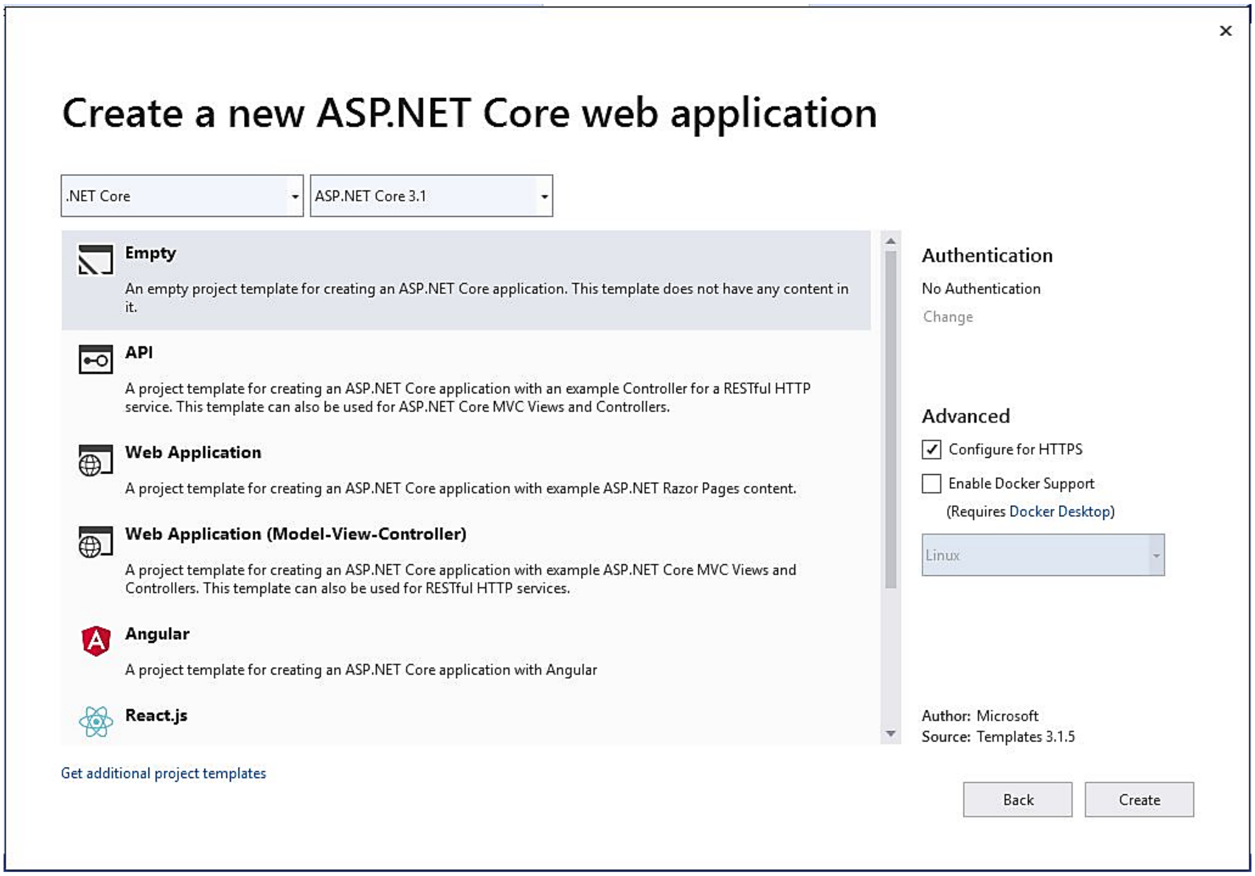


Figure 3.15 Snapshot of Creating a New Web Application in Visual Studio

Figure 3.15 above shows the second step in the creation of the web application. In this step the option web application is chosen since a web application is what is being created.

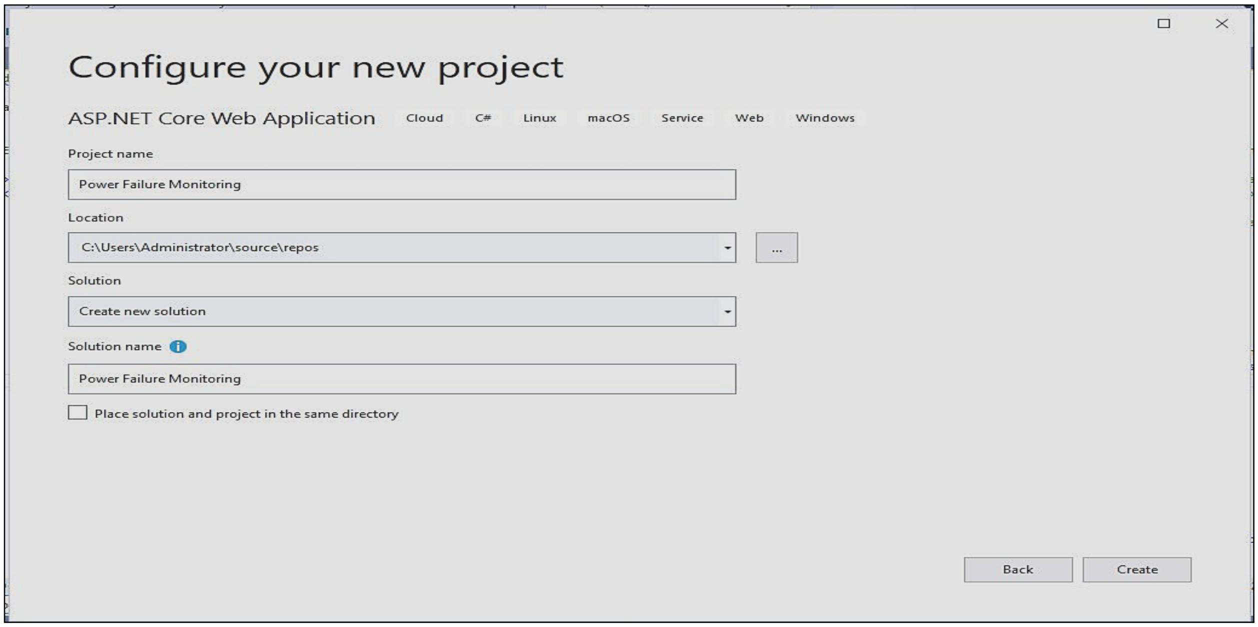


Figure 3.16 Snapshot of Web Application Configuration in Visual Studio

Figure 3.16 shows a snap shot of the third step in the creation of the web application. In this step a name is assigned to the project. In this case the name assigned was Power Failure Monitoring.

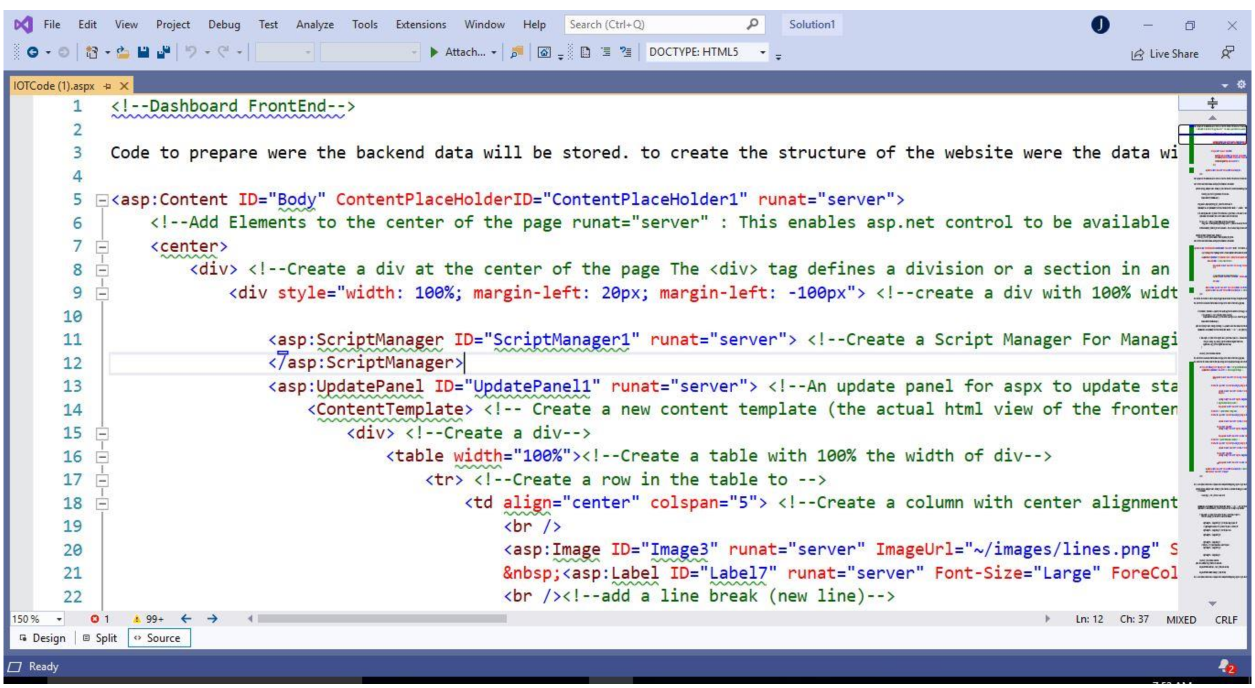


Figure 3.17 Snapshot of the ASP.net code in in Visual Studio

Figure 3.17 shows the final step in the creation of the web application with part of the code which was used in this research. This code is then downloaded into the web server of the website host of this research. In this research IOTGecko was used as the cloud service provider and their web servers were used for the storage of the web pages.

ii) Arduino Coding

The Arduino microcontroller board was coded using embedded C language through the integrated development environment provided by the Arduino. The IDE (Integrated Development Environment) is a special program that allows for the writing of code for the Arduino board. Once the code is uploaded to the board it is passed to the compiler that translates the code into the language understood by the microcontroller.

A laptop and Arduino Integrated Device Environment (IDE) software was used to program the Arduino. The Arduino board communicates with the computer using a communication port (COM port) which can be selected from the operating System's device manager. The COM port that was selected for use in the prototype implementation was COM1. The arduino was programmed to detect the voltage through its analogue inputs. Through the use of AT commands in the arduino program it was able to communicate with the SIM7600E 4G/GPRS/GSM/GPS wireless module. The steps followed in the coding are shown in Figures 3.10-3.13 above.

iii) Web Application Coding

Cloud services used are offered by the IOTGecko cloud services platform. IOTGecko cloud platform offers API support over Arduino and other controller boards. It provides a GUI builder and customized application creator system enabling developers to design desired IoT systems. The platform is built on the web stack consisting of the client and the server end. On the client side the software used was HTML (Hypertext Markup Language), CSS (Cascading Style Sheets) and JavaScript. HTML makes up the content of the website and enables the browser (like Internet Explorer or Google Chrome) to show the website. CSS was used to describe the presentation (the look and formatting) of the web-site. JavaScript is a programming language which was used to create interactive effects within the web browser. These softwares are referred to as client side because they are executed by the browser on the personal computer to enable viewing of the website. The client side software enables the alerts to be viewed in a certain presentation on a website. On the server side ASP.net programming language was used to program custom functionality on the web-site such as enabling the updates of power failure alerts from the Arduino microcontroller based device. The server consists of a database engine based on Microsoft SQL for storage of data such as the status, date, start time and end time of the power supply from each of the phases. The web server software used was Internet Information Services (IIS) and the operating system was Microsoft windows. The steps followed in the coding are shown in Figures 3.14-3.17 above.

3.3.5 Prototype Testing

To measure success and performance, the prototype – electronic part was simulated and tested using proteus simulation software to ensure that the electronic components used would produce the expected voltages and currents and that the Arduino code would produce the desired outcome. These tests were successful. The prototype was then setup and tested by connecting it to a three phase power supply and a battery for backup supply as shown in Figure 3.18. Connection to the cloud platform was established through a web browser interface on a laptop and a mobile phone was used to receive messages from the prototype.

When power supply was switched on, the voltage values of the three phases was successfully displayed on the LCD, cloud platform and an alert message was sent to the mobile phone. The time it takes the three phase voltage values to be displayed both on the local LCD display and on the cloud platform was measured and determined to be within 35 seconds. An SMS indicating the status of the three phase supply was also sent to a predefined mobile phone number within the same time. After this, the red phase supply was disconnected from the device. The red phase voltage value and status was successfully transmitted and displayed onto the local LCD, cloud platform and mobile phone and this transmission was measured to be within 35 seconds as well. This was repeated for the yellow and blue phases each time obtaining similar results. Once all the phases were disconnected a zero voltage value for all the phases was successfully reported to the local LCD, cloud platform and phase status to the mobile phone. With the three phases disconnected the device was able to run on the solar panel and battery. The three phase supply was then connected back and the status updates were again successfully sent to the local LCD display, cloud platform and predefined mobile number.

Apart from the display of voltage values, location of the power failure was successfully displayed on the cloud platform and mobile phone. The location was also determined to be correct once it was compared with the actual location of the prototype setup. The date and duration of the power failure was also indicated on the cloud platform. The start time, end time and date of the power failure displayed on the cloud platform was compared with a GPS synchronized time and date and found to be correct. To determine whether the voltage values displayed on the LCD and cloud platform were correct, they were compared with values of the voltages from the three phases measured using a digital multi-meter.

At the time of testing the prototype a call was made to the ZESCO call centre and it was noted that it took about four minute for the call to be answered. This tallies with the statistics from the call centre which indicate that average waiting and processing time for a customer calling call centre is four minutes. When this is compared to the average of 35 seconds processing time in the automatic power failure reporting system, the automatic power failure system performs better.

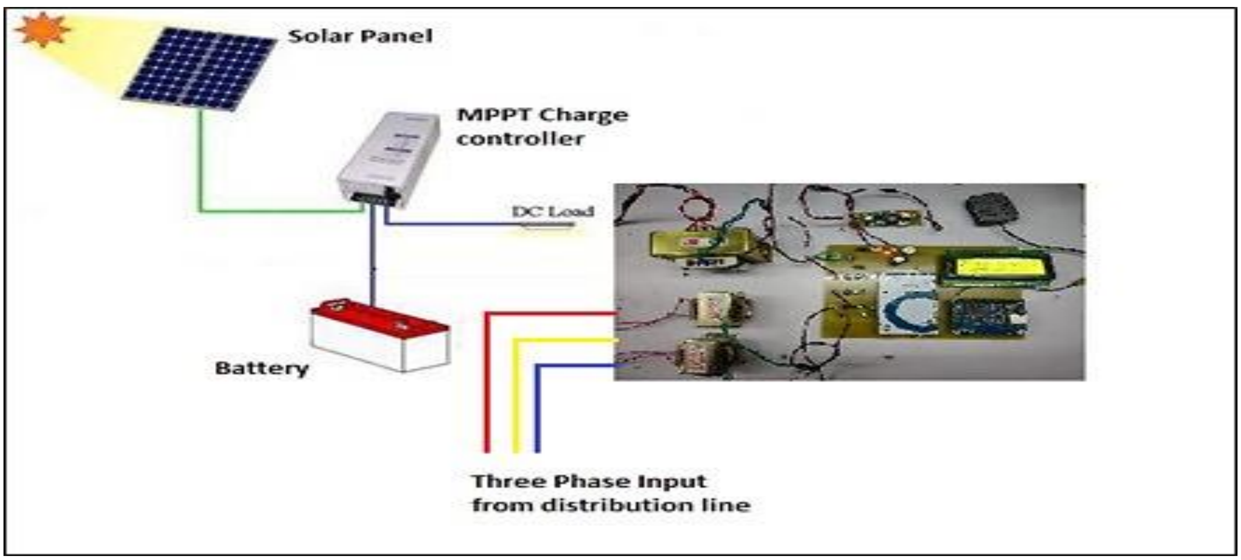


Figure 3.18 Prototype Testing Setup

3.4 Summary

In this chapter, the materials and methods that were used in the baseline study and the system automation prototype were outlined. Exploratory and survey design methodology was used in the baseline study. Krejcie and Morgan method was used in the selection of the sample size for the baseline study and a waterfall model system development method was used in the prototype system design and implementation. System models consisting of use case diagrams, sequence diagrams, entity relationship diagram, block diagrams and flow charts were presented to provide the means by which the cloud based power failure sensing system may be implemented.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, we present the results and the discussion of the results that were derived from the baseline study. We also present and discuss results of the system prototype using screenshots of the system application and hardware.

4.2 Baseline Line Study

In order to improve efficiency in power failure reporting management, a baseline study was conducted to establish the specific challenges ZESCO and the electricity clients face in the current power failure reporting management model. The challenges were identified through a survey conducted with electricity clients. Insights gained from interviews with ZESCO call centre and faults centre personnel were also analyzed. This section presents and discusses the results derived from the baseline study. The results presented are derived from the analysis of each variable through Statistical Package for the Social Sciences (SPSS) software. The presentation of the results is in form of tables, bar charts and pie charts.

4.2.1 Demographic Data

Quantitative data was collected from 383 respondents from Matero, Kalingalinga, Makeni, Emmasdale, Chilenje, Kaunda Square, Garden and Chawama townships located in Lusaka district. The demographic study results are as shown in the figures below

a) **Gender**

Table 4.1 Gender Distribution

Gender Distribution

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	197	51.4	51.4	51.4
	Female	186	48.6	48.6	100.0
	Total	383	100.0	100.0	

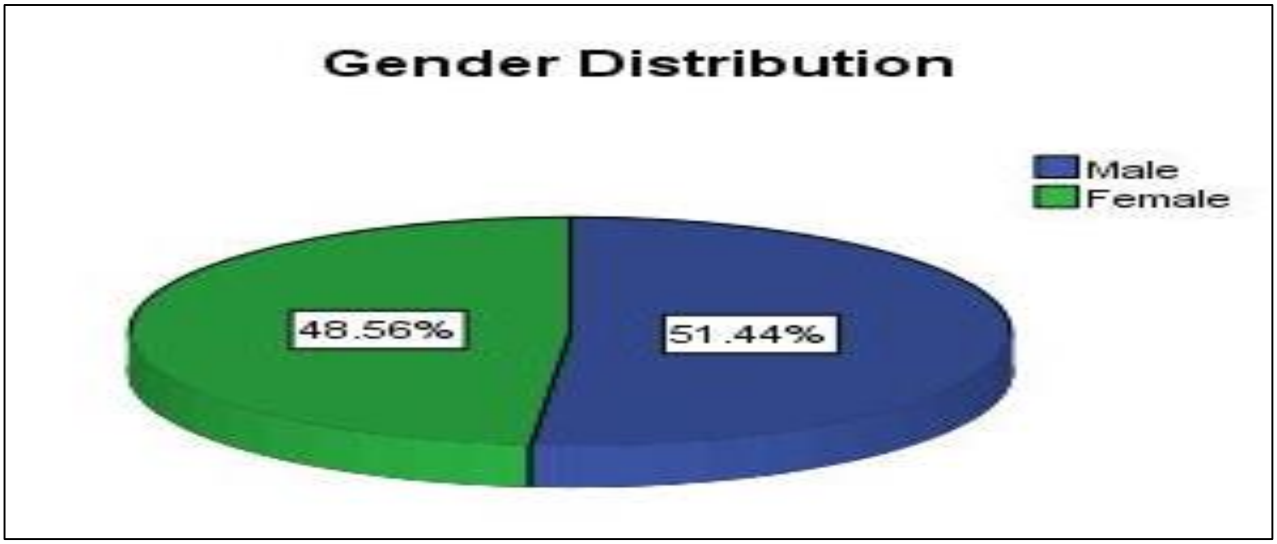


Figure 4.1 Gender Distribution

As regards to gender distribution out of the 383 respondents from the eight townships 197 were male representing 51.44% of the total respondents whilst the rest were female as shown in Figure 4.1 and Table 4.1. This represents a well distributed survey able to produce results and challenges which are reflective of the population thus assisting in achieving the first objective.

b) Age Distribution

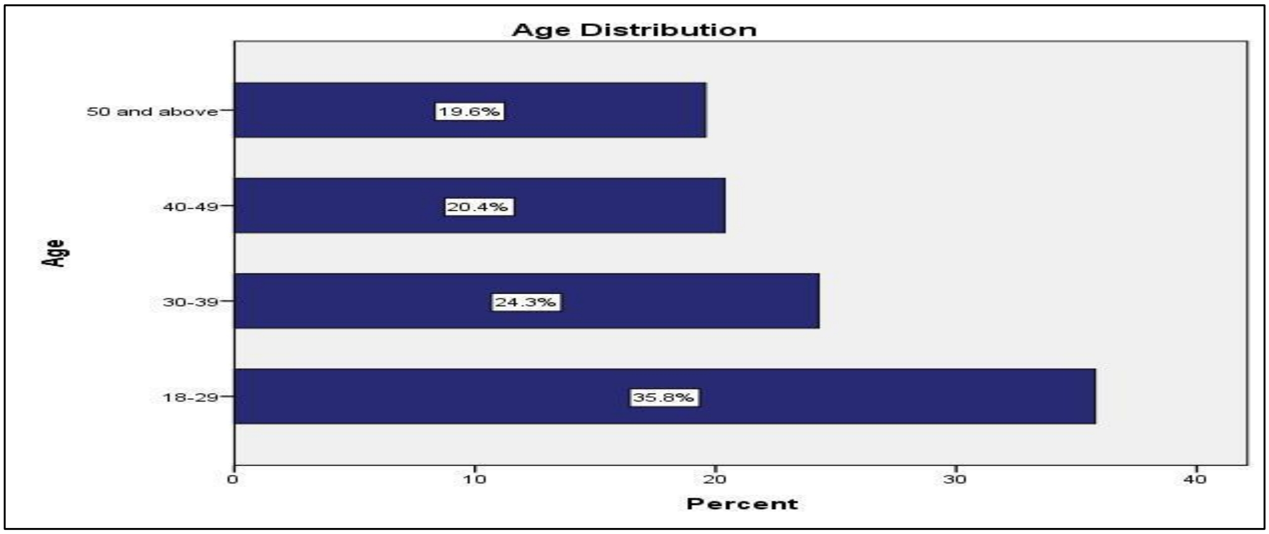


Figure 4.2 Age Distribution

Figure 4.2 shows age distribution with 35.8% of the respondents being in the age group 18-29. The respondents in the age group 30-39 and 40-49 were 24.3% and 20.4% respectively. Whilst 19.6% of the respondents were in the age group of 50 and above. This shows that the majority of the respondents are over 29 years which reflects maturity in the respondents as well as respondents who are in the age range of responsibility and therefore able to give accurate answers to the questions posed and challenges faced thus assisting in achieving the first objective.

4.2.2 Summary of Results on Electricity Usage and Power Failure Reporting

Table 4.2 Summary of Results on Electricity Usage and Power Failure Reporting

NO	RESULT		PERCENTAGE
1	**RELIANCE ON ELECTRICITY**		
a	Access to Electricity		100 %
b	Alternative power sources	YES	13.6 %
		NO	86.4 %
2	**POWER FAILURE EXPERIENCE**		
c	Power Failure experience	YES	93.7 %
		NO	6.3 %
d	Frequency of power failure	Once a day	19%
		Once a week	20.6%
		Once a month	33.2%
		Other	24%

		No applicable	3.2%
e	Longest Power failure experienced	Hours	36.3%
		Days	46.4%
		Weeks	14.1%
		Months	2.7%
	Clients Reporting & Efficiency In ZESCO Response		
f	Personally Made Power failure report to ZESCO	YES	72.6%
		NO	27.4%
g	Method used to report power failure	Walk to ZESCO	35%
		Call Call Centre	53%
		SMS	2%
		Neighbours Call	9%
h	Ease of getting in touch with call centre	Very Easy	9.02%
		Easy	8.75%
		Average	23.08%
		Difficult	33.95%
		Very difficult	18.3%
i	Reasons for Rating Given in Getting Through to Call Centre	Line busy	48.5%
		Line takes time to be answered	34%
		Line always answered	9.2%
j	Longest time taken for ZSECO to respond when a fault is reported	Minutes	1.1%
		Few hours	27.9%
		Days	60.5%
		Weeks	8%
		Months	2.7%
k	Personally made complaint through call centre		66.8%
l	Difficulties in contacting call centre	Line busy	55.2%
		Line takes time to be answered	31.2%
m	ZESCO request for directions	YES	72.6%
		NO	27.4%
	CUSTOMER SATISFACTION OF ZESCO SERVICES		
n	Customer satisfaction	YES	37.3%
		NO	62.7%
O	Reasons for lack of satisfaction	Response rate not good	90.4%
		Poor Service	7.1%
		Customer service not good	2.6%

4.2.3 Reliance on Electricity Discussion

The survey revealed that all the three hundred and eighty three (383) participants have access to electricity and that of these 383, 86.4% do not have alternative power supply sources and are solely dependent on power supply from ZESCO. This indicates that the majority of electricity consumers are affected by power supply failures and would be more likely to report a power failure thus would be able to give an accurate representation concerning the challenges being faced when reporting power failures and would assist in achieving the first objective. This also entails that an automatic power failure sensing system would be beneficial to a lot of customers who do not have alternative power supply since outage duration would be reduced.

4.2.4 Power Failure Discussion

a) Power Failure Experience

Out of the three hundred and eighty three (383) respondents the majority indicated that they had experienced power failure representing 93.7% of the total respondents whereas 6.3% indicated that they had not experienced power failure as shown in Table 4.2. This shows that the majority of the respondents had experienced power failure and would be more likely to report the power failure and thus give accurate answers to the challenges being faced when it comes to reporting power failures thus assisting in achieving the first objective. This also necessitates the need for an automatic power failure sensing system since the majority experience power failures.

b) Frequency of Power Failure

When asked how often the respondents experience power failure 33.2% indicated that they experience power failure once a month whilst the rest experience power failure once a day and once a week. The results also reveal that the longest power failure the respondents have experienced lasted days representing hundred and seventy five (175) respondents. Hundred and thirty seven (137) of the respondents indicated that the longest power failure lasted a number of hours whilst the rest indicated either that the power failure lasted weeks or months. This indicates that the majority experience power failure more often and longer and are likely to report the power failure thus assisting in achieving the first objective to determine the challenges faced when reporting the power failure. This also necessitates the need for an automatic power failure sensing system to reduce on the duration of power failure experienced by electricity consumers.

c) Power Failure Reporting

Of the three hundred and eighty three (383) respondents 72.6% have personally made a power failure report representing two hundred and seventy eight (278) of the total respondents while the rest have never personally reported a power failure as shown in Table 4.2.

When asked what method was used to report a power failure the majority of the respondents indicated that they called the ZESCO call centre representing 53% of the respondents. 35% indicated that they walked to ZESCO whilst the rest used either SMS or neighbors called on their behalf. Of the 72.6% respondents who reported a power failure fault to ZESCO 66.8% reported by calling the call centre indicating that the majority of the reported faults were done through the call centre. This shows that the majority have personally made a report of power failure and have called ZESCO call centre to report a fault thus showing that they are able to give an accurate representation of the challenges faced when accessing call centre and when reporting power failure thus assisting in achieving objective one.

4.2.5 Power Failure Reporting Challenges Discussion

a) The Ease with Which One Can Get in Touch With ZESCO

The majority of respondents had challenges with calling call centre with 52.2% of the respondents finding it either difficult or very difficult to contact the call centre. The reasons sighted for difficulties in contacting call centre were line constantly busy and lines taking long to be answered represented by 48.5% and 34% of the respondents respectively. A cross tabulation of those who reported through ZESCO call centre and the reasons for difficulties in contacting call centre indicated that the majority of those who called call centre indicated that they found it difficult to contact call centre either because the line was busy or the line took too long to be answered representing 86.4% of the respondents.

This shows that the majority who had reported a power failure fault by calling call centre had challenges to contact call centre due to busy line or calls taking too long to be answered indicating that electricity clients do face challenges when reporting power failure and an introduction of automatic power failure reporting system will ensure that these challenges are resolved as it would be able to report power failure automatically to the power utility without the need for the customer to report.

b) Response Time

The challenge faced by the service provider is long response time to power failures reported. The longest time taken by ZESCO to respond to a power failure fault reported was days followed by few hours then by weeks, months and finally by minutes. The statistics collected indicated that 60.5% of the response was that ZESCO took days to respond to power failures reported. This indicates that the response time of ZESCO to power failures reported is long. This response can be improved by the introduction of an automatic power failure reporting system. This system would automatically send an alert of power failure to the cloud platform as well as the cell phone of field personnel in a matter of seconds thereby removing delays caused by the customer reporting the power failure fault as well as the fault coordinator having to assign the power failure fault to a field personnel.

c) Request for Directions

Inability to know exactly where the power failure has occurred is also a challenge faced by the service provider ZESCO. When asked if ZESCO asked for direction to customer premises when there is a power failure fault, 72.6% of the respondents replied in the affirmative and the rest replied in the negative as indicated in Table 4.2. This shows that there is need for an automatic power failure reporting system showing the location of the fault to improve on response time. This would ensure that the location of the fault is known and there would be no need to call the client to determine the location of the power failure. The time which would be wasted to determine the location by calling the customer would be eliminated and this would in turn result in improved response times to power failures reported.

d) Customer Satisfaction

Another challenge faced by the power utility is to maintain customer satisfaction due to the power utility inability to respond to power failures reported on time. The majority of the respondents indicated not being satisfied with the way ZESCO responds to power failures reported represented by 62.7% of the respondents. The reasons indicated by the respondents for not being satisfied with the ZESCO response to power failure were response rate not good representing 90.4% of the respondents, poor service representing 7.1% of the respondents and 2.6% indicated that customer service was not good. This shows that the majority of the customers are not satisfied with the current power failure reporting management mainly because of the poor response rate and an improvement is needed which can be brought about by the introduction of an automatic power failure reporting system. This also supports the result above that the power utility has challenges in responding to power failure reported on time.

4.2.6 Call Centre Statistics

a) Customer Call Statistics

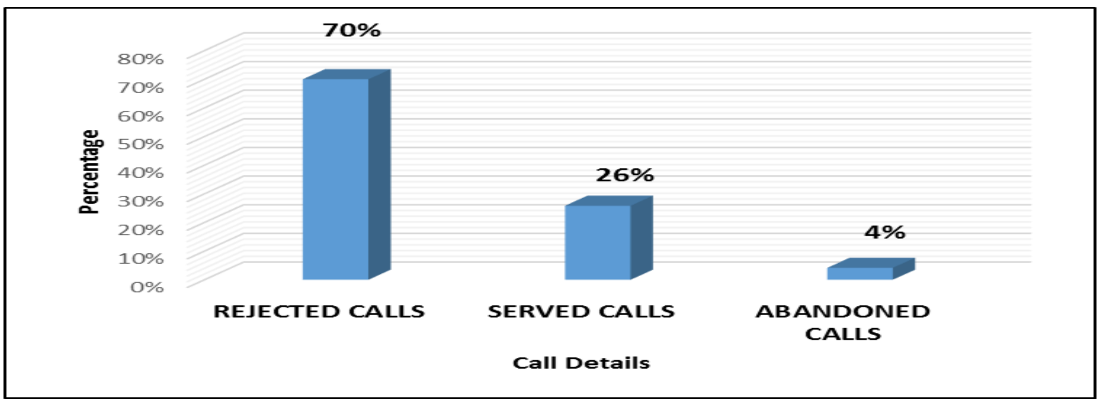


Figure 4.3 Customer Call Statistics

To determine challenges faced by the call centre, call centre statistics were analyzed and they revealed that about 70% of the total calls received from customers are rejected and 4% are abandoned by customers due to insufficient system resources as shown in Figure 4.3. The lack of resources at the call centre to attend to all the customer calls resulting in some calls being rejected by the system or being abandoned by the customer is another challenge being experienced by the power utility. These statistics support the results from the survey that customers experienced difficulties of line busy or line taking long to be answered resulting in customers abandoning the calls. An automatic power failure reporting system would ensure that power failure is reported automatically without the need to call the call centre which would decongest the call centre.

b) Call Centre Reported Faults

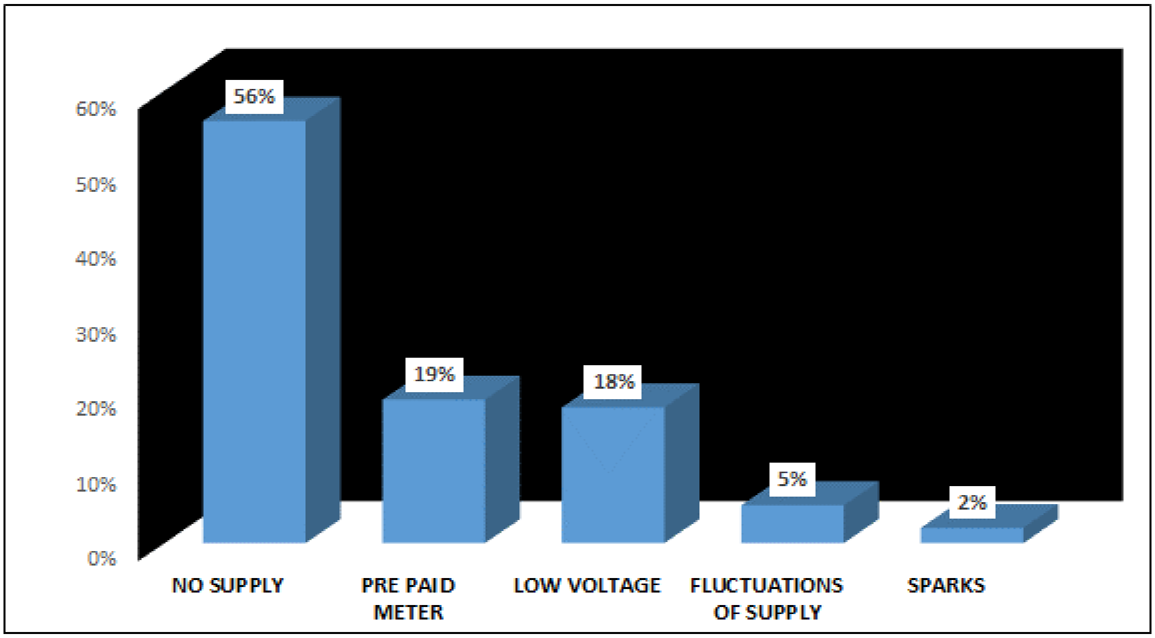


Figure 4.4 Call Centre Reported Faults

The call centre statistics analyzed also revealed that the majority of the faults reported were complaints of no supply representing 56% of the total faults reported as shown Figure 4.4. This shows that if an automatic power failure reporting system is introduced the call centre would be decongested and would concentrate on attending to other non-power failure faults reported by customers. This would assist in achieving the second and third objective as it would be one of the inputs to the design of the power failure model and prototype.

4.3 System Implementation

Manual methods of power failure reporting where the customer calls in to report the fault and where the field personnel are informed of the power failure fault by the fault coordinator can be replaced with automated systems in order to eliminate the challenges brought about by manual systems. In order to show how an automated power failure reporting management system will work, a prototype was developed to show proof of concept. The prototype was implemented using sensing and cloud based technology to show how an automated power failure reporting system can be done.

In this study, power failure reporting models were developed and a system prototype was implemented that shows the concept of how the automated cloud based power failure sensing system will work.

Firstly, information was gathered, analyzed and formulated into useful system requirements (see Chapter 3 Section 3.3.2). The system requirements were derived from data collected from electricity clients in Lusaka district and from the interviews with call centre personnel and faults coordinators that provided insight into the operations of ZESCO's current power failure reporting management system.

Secondly, the system requirements and interviews informed the design phase of the implementation. System models were developed using information obtained from primary sources and secondary sources (literature review).

Thirdly, a prototype of the system was developed which consisted of an electronic device made from a Voltage sensor circuit, Arduino Microcontroller board, 4G/GSM/GPRS/GPS module, solar based battery charge controller and Web Cloud services using cloud architecture, Web Application, Google Map API.

Finally, the prototype was tested to ensure that all functionalities were working correctly.

In this section, the current business processes that ZESCO uses in its power failure management are illustrated as determined from the information obtained from the interviews that were conducted with the call centre personnel and fault coordinators from faults centre. The proposed business processes that ZESCO can use to automate the power failure reporting management are also presented. The screenshots from the prototype implementation Graphical User Interfaces (GUI) are presented. The screenshots include the hardware setup, mobile phone GUI screenshots, local LCD and cloud platform screenshots. The functionalities that were implemented in the prototype were:

i) The ability to login to the system,
ii) Sensing the three phase power failure from a power supply line,
iii) Sending three phase power failure alerts to the cloud platform,
iv) Sending three phase power status alerts to a predefined mobile phone number,

v) Sending the location of the power failure to the cloud platform as well as to a predefined mobile phone number,

vi) Showing the voltage values of the three phases of the power line on the cloud platform and

vii) Showing the phase id, status, date and time of the power failure of the three phases and storing the information in the cloud database.

4.3.1 Current ZESCO Power Failure Reporting Management Business Processes

To assist in achieving the second objective the current business processes were determined by information obtained from the interviews with the call centre personnel and fault coordinators from fault centre. The current business processes are described in this section.

a) Current Power Failure Reporting Management System

The current business processes which ZESCO uses for power failure reporting are reliant on the customer reporting the power failure to ZESCO call centre. As shown in Figure 4.5, in the current power failure fault reporting business model the customer can either call, SMS or walk into the customer call centre to report a fault. After the power failure is reported to the call centre agent the customer is given a reference number which can be used to make a follow up on the power failure complaint. Once the report is entered into the system it is picked up by the fault coordinator who calls the field personnel to attend to the faults. The field personnel in turn calls the customer to get the location of the power failure. Once the fault is resolved the field personnel calls and updates the coordinator who in turn manually enters the information in the system. At the end of the shift the coordinator prepares a report which is emailed to the regional manager. The challenges identified with this model are difficulties in accessing call centre to report a fault due to either line being constantly engaged or line never answered, locating the power failure point, limited resources at the call centre leading to rejection of some of the calls from clients, poor response to power failures reported, coordinator inability to relay the information to the field personnel and inability to determine accurate durations of the power failure since update is done manually.

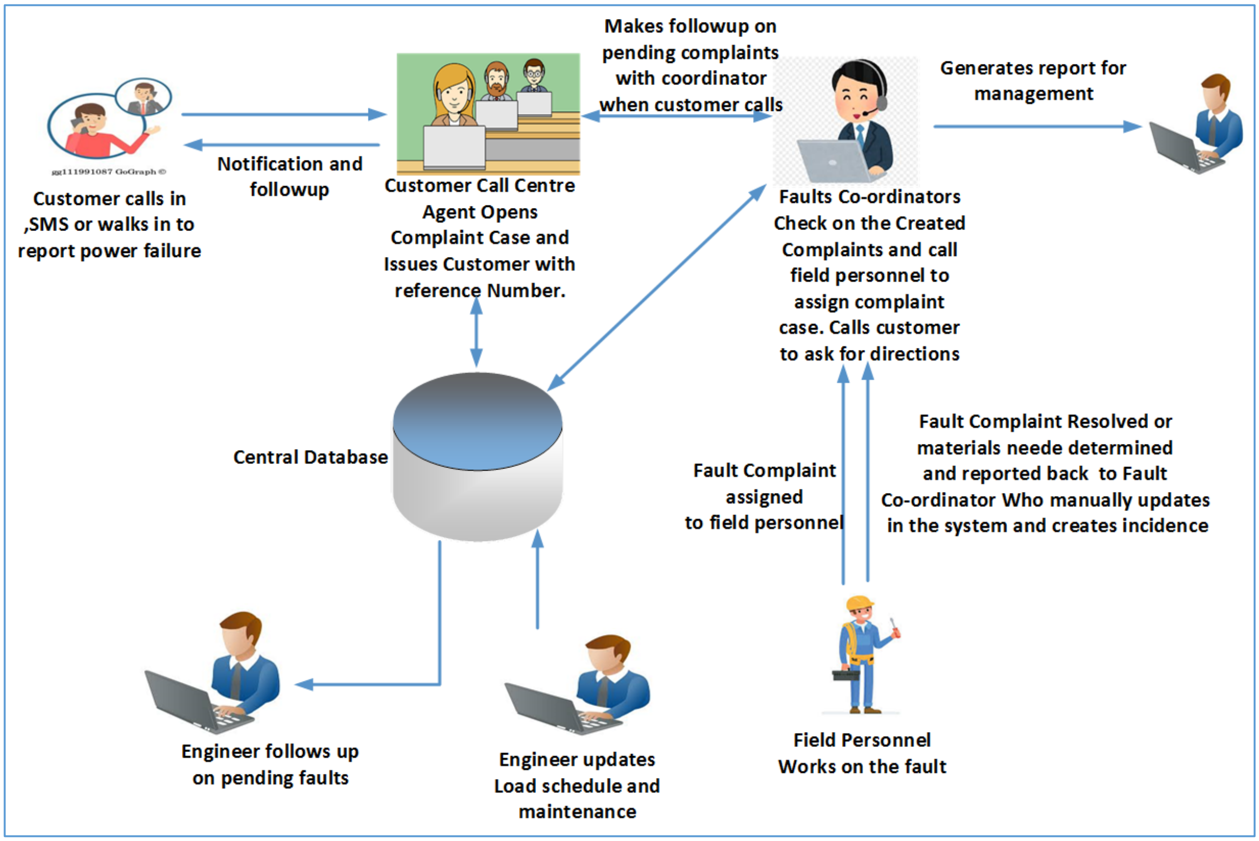


Figure 4.5 Current Power Failure Reporting Management Model

4.3.2 Proposed ZESCO Power Failure Reporting Business Process Model

In this research, an alternative business process model based on the current business process that is being used by ZESCO was proposed to achieve the second objective. Automating the current business processes that are being used by ZESCO is the change that is proposed in this section. The following is a description of the proposed ZESCO business process model as shown in Figure 4.6.

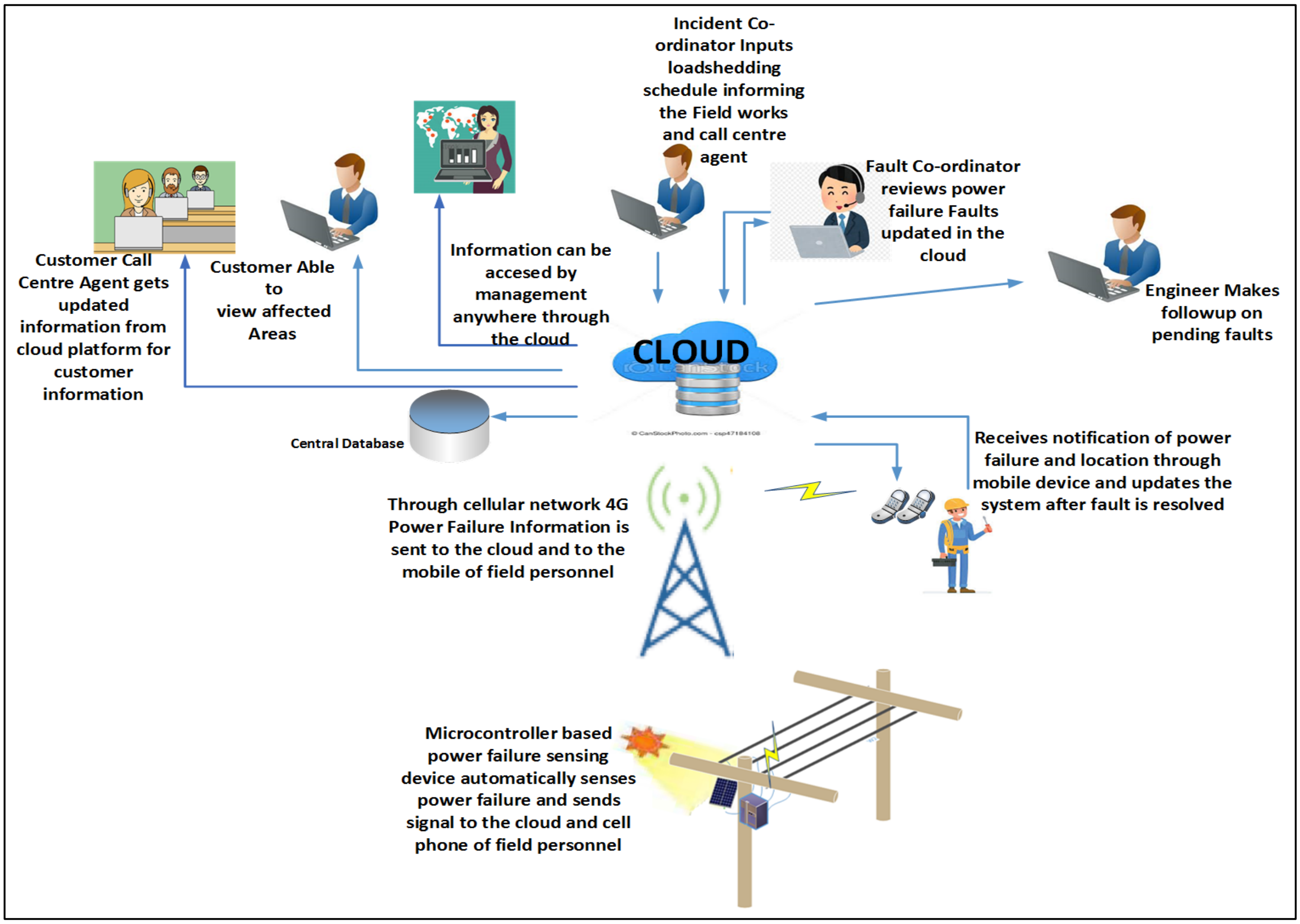


Figure 4.6 Proposed ZESCO Power Failure Reporting Business Process Model

The proposed business model consists of an electronic device composed of a Voltage sensor circuit, Arduino Microcontroller board, SIM7600E 4G/GSM/GPRS/GPS Wireless Communication module, solar charge controller and web Cloud services with a battery charged by solar as backup supply. This device is connected to the three phases of a Low Voltage 0.4kV power line. Power Supply on each phase is monitored by the voltage sensor circuit.

When there is loss of supply on any of the three phases input to the Arduino microcontroller becomes zero and this is detected by the Arduino. Through the embedded program in the Arduino microcontroller an SMS alert consisting of status of the supply on each phase as well as the location is sent to a predefined cell phone number of field personnel using the connected Wireless Communication module over the cellular network.

At the same time using the AT commands to the Wireless Communication module, the application on the remote server is invoked to insert the power failure status data, voltage values and location of the power failure data into the cloud database for storage enabling this information to be viewed by call centre and faults centre personnel as well as field personnel.

The power failure alerts are received on the Mobile phone and cloud application within 35 seconds as revealed in the prototype tests conducted. Through this model the utility is able to be notified of the power failure in a matter of seconds and would start responding immediately thereby improve on response time.

The proposed business model differs from the current model in that the power supply failure is automatically reported to ZESCO without the customer having to call in and report the fault.

4.3.3 Prototype Implementation

To achieve the third objective the business processes and models that have been presented in Chapter 3 Section 3.3 and Sections 4.3.2 serve as the building blocks upon which the prototype for the power failure management system is based and was developed. These will further serve as the foundation upon which the fully functional power failure reporting system can be developed in future. This section describes the prototype which was developed.

a) Hardware Setup

Figure 4.7 shows the hardware setup of the components used in the cloud based power failure sensing prototype implementation which include the Voltage sensor circuit, Arduino Microcontroller board, LCD screen, 4G/GSM/GPRS/GPS Wireless Communication module, solar panel, Battery Charge Controller, battery and web Cloud services. The voltage sensor circuit, LCD screen, Arduino microcontroller board and 4G/GSM/GPRS/GPS wireless module are on the same printed circuit board. The solar panel is connected to the battery charge controller which is in turn connected to the battery and the device. An on board power supply for the Arduino and wireless module is provided through the phases. When the three phases lose power supply the device is powered by the solar panel and battery through the charge controller.

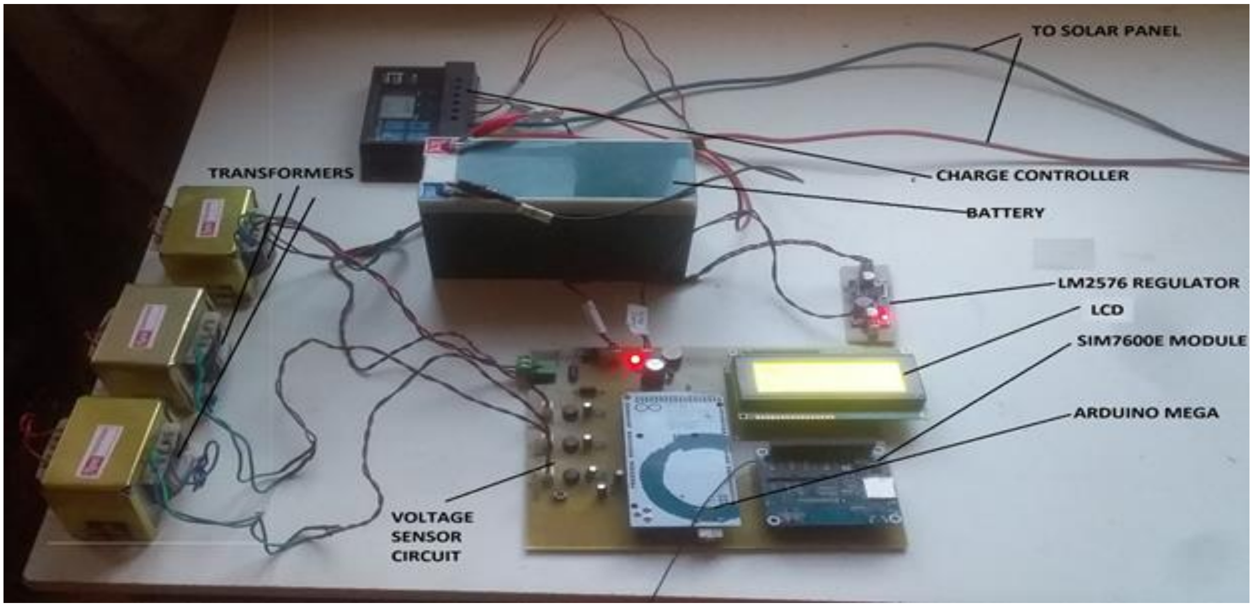


Figure 4.7 Hardware Setup of the Prototype

b) Electronic Device Three Phase Power Failure Sensing

The electronic device has an LCD display to show the voltage values of the three phases. The LCD screen gets its input from the Arduino as its embedded program detects the power supply failure from the three phases through the voltage sensor circuit. Appendix C shows the Arduino code which was used to realize this. In Figure 4.8 the voltage values are showing zero indicating that there is loss of power supply on all three phases**.**

Figure 4.8 Voltage Values of the Three Phases Displayed Showing Zero Voltage

In Figure 4.9 the display on the LCD screen is showing non-zero voltage values for all three phases indicating that there is power supply on the three phases.

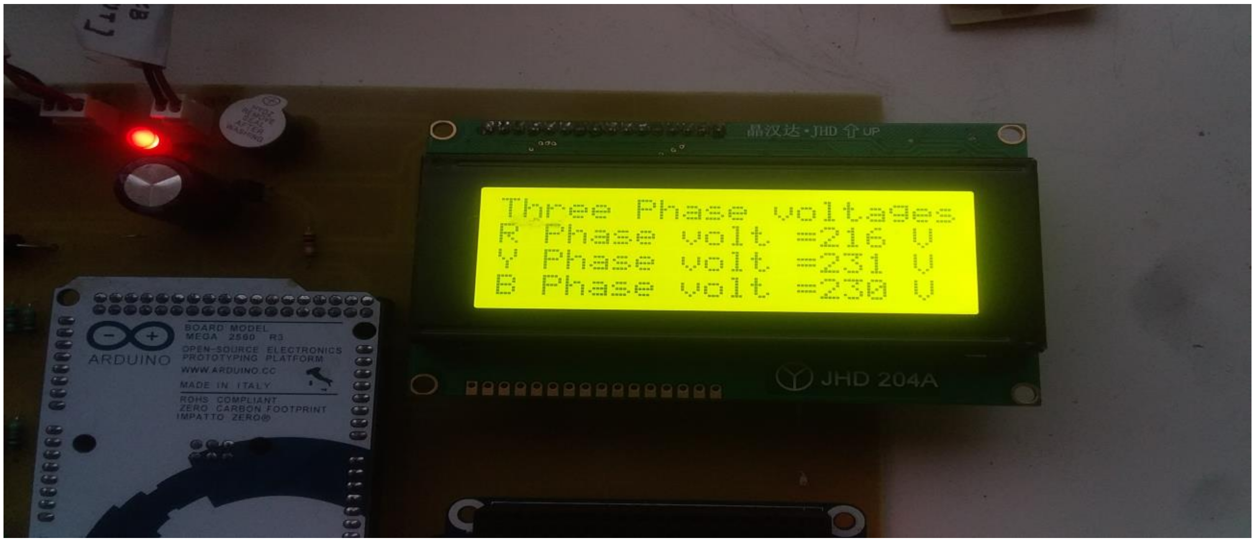


Figure 4.9 Voltage Values of the Three Phases Displayed Showing Non- Zero Voltage

Figure 4.10 is showing zero voltage value for red phase and non-zero voltage values for the other two phases indicating loss of power supply in the red phase.

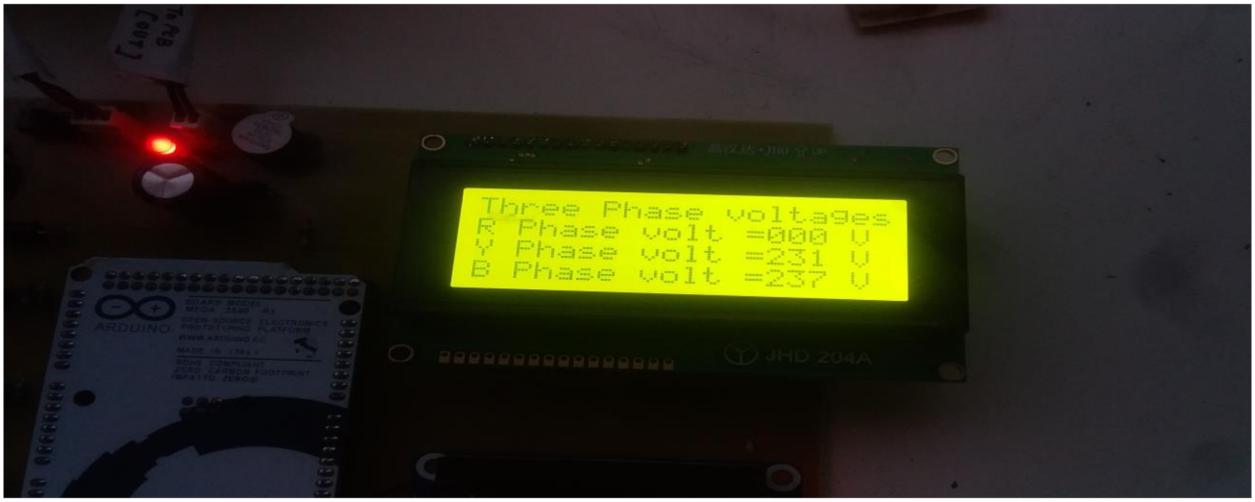


Figure 4.10 Voltage Values of the Three Phases Displayed Showing Zero Voltage for Red Phase

In Figure 4.11 the display on the LCD screen is showing zero voltage values for red and yellow phases indicating that there is loss of power supply on the red and yellow phases

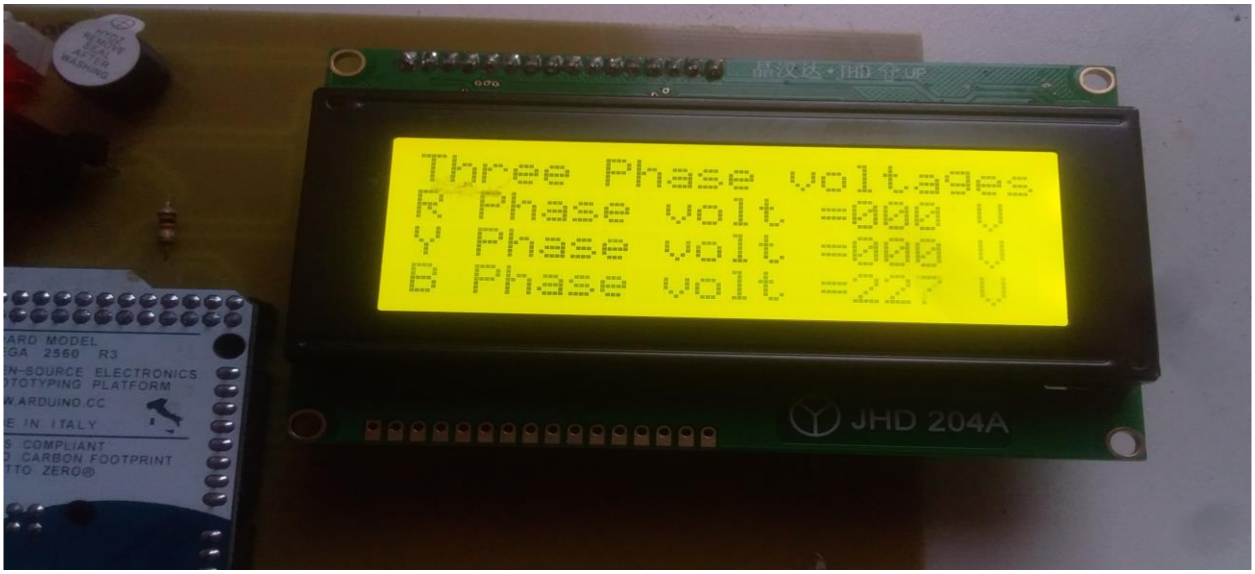


Figure 4.11 Voltage Values of the Three Phases Displayed Showing Zero Voltage for Red and Yellow Phases

c) Cloud Platform Login Authentication

Figure 4.12 is the screen that greets the user when they first run the cloud platform web application for the power failure sensing system. The purpose of login authentication is to enforce security measures to ensure only authorized individuals have access to the system.

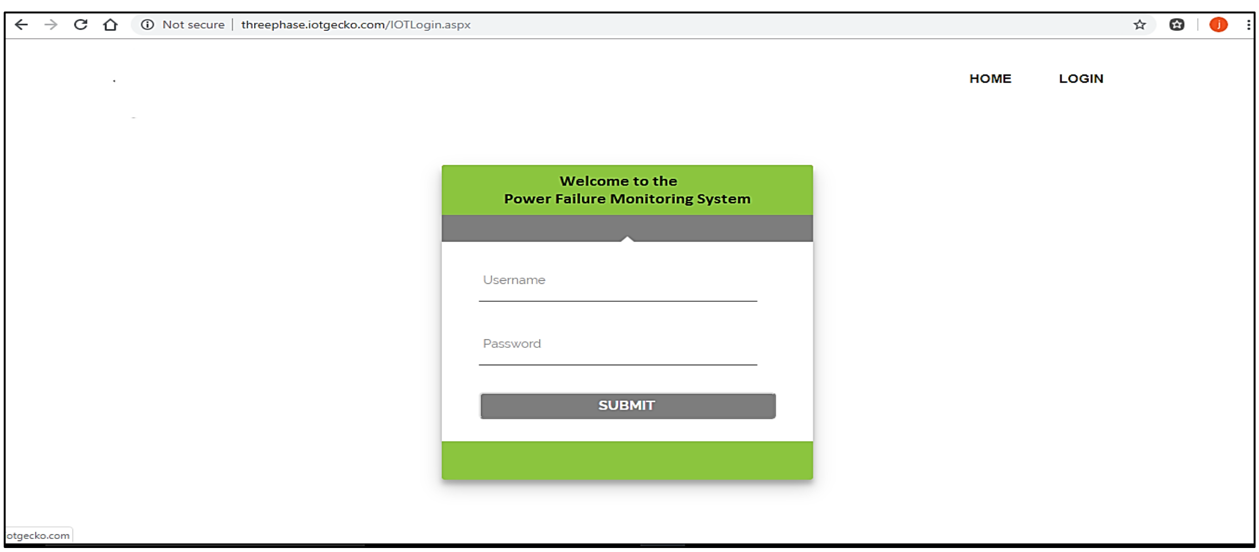


Figure 4.12 Cloud Platform Login Window

d) Cloud Platform Power Failure Alert

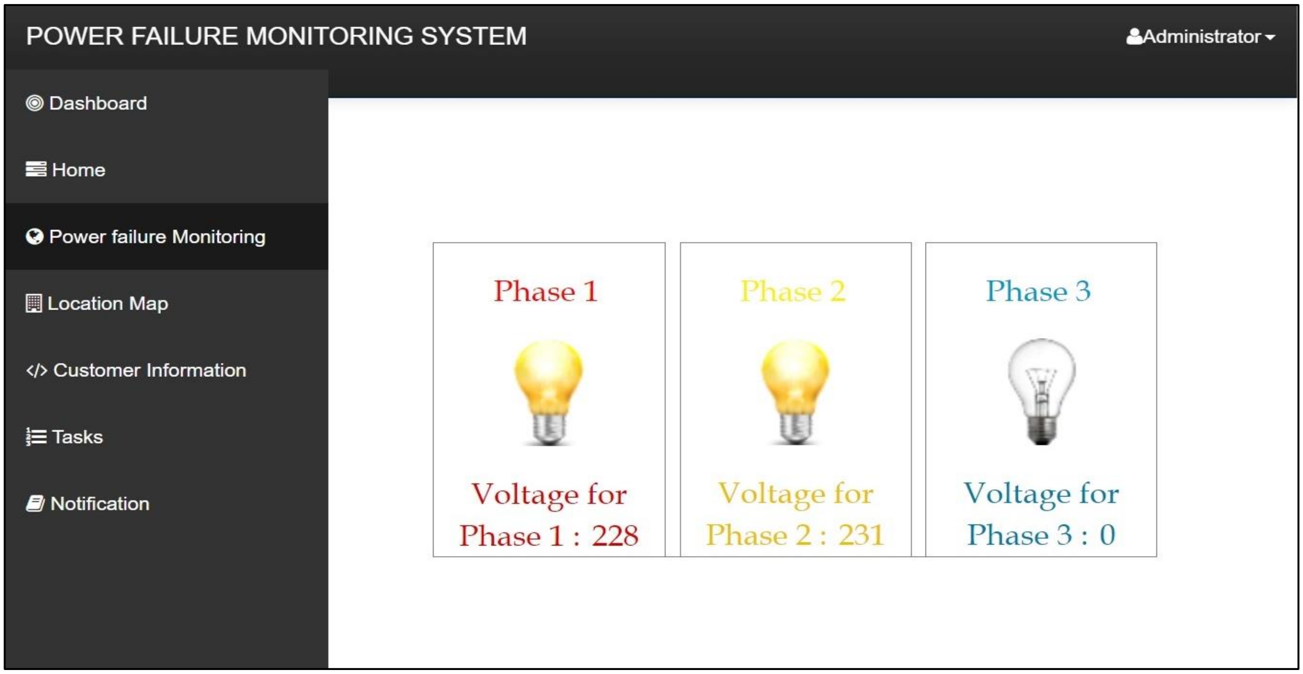


Figure 4.13 Cloud Platform Power Failure Alert and Voltage Monitoring

Figure 4.13 shows the graphical representation of the power failure alert on the cloud platform. On the cloud platform the three phases are graphically represented by bulbs distinguished by the phase colors. Whenever a loss of power supply is detected by the electronic component on the power line the power failure alert message is sent through the cellular network to display the voltage status of the three phases on the cloud platform. The display on the cloud platform consists of the voltage values for each of the three phases has shown above**.** The code used to realize cloud platform web application is shown in appendix D.

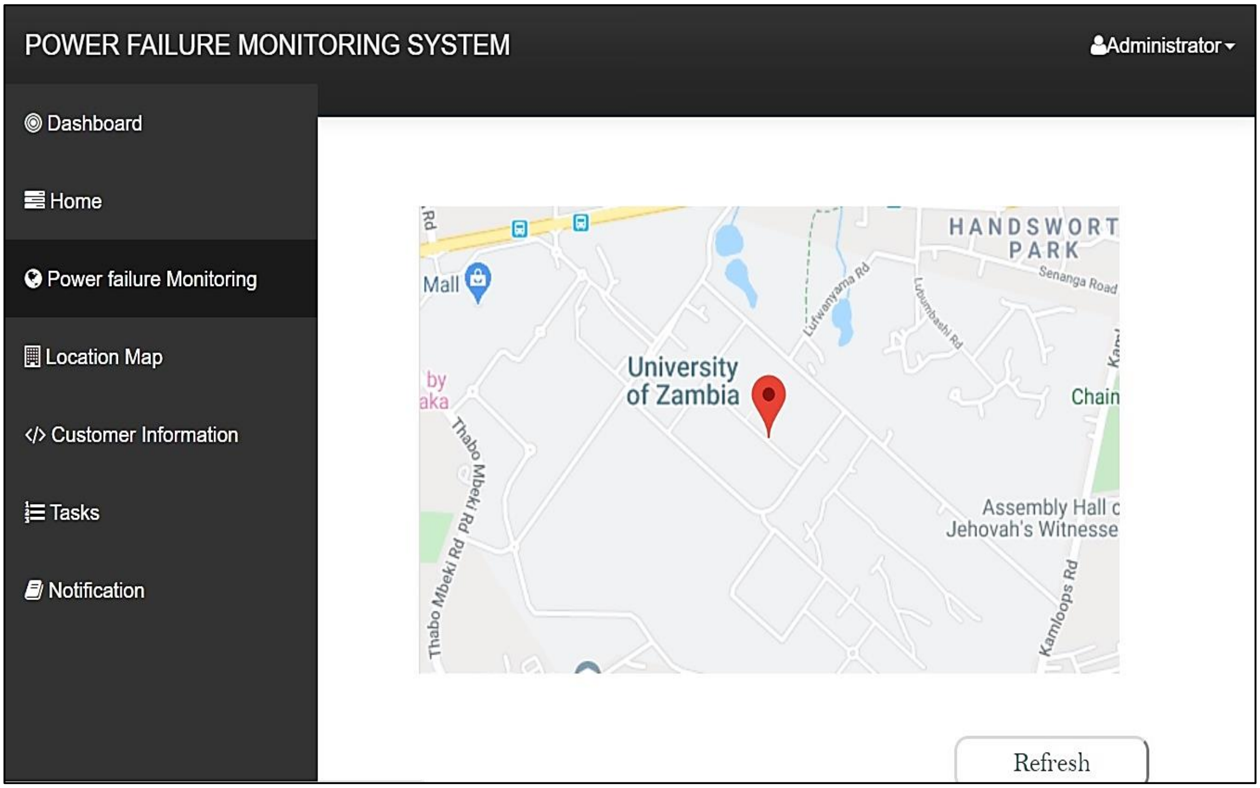


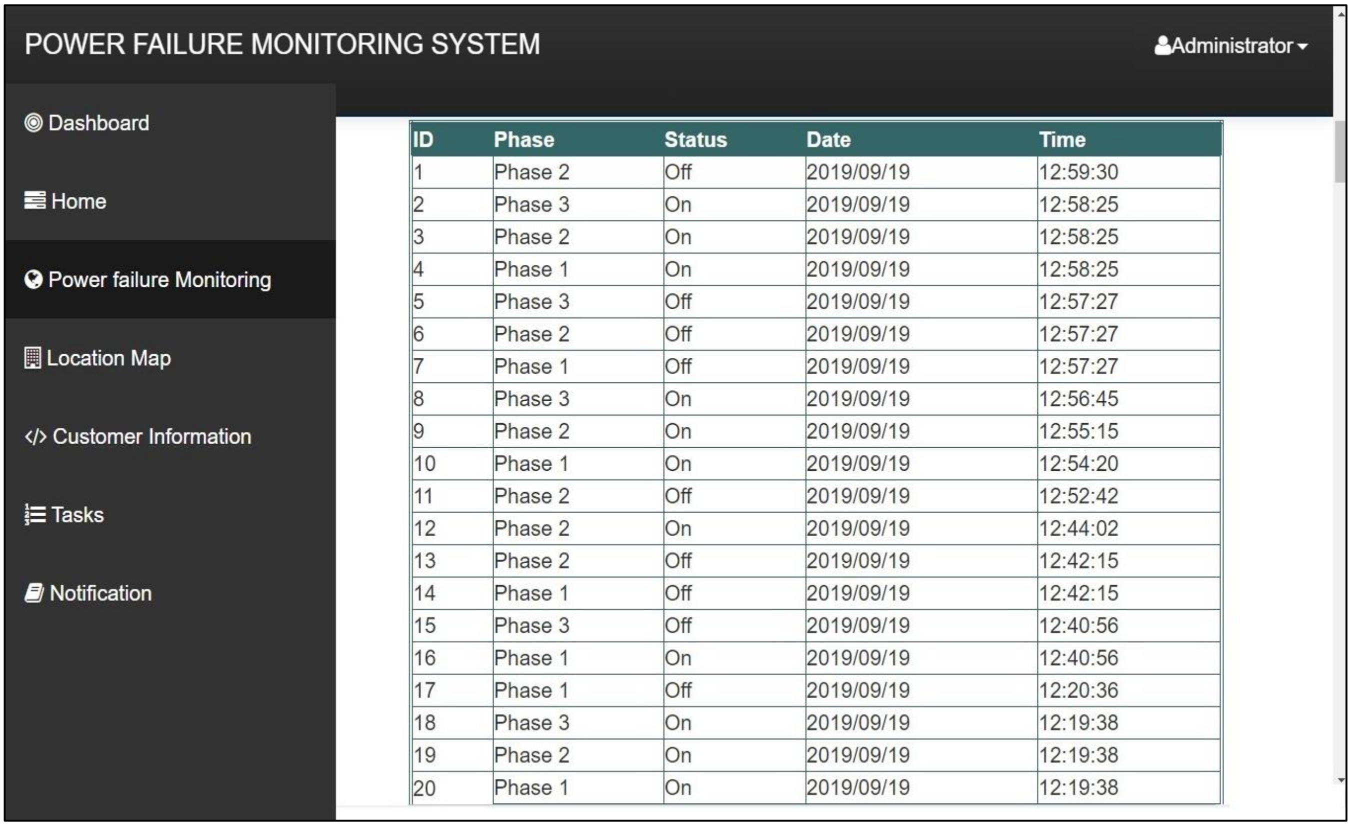
Figure 4.14 Power Failure Location

e) Cloud Platform Power Failure Location

As shown in Figure 4.14 the power failure location is displayed on the cloud platform web application. Upon detection of the loss of supply by the electronic device on the power line, location of the power failure determined by the 4G/GSM/GPRS/GPS module is sent to the web application through the cellular network. Google maps API is used to display the location of the power failure on a map indicating the name of the area in which the power failure has occurred**.**

f) Cloud Platform Three Phase Power Status, Date and Time

Figure 4.15 below shows the power failure status, date and time for the phases. As the power failure is detected by the electronic device the alert messages are sent to the cloud platform and displayed indicating the power supply status in the three phases, the date and time when the power status was detected. This information is stored in the database and it is possible to view historical information of the power failure alert messages. From this information it is possible to determine the duration of the power failure.



ID	Phase	Status	Date	Time
1	Phase 2	Off	2019/09/19	12:59:30
2	Phase 3	On	2019/09/19	12:58:25
3	Phase 2	On	2019/09/19	12:58:25
4	Phase 1	On	2019/09/19	12:58:25
5	Phase 3	Off	2019/09/19	12:57:27
6	Phase 2	Off	2019/09/19	12:57:27
7	Phase 1	Off	2019/09/19	12:57:27
8	Phase 3	On	2019/09/19	12:56:45
9	Phase 2	On	2019/09/19	12:55:15
10	Phase 1	On	2019/09/19	12:54:20
11	Phase 2	Off	2019/09/19	12:52:42
12	Phase 2	On	2019/09/19	12:44:02
13	Phase 2	Off	2019/09/19	12:42:15
14	Phase 1	Off	2019/09/19	12:42:15
15	Phase 3	Off	2019/09/19	12:40:56
16	Phase 1	On	2019/09/19	12:40:56
17	Phase 1	Off	2019/09/19	12:20:36
18	Phase 3	On	2019/09/19	12:19:38
19	Phase 2	On	2019/09/19	12:19:38
20	Phase 1	On	2019/09/19	12:19:38

Figure 4.15 Power Failure Status, Date and Time

g) Power Failure Alert on Mobile Phone

In Figure 4.16 power failure alert messages sent to mobile phone is shown. Once the power failure is detected by the electronic device on the power line a power failure alert message is sent through the cellular network to a predefined cell phone number. The alert message displayed on the mobile phone shows the status of power supply in the three phases. The alert message sent also consists of a link to Google maps to show the location of the power failure.

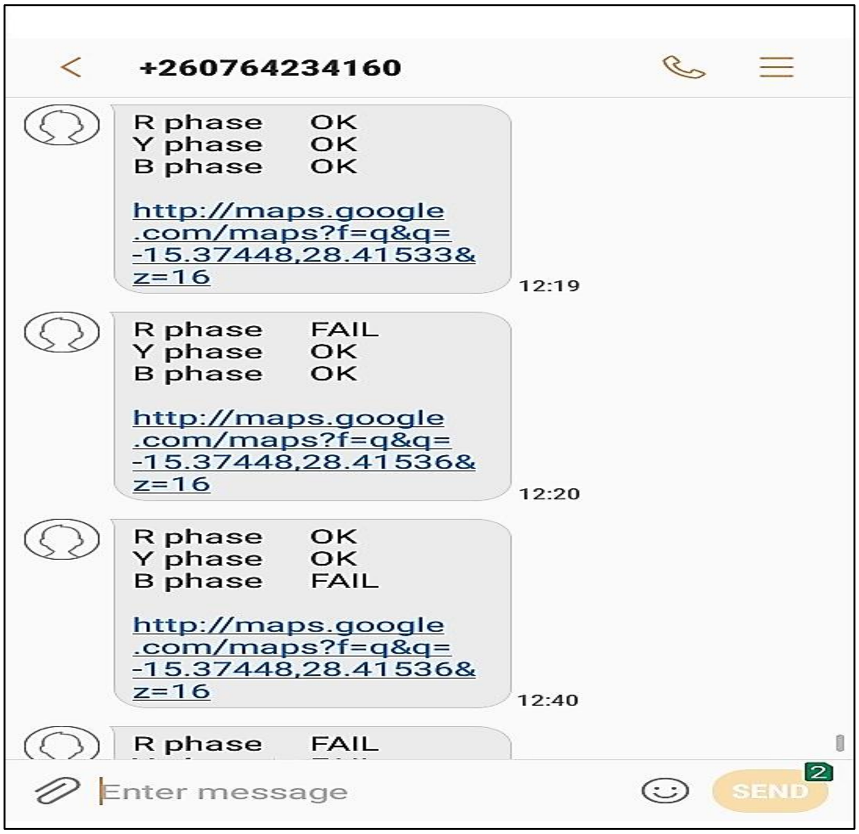


Figure 4.16 Power Failure Alert on Mobile Phone

h) Power Failure Location Display on Mobile Phone

The power failure location is also displayed on the mobile phone has shown in figure 4.17. The power failure alert message sent to the mobile phone is displayed with a link to Google maps which when clicked displays the location of the power failure on the mobile phone. The Google maps link is sent as part of the alert message from the electronic device and is made possible through the 4G/GSM/GPRS/GPS module which determines the location of the power failure based on the location of the detecting electronic device and this location is in turn sent to the mobile phone in form of a link to Google maps.

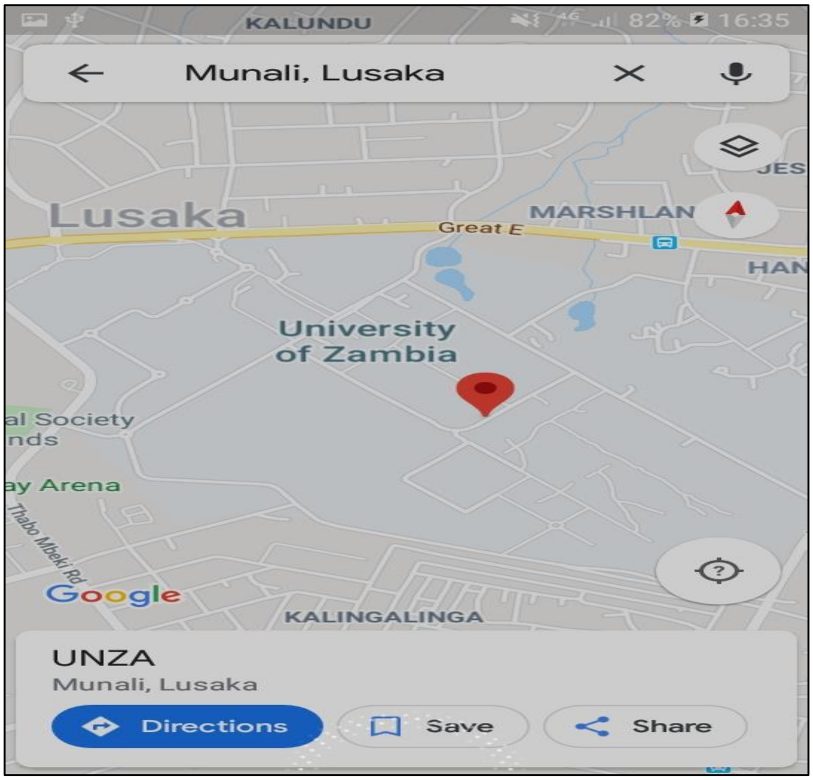


Figure 4.17 Power Failure Location Display on Mobile Phone

4.3.4 Discussion on the Prototype Implemented

As indicated in the proposed model and snapshots from the prototype in section 4.3.3, the prototype proposed is an example of how cloud based power failure sensing can be used to automate power failure reporting. The overall architecture of the proposed system utilizes cloud based power failure sensing technology for automatically reporting power failure to ZESCO personnel consisting of a microcontroller based electronic device which is connected to a low voltage distribution power line and uses a 4G/GSM/GPRS/GPS cellular wireless module to transmit power failure alerts and locations as well as voltage values to the cloud platform and mobile phone of field personnel. 4G/GSM/GPRS/GPS cellular wireless module ensures that the alerts can be sent from anywhere as long as there are cellular towers around. The challenges that are faced by the electricity clients and the service provider in the current power failure reporting management system such as failure to get through to the customer call centre due to busy line, unanswered calls and failed calls, the inability to attend to all the customers through the call centre as customer calls are rejected due to limited Call Centre system resources, difficulties in finding the location of the power failure, challenges in relaying power failure information to field personnel, challenges in determining duration of power failure and poor response time can be mitigated through the use of automation.

Automating the power failure reporting system can significantly reduce the various challenges that ZESCO and the electricity clients face regarding power failure reporting. The microcontroller based electronic device eliminates the need for the customer to report power failure to ZESCO as power failure is automatically detected and power failure alert messages are automatically relayed to ZESCO field personnel as well as fault coordinators. This overcomes the challenges of accessing call centre as well as the limited resources at call centre to attend to customer calls. Apart from that the field personnel will automatically receive the power failure alert messages eliminating the challenges fault coordinators face of relaying power failure information to field personnel. Location of the power failure is also sent to the cloud platform and mobile phone of field personnel thereby eliminating the challenges of locating the power failure site and in turn improving response times.

Tests conducted on the prototype confirm that it performs better than the current power failure reporting system which relies on the customer for fault reporting. The proposed prototype would contribute to reduction of system outage durations, enable quick response and reduce the burden on call centre resources as power failure would be reported automatically to mobile phone of field personnel and cloud platform. The ability to show the time and date of the power failure will enable determination of accurate power failure durations.

While all the business processes and models necessary for automation were mapped, the scope of the prototype implementation was limited to developing the cloud web application showing the location, time, duration, status and voltage values of the 3 phases of the power line and sending alert message to the mobile phone of field personnel and cloud platform as shown in section 4.3.3. The proposed prototype provides other benefits such as the ability to view the information about power failure anywhere and anytime through the cloud platform. Through the cloud platform managers can access the information about power failure and generate statistics anywhere they are in the world.

This system can be adopted in the Low Voltage network where it will be able to capture power failure and enable monitoring of the low voltage network as voltage readings of each phase are displayed on the cloud platform. From the cloud platform duration of the power failure is captured and this can be used to determine the performance of the service provider when it comes to responding to power failures.

Through the low latency SIM7600E 4G/GSM/GPRS/GPS module location and voltage values are quickly updated through the mobile phone and cloud platform enabling almost real time monitoring of the distribution network. This automatic and quick update enables monitoring of the distribution network and rapid response to power failures resulting in reduced System Average Interruption Duration Index (SAIDI) and Customer Average Interruption Duration Index (CAIDI) indices for the power utility. The prototype has a solar charged battery through the MPPT charge controller to ensure that it is still powered even after loss of all three phases for long periods of time. The system can be programmed to send systematic alerts to the utility after a specified period of power failure so that the utility is reminded of the power loss and avoid prolonged outage durations.

4.4 Summary

In this chapter, the results of the baseline study were presented in form of tables, bar and pie charts and discussed. The researcher established that ZESCO currently experiences challenges such as difficulties in accessing call centre to report a fault due to either line being constantly engaged or line never answered, locating the power failure point, limited resources at the call centre leading to rejection of some of the calls from clients, poor response to power failures reported, coordinator inability to relay the information to the field personnel and challenges in determining accurate duration of the power failure due to manual updates of power failures. Under system implementation, the current power failure business process was illustrated, and the proposed design for automation of the current power failure reporting management model were presented. Screenshots from the prototype implementation were presented and finally the prototype implementation was discussed.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

In this chapter, the conclusions and recommendations are presented. The conclusion starts by highlighting the research findings and goes on to discuss how these research finding correlate with existing knowledge as provided by literature, the recommendation is then given and finally, future work and chapter summary are presented.

5.2 Conclusions

Zambia is a developing country located in sub-Saharan Africa. Loss of Power supply is the main fault reported by customers. Power supply failure can be due to a number of causes such as High-speed wind, flying objects, falling trees, physical contact by animals, lightning, snow storms, and contamination of insulators, human errors, overloads, bad insulation, and protection failure. Zambia's power supply provider ZESCO and the electricity clients face challenges when it comes to power failure reporting management.

In this research we conducted a baseline study to establish the challenges faced by ZESCO the electricity service provider as well as the electricity clients in the current power failure reporting management model. Questionnaires were used to collect the quantitative and qualitative data needed for the baseline study. From the baseline study the challenges faced by ZESCO (power utility) and the electricity client were determined as being failure to get through to the customer call centre due to busy line, unanswered calls and failed calls, the inability to attend to all the customers through the call centre as customer calls are rejected due to limited Call Centre system resources, difficulties in finding the location of the power failure, challenges in relaying power failure information to field personnel, challenges in determining duration of power failure and poor response time. These challenges can be mitigated through use of automation as presented in chapter 4 section 4.3.2 and 4.3.3.

A detailed literature review was conducted to find related cloud based and sensing technology applications. The literature review covered the workings and characteristics of sensing systems, cloud services, microcontrollers, cellular technology, and software development methodologies as well as power failure management in the distribution grid. It was further noted that there are no sensors in the Zambian 0.4kV distribution network to enable visibility of the network and that this made this research necessary. The literature review indicated that having sensors in the distribution grid is indeed beneficial as it improves grid visibility and situational awareness for grid operators. The literature review further revealed that cloud computing services are necessary for the management of the huge amounts of data coming from the sensors in the electric grid. The benefits of huge storage, processing power for analysis, availability and reliability of resources offered by cloud computing makes it very useful in automation of the electric grid. Low latency and high bandwidth cellular communication systems make it possible to relay the information from sensors to the power utility operating centers. From the literature review it was noticed that there exists a number of research gaps in the sense that there were no experiments or projects which made use of cloud and sensor technology as applied in three phase power failure management and monitoring enabling alert, location and measurement information to be transferred to both the mobile phone and cloud services for storage and for location on location maps.

Qualitative data was obtained from interviews conducted with ZESCO call centre personnel and fault coordinators to determine the current power failure management model and to inform the system design process. The current power failure management model was determined to be dependent on customer calls to report power failures. Manual relay and update of power failure information is being used in the current power failure management model. The findings from the interviews with ZESCO call centre personnel and data collected from the electricity clients were used as a basis upon which the cloud based power failure sensing models were developed as indicated in chapter 3 section 3.3.

The business process model and the prototype that ZESCO can use to automate power failure reporting was proposed; these include the use of Voltage sensor circuit, Arduino Microcontroller board, 4G/GSM/GPRS/GPS module, Solar based battery charge controller and Web Cloud services using cloud architecture, Web Application, Google Map API. System models used to design the proposed prototype including interaction models (use case, sequence diagram models, block diagrams and flow charts) and data models (database schema and entity relationship models) were developed to provide the means by which the cloud based power failure sensing system may be implemented. The models were then used as a blueprint to inform the prototype development.

The functionality achieved in the prototype developed was that when the power supply input to the microcontroller based device becomes zero, the embedded program in the microcontroller sends an SMS alert consisting of information on the phase which has lost supply as well as the location to a predefined cell phone number using the connected 4G/GSM/GPRS/GPS Wireless Communication module over the cellular network.

At the same time by sending AT commands to the 4G/GSM/GPRS/GPS, the application on the remote server is invoked to insert the power failure voltage values and location of the power failure data into the cloud database for storage.

The power failure alerts are received on the Mobile phone and cloud platform in a matter of seconds. The prototype serves to demonstrate the proof of concept of how the cloud based power failure sensing can be implemented. An implementation of a full-fledged cloud based power failure sensing system was not carried out due to time and financial limitations. Based on the objectives of this study, the following conclusions were arrived at:

The challenges faced by the power utility and the electricity clients as determined in chapter 4 can be alleviated by replacing the current power failure management model which is dependent on humans with an automated power failure management model consisting of a cloud based power failure sensing device installed on a distribution electricity line. In the proposed model and prototype developed cloud and sensor technology is applied in three phase power failure management and monitoring enabling alert, location and measurement information to be transferred to both the mobile phone and cloud services for storage and for location on location maps. Power failure alerts are sent to the mobile phone and cloud application in a matter of seconds as previously mentioned this is definitely faster than having the customer report the fault. When adopted this system will

i) Improve response times to power failure reports and reduce system outage durations as the power failure will be reported automatically to the utility personnel through the cloud and mobile phone.

ii) Improve the power utility's SAIDI and CAIDI indices due to reduced power outage durations.

iii) Enable the service provider monitor the low voltage network and keep track of power failure durations through the cloud platform,

iv) Reduce the burden on call centre resources and remove the burden of the customer reporting power failures

v) Enable field personnel access to power failure information through the cloud platform.

5.3 Recommendation

As it has been noted earlier the low voltage electric grid in Zambia is not monitored resulting in the lack of situational awareness of this part of the grid for the power utility. This results in the challenges discussed in chapter 4. The prototype developed can be easily installed to provide the visibility of the low voltage network to eliminate these challenges. We therefore recommend that ZESCO automate power failure reporting for the 0.4kV low voltage network using sensing and cloud technology to enable grid visibility and situational awareness thus ensuring rapid response and reduction on the dependence on customer calls to report power failures and in turn reduce on SAIDI and CAIDI indices. This will enable the utility experience all the benefits this system has to offer.

5.4 Future Works

Further development of the system prototype to a full-fledged cloud based power failure sensing system will be carried out. The current prototype is but a simple system showing proof of the concept of power failure reporting automation using cloud and sensing technology. Implementation of an alert message sent to the utility if power outage has prolonged for a specified period of time can be done. The prototype can be improved by including the detection of low voltage faults and provide further measurements such as current and power apart from voltage values.

5.5 Summary

In this chapter, the conclusion and recommendations are presented. In the conclusion the research conducted is outlined. The literature review, gap identified and challenges are presented. The chapter then reviews the challenges identified, current and proposed power failure management model and the prototype developed. The chapter ends by presenting the recommendations and future work.

REFERENCES

[1] G. Amit and M. Krishna, "Cloud Computing: Need, Enabling Technology,Architecture, Advantages and Challenges," in *5th International Conference- Confluence The Next Generation Information Technology Summit*, Noida, 2014.

[2] D. Kiran, "Electric Power Distribution System Basics," Electrical Easy, 2017.

[3] The Electricity Forum Inc, "Overhead T&D," The Electricity Forum Inc, Ontario, 2020.

[4] S. Jayant, "Automating Low Voltage Distribution Networks Using Sensor Technologies," Electrical India, United Kingdom, 2016.

[5] Electrical4U, "Oil Winding and Remote Temperature Indicator of Transformer," Electrical4U, California, 2019.

[6] Superule, "Overhead Fault Indicator," [Online]. Available: https://www.suparule.com/products/overhead-fault-indicator/. [Accessed 5 June 2020].

[7] Z. Peng, Advanced Industrial Control Technology, William Andrew applied science, 2010.

[8] G. H. Sayed k, Smart Energy grid engineering, Ontario: Academic Press, 2017.

[9] W. L. Yee, A. Tansu, A. Lee, M. Slaven and P. Marimuthu, "Demand response architectures and load management algorithms for energy-efficient power grids: a survey," in *2012 Seventh International Conference on Knowledge, Information and Creativity Support Systems*, 2012.

[10] H. M, R. S, W. S, J. M, A. Ghani and B. Z, "Development of a novel fault management in distribution system using distribution automation system in conjunction with GSM communication," *International Journal of Smart Grid and Clean Energy,* vol. 2, no. 3, pp. 329-335, 2013.

[11] M. Mohammed, A. Sherif and K. Joni, "Review of Fault Types, Impacts, and Management Solutions in Smart Grid Systems," *Journal of Smart Grid and Renewable Energy,* vol. 10, no. 4, pp. 98-117, 2019.

[12] K. S. Osmo, S. Amir, L. Matti and F.-F. Mahmud, "Optimal Distribution Network Automation Considering Earth Fault Events," *IEEE Transactions on Smart Grid,* vol. 6, no. 2, pp. 1010-1018, March 2015.

[13] ZESCO, "Our Business, Transmission," ZESCO, Lusaka, 2015.

[14] Ministry of Energy, and, Water, Development, "Power System Development Master Plan for Zambia," Ministry of energy and Water Development, Lusaka, 2010.

[15] H. M. Zulu, "ZESCO Customer base hits one million," ZESCO, Lusaka, 2019.

[16] B. A. Thomas and D. Carl-Johan, "Power outages and economic growth in Africa," *International journal of enrgy economics,* vol. 38, pp. 19-23, 2013.

[17] M. Erastus, M. Innocent and M. Franco, "3rd International Conference on Development and Investment in InfrastructureStrategies for Africa," Livingstone, 2016.

[18] L. Wang, "The Fault Causes of Overhead Lines in Distribution Network," in *MATEC Web of Conferences* , Sichuan, 2016.

[19] E. Anton, R. M. Orvika and H. V. Shkaratan, "Africa's Power Infrastructure Investment, Integration, Efficiency," The International Bank for Reconstruction and Development/The World Bank , Washington, 2011.

[20] K. Gourav and P. M. Naran, "Outage management system for power distribution network," in *International Conference on Smart Electric Grid (ISEG)*, Guntur, 2014.

[21] M. Rossella and M. Konstantinos, "Communication network interdependencies in Smart Grids," European Union Agency for Network and Information Security (ENISA), Madrid, 2015.

[22] H. Yan, J. Nick and W. Jianzhong, "Smart Metering for Outage Management of Electric Power Distribution Networks," in *Applied Energy Symposium and Forum REM2016: Renewable Energy Integration with Mini/Microgrid*, Maldives, 2016.

[23] C. Po-Chen, D. Tatjana and K. Mladen, "The Use of Big Data for Outage Management in Distribution Systems," in *CIRED Workshop*, Rome, 2014.

[24] the U.S. Department of Energy , "the SMART GRID: an introduction," Litos Strategic Communication , 2009.

[25] U. Umesh, Y. Ajit, U. Sachin and S. Joydeep, "Distribution Line Fault Detection & GSM Module Based Fault Signaling System," *International Journal for Research in Applied Science & Engineering Technology (IJRASET)* , vol. 4, no. 2, pp. 452-455, 2016.

[26] S. Ankita and V. Sonia, "Cloud Computing: Taxonomy and Architecture," *International Journal of Advanced Research in Computer Science and Software Engineering*, vol. 3, no. 5, pp. 1410-1417, 2013.

[27] t. point, Cloud Computing Tutorial, Hyderabad: Tutorials Point India Limited , 2013.

[28] H. Alzahrani, "A Brief Survey of Cloud Computing," *Global Journal of Computer Science and Technology:B Cloud and Distributed*, vol. 16, no. 3, p. 7, 2016.

[29] K. D. Balaji and G. S. Reddy, "cloud computing," Vaagdevi Institute of technology, Proddatur, 2011.

[30] J. Hanen, K. Zied, B. A. Mounir and M. A. Adel, "Cloud Computing and Mobile Devices Based System for Healthcare Application," in *2015 IEEE International Symposium on Technology in Society (ISTAS) Proceedings*, 2015.

[31] J. Hui, "Application Discussion of Cloud Computing in Hospital Information Construction," *Journal of Applied Science and Engineering Innovation*, vol. 4, no. 4, pp. 144-147, 2017.

[32] V. Dimiter and Z. Plamena, "Principles of Cloud Computing Application in Emergency Management," in *2011 International Conference on E-business, Management and Economics*, Singapore, 2011.

[33] S. P. Bera, "Cloud Computing in brief," *IOSR Journal of Computer Engineering*, vol. 18, no. 6, pp. 101-103, 2016.

[34] P. K. Rupinder and K. Amanpreet, "Perspectives of Mobile Cloud Computing: Architecture, Applications and Issues," *International Journal of Computer Applications*, vol. 101, no. 3, p. 0975 – 8887, 2014.

[35] D. S. Manan and C. Dhiman, "Cloud Computing Architecture & Services," *International Journal of Computer Science and Mobile Computing*, vol. 4, no. 11, pp. 117-124, 2015.

[36] M. Faraz, R. Mahsa, A. Mohammad, K. Touraj and M. Kasra, "Cloud Computing: Vision, Architecture and Characteristics," in *IEEE 6th Control and System Graduate Research Colloquium,*, Shah Alam, 2015.

[37] B. Swati I and B. Ankur O, "Cloud Computing: History, Architecture, Security issues," *International Journal of Advent Research in Computer and Electronics,* no. special issue, pp. 102-108, 2015.

[38] B. Sosinsky, Cloud Computing Bible, Indianapolis: Wiley Publishing, Inc, 2011.

[39] A. Sherif and G. Mohsen, "Enabling Smart Cloud Services Through Remote Sensing: An Internet of Everything Enabler," *IEEE INTERNET OF THINGS JOURNAL,* vol. 1, no. 3, pp. 276-288, 2014.

[40] A. A.-R. Abdulelah, "E-Government Based on Cloud Computing and Service-Oriented Architecture," *International Journal of Computer and Electrical Engineering,* vol. 6, no. 3, pp. 201-206, 2014.

[41] M. Sun, "Introduction to Cloud Computing Architecture," Sun Microsystems inc, Santa Clara, 2009.

[42] M. Attaran, "Cloud Computing Technology: Leveraging the Power of the Internet to Improve BusinessPerformance," *Journal of International Technology and Information Management,* vol. 26, no. 1, pp. 112-137, 2017.

[43] A. Miha and A. Dustin, "Cloud Computing Use Cases," Cloud Computing Use Case Discussion Group, 2010.

[44] K. Ravneet, "Cloud Computing: Architecture and Services," *RESEARCH REVIEW International Journal of Multidisciplinary,* vol. 3, no. 6, pp. 20-23, 2018.

[45] R. Choudhary, "A Survey on Cloud Computing Architecture," *International Journl of Computer Technology & Applications,* vol. 3, no. 4, pp. 1400-1405, 2012.

[46] K. Ramesh R, "Understanding Cloud Computing and Its Architecture," *Journal of Computer and Mathematical Sciences,* vol. 10, no. 3, pp. 519-523, 2019.

[47] S. Chihana, J. Phiri and D. Kunda, "An IoT based Warehouse Intrusion Detection (E-Perimeter) and Grain Tracking Model for Food Reserve Agency," *International Journal of Advanced Computer Science and Applications,* vol. 9, no. 9, pp. 213-223, 2018.

[48] T. Muyumba and J. Phiri, "A Web based Inventory Control System using Cloud Architecture and Barcode Technology for Zambia Air Force," *International Journal of Advanced Computer Science and Applications,* vol. 8, no. 11, pp. 132-142, 2017.

[49] L. Qiang, M. Yujun, A. Musaed, P. Limei and Z. Yin, "Green data center with IoT sensing and cloud-assisted smart temperature controlling system," *International journal of computer networks,* vol. 101, pp. 104-112, 2015.

[50] B. Hongwei, M. Zhiwei and Z. Yongli, "The Application of Cloud Computing in Smart Grid Status Monitoring," in *IOT Workshop 2012*, Berlin, 2012.

[51] C. Sivapragash and K. S. Suresh, "Advanced Cloud Computing in Smart Power Grid," in *Third international conference on sustainable energy and intelligent system*, Tamilnadu, 2012.

[52] D. Gy¨orgy, B. B. Rakesh, G. George and C. Roy, "Cloud Computing for the Power Grid: From Service Composition to Assured Clouds," in *In Presented as part of the 5th {USENIX} Workshop on Hot Topics in Cloud Computing*, 2013.

[53] B. Samaresh and M. Sudip, "Cloud Computing Applications for Smart Grid: A Survey," in *IEEE Transactions on Parallel and Distributed Systems*, 2013.

[54] J. M. Micheal and N. S. Cliodhna, Sensor Technologies, Apress, 2013.

[55] J. M. Michael and N. S. Cliodhna, Sensor Technologies, Healthcare, Wellness, and Environmental Applications, New York: Apress Open, 2014.

[56] f. s. t. Association, Trends in future oriented sensor technologies, Berlin: AMA Association for sensor technology, 2010.

[57] W. H. Gary, R. S. Joseph, J. H. Peter and C.-C. Liu, "Smart Sensor Systems," *The Electrochemical Society Interface,* pp. 29-34, 2010.

[58] Y. Y. Sergey, "Digital and Intelligent Sensors and Sensor Systems:Sensor Systems:," International Frequency Sensor Association, Barcelona, 2012.

[59] E. Halit, "The Engineering Handbook," in *The Engineering Handbook,* CRC Press, 2005, pp. 158-188.

[60] Y. Bai, Practical Microcontroller Engineering with ARM Technology, Wiley-IEEE Press, 2016.

[61] ELPROCUS, "Different Microcontroller Boards and Its Applications," ELPROCUS, 2013. [Online]. Available: https://www.elprocus.com/different-types-of-microcontroller-boards/. [Accessed 1 December 2019].

[62] G. Ankit, " Microcontroller Development Boards," Electronicsforu, 4 December 2014. [Online]. Available: https://electronicsforu.com/buyers-guides/hardware-buyers-guide/microcontroller-development-boards. [Accessed 1 December 2019].

[63] Arduino, "Getting started with arduino Introduction," Arduino, 2019. [Online]. Available: https://www.arduino.cc/en/Guide/Introduction. [Accessed 1 December 2019].

[64] B. Massimo, Getting Started With Arduino, California: Make:Books, 2011.

[65] K. Chris, P. Joan and T. Emmanuel, "Advanced Electrical Power System Sensors," National Institute of Standards and Technology, columbia, 2017.

[66] US Department of energy, "Sensor Technologies and Data Analytics," advanced grid research, 2018.

[67] T. D. Jeffrey and D. M. Paul, "Sensing and Measurement for Advanced Power Grids," Resnick Sustainability Institute, California Institute of Technology, Tech. Rep, California, 2012.

[68] s. muthukumara, Principles of Wireless Communication, Beau Bassin: Scholar's Press, 2017.

[69] K. L. H, High-Speed Wireless Personal Area Networks: An Application of UWB Technologies, Novel Applications of the UWB Technologies, Boris Lembrikov, IntechOpen, 2011.

[70] S. JORDI, Wireless Networks, Prague: Czech Technical University of Prague Faculty of electrical engineering, 2017.

[71] T. Shrikant and K. Sushil, "Analysis and Survey on Past, Present and Future Generation in Mobile communication," in *National Conference on Recent Trends in Computer Science and Information Technology* , 2016.

[72] A. Arun, A. Kabita, A. Sumanshu and M. Gourav, "Evolution of Mobile Communication Technology towards 5G Networks and Challenges," *American Journal of Electrical and Electronic Engineering,* vol. 7, no. 2, pp. 34-37, 2019.

[73] S. Pankaj, "Evolution of Mobile Wireless Communication Networks-1G to 5G as well as Future Prospective of Next Generation Communication Network," *International Journal of Computer Science and Mobile Computing,* vol. 2, no. 8, pp. 47-53, 2013.

[74] B. Majid, N. Naira, M. Insha, N. Kamran and A. Suhaib, "Evolution of Mobile Wireless Communication Systems from 1G to 5G : A Comparative Analysis," *International Journal of Scientific Research in Computer Science, Engineering and Information Technology,* vol. 4, no. 1, pp. 1-8, 2018.

[75] K. Arjun, R. Mayur, K. Pavan and H. Rajeshwari, "Evolution of Wireless Mobile Communication Networks and future of Cellular Market in India," *International journal of Computer Science & Information Technology,* p. 453–462, 2012.

[76] U. G. Anju, "An Overview on Evolution of Mobile Wireless Communication Networks: 1G-6G," *International Journal on Recent and Innovation Trends in Computing and Communication,* vol. 3, no. 5, p. 3130 – 3133, 2015.

[77] T. Shrikant and K. Sushil, "Analysis and Survey on Past, Present and Future Generation in Mobile communication," *Analysis and Survey on Past, Present and Future Generation in Mobile communication,* pp. 30-36, 2016.

[78] A. Jyotsna, P. Rakesh, M. P, P. Dubey and J. keller, "Evolution of Mobile Communication Network: from 1G to 4G," *International Journal of Multidisciplinary and Current Research,* vol. 3, pp. 1100-1103, 2015.

[79] T. Rehman and S. Mridul, "Evolution and Innovation in 5G Cellular Communication System and Beyond: A Study," Department of Information Technology,North-Eastern Hill University, Shillong, 2014.

[80] T. David, K. Prashant and J. James, "Network architecture and protocols for mobile positioning in cellular wireless systems," Department of Information Science and Telecommunications University of Pittsburgh, Pittsburgh, 2019.

[81] K. S. RONY, Cellular Mobile Communication a Fundamental Perspective, Bangkok: R&D NEXTEVOLUTION, 2013.

[82] L. B. Jack, A. Julia, S. E. Jared and T. K. William, Wireless Networking Understanding Internetworking Challenges, New Jersey: John Wiley & Sons, Inc, 2013.

[83] R. Naeem, Q. A. Muhammad, A. A. S. and A. Samia, "Study of Smart Grid Communication Network Architectures and Technologies," *Journal of Computer and Communications,* vol. 7, pp. 19-29, 2019.

[84] C. Lipi, S. Paawan, B. Govind and K. Adesh, "Wireless Sensor Network Based Smart Grid Communications: Cyber Attacks, Intrusion Detection System and Topology Control," *MDPI Journal in electronics,* vol. 6, no. 5, pp. 1-22, 2016.

[85] B. Dmitry, T. Saad and B. Nina, "Smart Grid Communication Technologies," *Journal of Power and Energy Engineering*, vol. 4, pp. 1-8, 2016.

[86] R. V. Leo and W. Charles, "Choice of software development methodologies," *IEEE COMPUTER SOCIETY*, pp. 86-94, September 2016.

[87] P. Sheilly, A. Apoorva, G. Sonali and S. Priya, "Review of Software Development Methodologies Used in Software Design," *International Journal of Advanced Trends in Computer Science and Engineering,* vol. 3, no. 5, pp. 88-93, 2014.

[88] S. Ian, Software engineering, Boston: Pearson Education, Inc, 2011.

[89] P. Aswin, "Software Development Methodologies.," in *Product Management essentials*, Berkeley, Apress, 2017, pp. 65-74.

[90] S. Soobia, Z. J. N, N. Mehmood and H. Mamoona, "Analysis of Software Development Methodologies," *International Journal of Computing and Digital Systems,* vol. 8, no. 5, pp. 445-459, 2019.

[91] S. Alexander, "Waterfall Process Model: Principles," Hygger, 2016.

[92] R. Preeti and D. Saru, "Impact of Different Methodologies in Software Development Process," *International Journal of Computer Science and Information Technologies,* vol. 5, no. 2, pp. 1112-1116, 2014.

[93] L. D. Mihai, "Comparative study on software development methodologies," *Database Systems Journal,* vol. 5, no. 3, pp. 37-56, 2014.

[94] A. R. Mojeeb, K. Al and A. Moataz, "UML Class Diagrams: Similarity Aspects and Matching," University of Petroleum and Minerals, Saudi Arabia, 2016.

[95] S. E. Ingle and M. R. Mahamune, "An UML Based software Automatic Test Case Generation: Survey," *International Research Journal of Engineering and Technology,* vol. 2, no. 2, pp. 971-973, 2015.

[96] R. Nisha and S. Rajender, "A Survey on Test Case Generation Techniques Using UML Diagrams," *International Journal of software,* vol. 12, no. 8, pp. 643-648, 2017.

[97] F. Flávio and M. Song, "UML-Checker: An Approach for Verifying UML Behavioral Diagrams," *International JOURNAL OF SOFTWARE,* vol. 9, no. 5, pp. 1229-1236, 2014.

[98] Y. A. Arwa, "Comparative Study between Data Flow Diagram and Use Case Diagram," *International Journal of Scientific and Research Publications,* vol. 6, no. 3, pp. 124-127, 2016.

[99] A. D. Shinde and S. P. M, "Transforming Data Flow Diagram to use Case Diagram," *International Journal of Management, IT and Engineering,* vol. 4, no. 1, pp. 561-573, 2014.

[100] S. Martina, S. Marion, H. Christian and K. Gerti, "The Use Case Diagram," in *UML @ Classroom An Introduction to Object-Oriented Modeling*, Switzerland, Springer International Publishing, 2015, pp. 23-47.

[101] R. Bernhard, Modeling With UML; Language, Concepts, Methods, Switzerland: Springer International Publishing, 2016.

[102] F. Martin, UML Distilled, Addison-Wesley Professional, 2004.

[103] D. Alan, H. W. Barbara and M. R. Roberta, Systems analysis and design, John Wiley & Sons, Inc, 2012.

[104] G. T and S. D, "Automatic Street Light Control and Fault Detection System with Cloud Storage," *International Journal of Scientific and Engineering Research,* vol. 8, pp. 1-5, 2017.

[105] K. C. Prafulla, P. Shubham, S. Aseem, P. C. S. Vaisakh, K. J. Krishna and B. P. Sharana, "Power Efficient, Bandwidth Optimized and Fault Tolerant Sensor Management for IOT in Smart Home," in *IEEE International Advance Computing Conference (IACC),* Bangalore, 2015.

[106] C. Mulima and P. Jackson, "A Remote Sensor Network using Android Things and Cloud Computing for the Food Reserve Agency in Zambia," *International Journal of Advanced Computer Science and Applications,* vol. 8, no. 11, pp. 411-418, 2017.

[107] K. Okokpujie, E. Amuta, R. Okonigene and J. Samuel, "Monitoring and Fault Detection System for Power Transmission Using GSM Technology," in *International Conference on Wireless Networks*, 2017.

[108] S. SUJATHA M and K. M. VIJAY, "On-line Monitoring and Analysis of Faults in Transmission and Distribution Lines Using GSM Technique," *Journal of Theoretical and Applied Information Technology,* vol. 33, no. 2, pp. 258-265, 2011.

[109] R. P. Vikramsingh, J. Shivani, D. Anand, S. Arti and C. Kapil, "Automatic Fault Detection in Transmission Lines using GSM Technology," *International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering,* vol. 6, no. 4, pp. 90-95, 2018.

[110] D. Vihar, D. Avee, S. Rishi and J. Arjun, "Implementation of Remote Monitoring of Substation EquipmantsUsing GSM," *International Journal of Advanced Research in Electrical,Electronics and Instrumentation Engineering,* vol. 5, no. 6, pp. 5565-5571, 2016.

[111] D. Krupal, P. Jenish, S. Yasin, M. Anas and P. Krishn, "Substation Monitoring and Control Using Microcontroller & GSM," *International Research Journal of Engineering and Technology,* vol. 4, no. 4, pp. 398-403, 2017.

[112] A. S. Hassan, "Monitoring and Controlling of Distribution Transformer Using GSM Module (AVR Microcontroller Based)," *International Journal of Advanced Research in Science and Engineering,* vol. 6, no. 8, pp. 1645-1653, 2017.

[113] P. Sandeep, B. Ashish, B. Nitishsingh, K. Neelam and U. Prag, "Web Based Substation Monitoring, Protection and Control," *International Journal of Application or Innovation in Engineering & Management*, no. Special Issue for National Conference On Recent Advances in Technology and Management, pp. 1-7, 2013.

[114] A. Gerald, A. R. Catherine and M. S. Scott, "Topic sensitivity and research design: effects on internet survey respondents' motives," *Asia Pacific Journal of Marketing and Logistics,* vol. 26, no. 1, pp. 147 - 161, 2014.

[115] K. S. Pradip, Research Methodology:A Guide for Researchers in Agricultural Science Social Science and Other Related Fields, New Delhi: Springer, 2013.

[116] C. Joseph and K. S. Russell, Research Methods in Education, Thousand Oaks, CA: SAGE Publications, 2011.

[117] P. Julie, "Understanding and Evaluating Survey Research," *Journal of the advanced practional in oncology,* vol. 6, no. 2, p. 168–171, 2015.

[118] K. Ranjit, Research Methodology; A step by step guide for beginners, London: SAGE Publications Ltd, 2011.

[119] R. David, A. T. Bruce and K. P. Deborah, Program Evaluation: An Introduction, Belomont, CA: Cengage Learning, 2010.

[120] F. Sheikh and L. Xinrong, "Wireless Sensor Network System Design using Raspberry Pi and," in *The 9th International Conference on Future Networks and Communications*, texas, 2014.

[121] L. ,. Jeffrey and D. B. Lonnie, Systems analysis and design methods, New York: Mcgraw Hill/Irwin, 2007.

[122] W. S. John, B. J. Robert and D. B. Stephen, Systems Analysis and Design in a Changing World, Boston: Course Technology, Cengage Learning, 2012.

[123] E. Ramez and B. shamkant, Fundamentals of Database Systems, New Jersey: Pearson Education Limited, 2016.

[124] A. H. Jeffrey, V. Ramesh and T. Heikki, Modern database management, New Jersey: Prentice Hall, 2011.

[125] I. Poole, "Capacitor Smoothing Circuits & Calculations," Adrio Communications Ltd, 2016.

[126] Y. Chuck, "How much AC ripple in a DC power supply is too much?," Electrical Appliance Service Association, 2016.

[127] D. G. W. A and R. J. Mackenzie, American Ultraminiature Component Parts Data 1965-66; Pergamon Electronics Data Series, Elsevier, 2014.

[128] D. Theventhira, C. S. Leow and L. Vincent, "Power Divider Rule: AC circuit analysis," *International Journal of Engineering Trends and Technology (IJETT)*, vol. 39, no. 5, pp. 274-283, 2016.

APPENDICES

APPENDIX A: Data Collection Customer Questionnaire

The University of Zambia

School of Engineering

By Janet Nanyangwe Sinkala (2017024198)

Contact Number: 0977 998659

Dear Respondent,

I am a student at the University of Zambia in my final year pursuing a Master of Engineering – ICT. As partial fulfillment for the award of a Master's degree, I am conducting a baseline study on "**CLOUD BASED POWER FAILURE SENSING AND MANAGEMENT MODEL FOR THE ELECTRICITY GRID IN ZAMBIA".**

Your household has been randomly sampled to provide information for the topic indicated above. The information being collected is purely for academic purposes as such, it will be treated with maximum confidentiality. Subsequently, you are not supposed to indicate your name or any personal information that can lead to revealing of your identity. Your co-operation will be greatly appreciated.

Research Supervisor: Dr. Jackson Phiri on 0966 693 731 or

Assistant Dean: Dr. Mwanaumo on 0969 561 353

SECTION A: GENERAL INFORMATION

1) **Sex:**

a) Male ☐ b) Female ☐

2) **Age in years.**

18 – 29	30 – 39	40 – 49	50 and above

3) **Marital status**

a) Single ☐ (d) Separated ☐
b) Married ☐ (e) Divorced ☐
(c) Widowed ☐

4) **Level of education**

a) Primary School Certificate ☐ d) Secondary School Certificate ☐
b) College Certificate ☐ e) College Diploma ☐
c) University Degree ☐ f)University Masters ☐

If others, please specify………………………………………………………….

5) Which town and township of Zambia do you reside in?

Please Specify………………………………………………………………………………

6) What is the size of your family?

a) 2 people ☐ b) 3 people ☐ c) 4 people ☐ d)Above 4 people ☐

SECTION B: ELECTRICITY USAGE

7) Do you have access to electricity at your house/premises?

a) Yes ☐ b) No ☐

8) How do you pay for electricity?

a) Prepaid ☐ c) Postpaid ☐

b) Fixed ☐ Other………………………..

9) What Electricity Tariff are you on?

a) Residential ☐ c) Commercial ☐

b) Social ☐ d) Maximum Demand ☐

10) How much worth of Electricity do you consume per month?

a) K50 –K500 ☐ d) K500 – K1000 ☐

b) K1000 - K2000 ☐ e) K2000 – K5000 ☐

c) Over K5000 ☐

11) Do you have alternative Electricity supply like Genset, Solar panel etc.?

a) Yes ☐ b) No ☐

12) If yes to question 11 above, specify the source of electricity…………………………

13) What do you use the electricity for?

a) Household lighting, cooking ☐ b) Pumping Water into Tank ☐

b) Irrigating crops ☐ c) Running a Business ☐

c) Other ☐

If other please specify…………………………………………………..

14) Do you experience electricity power failure at your premises, which is not due to load shedding but due to a fault? a)Yes ☐ b) No ☐

If you are using electricity for running a business kindly answer questions 15, 16, 17 and 18 and if you are not using electricity for running a business kindly indicate N/A for 15, 16, 17 and 18

15) What business are you running which uses electricity?

Please specify………………………………………………………………….

16) Approximately how much does your business lose per month due to power failure caused by a fault?

Please Specify……………………………………………………………………………

17) Have you lost business or business products as a result of electricity power failure caused by a fault?

a) Yes ☐ b) No ☐

18) In what ways has electricity power failure due to a fault caused you to lose business?

a) Loss of customers ☐ c)Loss of products/goods ☐

b) Loss of Revenue ☐ d)Other ☐

If other please specify…………………………………………………………………………

19) How often do you experience electricity power failure at your premises i.e. power failure which is not due to load shedding but due to a fault?

a) Once a day ☐ c)Once a week ☐

b) Once a month ☐ d) Other ☐

If other please specify…………………………………………..

20) What is the longest electricity power failure due to a fault have you ever experienced in your residential area?

a) Hours ☐ b) days ☐ c)Weeks ☐ d) Months ☐

21) In what ways has electricity power failure caused by a fault affected your general livelihood?

a) Loss of business customers ☐ c) Damage of perishable food at home ☐

b) Loss of Revenue ☐ d) Damage to household equipment ☐

Other specify…………………………

SECTION C: CHALLENGES OF POWER FAILURE FAULT REPORTING SYSTEM

22) Have you ever personally made a complaint to ZESCO regarding an electricity power failure that you had experienced?

a)Yes ☐ b) No ☐

23) Do you know the number to use to report power failure to ZESCO i.e. the ZESCO call centre number?

a)Yes ☐ b) No ☐

24) When you have an electricity power failure

a) Do you report it yourself ☐ c) Others report it ☐

b) ZESCO lets you know of the power failure ☐

25) If you have made a complaint regarding electricity power failure, which method of complaint do you mostly use to make your reports to ZESCO?

a) Walk to ZESCO offices ☐ b) Called their Call Centre ☐ c) Email ☐

d) Neighbors called ZESCO on behalf ☐ e) Not Applicable ☐ Other specify …………

26) If response to above is d) why is that so?

Please specify……………………………………………………………………………

27) Have you ever experienced difficulties with calling ZESCO call centre e.g. network problems, call falling to go through, call not being answered etc.?

a) Yes ☐ b) No ☐

28) When there is an electricity power failure caused by a fault and not by load shedding how long does ZESCO take to restore the power supply?

a) Hours ☐ b) Days ☐ c) Months ☐

29) When there is an electricity power failure caused by a fault how long does ZESCO take to come to your premises to check the cause of power failure?

b) Hours ☐ b) Days ☐ c) Months ☐

30) Based on your experiences with reporting electricity power failure to ZESCO, how would you rate the extent to which it is easy to get in touch with the ZESCO call centre?

a) Very easy ☐ b) Easy ☐ c) Average ☐ d) Difficult ☐ e)Very difficulty ☐

31) Outline the reasons for your response on question 29 above……………………….........
……………………………………………………………………………………………………
……………………………………………………………………………………………………

32) From your experience, what was the longest time that ZESCO took to respond when a report was made about an electricity power failure fault in your township?

a) Minutes ☐ b) Few hours ☐ c) Days ☐ d) Weeks ☐ e) Months ☐

33) From your experience how would you rate ZESCO restoration response to an electricity power failure caused by a fault?

a) Excellent b) Good c) Fair d)Poor e)Fail

34) From your experiences reporting electricity power failure faults to ZESCO, does their Customer Service Center ask directions to your premises before they come to restore power?

a) Yes ☐ b) No ☐

35) Does ZESCO call you back to confirm if power has been restored after reporting power failure? a) Yes ☐ b) No ☐

36) Are you satisfied with the way ZESCO attends to reported power failure cases?

a) Yes ☐ b) No ☐

37) If your answer to above question is NO above why is that?

Please specify…………………………………………………………………..

38) Do you experience low voltage in your township?

a) Yes ☐ b) No ☐

39) If answer to above question is YES how often do you experience low voltage per month?

a) Once ☐ b) Twice ☐ c)Three Times ☐ Other ☐

If other please specify…………………………………………………………………..

40) What recommendations would you make to improve the performance of ZESCO in attending to electricity faults reported by the public?..

…………………………………………………………………………………………………

…………………………………………………………………………………………………

41) Would you be in favor of a system which would automatically detect power failure so that you would not have to report power failure to ZESCO?

a) Yes ☐ b) No ☐

Thank you very much for your valuable cooperation

APPENDIX B: Data Collection ZESCO Questionnaire

The University of Zambia

School of Engineering

By Janet Nanyangwe Sinkala (2017024198)

Contact Number: 0977 998659

Dear Respondent,

I am a student at the University of Zambia in my final year pursuing a Master of Engineering – ICT. As partial fulfillment for the award of a Master's degree, I am conducting a baseline study on "**CLOUD BASED POWER FAILURE SENSING AND MANAGEMENT MODEL FOR THE ELECTRICITY GRID IN ZAMBIA".**

You have been purposively sampled to provide information for the topic indicated above. The information being collected is purely for academic purposes as such, it will be treated with maximum confidentiality. Subsequently, you are not supposed to indicate your name or any personal information that can lead to revealing of your identity. Your co-operation will be greatly appreciated.

Research Supervisor: Dr. Jackson Phiri on 0966 693 731 or

Assistant Dean: Dr. Mwanaumo on 0969 561 353

SECTION A: DEMOGRAPHIC CHARACTERISTICS OF RESPONDENT

SECTION ONE - EMPLOYEE DATA

1. SEX

a) Male ☐ b) Female ☐

2. AGE

a) Below 26 ☐ b) 26 - 30 ☐ c) 31 – 35 ☐

d) 36 - 40 ☐ e) 41 – 50 ☐ f) 50 and above ☐

3. HIGHEST QUALIFICATION

a) Primary School Certificate ☐ b) Secondary School Certificate ☐
c)College Certificate ☐ d) College Diploma ☐
e) University Degree ☐ f)University Masters ☐

4. State the department as well as your formal position in the Organization.

DEPARTMENT **POSITION**

……………………………….. ………………………………..

5. MANAGEMENT LEVEL?

a) Top Management ☐ c) Middle Management ☐
b) Lower Management ☐ d) Classified Daily Employees ☐

6. How long have you worked for Zambia Electricity Supply Corporation?

a) Less than one year ☐ c) 1-5 Years ☐ e) 6-10 Years ☐
b) 11-15 Years ☐ d) More than 15 Years ☐

SECTION B: CURRENT POWER FAILURE MANAGEMENT PROCESSES

42) Indicate the current number of ZESCO employees……………………………………

43) Break down the numbers of these employees according to the category below

Residential	Commercial	Social Services	Maximum Demand
……….	………….	……………..	……………..

44) From your experience in your work place, what are the most common power failure faults experienced in the Low Voltage network?

……………………………………………………………………………………………

……………………………………………………………………………………………

45) Approximately how many unplanned outages do you have per month?

……………………………………………………………………………………………

………………………………………………………….

46) What is the total outage duration for Lusaka District i.e. SAIDI (System Average Interruption Duration Index)?

Specify……………………………………………………………………………………
…………………………………………………….

47) What is the total outage frequency for Lusaka District i.e. SAIFI (System Average Interruption Frequency Index)

Specify……………………………………………………………………………………
…………………………………………………

48) In which season do you experience the most power failures?

a) Summer ☐ b) Autom ☐

c) Winter ☐ d) Spring ☐

49) How many employees are there to attend to faults in each region………………………

50) Briefly describe the order of steps or procedures of power failure faulty reporting by customers.

i. …………………………………………………………………………………….
ii. …………………………………………………………………………………….
iii. …………………………………………………………………………………….
iv. …………………………………………………………………………………….

51) From your experience, how long on average does ZESCO take to attend to power failures?

Minutes ☐ ho☐ ☐Days ☐
Months

52) Indicate the common ways through which faults are reported by the electricity consumers

a) Walk to ZESCO offices ☐ b) ZESCO Call Centre ☐ c) Email ☐

Other specify ……………………………………………………………………………

53) Do you have a system which stores the power faults for further analysis and archiving

a) Yes ☐ b) No ☐

54) If yes to Q12 above, how are the reported faults recorded at your offices?

a)Books/papers☐ **b)** Electronic ☐

Other specify……………………………………………………………………………

55) How are the recorded faults stored?

a) Books/papers ☐ **b)**Electronic ☐

56) Is there a toll free number for calling ZESCO call centre

a) Yes b) No

57) How much revenue does ZESCO lose due to power failures faults

Please specify……………………………………………………………………………………………..

SECTION C: CHALLENGES OF THE CURRENT POWER FAILURE MANAGEMENT SYSTEM

58) What major challenges do you face with the current management system for power failure?……………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

59) Does ZESCO have a deliberate policy to share the information on the processes of power failure management for the Utility Company?

a) Yes, ☐ b) No ☐ **c)** don’t know ☐

60) If the answer to Q16 is yes, what kind of communication media do you use to share the information to the public?

a) Television ☐ b) Radio ☐ c) Magazine ☐ d)Website Social Networks ☐

61) Do you agree that implementing of a cloud based power failure sensing and management system could mitigate some challenges faced in power failure and fault management?

a)**Yes** ☐ **b)No** ☐

62) Briefly explain the reasons for your response to question 18 above………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

Thank you very much for contributing to my Research
God bless you

APPENDIX C: System Prototype Code

Arduino Code

```
// standard pins for the shield, adjust as necessary

#include <SoftwareSerial.h>//software serial library to make serial communication on arduinos digital pins

#include <LiquidCrystal.h>/////////lcd library

#include <EEPROM.h>//eeprom library to store, admin's mobile number in arduino's eeprom memory

LiquidCrystal lcd(21, 20, 19, 18, 17, 16);//lcd pin defined as per hardware connections

#define RECEIVINGCALL 1          //constant value assigned to name

#define IDLE 2                   //constant value assigned to name

#define BUSY 3                   //constant value assigned to name

#define NO_ANSWER 4              //constant value assigned to name

#define TALKING 5                //constant value assigned to name

#define ERROR 6                  //constant value assigned to name

#define Pin "pin"                //constant value assigned to name

#define ok "OK"                  //constant value assigned to name

#define ERROR_str "ERROR"        //constant value assigned to name

#define Connected "Connected"    //constant value assigned to name

#define Connecting "connecting"  //constant value assigned to name

#define CLCC "+CLCC:"            //constant value assigned to name

#define atCLCC "AT+CLCC"         //constant value assigned to name

#define CMGF "AT+CMGF=1"         //constant value assigned to name

#define CMGL "+CMGL:"            //constant value assigned to name

#define CMGS "AT+CMGS=\""        //constant value assigned to name

#define CMGD "AT+CMGD="          //constant value assigned to name

#define UNREAD "AT+CMGL=\"REC UNREAD\""      //constant value assigned to name
```

```
#define CMGDA "AT+CMGDA=0,4"                    //constant value assigned to name
#define CNMI "AT+CNMI=0,0,0,0"                  //constant value assigned to name
#define r_phase_pin A13           //pin name assigned
#define y_phase_pin A1            //pin name assigned
#define b_phase_pin A0            //pin name assigned
#define FONA_PWRKEY 11                  //pin name assigned
#define buzzer 25                     //pin name assigned
#define status_led 27                  //pin name assigned
///////// integer veriables//////
int r_phase_volts;
int y_phase_volts;
int b_phase_volts;
int index1;
int index2;
int no_configured = 0;
unsigned int first = 1;
unsigned long current_time ;
///////// string veriables//////
String r_phase_status;                    //string names
String y_phase_status;                    //string names
String b_phase_status;                    //string names
String lat5 = "";                        //string names
String lon5 = "";                        //string names
String r_phase_text = "R phase ";          //string names
String y_phase_text = "Y phase ";          //string names
String b_phase_text = "B phase ";          //string names
String call_number, num;
String sms_num, sms; // = get_sender_number();
```

```
String numtel;
String msg = "";
String indata = "";
String inputString = "";
String msg_index;
///////// bool veriables//////
bool round_one = 0;
bool r_phase_bit = 1;
bool y_phase_bit = 1;
bool b_phase_bit = 1;
bool new_r_phase_bit = 1;
bool new_y_phase_bit = 1;
bool new_b_phase_bit = 1;
bool gsm_set = 0;
bool gsm_connect = false;
bool notConnected = true;
/////////////EEPROM ADDRESS////////////
const unsigned int config1_add = 0;
const unsigned int mobile_save_add_ = 100;
SoftwareSerial gsm(13, 12);        //software serial pins assigned
void setup()
{
  // put your setup code here, to run once:
  //////////pins I/O functions defined
  pinMode(buzzer, OUTPUT);
  pinMode(status_led, OUTPUT);
  pinMode(FONA_PWRKEY, OUTPUT);
  //////////power key activated for gsm module
```

```
powerOn();
/////////////display name on lcd
lcd.begin(20, 4);
lcd.print("Three Phase Power");
lcd.setCursor(0, 1);
lcd.print("Monitoring");
lcd.setCursor(0, 2);
lcd.print("Using 4G GSM");
lcd.setCursor(0, 3);
lcd.print("And ArduinoMega");
delay(2000);
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("Connecting GSM...");
////////////serial poer defined
Serial.begin(9600);
Serial.println(F("Start"));
///////////gsm module  com port started
gsm.begin(9600);
gsm.listen();
delay(20000);
//////////////////initialised gsm
connect_gsm();
delay(1000);
gsm.end();///////////stop gsm serial port
delay(2000);
gsm.listen();////////////start gsm serial port
lcd.setCursor(0, 1);
```

```
  lcd.print("GSM Connected...");
  delay(3000);
  ///////////check if mobile number is saved in memory or not
  if (data_configured1() == 1)
  {    numtel = get_saved_data(mobile_save_add_);
    Serial.println("eeprom get numtel= " + String(numtel));  }
  ////////////display admins mobile number
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("ADMIN Mob.=");
  lcd.setCursor(0, 1);
  lcd.print(numtel);
  delay(10000);
  ///////////////enable internet to gsm module
  connect_internet();///////////// activate internet connection
  flushsoftSerial();///////////wait for any data available on gsm serial port
  gsm.end();}
void loop() {
  // put your main code here, to run repeatedly:
  r_phase_volts = calculate_r_phase();//////////measure voltage
  y_phase_volts = calculate_y_phase();//////////measure voltage
  b_phase_volts = calculate_b_phase();//////////measure voltage
  tune_voltage_reading();//////////tune voltages
  display_values();////display voltages on lcd
  update_phase_status();///////////update status of phases
  ///////////////////check phases for failure or recovery
  if ((r_phase_bit != new_r_phase_bit) or ( y_phase_bit != new_y_phase_bit) or (b_phase_bit != 
new_b_phase_bit))
  {    ////////////////this for loop id for confirmation of failure or recovery of phases
```

```
for (int i = 0; i <= 150; i++)    {
  r_phase_volts = calculate_r_phase();
  y_phase_volts = calculate_y_phase();
  b_phase_volts = calculate_b_phase();
  tune_voltage_reading();
  display_values();
  update_phase_status();    }
////////////if failure or recovery if confirmed after few checks then execute below action
if ((r_phase_bit != new_r_phase_bit) or ( y_phase_bit != new_y_phase_bit) or (b_phase_bit != new_b_phase_bit))
{     digitalWrite(buzzer, HIGH);//////turn ON buzzer
  delay(2000);
  digitalWrite(buzzer, LOW);//////turn OFF buzzer

  String r_phase_status_sent = String(r_phase_bit);///////////convert bits to string
  String y_phase_status_sent = String(y_phase_bit);///////////convert bits to string
  String b_phase_status_sent = String(b_phase_bit);///////////convert bits to string
  String volt_status_sent = String(r_phase_volts) + '*' + String(y_phase_volts) + '*' + String(b_phase_volts) + '*' + String(r_phase_bit) + '*' + String(y_phase_bit) + '*'  + String(b_phase_bit);//////////////combine the voltage data
  String gps_msg = get_gps_info();////////////////get gps location data
  String IoT_data1 = volt_status_sent + '*' + lat5 + '*' + lon5;//////////////combine voltage data with location details
  hit_IoT_data(IoT_data1);///////////////////send data to IoT website
  delay(10000);
  String alert_msg = r_phase_text + r_phase_status + y_phase_text + y_phase_status + b_phase_text + b_phase_status + gps_msg;/////////////combine strings for sms text
  sendsms(alert_msg, numtel);                    ///////////////send sms to the admin number
  delay(10000);
  gsm.end();
```

```
    ////////////reset the phase status to avoid continuous triggering of failure detection
    new_r_phase_bit = r_phase_bit;
    new_y_phase_bit = y_phase_bit;
    new_b_phase_bit = b_phase_bit;    }  }
  gsm.listen();
  if (sms_available(sms_num, msg))          /////////check if any new sms receiving or not
  {    checksms(sms_num, msg);              //////////check sms for text admin string
   delay(1000);  }
  gsm.end();
  delay(200);}
/////////////////////////exaplanation of r phase calculations appies for all three phases
int calculate_r_phase()////////////measure r phase voltage
{
  long analog_r  = 0;
  for (int i = 0; i < 200 ; i++)                     //for loop for proper measurment
  {    long new_analog_r = analogRead(r_phase_pin);          //measure analog value of r phase
voltage
   analog_r = analog_r + new_analog_r;  }
  analog_r = analog_r / 200;                          //divide by 200 since we measured it 200 times in
above for loop
  float resister_dc_voltage = 1.5;
  float x  = 204.6 * resister_dc_voltage;                    // 1023/5 = 204.6(1023 is max analog read
count and 5 is corrosponding max dc volt controller can maeasure for 1023
  int rphase_value = (analog_r * (230 / x));                  //considering that we are measuring 230
volts
  rphase_value = average_voltages(rphase_value);               //averaging of values done
  if (rphase_value < 30)                              //////////if voltage is less than 30 consider it as
phase failure
  {    rphase_value = 0;  }
  return (rphase_value);   }                          //return the output value
```

```
int calculate_y_phase()
{  long analog_y = analogRead(y_phase_pin);
  for (int i = 0; i < 200 ; i++)
  {    long new_analog_y = analogRead(y_phase_pin);
    analog_y = analog_y + new_analog_y;  }
  analog_y = analog_y / 200;
  float resister_dc_voltage = 1.5;
  float x  = 204.6 * resister_dc_voltage;
  int yphase_value = (analog_y * (230 / x));
  yphase_value = average_voltages(yphase_value);
  if (yphase_value < 30)
  {    yphase_value = 0;  }
  return (yphase_value);}
int calculate_b_phase()
{  long analog_b = analogRead(b_phase_pin);
  for (int i = 0; i < 200 ; i++)
  {    long new_analog_b = analogRead(b_phase_pin);
    analog_b = analog_b + new_analog_b;  }
  analog_b = analog_b / 200;
  float resister_dc_voltage = 1.5;
  float x  = 204.6 * resister_dc_voltage;
  int bphase_value = (analog_b * (230 / x));
  bphase_value = average_voltages(bphase_value);
  if (bphase_value < 30)
  {    bphase_value = 0;  }
  return (bphase_value);}
int average_voltages(int average_value)
{  if ((average_value >= 1) and (average_value < 40))
```

```
 {    average_value =  average_value + 10;  }
 else if ((average_value >= 40) and (average_value <= 50))
 {    average_value =  average_value * 1.315;  }
 else if ((average_value > 50) and (average_value <= 100))
 {    average_value =  average_value + 10;  }
 else if ((average_value > 100) and (average_value <= 130))
 {    average_value =  average_value + 6;  }
 else if ((average_value > 130) and (average_value <= 160))
 {    average_value =  average_value + 4;  }
 else if ((average_value > 160) and (average_value <= 180))
 {
   average_value =  average_value + 2;  }
 else if ((average_value > 235) and (average_value <= 240))
 {    average_value =  average_value - 10;  }
 else if ((average_value > 240) and (average_value <= 260))
 {    average_value =  average_value - 15;  }
 return (average_value);}
//////////////////////////tune voltages for better accuracy
void tune_voltage_reading()
{  if ((r_phase_volts == 0) and (y_phase_volts == 0) and (b_phase_volts > 150 and b_phase_volts < 200))
{    b_phase_volts = b_phase_volts + 10;  }
 if ((y_phase_volts == 0) and (b_phase_volts == 0) and (r_phase_volts > 150 and r_phase_volts < 200))
 {    r_phase_volts = r_phase_volts + 10;  }
 if ((b_phase_volts == 0) and (r_phase_volts == 0) and (y_phase_volts > 150 and y_phase_volts < 200))
 {    y_phase_volts = y_phase_volts + 10;  }}
///////////////////////////this updates the status of all phases according to the failure or recovery
```

```
void update_phase_status()
{  if (r_phase_volts > 70)
  {    r_phase_status = "OK\n";
    r_phase_bit = 1;  }
  else
  {    r_phase_status = "Fail\n";
    r_phase_bit = 0;  }
  if (y_phase_volts > 70)
  {    y_phase_status = "OK\n";
    y_phase_bit = 1;  }
  else
  {    y_phase_status = "Fail\n";
    y_phase_bit = 0;  }
  if (b_phase_volts > 70)
  {    b_phase_status = "OK\n";
    b_phase_bit = 1;  }
  else
  {    b_phase_status = "Fail\n";
    b_phase_bit = 0;  }}
/////////////////////////////////display values on lcd
void display_values()
{  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Three Phase voltages");
  lcd.setCursor(0, 1);
  lcd.print("R Phase volt = ");
  lcd.setCursor(14, 1);
  if (r_phase_volts < 11)
```

```
 {    lcd.print("00");  }
 else if (r_phase_volts <= 99)
 {    lcd.print("0");  }
 lcd.print(r_phase_volts);
 lcd.setCursor(18, 1);
 lcd.print("V");
 lcd.setCursor(0, 2);
 lcd.print("Y Phase volt = ");
 lcd.setCursor(14, 2);
 if (y_phase_volts < 11)
 {
   lcd.print("00");  }
 else if (y_phase_volts <= 99)
 {    lcd.print("0");  }
 lcd.print(y_phase_volts);
 lcd.setCursor(18, 2);
 lcd.print("V");
 lcd.setCursor(0, 3);
 lcd.print("B Phase volt = ");
 lcd.setCursor(14, 3);
 if (b_phase_volts < 11)
 {    lcd.print("00");  }
 else if (b_phase_volts <= 99)
 {    lcd.print("0");  }
 lcd.print(b_phase_volts);
 lcd.setCursor(18, 3);
 lcd.print("V");}
// Power on the module
```

```
void powerOn() {  digitalWrite(FONA_PWRKEY, LOW);
  delay(500);
  digitalWrite(FONA_PWRKEY, HIGH);}
void checksms(String sms_number, String msg)
{  if (msg.indexOf(F("ADMIN")) >= 0)/////////////////////////////check sms with word ADMIN id yes
then execute below code
  {    sms_num = sms_number;
    Serial.println("sms_num" + sms_number);
    sendsms(F("YOU ARE ADMIN"), sms_number);////////////send sms you sre admin to admin
number
    numtel = sms_number;
    save_data(numtel, mobile_save_add_);//////////////save number in eeprom memory
    EEPROM.write(config1_add, 1);
    Serial.println(F("1 CONFIGURED"));
    delay(2000);  }}
bool sms_available(String &sms_number , String &sms)///////////////////check for any incoming
sms
{  inputString = sendcmd(UNREAD, 1);
  if (inputString.indexOf(CMGL) >= 0)
  {    Serial.println("sms recieved");
    index1 = inputString.indexOf(CMGL);
    inputString = inputString.substring(index1);
    index1 = inputString.indexOf(':');
    index2 = inputString.indexOf(',');
    msg_index = inputString.substring(index1 + 1, index2);
    Serial.print("msg index :");
    msg_index.trim();
    Serial.println(msg_index);
    sms_number = inputString.substring(index2 + 1);
```

```
    index2 = sms_number.indexOf(',');
    sms_number = sms_number.substring(index2 + 2);
    index2 = sms_number.indexOf(',');
    sms_number = sms_number.substring(0, index2 - 1);
    Serial.print("sms_number :");
    sms_number.trim();
    Serial.println(sms_number);
    index1 = inputString.indexOf('\n');
    index2 = inputString.indexOf(ok);
    sms = inputString.substring(index1 + 1, index2 - 1);
    sms.trim();
    Serial.print("sms :");
    Serial.println(sms);
    String del_sms_cmd = CMGD + msg_index;
    sendcmd(del_sms_cmd, ok, 2000, 1);
    Serial.println(F("sms delete..."));
    return true;  }
  else
  {    Serial.println(F("waiting for sms"));
    return false;  }}
bool connect_gsm()
{  //  ////Serial.println(F(" in connect_gsm()"));
  delay(10000);//////////delay for module to become ready and find network and gps location
  exicute_cmd(F("AT"), ok, 5000);
  exicute_cmd("ATE0", ok, 5000);///////enable echo
  exicute_cmd(F("AT+CLIP=0"), ok, 5000);
  exicute_cmd(CMGF, ok, 5000);//sms text mode
  exicute_cmd(CNMI, ok, 5000);
```

```
  exicute_cmd(CMGDA, ok, 5000);//delet old sms
  exicute_cmd(F("AT+CNMP=2"), ok, 5000);//
  exicute_cmd(F("AT+CLCC=1"), ok, 5000);//list current call information
  exicute_cmd(F("AT+CGPS =1"), ok, 5000);///enable gps section
  return true;}
bool exicute_cmd(String c , String r, int t)
{  //  Serial.println(F("in exicute_cmd()"));
  long current_time2 = millis();
  gsm_connect = false;
  while (!gsm_connect)
  {    //    Serial.println("while gsm! connect loop ");
    delay(2000);
    if (sendcmd(c, r, t, 1))
    {      gsm_connect = true;
      break;    }
    else if ((millis() - current_time2) > t)
    {      gsm_connect = true;
      Serial.println("Command failed");
      break;    }
    delay(1000);  }
  return true;}
bool sendcmd(String gsmcmd, String response, int timeout, int debug)
{  //  Serial.println(F(" in sendcmd1"));
  Serial.println("");
  Serial.println("cmd " + String (gsmcmd));
  gsm.println(gsmcmd);
  if (debug == 1)
  {    return get_gsm_cmd_response(response, timeout);  }}
```

```
bool get_gsm_cmd_response(String resp, int tout)
{  //  Serial.println(F("in get_gsm_cmd_response()"));
  char inChar;
  bool cmd_exicute = false;
  first = 1;
  Serial.print("Waiting for response");
  current_time = millis();
  if (gsm.available() <= 0)
  {    Serial.print(" NA ");
    while (gsm.available() <= 0)
    {      Serial.print(".");
      if ((millis() - current_time) > tout)
      {        Serial.print("no response in 5 sec");
        return 0;
        break;      }   }  }
  if (gsm.available() > 0)
  {    Serial.print(" Available ");
    while (gsm.available() > 0)
    {      Serial.print(" Reading ");
      inputString = gsm.readString();    }
    Serial.print("inputString= ");
    Serial.print(inputString);
    Serial.print(" return 1 success");
    return 1;
    //    Serial.println("INPUT STRING" + inputString);  }}
String get_call_number()
{  String call_data = sendcmd(atCLCC, 1);
  if (call_data.indexOf(CLCC) >= 0)
```

```
  {    index1 = call_data.indexOf('\"');
    num = call_data.substring(index1 + 1);
    index2 = num.indexOf("");
    num = num.substring(0, index2);
    if (num.indexOf('+') < 0)
    {      num = '+' + num;    }
    return num;  }}
String sendcmd(String gsmcmd, int wait)
{ //  Serial.println(F(" in sendcmd2"));
  Serial.println(gsmcmd);
  gsm.println(gsmcmd);
  if (wait == 1)
  {    long z = millis();
    while (!gsm.available())
    {      if ((millis() - z) >= 20000)
      {        return ERROR_str;      }    }  }
  else if (wait == 0)
  {    return "";  }
  if (gsm.available() > 0)
  {    return get_data();  }
  //  return 1;}
void hangcall()
{  sendcmd(F("AT+CHUP"), ok, 1000, 1);}
int call_status()
{  if (gsm.available() > 0)
  {    indata = get_data();
    if (indata.indexOf(CLCC) >= 0)
    {      return RECEIVINGCALL;    }
```

```
    else
    {      return IDLE;    }  }
  else
  {    return IDLE;  }}
String get_data()
{  //  Serial.println(F("in get_data()"));
  char c;
  Serial.println(F("data available"));
  while (gsm.available() > 0)
  {    c = (char)gsm.read();
    //     Serial.print(c);
    delay(1);  }
  Serial.println(indata);
  return indata;}
bool connect_internet()
{  exicute_cmd(F("AT+CIPMODE=1"), ok, 10000);
  exicute_cmd(F("AT+CSOCKSETPN=1"), ok, 10000);
  delay(5000);}
String get_saved_data(int addr)
{  String eeprom_read_data = "";
  int data_len = EEPROM.read(addr);
  addr++;
  for (int i = 0; i < data_len; i++)
  {    eeprom_read_data = (char)EEPROM.read(addr);
    addr++;  }
  return eeprom_read_data;}
bool save_data(String data_to_save, int add)
{  int l = data_to_save.length();
```

```
  if (add < 10)  {    EEPROM.write(add, l);
    add++;
    for (int i = 0; i < l; i++)
    {      EEPROM.write(add, data_to_save[i]);
      add++;    }
    return true;  }
  else
  {    return false;  }}
void clear_eeprom(int addr)
{  int data_len = EEPROM.read(addr);
  for (int i = addr; i <= (addr + data_len); i++)
  {
    EEPROM.write(i, 0);  }}
int data_configured1()
{  return EEPROM.read(config1_add);}
String get_gps_info()
{  delay(1000);
  gsm.end();
  delay(2000);
  gsm.listen();
  Serial.println(F("tracking..."));
  delay(1500);
  exicute_cmd(F("AT+CGPSINFO"), ok, 5000);
  if (inputString.indexOf("+CGPSINFO:") >= 0)
  {    //    Serial.println("indata:" );
    //    Serial.println(indata);     //+CGPSINFO:
1909.674576,N,07251.414932,E,160120,134843.0,10.6,0.0,135.8
    //***************************************************************************
    inputString.trim();
```

```
char gpsbuffer[120];
inputString.toCharArray(gpsbuffer, 120);
Serial.println("gpsbuffer : " + String(gpsbuffer));
//    char gpsbuffer = String(indata);
char useless[20];
char lat[15];
char lat_dir[10];
char lon[15];
char lon_dir[10];
sscanf(gpsbuffer, "+%[^,]:%[^,],%[^,],%[^,],%[^,]", &useless, &lat, &lat_dir, &lon,
&lon_dir);
Serial.println("useless: " + String(useless));
Serial.println("lat: " + String(lat));
Serial.println("lat_dir: " + String(lat_dir));
Serial.println("lon: " + String(lon));
Serial.println("lon_dir: " + String(lon_dir));
String lat1 = lat;
double latitude1 = lat1.toFloat();
String latitude2 = String(latitude1, 6);
double latitude = atof(lat);
float degrees = floor(latitude / 100);
double minutes = latitude - (100 * degrees);
minutes /= 60;
degrees += minutes;
// turn direction into + or -
if (lat_dir[0] == 'S') degrees *= -1;
lat5 = String(degrees, 6);
Serial.println("lat: " + String(lat5));/////////////////////////////////////
double longitude = atof(lon);
```

```
   String longitude1 = String(longitude, 6);
   longitude = longitude1.toFloat();
   //    Serial.println("longitude1: " + String(longitude));
   // convert latitude from minutes to decimal
   //************************************************
   //*************************************************
   // convert longitude from minutes to decimal
   degrees = floor(longitude / 100);
   minutes = longitude - (100 * degrees);
   minutes /= 60;
   degrees += minutes;
   // turn direction into + or -
   //    if (longdir[0] == 'W') degrees *= -1;
   if (lon_dir[0] == 'W') degrees *= -1;
   //    String lon5 = String(degrees, 6);
   lon5 = String(degrees, 6);
   Serial.println("lon: " + String(lon5));/////////////////////////////////
   String site = "\nhttp://maps.google.com/maps?f=q&q=";
   String msg = site + lat5 + "," + lon5 + "&z=16";
   return (msg);

//**************************************************************************
**  }}
bool hit_IoT_data(String dataToSend)
{  String IoT_id = "janetsinkaka@gmail.com";                          //edit your
IoT id here
  String IoT_pass = "8471";                                          //edit your IoT
password here
  String IoT_site = "GET http://www.IoTgecko.com/IOTHit.aspx?";
  String hitlink = IoT_site + "ID=" + IoT_id + "&Pass=" + IoT_pass + "&Data=" + dataToSend;
```

```
  //test this hitlink------ if
(sendcmd(F("AT+HTTPPARA=\"URL\",\"IoTgecko.com/IoThit.aspx?ID=smithgarry93@yahoo
.com&Pass=7888&Data=231*232*235*1*1*0*75.00*19.22\"\r\n"), ok, 10000, 1))
  String IoT_path = "AT+CIPOPEN=0,\"TCP\",\"www.IoTgecko.com\",80";
  if (sendcmd(IoT_path, "CONNECT", 30000, 1))
  {    flushsoftSerial();
    if (sendcmd(hitlink, "Label1", 20000, 1))
    {      flushsoftSerial();
      if ((indata.indexOf(F("true")) >= 0))
      {        flushsoftSerial();
        return true;      }
      else
      {        return false;      }    }
    else
    {      return false;    }  }
  else
  {    return false;  }}
void flushsoftSerial() {
  while (gsm.available())
    gsm.read(); }
bool sendsms(String sms_data, String recivr_num)
{  sendcmd(CMGF, ok, 1000, 1);
  delay(1000);
  String sms_cmd = "";
  sms_cmd = CMGS;
  sms_cmd += recivr_num;
  sms_cmd += "\"";
  sendcmd(sms_cmd, ">", 2000, 1);
  gsm.print(sms_data);
```

```
  delay(2000);
  if (writecmd(26, ok, 10000, 1))
  {    //    Serial.println(F("send"));
    return true;  }
  else
  {    //    Serial.println(F("failed"));
    return false;  }}

bool writecmd(uint8_t gsmcmd, String response, int timeout, int debug)
{
  //  Serial.println(F(" in writecmd"));
  gsm.write(gsmcmd);
  //  Serial.println(cmd);
  if (debug == 0)
  {    return get_gsm_cmd_response(response, timeout);  }
  return 0;}
```

APPENDIX D: Cloud Platform Code

A) Dashboard Backend

```
public partial class CustomDash : System.Web.UI.Page
{    protected void Page_Load(object sender, EventArgs e)
    {
        if (!IsPostBack)
        {
            try
            {
                fillGrid();
            }
            catch (Exception exx)
            {
                Response.Redirect("CustomHome.aspx");
            }
        }
    }

    public void fillGrid()
    {
        string emailid = Request.QueryString["id"];
        string type = "IOT Three Phase";
        SqlDataAdapter da = new SqlDataAdapter("Select Data from DataList Where EmailId = '"
+ emailid + "' AND type = '" + type + "' Order By ID Desc", con);
        DataSet ds = new DataSet();
        da.Fill(ds);
```

```
    int count = ds.Tables[0].Rows.Count;

    if (ds.Tables[0].Rows.Count > 0)
    {
        DataTable dt = new DataTable();
        dt.Columns.Add("ID");
        dt.Columns.Add("Phase");
        dt.Columns.Add("Status");
        dt.Columns.Add("Date");
        dt.Columns.Add("Time");

        for (int i = 0; i < count; i++)
        {
            string[] data = ds.Tables[0].Rows[i][0].ToString().Split('*');

            dt.Rows.Add("" + (i + 1), data[0], data[1], data[2], data[3]);
        }
        GridView2.DataSource = dt;
        GridView2.DataBind();
    }
    else
    {
        GridView2.DataSource = null;
    }
}
protected void Timer1_Tick(object sender, EventArgs e)
{
```

```
        fillGrid();
```

B) MAP BackendEnd

```
public partial class CustomMap : System.Web.UI.Page
{
    protected void Page_Load(object sender, EventArgs e)
    {
        if (!IsPostBack)
        {
            try
            {
                if (Session["UType"] != "User")
                {
                    Response.Redirect("index.aspx");
                }
            }
            catch (Exception exx)
            {
                Response.Redirect("Dashboard.aspx");
            }
        }
    }


    public void fill(object sender, EventArgs e)
    {
        string id = Request.QueryString["id"];
        SqlCommand cmd = new SqlCommand("Select Data from Data Where EmailID = '" + id +
"'", con);
        con.Open();
        SqlDataReader dr = cmd.ExecuteReader();
```

```
        if (dr.HasRows)
        {
            dr.Read();
            string[] data = dr[0].ToString().Split('*');
            con.Close();

            if (data.Length >= 5)
            {
                try
                {
                    string lat = data[6], lng = data[7];
                    lblLoc.Text = data[6] + "," + data[7];

                    latdata.Value = lat;
                    lngData.Value = lng;
                                                }
                catch (Exception ep)
                {

                }
            }
        }
        else
        {
            con.Close();
        }
    }
}
```

C) Three Phase Backend

```
public partial class CustomThreePhase : System.Web.UI.Page
{
    protected void Page_Load(object sender, EventArgs e)
    {
        if (!IsPostBack)
        {
            try
            {
                fill(sender, e);
                Session["Page"] = "IOT";
            }
            catch (Exception exx)
            {

            }
        }
    }

    public void fill(object sender, EventArgs e)
    {
        string id = Request.QueryString["id"];
        SqlCommand cmd = new SqlCommand("Select Data from Data Where EmailID = '" + id +
"'", con);
        con.Open();
```

```
SqlDataReader dr = cmd.ExecuteReader();
if (dr.HasRows)
{
    dr.Read();
    string[] data = dr[0].ToString().Split('*');
    con.Close();

    if (data.Length >= 5)
    {
        lblV1.Text = data[0];
        lblV2.Text = data[1];
        lblV3.Text = data[2];

        if (data[3] == "0")
        {
            alarm(true);
            imgP1.ImageUrl = "~/images/boff.gif";
        }
        else
        {
            if (imgP1.ImageUrl.Contains("off"))
            {
                alarm(false);
            }
            imgP1.ImageUrl = "~/images/bon.gif";
        }

        if (data[4] == "0")
```

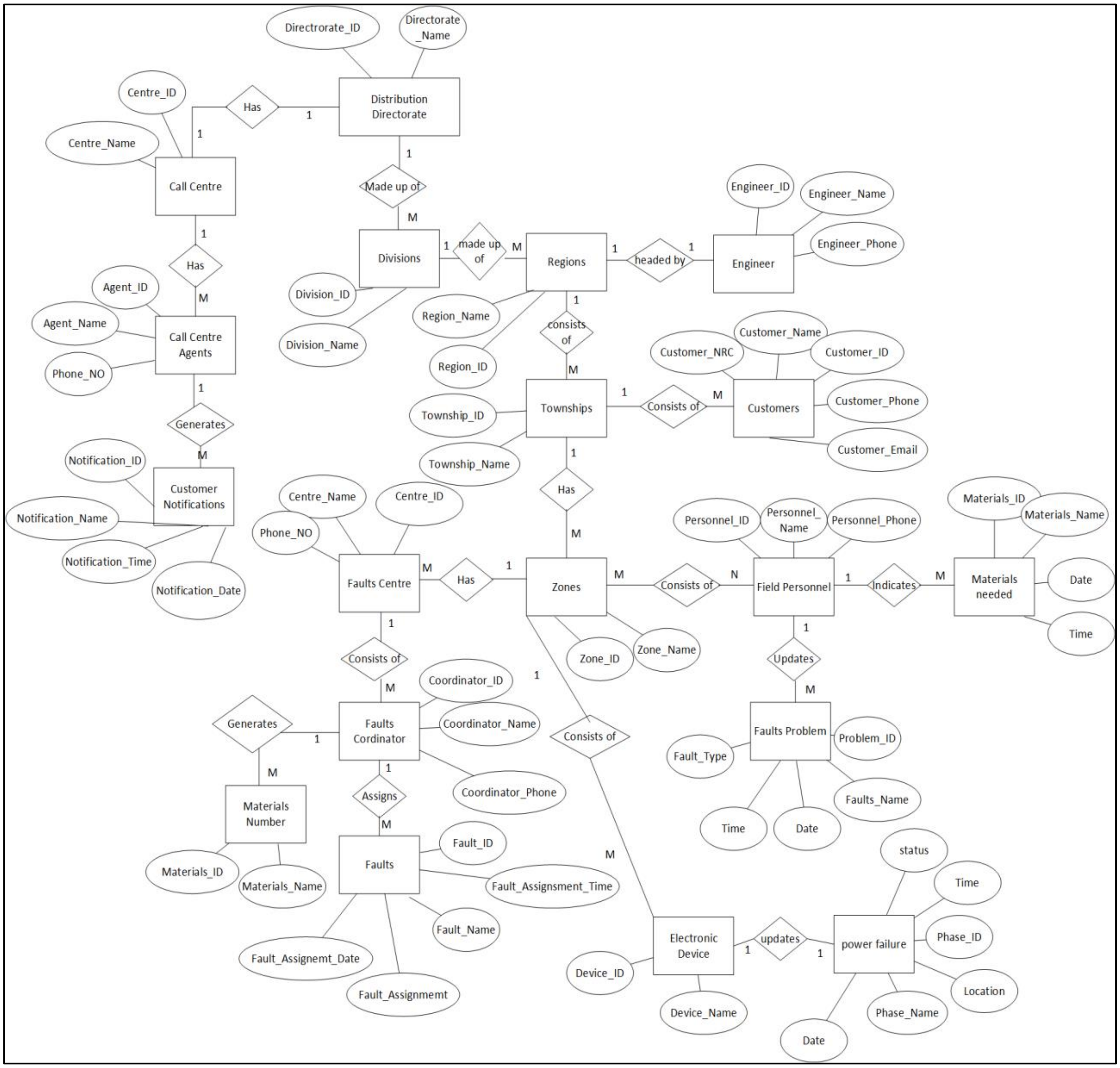
```
        {
            alarm(true);
            imgP2.ImageUrl = "~/images/boff.gif";
        }
        else
        {
            if (imgP2.ImageUrl.Contains("off"))
            {
                alarm(false);
            }
            imgP2.ImageUrl = "~/images/bon.gif";
        }

        if (data[5] == "0")
        {
            alarm(true);
            imgP3.ImageUrl = "~/images/boff.gif";
        }
        else
        {
            if (imgP3.ImageUrl.Contains("off"))
            {
                alarm(false);
            }
            imgP3.ImageUrl = "~/images/bon.gif";
        }
    }
}
```

```
            else
            {
                con.Close();
            }
        }

        public void alarm(bool flag)
        {
            if (flag)
            {
                beep_one.Attributes.Add("loop", "loop");
                beep_one.Attributes.Add("autoplay", "");
            }
            else
            {
                beep_one.Attributes.Remove("loop");
                beep_one.Attributes.Remove("autoplay");
            }
        }
    }
```

APPENDIX E: Entity-Relationship Diagram for the Cloud Application Database



APPENDIX F: Main Circuit Board