AUTOMATIC POWER FAILURE SENSING BASED ON LTE (4G) AND SOLAR CHARGED BATTERY AS BACKUP SUPPLY

Janet Nanyangwe Sinkala
Department of Electrical and Electronics Engineering
University of Zambia
Lusaka, Zambia
jnanyangwe@yahoo.co.uk

Jackson Phiri
Department of Computer Science
University of Zambia
Lusaka, Zambia
jackson.phiri@cs.unza.zm

***Abstract* – Power outages also called power failures are a major issue in most sub-Saharan countries. On average there are about 10.5 outages per month each lasting for about 6.6 hours. These outages result in economic losses, lost productivity and customer inconvenience with about 80% of these outages occurring in the distribution network. The aim of most utilities is to ensure reduced number of customers interrupted and the associated customer minutes of interruptions through the automation of the distribution network. This study proposes the use of Arduino microcontroller, SIM7600E 4G/GPS module, cloud application, Google API ,solar panel, MPPT solar charge controller and battery to enable automation of the distribution network and thus reduce on the duration of the power failures. This system is able to transmit power failure alerts to the cloud platform and mobile phone. This system was found to be effective in the reduction of power outage durations.**

***Key words* – Cloud application, 4G, GPS, power failure, power outage**

I. INTRODUCTION

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 it is informed by the customer or substation attendants. Due to this, power failure durations are usually long and have a negative impact on the social economic activities of the country.

In the southern African state of Zambia, with a population of approximately 16 million people [1], availability and reliability of electricity supply is a major concern. The country has vast natural resources essential 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. Reports have been received were customers have complained of power outages affecting their businesses and long response to outages with outages lasting a number of days [2]. Most customers report that they never receive notifications of outages or that they received inaccurate notifications thus leading to inconveniences [3]. In the Zambia energy regulation board report, it was observed that the country's System Average Interruption Duration Index (SAIDI) is an annual average of 37.5 hours per customer which is above the target of 36 hours and the Customer Average Interruption Duration Index (CAIDI) was 9.9 hours per customer which was also above the target of 6 hours [4]. Not only are these figures extremely high and totally impracticable when compared with the internationally-accepted standards of 90 – 180minutes [5].

All these issues occurring together greatly hamper the reliability of the Zambian electricity power system. It bears a huge negative impact on commercial and industrial activities and consequently stunts the country's economic growth.

Automation of the distribution grid through the use of microcontrollers, solar energy and cellular communication can greatly reduce the duration of power outages.

II. LITERATURE REVIEW

A. *Cellular mobile communication*

The field of Cellular Communication is highly emerging. Cellular Communication technologies have moved towards achieving ever increasing user needs for rich multimedia services. In the past less than three decades, enormous changes in Cellular Communication have been addressed in technology, standard and system level [6]. The cellular network has evolved from providing basic wireless and mobile phone services to a complex system providing also Internet connectivity and interworking with other technologies [7].The cellular idea is to use a large number of low-power transmitters, each of them designed to serve only a small coverage area, called a cell, with a radius of a couple of kilometers so that the same radio channels may be reused by another base station located some distance away thus able to accommodate large numbers of users over a large geographical area [6].

The main elements of a cellular system are a mobile station, base station, base station controller and mobile switching centre. These elements enable communication between two or more entities possible [8].

In process automation, cellular technologies can be used to collect measurement data from remote locations via public cellular networks. This enables more efficient and accurate information about asset status than sending a person to do physical visits [9].

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 [10]. Currently 4G systems are mostly in use worldwide with 5G system quickly being introduced.

4G systems have an advantage over the 3G systems in terms of providing high speed, high quality, high capacity, security and low cost services for voice and data services, multimedia and internet over IP [11]. 4G is also called LTE (Long Term Evolution) and has been developed to be able to inter-operate with the other cellular systems making it possible for use even in systems where other cellular technologies are supported [12]. LTE has grown in popularity because it offers downloading speed of up to 100Mbps, increased battery efficiency and has ultra-low latency compared to 3G, about 50 milliseconds latency rate [13]. An operator with a GPRS/EDGE network can connect to a LTE network. Due to this increased flexibility, LTE is the choice of majority of operators worldwide.

For obtaining data communication coverage quickly and inexpensively over a large geographical area, Wireless communications are flexible and low cost in deployment and maintenance compared to wire line deployments and can be deployed anywhere and anytime [6]. Sensors with wireless capabilities can be easily deployed and relocated in most cases within a few hours.

B. Arduino

The Arduino is the simplest and most powerful open source electronics and prototyping hardware and software platform based on the Atmel AVR processor [14]. There are about 15 Arduino based boards differentiated by the type of processor, number of inputs and outputs and form factor [15]. Arduino is based on a simple input/output (I/O) board and a development environment that implements the Processing language [16]. Arduino is composed of two major parts: the Arduino board and the Arduino IDE (Integrated development environment).

The arduino input/output board is combined with a processor, memory, chipset and on-board peripherals like Liquid Crystal Display(LCD), Keypad, Universal Serial Board, serial port, Analogue to Digital Converter, Motor Driver Integrated Circuits, Secure Digital card slot, Ethernet etc. [17] [16]. The IDE is the software used to write code for the arduino to enable it perform various functions. The Arduino is able to detect inputs and produce a specific output according to the embedded program [16].

C. Solar Power

Affordable and clean energy is one of the Sustainable Development Goals designed to promote investment in clean access to energy by communities around the world [18]. Renewable energy sources are easily accessible and clean to the environment. Solar energy is one of the best forms of renewable energy, particularly for a country such as Zambia [19].

Solar energy is in the form of light from the sun that is harnessed by various technologies such as solar photovoltaic (PV) panels/cells. The harnessed solar energy is usually converted to other forms of energy such as electrical energy in lamps and generators [20]. The most common use of solar energy is in the generation of solar power i.e. the production of electricity from the sun's rays by using photovoltaic (PV) cells which contain a semiconducting material that emits electrons upon absorbing solar radiation [20].

The sunlight energy received by the Earth in one hour of about 4.3 × 1020 J is more than all the energy consumed on the planet in a year of about 4.1 × 1020J [21]. Sunlight is the solution to our need for clean, abundant source of energy in the future because it is readily and freely available, not exhaustible, gives solid and increasing output efficiencies than other sources of energy, secure from geopolitical tension, and poses no threat to our environment through pollution or to our climate through greenhouse gases.

Sub-Saharan Africa has enormous renewable energy sources, such as solar, wind, hydro, geothermal and bioenergy. Amongst the renewable resources, solar energy stands out due to its abundance, and its distribution pattern in the region [22]. Solar photovoltaic energy meets the modern energy attributes of being clean, reliable, secure, and affordable energy in accordance with the Sustainable Development Goals (SDGS) requirements [22]

In many developing countries like Zambia a country in sub-Saharan Africa solar radiation is intrinsic in quantity. Zambia has a good insolation per year of about 2,200 kWh/m^2 and about 583,836.2482 GW solar energy strikes the Zambian soil per year. One percent of the solar energy reaching Zambia's soil is about 2000 times higher than the energy from Zambia's conventional electricity [19].

This solar energy if properly harnessed would provide the much needed power to bring about efficient and reliable electricity supply.

III. Related Work

Related research includes research in the use of cellular and solar technology.

Researchers in [23] propose a smart health monitoring system based on GSM (Global System for Mobile Communications) which uses ARM7LPC2148 controller. They use LM 35 sensors, TCRT1000 sensors and BP KIT sensors to detect temperature, heart beat and blood pressure respectively. Once this information is detected it is transmitted to a mobile phone through the GSM 900 module as an SMS (short message service). The information is also displayed on an LCD screen. They conclude that this system is beneficial to patients in remote areas where access to hospitals is difficult. The study did not however explore the use of 4G module to send alerts and location of the patients to a mobile phone or cloud platform.

The study in [24] uses GSM modem, fire sensor, smoke sensor, buzzer,LCD display and Atmega 32 microcontroller to develop an automatic fire detector system. The smoke and fire detectors are able to detect the fire and send the signal to a mobile phone, an LCD and a buzzer activated through the microcontroller and GSM modem. A motor is incorporated to sprinkle water and put out the fire. They conclude that their system is effective and fast and could aid in minimization of human loss, property loss and fire accidents. The researchers however do not explore how alert messages and location of the fire can be sent to a cloud based application.

The researchers in [25] propose a solar tracking system to enable the solar panel track the location of the sun. They use atmega16 AVR microcontroller, a light dependent resistor and a servo motor. The light dependent resistor is used to sense the intensity of light at 30 degree each or 180 degree total and send data to the AVR microcontroller which reads the data and rotates the servomotor in the right, middle or left direction. The servomotor in turn rotates the solar panel based on the highest intensity of light and displays the output voltage on the LCD. They conclude that this system can be used to improve efficiency of the solar panel. The researchers concentrate on how the solar panel can truck the sunlight and not on how the solar panel can be utilized to power up devices once it is able to track the sun.

The study in [26] propose a solar desalinator. They use CSP (Concentrated Solar Power) technology through parabolic mirrors that concentrates solar energy on a water container and raises its temperature. To build the solar desalinator they make us of carbon filters to remove sediments, parabolic mirrors to concentrate solar energy, copper container for holding the water and volumetric flask which is used to collect fresh water by the condensation of the steam generated. So the water is first filtered by the carbon filters and placed in the copper container. The copper container is then heated up by the use of parabolic mirrors which concentrate the solar energy. Once the water is heated up it evaporates and is collected by the volumetric flask through condensation. They conclude that solar energy can be efficiently used in supplying fresh drinkable water. The researchers concentrate on how the solar panel can be used to provide clean water and not on how the solar panel can be utilized to power up devices.

In [27] the researchers design and develop a solar powered water pumping system. They use two 100 watts, 20Amps Photovoltaic panels and 0.125 horse power pump and 150Ah battery. The DC current produced from the solar panel is utilized to charge the battery through the charge controller. The charged battery supplies power to the pump which in turn pumps water. After conducting efficiency tests they conclude that photovoltaic power is very cost competitive when used to power a micro irrigation system. The researchers concentrate specifically on solar and battery and not on how power supply from the electric grid can be used in supplying power in the case where there is not enough sunlight to charge the battery.

The study in [28] propose a cellular based automated industrial control and monitoring system using a GSM modem, a Graphical User Interface (GUI) and a Programmable Interface Controller (PIC) microcontroller to control industrial machines as well as motor speed and rotating direction. Through the GUI and an SMS sent through the GSM network it is possible to switch the industrial machines on or off and control the speed of the motor. They conclude that the low cost system can be a promising device to fulfil the industrial monitoring and controlling setup. The researchers do not explore how a 4G module can be used to send information to a mobile phone or to a cloud based application so that the machines can be viewed anywhere in the world.

The researchers in [29] propose a smart irrigation system observed using GSM. The automatic irrigation system consists of Arduino Uno, moisture sensor, relay board, electronic pump, and a GSM system to observe the operation of the watering system. The moisture sensor senses the moisture of the soil, if the moisture is above a preset threshold the motor is energized and a GSM message is sent to a mobile and the pump is turned on. This system will assist in conserving water as irrigation is done automatically based on the moisture content of the soil. The researchers do not explore how the information alerts can be sent to a cloud based application nor do they explore the use of solar energy.

In [30] [31] a distributed transformer energy meter using GSM technology is proposed. A GSM based energy meter is used to measure the parameters of the transformer and distribution system. This information is sent to a central database and compared with predefined values and if any difference occurs between the predefined and received values then it indicates illegal usage of specific transformers. They conclude that this system can be used to prevent theft and leakage. The study however does not explore how this information can be transmitted to a mobile phone or cloud platform.

The study in [32] propose a Global System for Mobile Communication Based Smart Home Security System. They use a General Packet Radio Services (GPRS) gateway, door security node, anti-intrusion node, SMS node and a microcontroller. The door security node consists of a step motor connected to a Radio-frequency identification (RFID) system which locks and unlocks depending on the tag presented to it. The free standing intrusion detector consists of an infrared transmitter and receiver pair which activates the transmitter upon the detection of intrusion, a signal is then sent to the microcontroller which instructs the GSM module to send an alert message to the owner and the police informing them that a break in has occurred. The microcontroller then turns on the lights and instructs the camera to take an image. They concluded that this system is important for maintaining security in remote places. The researchers however do not explore how to make use of GPS technology to send the location of the detected intrusion to the police.

The researchers in [33] propose a Wireless Digital Notice Board Using GSM Technology. They make use of GSM modem, Microcontroller 89C52, 20 X 4 LCD Display and a buzzer. In this system a message can be sent from the mobile of an authorized user to a GSM module which is located on the notice board. This GSM module receives the message and displays it on the notice board through the program embedded in the microcontroller, at the same time this message will be sent to different mobile numbers stored in the memory of the microcontroller. The buzzer beeps whenever a new message is received at the notice board to alert the people around. They conclude that this project reduces the cost of printing and photocopying as information can be given to a large number of people through the notice board. The researchers however did not look at how alert messages can be sent to a cloud platform to enable it be accessed and viewed from anywhere in the world nor did they explore the use of solar energy to power the notice board.

The study in [34] propose a Smart Real-Time Healthcare Monitoring and Tracking System using GSM/GPS Technologies. They make use of the arduino uno microcontroller, GPS/GPRS/GSM module, heart beat pulse sensor and human body temperature sensor. The heart beat sensor and temperature sensor detect the heart beat and temperature of the patient. This measurement is detected by the microcontroller and compared with a predefined threshold. If the threshold is crossed the arduino sends a command to the GSM/GPS module which in turn sends the heartbeat, temperature signal and location of the patient to the mobile phone of the doctor. They conclude that the proposed system can significantly improve the quality of health services and reduce the total cost in healthcare by avoiding unnecessary hospitalizations and ensuring that those who need urgent care get it sooner. The researchers however did not look at how the heart beat and temperature readings can be sent to a cloud platform by the use of a high speed 4G module to enable the information be accessed and viewed from anywhere in the world.

The researcher in [35] propose an SMS Based Kids Tracking and Safety System by Using RFID and GSM. They make use of a GSM\GPRS Unit, GPS Unit, sensing unit, RFID and RF (Radio Frequency) receiver and transmitter module. Each student is issued one or more unique RFID cards which are embedded in the students' bag. The students' card is detected by the reader installed in the school bus upon entering or leaving the bus, the time, date and location is logged and transmitted to a secure database. Through RF communication this information is sent to a microcontroller which in turn sends commands to the GSM and GPS module to send the location of the child to the parents' mobile phone. The main advantage of the system is that it works automatically, the child has nothing to do with this kit as it will be simply kept in the bag. The researchers do not explore how alert messages can be sent to a cloud platform accessible anywhere in the world with the location viewable on google maps to show the name of the location instead of just coordinates.

From the proposed and implemented projects reviewed from literature it can be noted that there exists a number of research gaps in the sense that there were no experiments or projects which made use of Long Term Evolution (LTE) (4G) and solar 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 platform for storage and for location determination on location maps.

IV. METHODOLOGY

A. Baseline study

First and foremost a baseline study was conducted to determine the challenges being faced by electricity clients and the power utility in power failure management in Zambia. The baseline study involved the use of questionnaires and interviews to gather data. The data gathered revealed that the current power failure reporting management system relied on customer calls to report power failure and manual relay of power failure information from fault coordinators to field personnel. Electricity clients and the power utility face challenges in the current power failure reporting management such as difficulties in accessing the 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. Therefore a new power failure management model and prototype was developed based on LTE (4G) cellular network and solar energy to overcome these challenges.

B. Proposed Model

The proposed model involves the use of a 4G cellular solar powered microcontroller based device which consists of voltage sensor circuit, arduino mega microcontroller, SIM7600E 4G/GPS module, solar charge controller, solar panel and battery. A prototype was designed and developed and is able to automatically detect power failures and transmit the information to the mobile phone of the customer, utility personnel and to the cloud platform thus eliminating the need for customers to report the fault, improving response time and reducing on power outage duration. The device has a solar charged battery to keep the device on even after loss of supply from all three phases enabling the utility to still monitor the status of the electricity network even if there is no supply thus distinguishing normal devices from faulty devices. Figure 1 below shows the proposed model.

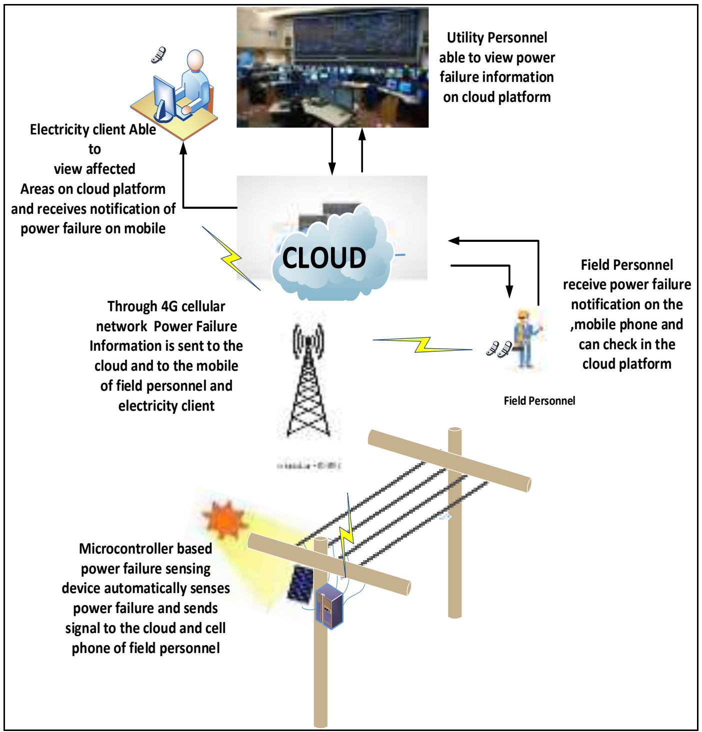

Figure 1. Proposed power failure detection model

C. *Prototype development*

The prototype was developed by using the waterfall development model. The waterfall model is also known as linear sequential model and describes the process model organized in a linear way consisting of – requirements analysis, design, implementation, testing and maintenance [36]. Each step is completed independently, and the next stage cannot begin without successful completion of the one that precedes it [37].

i) Requirements analysis

The analysis phase consisted of determining the functional requirements (FR) for the new system. The functional requirements were determined from the baseline study findings. The requirements determined are presented in table 1.

TABLE 1. Prototype System functional Requirements

FR1	The system shall be able to sense loss of power supply in any of the three phases in an electricity distribution line
FR2	The system shall receive data from the arduino microcontroller through the 4G/GPS Module
FR3	The system power shall be supplied by one of the phases of the electricity line
FR4	An electronic circuit shall be used for stepping down the 230V AC to 12 V AC and then rectified to 12V DC.
FR5	Upon loss of supply from all three phases the system shall be supplied by a solar panel and a battery charged by a solar panel
FR6	The system shall generate power failure notification on the cloud platform and mobile phone of field personnel and customer
FR7	The system shall capture history of any power failure events
FR8	The system shall display the status of the three phases and voltage values for the three phases on a cloud platform
FR9	The system shall display the start time and end time of the power failure and date on which they occurred

These functional requirements of the proposed power failure reporting system were arrived at so that most of the challenges identified in the base line study may be addressed.

ii) Design Phase

The design phase involved both hardware and software design. Software design involved design of the web application and made use of use case diagrams. The hardware design made use of electronic hardware components and block diagrams as shown below.

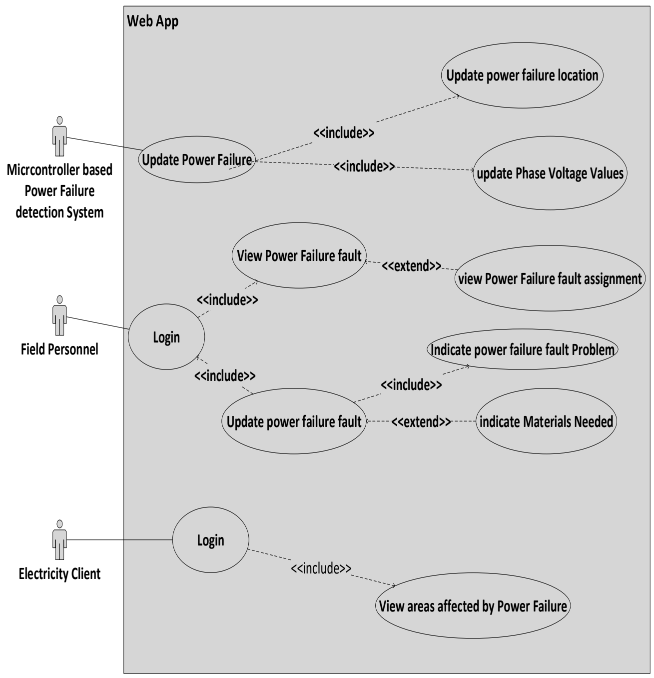

Figure 2. Web application use case diagram

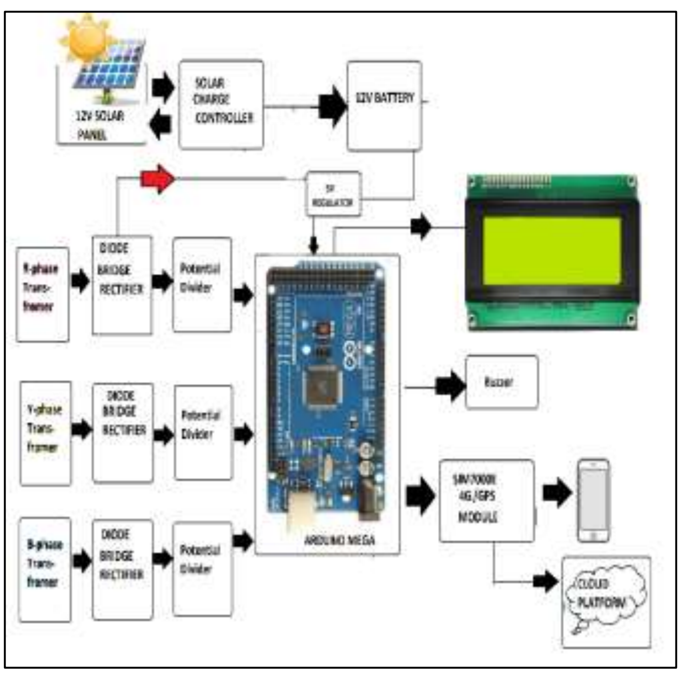

Figure 3. Block diagram of the prototype

iii) *Software and hardware implementation*

The software implementation involved the use of ASP.net programming language, Cascading style sheet, hypertext markup language, java script and Microsoft SQL database to build the web application of the cloud platform. The hardware implementation involved the use of voltage sensor circuit, arduino mega microcontroller, SIM7600E 4G/GPS module, solar charge controller, solar panel and battery.

- *Voltage sensor circuit*

The voltage sensor circuit is made up of step down transformers and diode bridge rectifiers used to convert the voltage from ac to dc and reduce it so that it can be used as input to the arduino microcontroller. A full wave diode bridge rectifier is used because it is more efficient, provides higher voltage and power output and requires a simple filtering circuit. The arduino microcontroller senses the loss of supply and through its' embedded program sends the information to the LCD, cloud platform and mobile phone. The prototype is supplied by the power from the phases during normal operation and by the solar charged battery when there is power loss from all three phases through the LM2596 regulator. Figure 5 below shows the main circuit of the prototype.

- *Arduino mega*

The arduino mega microcontroller is an open source microcontroller using Atmega2560 microprocessor to control input and output functions through the code uploaded to it. 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 ground to 5V and in this research 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 arduino through the embedded program to determine loss of supply. Through a calculation defined in the embedded software the voltage values for each phase are calculated and displayed on the cloud platform. The arduino was implemented to communicate with the SIM7600E module through the Universal asynchronous receiver transmitter (UART) pins which are able to receive AT commands at baud rate of 9600bps.

- *SIM7600E Module*

The SIM7600E is a 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 tracking, SMS, Voice as well as data transfer application in Machine to Machine interface and vehicle tracking applications. This module was used because it offers better data upload speeds making it suitable for use in the application of electrical network monitoring which requires almost real time data updates.

- *Solar Charge controller*

A solar charge controller was used to charge the battery in the proposed prototype.
The charge controller or charge regulator 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 over voltage. The solar charger is used to manage the power going into the battery from the solar panel. 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 a solar array's effectiveness by 30% and extracts maximum power from the PV module by forcing the PV 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 [38]. 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 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 [38]. The MPPT module has outputs connecting to the solar panel, the battery and the electronic device.
.When there is no power supply from all three phases, the device will be powered by solar during the day and by the battery during the night. 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 ~ 9W
Consumption per day whilst on battery = 9W x16hours = 144watt-hour (1)

To determine battery rating

Divide the value calculated in (1) by the supply voltage = 144/12 = 12AH,

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 from being damaged and in this case it is determined to be 50%. So 24AH is the rating of the battery to be used

To determine solar panel rating

Required Load in WattsHour
P-Total= (24hrs x 9W) = 216 Watthour.
This is the daily load in watthours

If we assume to have an average of 8 hours complete sunshine per day. The solar rating will be
Power = 216Whour / 8Hrs = 27W
So solar rating of 27 Watts is required
If we take the battery charging into consideration we get
Battery rating in watthour = 24AH X 12V = 288wattshour
Taking into consideration the number of hours of sunshine per day
Solar Panel Rating in Watts = 288watthour/8hrs = 36Watts

So total Solar Panel rating will be 27 + 36 = 63 Watts ~ 60 Watts

- *Prototype implementation*

Prototype implementation involved integrating the electronic components on a printed circuit board and connecting the battery, solar panel and three phase supply as shown in figure 4

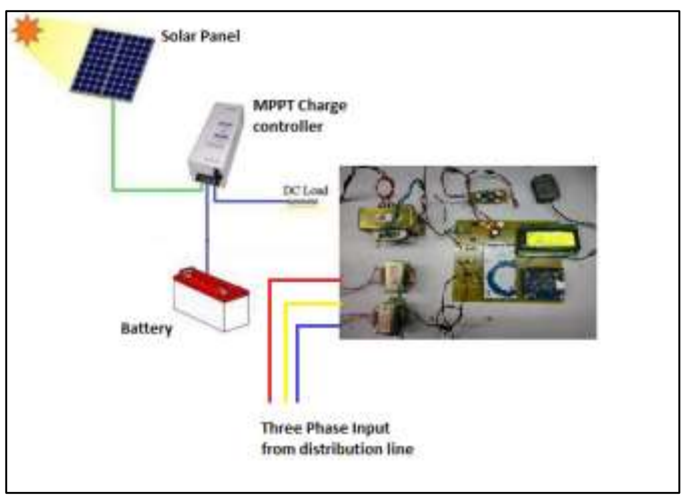

Figure 4. Prototype implementation

iv) *Prototype Testing*

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. After simulation and testing with proteus software the hardware components were set up as shown in figure 6 and tests were done in terms of how long it takes for the information to be updated on the LCD, cloud platform and mobile phone. This was found to be within 20 seconds. The voltage values displayed on the LCD and cloud platform were found to be corresponding.

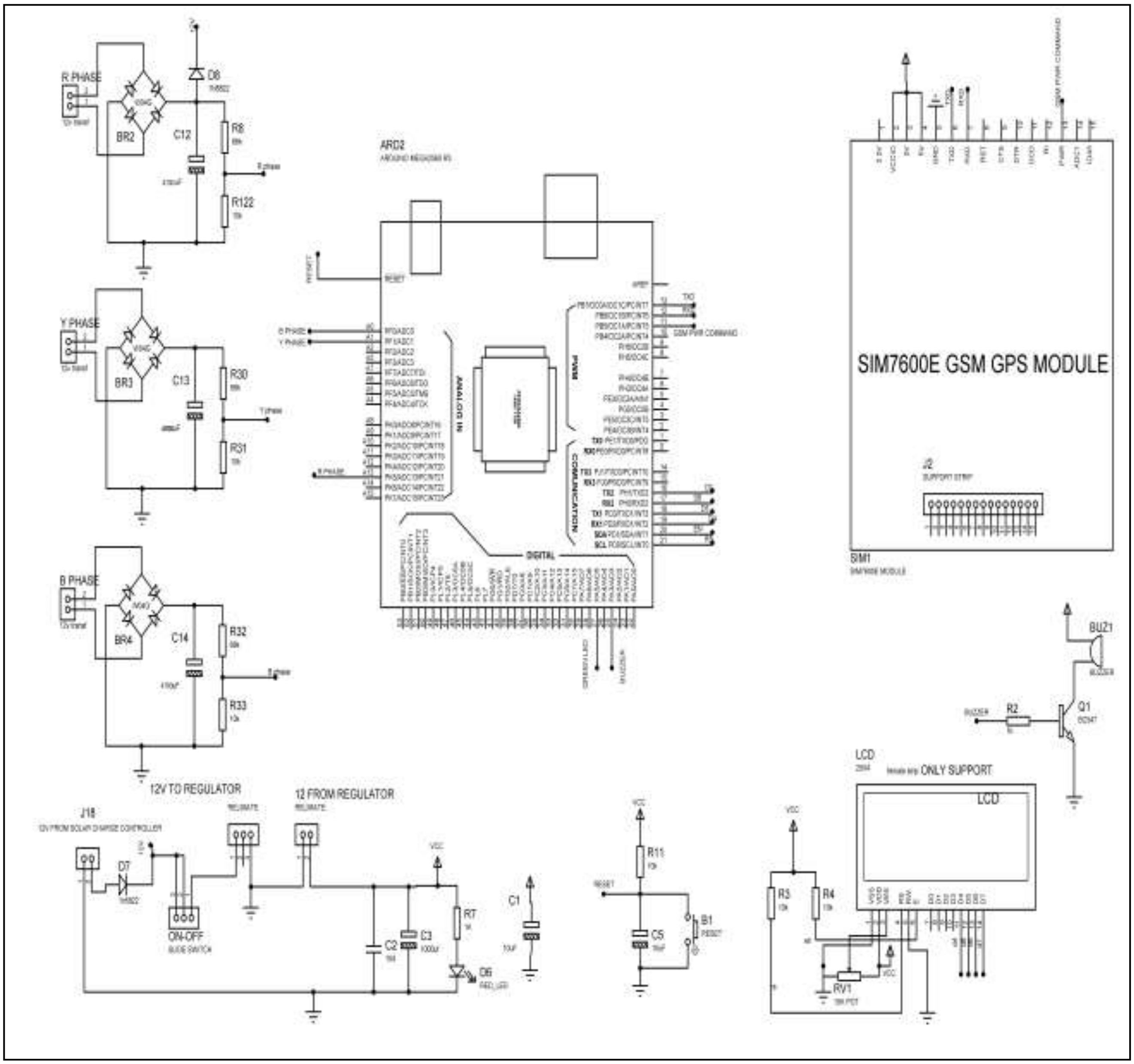

Figure 5. Main circuit board showing voltage sensor, arduino, LCD and SIM7600E module

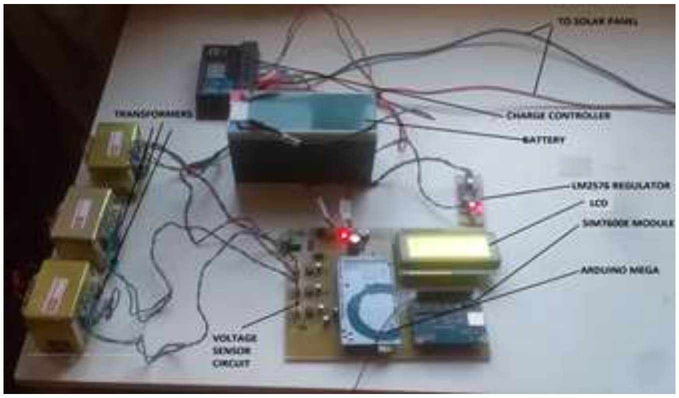

Figure 6. Hardware setup

V. RESULTS

The prototype was implemented by connecting it to power from a distribution electricity line. Once there was loss of power supply, power failure was sensed and detected through the voltage sensor circuit and arduino mega microcontroller. The embedded program in the microcontroller then sends AT commands to the SIM7600E module to transfer the power failure information to the mobile phone and cloud platform as shown in the figure 7 below. When power is lost from all three phases the prototype remains powered on by the solar panel and battery.

Figure 7. Power status and location on the web application of cloud platform

The power failure alert and location message is also sent to the mobile phone indicating the status of each phase as shown in figure 8 and 9. The use of 4G cellular network ensures quick and efficient transmission of information to the mobile. From the alert messages sent to the mobile phone it is possible to determine the duration and date of the power failure as it is indicated.

Figure 8. Mobile phone showing status of each phase

Figure 9. Location of power failure shown on mobile phone

The status of each phase is also displayed locally on the LCD as shown in figures 10, 11 and 12. Figure 12 shows loss of supply from all three phases. The prototype is still able to display loss of supply from all three phases because once supply is lost from the phases it is powered up by the solar charged battery.

Apart from the display of phase status an audible alarm is produced on the electronic device and cloud platform to alert the power utility personnel who are monitoring the status of the lines to the loss of power in the lines.

The device will remain powered up even after prolonged outages because it is powered up by solar panel and the battery which is continuously being charged by the solar energy.

Figure 10. LCD Phase voltage value display

Figure 11. LCD showing loss of supply in red phase

Figure 12. LCD showing loss of supply from all three phases

VI. Discussion

The power failure monitoring prototype was built using voltage sensor circuit, arduino microcontroller, SIM7600E LTE(4G)/GPS module, solar panel, MPPT solar charge controller , battery, cloud architecture and google API. This prototype is able to automatically detect and transmit power failure information to LCD, mobile and cloud platform with minimal latency through the use of 4GLTE/GPS module enabling this information to be easily and quickly viewed on the cloud platform and mobile by the power utility personnel. Location and voltage values are also quickly updated through the mobile phone and cloud platform enabling almost real time monitoring of the distribution network through the low latency SIM7600E 4GLTE/GPS module. This automatic and quick update enables monitoring of the distribution network and rapid response to power failures resulting in reduced SAIDI and CAIDI indices for the power utility. The module 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 and to also ensure that the utility is able to distinguish between the devices which have failed and those which have just completely lost supply. The system can be programmed to send systematic alerts to the utility after a specified period of power failure so that the utility is constantly reminded of the power loss and avoid prolonged outage durations. The proposed prototype is able to alleviate the challenges identified in the baseline study conducted as it is able to eliminate reliance on customer calls to report power failure and manual relay of power failure information from fault coordinators to field personnel by automatically detecting and report power failure thereby improving response times and reducing power outage durations.

VII. Conclusion

This prototype is able to transmit power alert information rapidly through the use of the low latency 4GLTE/GPS module ensuring quick transmission of information to the mobile phone and cloud platform. The use of the solar charged battery ensures that the device remained on in spite of a prolonged outage. With the device on it would be easy to distinguish the devices which are faulty and those devices which have just completely lost supply.

VIII. Future work

Future work would involve the implementation of an alert message sent to the utility if power outage has prolonged for a specified period of time as well as implementation of low voltage detection.

IX. RECOMMENDATION

Such a system should be implemented country wide to reduce on system outage durations and improve on the SAIDI and CAIDI indices of the power utility thus meeting its performance goals.

X. REFERENCES

[1] Central Statistical Office, "Zambia in fiures 2018," Central Statistical Office, Lusaka, 2018.

[2] M. Paul, "Power Outages Hit Copperbelt," Zambia Reports, Lusaka, 2017.

[3] A. Imaduddin, B. Michelle, C. D'Maris, M. Jim, O. Musiliu and S. Graham, "The cost of power outages to Zambia's manufacturing firms," International Growth Centre, London, 2019.

[4] Energy Regulation board, "Energy sector report," Zambia Energy regulation board, Lusaka, 2018.

[5] 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.

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

[7] G. F. Andrea, W. Wei, V. Luca and F. Gianluigi, "A Next-Generation Core Network Architecture for Mobile Networks," MDPI, New York, 2019.

[8] 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.

[9] A. Brian, "Cellular communications for industrial automation," CFE Media LLC, 2012.

[10] 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.

[11] 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.

[12] 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.

[13] 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.

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

[15] J. Bayle, C Programming for Arduino, Birmingham: Packet Publishing, 2013.

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

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

[18] S. B. Aliyu, H. A. Aliyu and I. K. Abdul-Hakim, "Not There Yet: Mapping Inhibitions to Solar Energy Utilisation by Households in African Informal," MDPI, Kano, 2020.

[19] M. Shadreck, K. Mwansa and Z. Ackim, "Paving the Way for Energy Efficiency through Solar Power Projects in Zambia," *International Journal of Civil, Mechanical and Energy Science,* vol. 2, no. 2, pp. 1-5, 2016.

[20] S. BAWEJA, "The Feasibility of Solar Power," University of Houston, Houston Texas, Houston, 2014.

[21] I. J. D. Caraan, L. T. M. De, J. K. R. P. De, S. D. O. Llamzon and C. J. M. Parreño, "Solar-Powered AC/DC Power Supply for Electronics Engineering Laboratory," Bataan Peninsula State University, Balanga, 2015.

[22] S. W. Ebhota, "Photovoltaic Solar Scheme in Sub-Saharan Africa: Socioeconomic Booster," *International Journal of Mechanical Engineering and Technology,* vol. 10, no. 10, pp. 28-42, 2019.

[23] G. A. Kavya, "ARM Based Smart Health Monitoring Using GSM Technology," *International Journal of Computer Science and Mobile Computing,* vol. 7, no. 6, pp. 59-63, 2018.

[24] R. Yaswanth and A. Harshavardhan, "Automatic Fire Sensing and Communicating Through GSM Modem," *International Journal of Engineering Sciences & Research Technology,* vol. 3, no. 4, pp. 2076-2079, 2014.

[25] W. Vaijantee, J. Joel and L. B, "Solar Tracking System," *International Research Journal of Engineering and Technology (IRJET),* vol. 4, no. 3, pp. 1770-1772, 2017.

[26] G. Ajinkya, S. Anup, B. Paras, P. Shubham and D. Deepak, "Solar Desalinator," *International Research Journal of Engineering and Technology (IRJET),* vol. 3, no. 2, pp. 1164-1167, 2016.

[27] K. M and K. S, "Solar Pump with Solar Panel Tilting Arrangement," *International Research Journal of Engineering and Technology,* vol. 3, no. 5, pp. 2263-2270, 2016.

[28] S. D. Farzana and R. K. Sadeque, "Cellular based Automated Industrial Control and Monitoring System," *Inernational journal of Advanced Computational Intelligence,* vol. 2, no. 4, pp. 12-17, 2015.

[29] M. j. Mohammed, R. Hana'a M, l. s. Ameer, A.-a. Mustafa and F. A. Abed, "Design and implementation of smart irriagation system observed using GSM system," *International journal of engineering and applied sciences,* no. 13, pp. 1060-1063, 2018.

[30] M. L. Vignesh, S. Rajanand and D. Dhayalan, "Distributed Transformer Energy Meter Using GSM Technology," *International Journal of Electrical & Computer Engineering,* vol. 4, no. 1, pp. 21-26, 2015.

[31] D. R. More, A. P. Vijay, M. P. Pravin and S. S. Avinash, "GSM based power theft monitoring at local distribution system with Prepaid Energy Meter," *Global Journal of Engineering Science and Researches,* vol. 3, no. 2, pp. 25-28, 2016.

[32] Z. Amrit and S. Nadeem, "Global System for Mobile Communication Based Smart Home Security System," *International Journal of Engineering Research and Applications,* vol. 4, no. 7, pp. 50-55, 2014.

[33] G. K. Ramchandra and J. Rohit, "Wireless Digital Notice Board Using GSM Technology," *International Research Journal of Engineering and Technology,* vol. 2, no. 9, pp. 57-59, 2015.

[34] T. Saed, A. Kahtan and A. Shadi, "Smart Real-Time Healthcare Monitoring and Tracking System using GSM/GPS Technologies," *International Journal of Computer Applications,* vol. 142, no. 14, pp. 19-26, 2016.

[35] S. Nitin, K. Narendra, S. Maya and K. Devesh, "SMS Based Kids Tracking and Safety System by Using RFID and GSM," *International Journal of Innovative Science, Engineering & Technology,* vol. 2, no. 5, pp. 793-799, 2015.

[36] 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.

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

[38] Leonics, "Leonics," Leonics Company Limited, 2013. [Online]. Available: http://www.leonics.com/support/article2_14j/articles2_14j_en.php. [Accessed 20 February 2020].

[39] P. S. Abhishek and J. Amol, "Implementation of Home Security System using GSM module and Microcontroller," *International Journal of Computer Science and Information Technologies,* vol. 6, no. 3, pp. 2950-2953, 2015.