Cloud based Power Failure Sensing and Management Model for the Electricity Grid in Developing Countries: A Case of Zambia

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Abstract—**In most developing countries, huge parts of the electric power grid are not monitored making it difficult for the service provider to determine when there is a power failure in the electric grid, especially if the power failure occurs in the Low Voltage level. Clients usually have to call and inform the utility's customer service centre to report a power failure. However, this system of addressing power outages is not very effective and usually results in long durations of system interruptions. This paper 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 in Zambia, a developing country in Southern Africa. A baseline study was conducted to determine the challenges faced by both the electric power utility company called Zambia Electricity Supply Corporation (ZESCO) and the electricity consumers in the current power failure reporting management model. The results from the baseline study indicate that challenges are being faced by electricity consumers when it comes to reporting power failures. These include failure to get through to the customer call centre due to constantly engaged lines, unanswered calls, failed calls and network failure. The challenge faced by the electricity service provider is the inability to attend to all the customers through the call centre as customer calls are rejected due to limited Call Centre system resources. To address these challenges the proposed cloud based power failure sensor model made use of a Voltage sensor circuit, Arduino Microcontroller board, SIM808 GSM/GPRS/GPS module, cloud architecture, Web Application and Google Map API. Results from the proposed model show improved reporting time, location information and quick response to power failures.**

Keywords*—*Cloud architecture; power failure sensing; low voltage network; electric grid

I. Introduction

Electrical power systems are extremely huge and complex networks. Such electric power systems provide a secondary source of energy essential to meeting man's needs, improve living standards and boost socio-economic development [1] [2]. These systems are integrated to provide economic benefits, increased reliability, operational advantages making them the most important national and global infrastructure such that when they collapse it leads to major direct and indirect impacts on the economy and national security [1]. A power system is usually made of many components such as transmission lines, substations, switches and transformers with widely dispersed power generating systems and loads being the main features. A power system consists of three subsystems being generation, transmission and distribution. According to [5] the distribution network is a major element of the total electrical supply scheme, providing the final link between the bulk transmission systems and the customers with 80% of the outages that occur at the customer electricity service being due to failures in the distribution network.

Urbanization and computerization of society has increased demand for reliable electricity supply. Power outages also referred to as power failures cause an interruption to this urbanization and computerization resulting in welfare losses, slow economic growth and low productivity for firms [3] [4]. High-speed wind, flying objects, falling trees, physical contact by animals, lightning, snow storms, contamination of insulators, human errors, overloads, bad insulation and protection failure are some of the causes of power failures [4].

The aim of most power utility companies is to ensure reduced economic losses, lost productivity, and customer inconvenience brought about by power failures. To mitigate the customer interruption costs due to power failures, distribution systems need a distribution automation system for power failure detection [4] [6]. Automation of the power failure management model 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 [4] 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 and fault management. This study is an attempt to develop a power failure sensing and management model for the electricity grid in Zambia. This model will be cloud based.

II. Background

The Zambia electricity grid is an interconnected system of electric transmission lines linking generators to loads and comprises transmission lines and substations at 330 kV, 220 kV, 132 kV, 88kV, 66 kV, 11kV, 33kV and 0.4kV voltage levels [7]. The backbone of the grid is built on a robust 330 kV system from the southern part of the country through Lusaka and Central provinces to the Copper belt.

Due to the favorable economic development, the demand for electricity in Zambia has been increasing at average annual rates of 3-4 percent in recent years [8]. 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 the current 48 to 90 percent by 2030 [8]. On 27th July 2019, the Zambia electricity service provider ZESCO connected the one millionth customer to the national grid. The corporation had 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 [9] .With Zambia being part of the sub Saharan African countries which have a total duration of outages averaging approximately 800 hours a year [10], it is important that reliable and efficient automatic power failure-sensing systems be put in place to reduce on outage durations as well as ensure customer satisfaction. This will ensure adequate, 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.

The degree to which the electric-powered technology has become embedded in all human activities makes the security and reliability of the electrical energy infrastructure of vital importance today more than ever.

III. Literature Review

Related work carried out includes research on the use of sensors to sense various parameters such as substation and transformer measurements, street lighting and condition monitoring of equipment.

Researchers in [11] propose a Global System for Mobile Communications (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. A GSM module is used to send an alert SMS to a mobile phone and Arduino microcontroller is used to sense and control the streetlights. A light dependent resistor detects whether it is light or dark and switches the lights on and off as well as determines which light is faulty. The study in [12] propose and develop an internet of things (IOT) based prototype model using the APC220 transceiver, GSM, General Packet Radio Services (GPRS), radio-frequency identification (RFID), passive infrared sensor (PIR), Arduino microcontroller and cloud storage to curb theft of grain at the storage points of the food reserve agency(FRA). 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. In [13] a base line study was conducted on the challenges faced by Zambia Air Force (ZAF) in inventory management of spares and it was discovered that the major challenge was due to the manual inventory management which resulted into incorrect inventory reporting and pilferage of items. To address this challenge 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 through either a cloud application or an SMS to a mobile phone when spares are being pilfered.

In [14] 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 in Zambia is proposed. A baseline study was conducted which identified the challenges FRA faced, 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, Global Positioning System (GPS) sensor, ZigBee transceivers and Wi-Fi access. Through these devices they were able to monitor temperature, humidity, location and motion via 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 sending alerts using Wi-Fi which covers distances of about 100metre and did not look at how GPRS can be used for the same purpose. The researchers in [15] 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 on the system. A Programmable Interface Controller (PIC) microcontroller is used to sense the current, voltage and frequency of the system. The PIC microcontroller is also 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 setting of the short circuit current limit from a mobile phone possible. 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.

In [16] [17] researchers 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 and presented on a computer through serial RS232 communication. The researchers however do not explore the use of cloud technology through the use of GPRS nor do they explore the benefits of the use of location maps for locating the faults detected. The study in [18] [19] propose the use of GSM technology to monitor substation parameters such as voltage and current (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, GPRS nor do they explore the benefits of the use of location maps for locating the faults detected. The researchers in [20] use the combined GSM, SMS and Atmega16 microcontroller system to monitor transformer parameters such as oil level, temperature and load current. In [21] the researcher 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 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 applied in three phase power failure management and monitoring enabling alert, location, status, duration and measurement information to be sent to both the mobile phone and cloud services for storage and for location determination on location maps.

IV. Methodology

This section gives a description of the research process and an explanation of the methods used to gather data. The research involved conducting a baseline study whose results where then used to develop a power failure reporting management model and a prototype based on the model.

A. Base Line Study Methodology

1) Research design: This study employed survey, exploratory and Water fall system development research designs. Exploratory research design is a research design described as the problem-finding phase of research wherein the researcher focuses on the scope of study but with anticipation of arising problems at a later stage of the study [22]. Further, Survey research design is described as a type of research which is used to give a wider picture or an overview, assessing opinions, trends, beliefs and feelings of selected groups of individuals [23]. Exploratory and survey research was used to determine the challenges faced by both ZESCO the Service provider and the electricity clients in reporting and addressing power failure. Water fall system development research design was used for the development of a prototype for sensing and reporting power failure.

2) Data collection and sources: This study 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 and electricity clients.

3) Study population: The population target for this study was employees from ZESCO who work in the Call Centre customer service department, Fault Co-coordinators as well as electricity clients in Lusaka district.

4) Sampling technique: The study selected the people who use electricity in Lusaka district townships, ZESCO employees in the customer service department as well as fault coordinators. Questions in the data collection tools were both open and close-ended. This enabled the study extract both quantitative and qualitative responses. 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 reporting management model. However, in selecting the electricity consumers, a multistage cluster sampling method was employed in which Lusaka district townships were selected using simple random sampling. Following that selection, convenience sampling was then applied in which households were selected for questionnaire distribution. 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. The sample size was determined to be 383.

5) Data analysis: Primary data collected from the respondents was entered and analyzed both qualitatively and quantitatively using Statistical Package for Social Scientists. Quantitative analysis was done using frequencies and percentages, presenting them in tables and bar charts. The qualitative data as well as secondary data analysis was carried out by use of content analysis.

B. System Design

The system requirements specification and model design phase of the research study employed the use of quantitative and qualitative data from interviews conducted with ZESCO personnel as well as data collected from electricity clients in Lusaka District through questionnaires. The quantitative and qualitative data from ZESCO personnel and electricity clients provided the information needed to come up with the current business process and thereafter develop the prototype based on cloud and sensing technology.

1) Current business process for power failure reporting: The current business process for power failure reporting is as shown in Fig. 1. It is derived from the baseline study that was conducted.

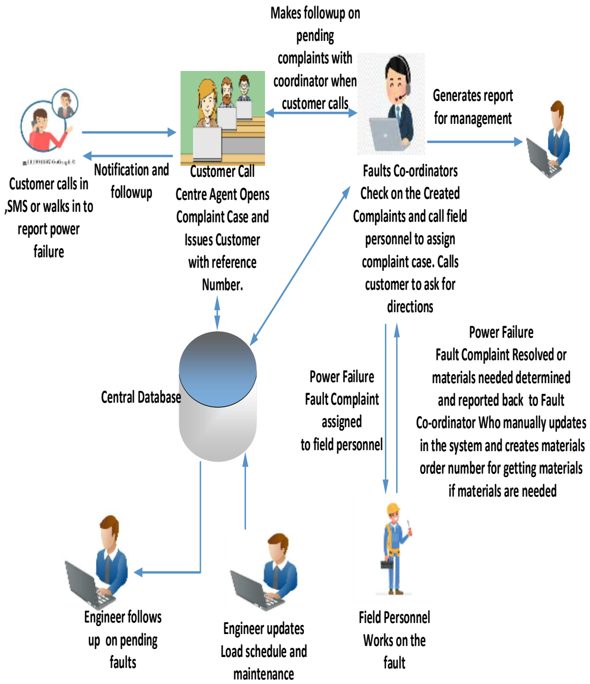


Fig. 1. Current Business Model for Power Failure Reporting.

The data collected from the service provider indicate that in the current power failure reporting management business model customers need to either call, SMS or walk into a customer call Centre to report a power failure fault. The customer is then given a complaint number to use for complaint case follow-up. This customer complaint case is then captured by the faults coordinator who calls and assigns the reported power failure fault case to the field personnel. In case the power failure location is not known, the fault coordinator calls the customer to get the location of the power failure. Engineers and managers also have access to the power failure information but only when they are connected to the ZESCO Local Area network (LAN).

2) Proposed business model for power failure reporting: Based on the results obtained from the baseline study a power failure reporting management business model based on sensor and cloud technology was proposed to address the challenges ZESCO and the clients are facing when making power failure reports. Fig. 2 shows the proposed model.

The proposed model was designed to make use of a microcontroller based electronic device installed on a distribution electricity line to automatically detect and report power failure and location to ZESCO personnel through cloud and mobile services. This eliminates the need for the customer to report the power failure thus addressing the challenges of call Centre access revealed in the baseline study. This model is intended to ensure that the overall response time of ZESCO personnel to power failures is improved as well as enable access to information regarding the status of the Low Voltage electricity network by anybody, anywhere and anytime through cloud services even when not connected to the ZESCO LAN.

3) Use case diagram: The Use Case diagram describes the proposed functionality of the new system. Use cases represent how a system interacts with its environment by illustrating the activities that are performed by the users of the system and the system's responses [24]. Use case diagrams model the functionality of a system using actors and use cases. The web application for the cloud platform was designed using a use case diagram. For this study the use case diagram consists of seven actors namely the Call Centre Agent, Faults Coordinator, Manager, Engineer, Customer, Field personnel and power failure detection system as shown in Fig. 3. The power failure detection system updates the status, location and duration of power failure. The call centre agent is able to view power failure faults and notify customers of the failure. The faults coordinator and engineer are capable of updating faults, generating materials order number and assigning faults whilst the field personnel is able to view faults, update faults, indicate the fault problem and materials needed. The cloud based nature of the model enables the customer to be able to login from anywhere and view areas affected by the power failure. The manager is able to view power failure statistics and generate reports. The web application was built on an open source cloud services provider which offers a platform for development of microprocessor based systems. This cloud based platform is built on Hypertext Markup Language (HTML), Cascading Style Sheets (CSS), and Java Script as client software with ASP.net and Microsoft SQL database as server software. Google API was used for accessing Google Maps to determine location of the power failure.

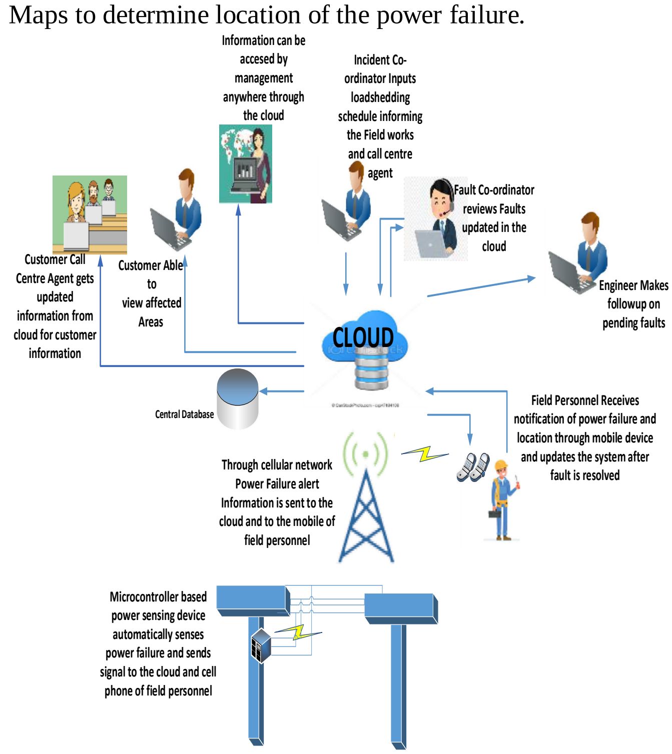


Fig. 2. Proposed Model for Power Failure Reporting.

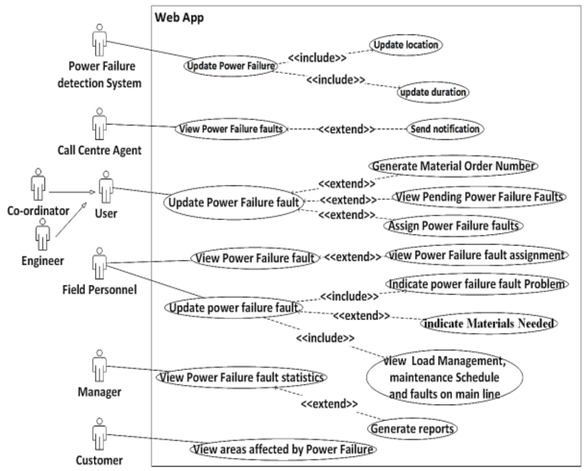


Fig. 3. Use Case Diagram for the Web Application.

C. Prototype Development

From the proposed model a prototype was developed which consisted of an electronic device made from a Voltage sensor circuit, Arduino Microcontroller board, Atmega 328 microprocessor, GSM/GPRS/GPS module, battery charge control circuit and Web Cloud services using cloud architecture, Web Application and Google Map API. Fig. 4 shows the block diagram of the Arduino Microcontroller based power sensing device. Fig. 5 shows the flow chart of the Power failure sensing functionality.

1) Prototype implementation materials and methods: The software used in prototype implementation was

- Arduino Integrated development environment (IDE) for programing the Arduino microcontroller board
- Java script
- HTML
- CSS
- ASP.net
- Microsoft SQL database
- Arduino Development board API

The hardware used was

- Arduino Development board
- Atmega 328 microprocessor
- MAX 232 Chip
- SIM808 GSM/GPRS/GPS Module
- Electronic components
- 12 Volts battery
- Liquid-crystal display (LCD)
- Laptop for accessing cloud services
- Mobile phone for receiving power failure alert notification

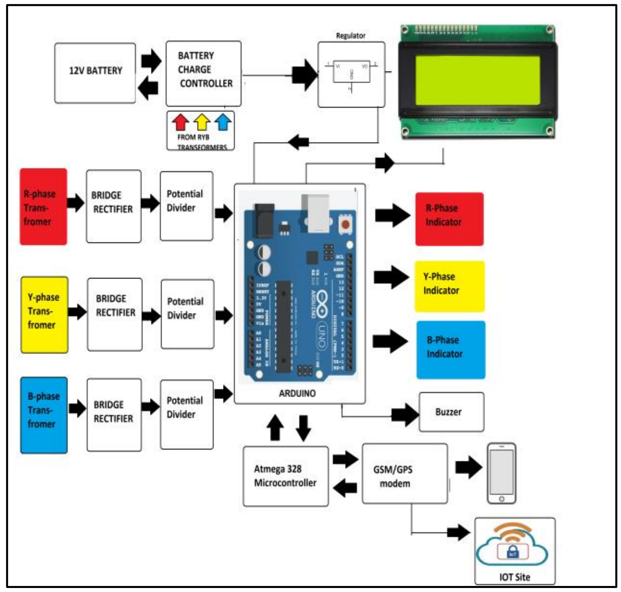


Fig. 4. Block Diagram of Arduino Microcontroller based Power Sensing Device.

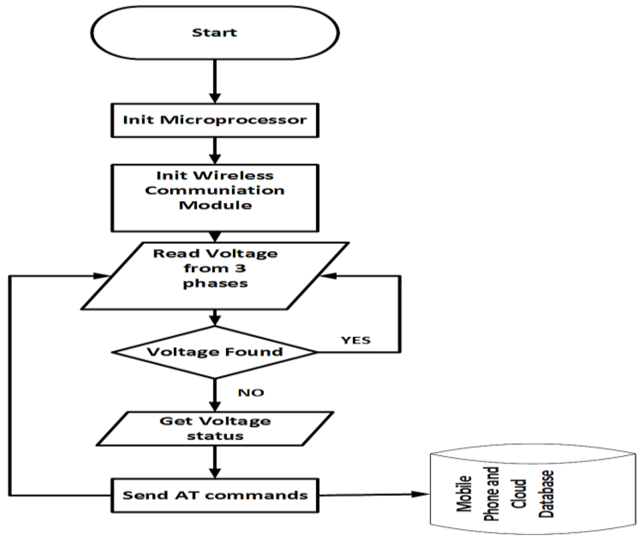


Fig. 5. Flow Chart of Arduino Power Failure Sensor Functionality.

2) Power failure sensor functionality: The power failure sensor functionality is made possible by a voltage sensor circuit in which voltage is stepped down from 230V AC to 12 V AC then rectified and approximately 2V DC used as input to the Arduino. When there is loss of supply, the 2V DC input to the Arduino becomes zero and the embedded program in the Arduino microcontroller and Atmega microprocessor sends an SMS alert consisting of information on the status of the supply from the three phases as well as the power failure location to a predefined cell phone number using the connected SIM808 GSM/GPRS/GPS module over the GPRS cellular network. At the same time through the AT command HTTP POST request the application on the remote server is invoked to parse the power failure alert data and location of the power failure data and insert it into the cloud database for storage and display on the cloud platform.

3) Voltage sensor circuit: The voltage sensor circuit consists of three 230/12V Voltage transformers stepping down the 230V AC input voltage from the Red, Yellow and Blue phases to 12V AC output voltage. A diode bridge rectifier rectifies the 12V AC to DC and a potential divider ensures input of approximately 2V DC to the Arduino board analogue input pins. The analogue input pins take the voltage readings from the sensor and convert them into a number between 0 and 1023 which is later converted back to voltage values for display on LCD and cloud platform. Loss of power in any of the three 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 and predefined mobile phone number. The Arduino through a calculation in the embedded program is able to send the voltage values of the three phases to the cloud platform. The date and time of the alert messages are also displayed on the cloud platform. Fig. 7 shows the main circuit board. Apart from the voltage sensor circuit there is a regulator LM7805 for maintaining the 5V DC supply voltage to the main board circuit. In addition there is a battery controller circuit which controls the charging of the battery and an LCD display for display of voltage values on the electronic device.

4) Battery charge control circuit: The battery charge control circuit controls the charging of the battery. The Arduino microcontroller is programmed to read the battery voltage and depending on the value of the voltage it will send a signal to start or stop the charging of the battery through a Transistor-MOSFET switch combination circuit. To start the charging of the battery the Arduino microcontroller turns on the Negative-Positive-Negative (NPN) transistor which in turn turns on the MOSFET to connect the battery to the 13.5V for charging. Once the battery is charged the Arduino microcontroller turns off the NPN Transistor which in turn turns off the MOSFET to disconnect the battery from the 13.5V charging supply. The battery is needed to power the device when there is loss of supply from all three phases. The device also consists of the LM 2576 regulator to provide the 13.5V charging voltage as well as provide power supply to the SIM808 module. Fig. 6 shows the flow chart for the battery charging functionality and Fig. 8 shows the battery charge control circuit.

5) Arduino microcontroller board: The Arduino is an open source microcontroller interface based board consisting of a circuit board and software called Arduino IDE (Integrated Development Environment), which is used to write and upload the computer code to the physical board [25].

Arduino boards consist of digital and analogue pins which can be programmed to either input or output signals through the IDE [26].

The Arduino microcontroller board is programmed in simplified C++. It is used with the SIM808 module to transfer information to the mobile phone and cloud platform. SIM808 module is a complete Quad-band GSM/GPRS module which combines GPS technology for satellite navigation. It has high GPS receive sensitivity with 22 tracking and 66 acquisition receiver channels [27].

In this study the Arduino was programmed to use the analogue input pins to sense the power failure through the input of the 2 V DC. An Atmega 328 microprocessor is introduced to communicate with the SIM808 module through the MAX232 receiver/transmitter chip and RS232 serial interface. The MAX 232 converts the signals from the microprocessor to RS232 signals to interface with the SIM808 module. Through the use of AT- HTTP commands to the SIM808 module, power failure alert messages were sent to the mobile phone and cloud platform.

6) Cloud services: Cloud services used are offered by the IOTGECKO cloud services platform. IOTGecko cloud platform offers API support over Arduino, Raspberry Pi Microcontrollers and other controller boards. It provides a GUI builder and customized application creator system enabling developers to design desired IOT systems. On the client side the software used was HTML, CSS and JavaScript. HTML makes up the content of the website and enables the browser (like Internet Explorer or Google Chrome) to show the website content. CSS was used to describe the presentation (the look and formatting) of the website. JavaScript is a programming language 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 power failure 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 website such as enabling the updates of power failure alerts from the microcontroller based device. The server consists of a database engine based on Microsoft SQL for storage of data such as the status and duration of the power failure from each of the phases. The web server software used was Internet Information Services (IIS) with Microsoft windows as the operating system.

From the cloud platform it is possible to see which phases have no supply, what time the power failure occurred, what time power was restored and voltage values for each phase as well as the location of the power failure.

7) Prototype testing: To measure success and performance, the prototype was setup and tested in a lab environment by connecting it to a three phase power supply and a battery for backup supply as shown in Fig. 10. 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 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 lab environment. 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 synchronised 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 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.

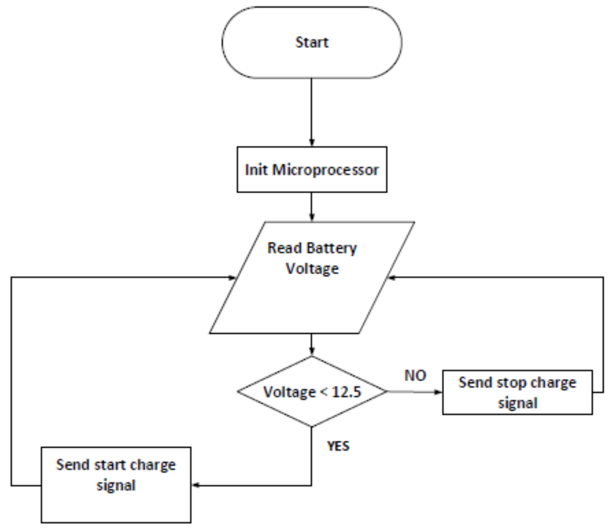


Fig. 6. Flow Chart of Battery Control Functionality.

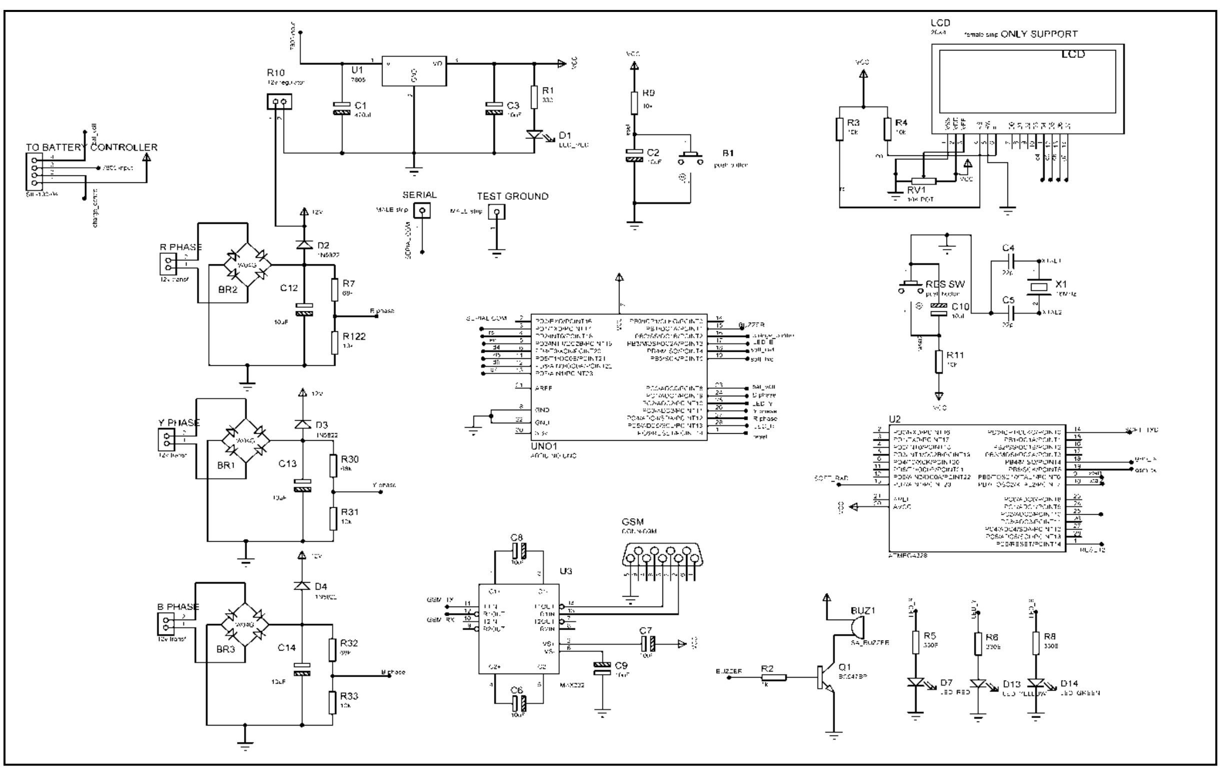


Fig. 7. Prototype Main Board Circuit.

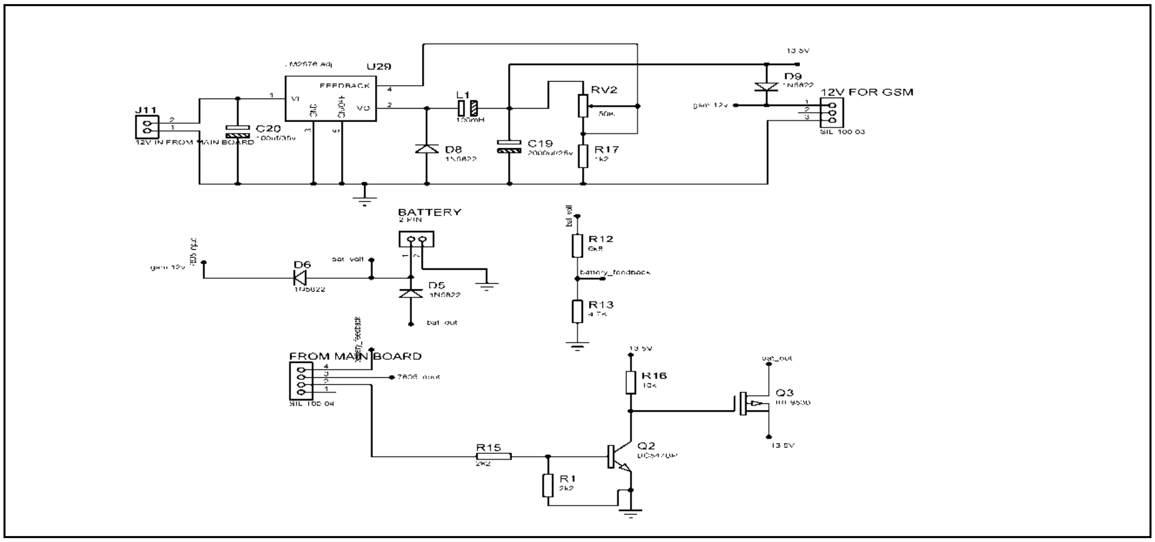


Fig. 8. Battery Charge Control Circuit.

V. Results

The results obtained from the baseline study and system prototype development and testing are presented in this section. The main purpose of conducting the baseline study was to ascertain the challenges that the electricity service provider ZESCO and the customer in the current power failure reporting management model face. The proposed prototype was developed to show as proof of concept of how the fully implemented system would work to alleviate the challenges currently faced by ZESCO and the electricity clients.

A. Baseline Study

The data collected from the baseline study was analyzed using descriptive statistics and the results were presented in form of charts. Data collected from the 383 electricity clients indicated that 100% of the respondents have access to electricity supply with 86% entirely relying on electricity from the power utility company ZESCO and 14% have alternative power sources in the case of power failure.

The results further indicated that 94% of the respondents had experienced power failure.

The majority of the respondents indicated that the longest power failure experienced lasted a number of days resulting in the loss of perishable goods, business customers and damage to equipment.

A cross tabulation of those who reported a power failure complaint to the service provider and those who called ZESCO Call Centre indicate that of the 383 respondents 73% have personally made a power failure complaint to ZESCO with 67.2% of these having made the complaint through the ZESCO call centre.

53% of the 383 respondents have reported power failure by calling the call centre and a cross tabulation of respondents who called the call centre and their experience showed that 86% of those who called call centre have experienced difficulties with accessing the call centre due to either line being constantly engaged or never answered.

When it came to service provider personnel asking for directions to the site of the power failure when a power failure is reported, 73% of the respondents agreed that the service provider personnel ask for directions when a power failure is reported. Further the study revealed that 90.4% of respondents complained of poor response time of ZESCO to power failures reported. Fig. 9 shows the baseline study statistics.

B. Dependency Tests

1) Complaint made to ZESCO by calling call centre:* In determining the extent to which the service provider (ZESCO) Call centre is being utilized by the electricity clients, a cross tabulation was carried out between those that had personally made a power failure complaint to ZESCO, and those that had made such a complaint by calling the Call Centre. Findings revealed that of the total 383 respondents who participated in the study, 202 respondents, representing 53% of the respondents indicated that they had made a power failure complaint to ZESCO by calling call centre, while 47% used other means to report power failure. Out of those that had personally reported power failure to ZESCO, 67.2% had done so by calling the call Centre, while the rest indicated that they had not used the Call Centre.

The null hypothesis for the above test was that the number of reports made to the service provider (ZESCO) through the Call Centre is not significantly high, compared to other methods of reporting. The results revealed a large Chi-square value of 78.226, with a P-value of 0.000 or $P<0.05$. Based on this result, the Null hypothesis was rejected, implying that the number of reports made through the call Centre is significantly high, at 5% significant level.

2) Call centre rating: Further, in determining the ease with which clients can get in touch with ZESCO through the call centre, a cross tabulation was carried out between those that had personally made a power failure complaint to ZESCO by calling call centre, and how they rated the ease with which they managed to get in touch with ZESCO call centre.

Findings of the results revealed that out of those that had reported to ZESCO through the Call Centre, only 16.3% of respondents indicated that they found it either easy, or very easy to get in touch with ZESCO Call Centre, while 48.6% indicated it was either difficult or very difficult. About 34.7% rated ZESCO Call Centre as average in terms of the extent to which it is easy to get in touch with.

In carrying out the dependence test for the above variables, the null hypothesis stated that it was not difficult to get in touch with ZESCO through the Call Centre. The results revealed a large Chi-square value of 31.694, with a P-value of 0.000 or $P<0.05$. Based on this result, the Null hypothesis was rejected, implying that getting in touch with ZESCO through the Call Centre was not easy at all, and this result was significant at 5% significant level.

The customer call centre further indicated that customer's calls were being rejected due to system resource limitations with the highest number of calls received being related to power failure reports. Statistics collected from the call centre indicate that in a typical month, 70% of customer calls are rejected due to limited system resources at the call centre.

C. System Prototype Results

As already outlined in the previous section the prototype developed consists of an electronic device based on the Arduino microprocessor and web application built on the cloud platform. The electronic device consists of the voltage sensor circuit, Arduino Microcontroller board, Atmega 328 microprocessor, MAX232 chip, SIM808 module and battery voltage control circuit. The hardware setup is as shown in Fig. 10.

The electronic device through its voltage sensor circuit is able to detect when there is a power failure and send the power failure alert message to the mobile phone of the field personnel and cloud application, making it possible to be viewed by the ZESCO customer service personnel. The power failure alert message showing the power supply status of each of the three phases and a link to Google maps to show the location of the power failure is sent to a predefined mobile phone number as shown in Fig. 11. A power failure status alert message for a phase is indicated as Phase Fail and a normal power supply status alert message for a phase is indicated as Phase OK.

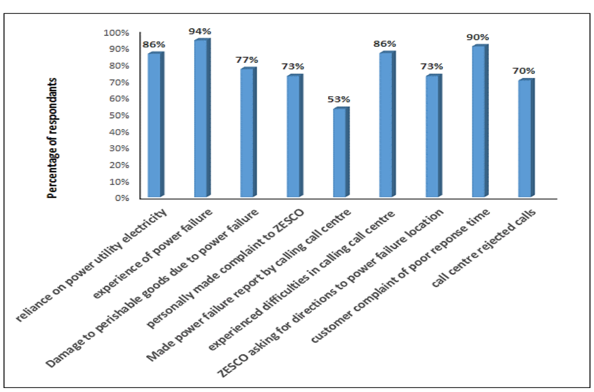


Fig. 9. Baseline Study Statistics.

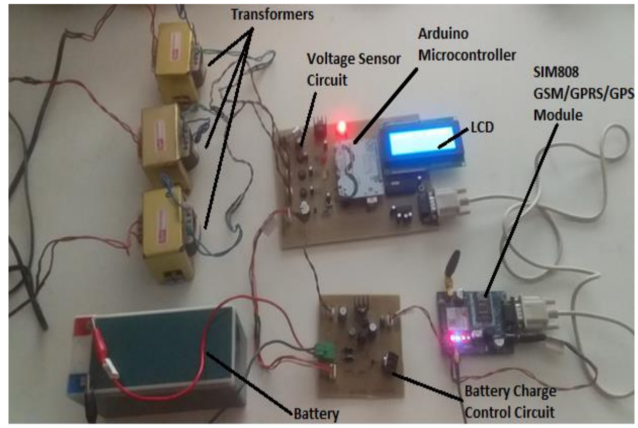


Fig. 10. Hardware Set up of the Microcontroller based System.

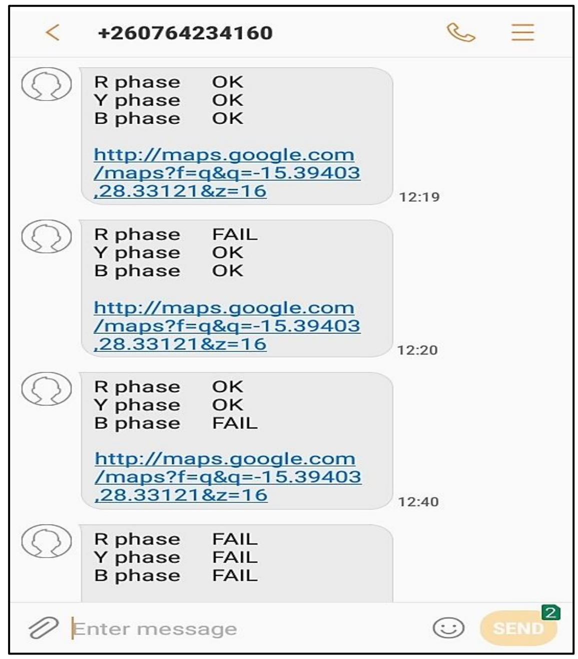


Fig. 11. Power Failure Alert Information Sent to Mobile Phone.

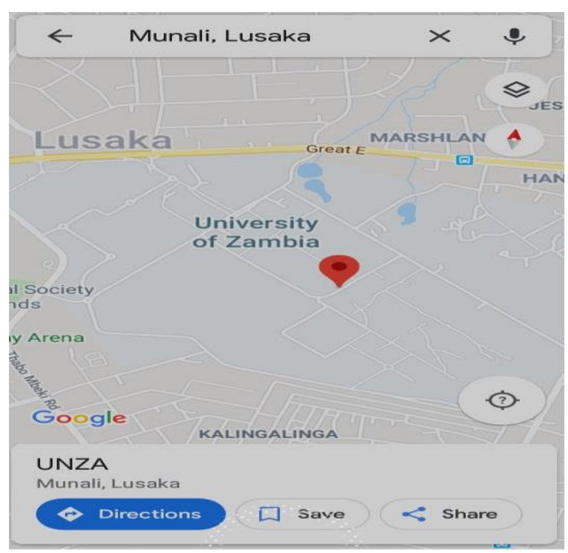


Fig. 12. Power Failure Location Information Sent to Mobile Phone.

When the link to the Google maps sent to the mobile phone is clicked the location of the power failure is shown. See in Fig. 12.

The power alert message indicating the phase which has lost power and the voltage values of the phases with power is also sent to the cloud platform as shown in Fig. 13.

The power failure alert to the cloud platform shows the location of the power failure through the Google API embedded in the cloud application as shown Fig. 14.

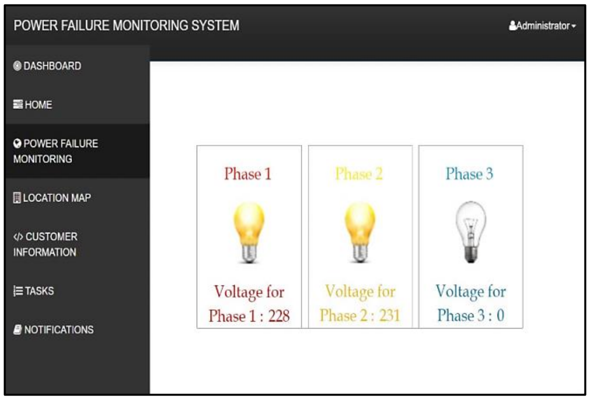


Fig. 13. Three Phase Voltage Values on the Cloud Platform.

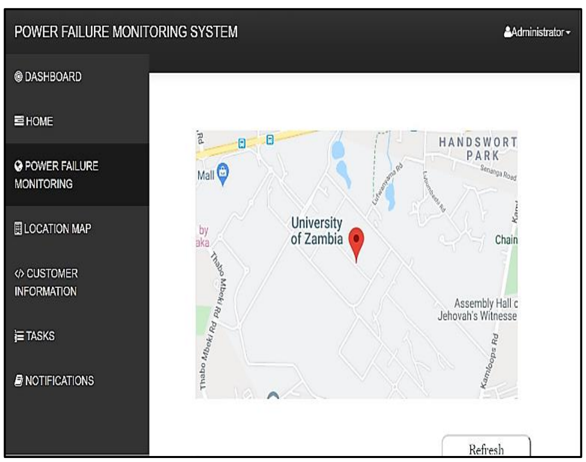
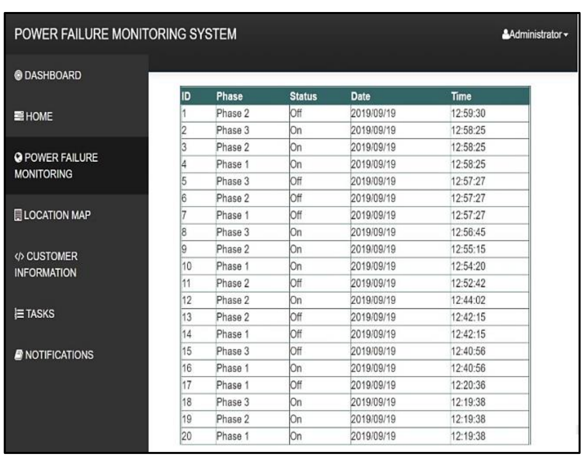


Fig. 14. Location of Power Failure on Cloud Platform.



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

Fig. 15. Power Failure Alert Date and Time on Cloud Platform.

The power failure alert message sent to the cloud platform is able to display the status of each phase, the date and the time enabling the duration of the power failure to be determined as shown in Fig. 15.

VI. Discussion

The study conducted research on the power failure reporting management model for the Zambian electricity Provider ZESCO. A base line study was conducted which revealed the challenges being faced by both the service provider and electricity clients in the current power failure reporting management model. Amongst these challenges were difficulties in accessing call centre to report a fault, challenges in locating the power failure point, limited resources at the call centre leading to rejection of client calls and failure to respond quickly to the power failures reported. Cross table tabulations and chi-square tests revealed a strong relationship between those who made a power failure complaint to the service provider ZESCO and those who reported by calling the call centre implying that most of the complaints are reported through the call centre. A strong relationship was also established between those who called the call centre and those who experienced difficulties in calling the call centre, indicating that clients do face difficulties when calling call centre. The majority of those who called call centre have experienced difficulties in accessing the call centre due to either the line being constantly engaged or the line never answered with most of these calls being rejected as revealed from the Call Centre statistics.

From the findings of the base line study a power failure reporting management model based on sensing and cloud technology was proposed to address the challenges of reporting power failure. In this model power failure is sensed and automatically reported to the service provider without the customer having to report the power failure. Automatic indication of the location of the power failure is also included in the proposed model to enable fast response as there would be no need to call the customer to determine the location. 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 model would contribute to reduction of system outage durations and reduce the burden on call centre resources as power failure would be reported automatically.

The proposed model 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 in responding to power failures.

VII. Conclusion

In the proposed model and prototype developed, power failure alerts are sent to the mobile phone and cloud platform in a matter of seconds which is definitely faster than having the customer report the fault. When adopted this system will.

- Improve response times to power failure reports and reduce system outage duration as the power failure will be reported automatically to the utility personnel through the cloud and mobile phone.
- Enable the service provider monitor the low voltage network and keep track of power failure durations through the cloud,
- Reduce the burden on call centre resources and remove the burden of the customer reporting power failures.
- Enable field personnel access to power failure information through the cloud platform.

VIII. Recommendations and Future Works

A. Recommendations

The study has revealed that automating the power failure reporting system is desirable and therefore this system should be fully implemented in order to realize its full benefits.

B. Future Works

The proposed future works, which should be done on this system, are to integrate SMS customer notification from the cloud platform, incorporate the detection of low voltage as it is one of the other main reported fault and investigate how the transmission time of the power failure alerts can be reduced.

References

[1] Sachan, "Microcontroller Based Substation Monitoring and Control System with GSM Modem," Internationsl Journal of Electrical and Electronics Engineering, vol. 1, no. 6, pp. 13-21, 2012.

[2] E. Christie, A. Ademola and A. Olayinka, "The Daunting Challenges of the Nigerian Electricity Supply industry," International Journal of Energy Technologies and Policy, vol. 5, no. 9, pp. 25-32, 2015.

[3] H. Tao, L. Simona, A. P. Anca and E. Abouzar, "Analysis of Chain of Events in Major Historic Power Outages," Advances in Electrical and Computer Engineering, pp. 63-70, August 2014.

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

[5] 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.

[6] 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.

[7] ZESCO, "Our business - Transmission," ZESCO, Lusaka, 2015.

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

[9] H. M. Zulu, "ZESCO Customer Base Hits one million," ZESCO, Lusaka, 2019.

[10] 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.

[11] T. Gowdhaman and D. Surendran, "Automatic Street Light Control and Fault Deection System with Cloud Storage," International Journal of Scientific & Engineering Research, vol. 8, no. 5, pp. 1-5, 2017.

[12] 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.

[13] 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.

[14] 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.

[15] K. Okokpujie, E. Amuta, R. Okonigene and J. Samuel, "Momitoring and fault detection system for power transmission using GSM technology," in International Conference of Wireless Networks, 2017.

[16] 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.

[17] 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.

[18] 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.

[19] 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.

[20] A. 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.

[21] P. Sandeep, B. Ashish, B. Nitishsingh, K. Neelam and U. Prag, "Web based substation monitoring and 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.

[22] 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.

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

[24] D. Alan, H. W. Barbara and R. Roberta, System Analysis and Design, USA: John Wiley & Sons, Inc, 2012.

[25] S. Monk, 30 Arduino Projects for the evil genus, McGraw-Hill Companies, Inc publisher, 2010.

[26] B. Massimo, Getting Started With Arduino, California: O'Reilly Media Inc , 2011.

[27] S. ShengWu and W. Xuegang, "SIM808 Hardware design V1.00," Shanghai SIMcom Wireless Solutions Limited, Shanghai, 2014.