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A GSM-Based Fault Detection on Overhead Distribution Lines

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A B S T R A C T

Power distribution in Ghana is managed by the Electricity Company of Ghana (ECG) which is responsible for ensuring accessibility of electricity to consumers. One of the challenges that affect the effective operation of ECG is the slow response to faults on the overhead distribution lines. Fault detection on the distribution lines is a very tedious activity but a necessary procedure to ensure efficient power distribution to consumers. This paper seeks to design a system that can detect faults, the type of faults and their location before they cause any casualties to transformers and other power system equipment. This would replace the primitive method of patrolling and manual inspection of faults currently done by the Electricity Company of Ghana (ECG). This objective was achieved using a GSM-based system on an Arduino platform and ATmega 328P microcontroller to locate the occurrence of faults efficiently. Faults are introduced into the system by triggering the type of fault on the Arduino platform which opens the corresponding relay of the line fault. The opening of this relay sends a signal to the microcontroller and a corresponding LED which switches to display the type of fault. The microcontroller then communicates to the GSM module which displays the said fault and location on a display screen with the help of a virtual terminal. This system was tested under the various unsymmetrical faults to show the efficiency of the system using C++ programming. The simulation shows that the system offers a fast fault response time.

INTRODUCTION

Efficient energy supply and access is an important aspect of a country's industrialization and sustainable economic development. The constraints in Ghana's electricity sector threaten the economic growth and ability of the country to achieve desired industrialization. Universally, the three stages in the electric power supply are the generation stage, transmission stages and distribution stages. These different stages in Ghana are controlled by different institutions. Bui Power Authority, Volta River Authority (VRA) and several independent Power Producers oversee the generation of power. The Ghana Grid Company (GRIDCo) oversees the transmission of electricity to distribution companies in the country. The main distribution companies in the country are the Northern Electricity Distribution Company (NEDCo) and the Electricity Company of Ghana (ECG). Most customers who are predominantly in the southern part of the country are served by Electricity Company of Ghana while NEDCo serves consumers in the northern region of the country. All distribution companies are state-owned and responsible for ensuring electricity access to consumers. Figure 1 shows the electricity stages in Ghana and the various companies responsible for each stage. Achieving any of the stages or phases is accompanied by distinct processes, work activities and hazards. The consumption of electricity in Ghana is on the rise which requires that adequate measures be put in place to ensure efficient distribution of electricity.

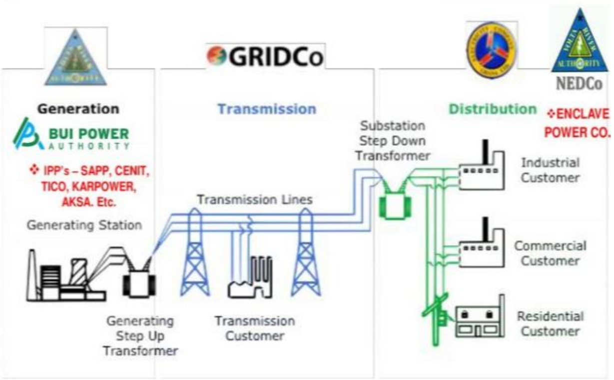

Figure 1. Electricity Network in Ghana [1]

One of the challenges that affect the smooth distribution of electricity to consumers is faults [2]. The highest percentage of losses recorded in Ghana are usually in the distribution stage. These losses have stifled investment in this sector and have worsened the brownouts and blackouts situation in the country. About 80% of the interruptions of consumer's service is due to failure in the distribution system [3]. Detecting and locating faults is of great concern to power distribution companies like ECG.

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Some of the common faults associated with distribution systems are usually due to insulation failure of the distribution system and bridging of energized phase conductors by trees and other human activities. As shown in figure 2, the percentage of distribution losses as compared to the percentage of the total power purchased is significantly high as compared to transmission losses.

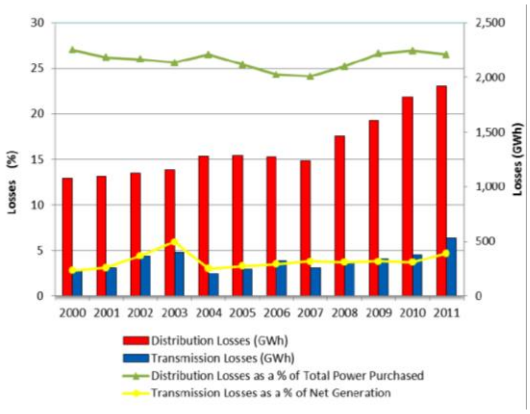

Figure 2. Percentage of Distribution and Transmission Losses in Ghana [4]

Electric power generated by short circuit current can be devastating which is why early detection of faults is important [5]. These faults need to be easily located and resolved to prevent further damage to transformers and other power equipment. Electric power generated by short circuit current can be devastating which explains the need for early detection [6]. The distribution system in Ghana stretches across several kilometers, making it tedious to monitor and precisely locate abnormalities in the system. At the occurrence of a fault on any of ECG's distribution lines, protective devices like circuit breakers are initiated to isolate the faulted part. The isolation of these circuit breakers is kept in place until the fault is detected and resolved. One of the methods used for fault detection and location of these distribution lines is by patrolling and inspecting [7]. This method used by ECG is laborious and time-wasting. This creates a lot of inconvenience to both the customer and the power distribution company. There is currently no system being used by ECG to know in real-time when a fault occurs.

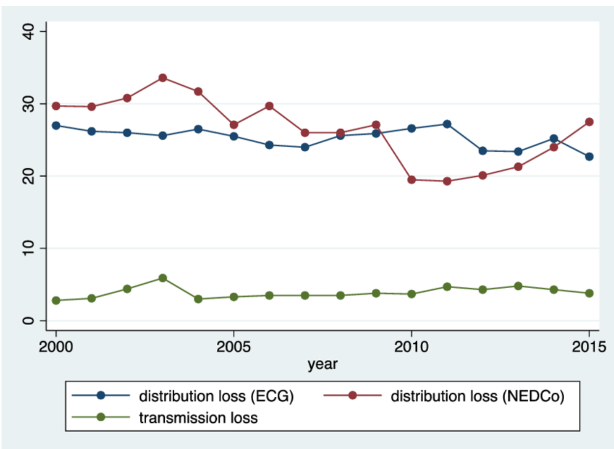

Figure 3. Distribution and Transmission Losses in Ghana [8]

As shown in figure 3, the distribution losses by ECG keeps rising which calls for the need to find measures to mitigate such a situation. In recent times, reliable and relatively cheap electronic devices coupled with remote communication ways has made live detection of events easy. GSM technology is a very important platform that can be easily employed in the early detection of electrical faults [9]. Due to its simplicity, affordability, and accessibility, it can easily be implemented in all distribution systems across the country. This makes it an easy option for wireless communication applications [10]. Fault lines must be repaired and returned to service in the shortest possible time to ensure reliable service to customers.

Related Work

Over the years, several methods for fault location in power systems (transmission and distribution) have been employed to ensure the easy identification of faults. The aim of these approaches is to identify the type and fault location so they can be resolved within the shortest possible time. These techniques can generally be categorized into the conventional technique and the artificial intelligence technique. The conventional methods are widely accepted and are either the travelling wave method or the impedance-based method. The travelling-based method involves capturing the travel time of fault transients on monitored lines in the form of a waveform [11]. The impedance-based method involves comparing voltage and current signals continuously against a set value for voltage and current [12]. This method is popular because of its simplicity to implement.

Artificial Intelligence methods are generally categorized into Support Vector Machine, Artificial Neural Networks, Fuzzy Logic and Matching Approach. Support Vector Machine is used when the detection of the fault would involve a classification and regression technique [13]. Artificial Neural Network for fault detection involves a training process and usually employ multiple information data to ensure efficient fault detection [14]. Fuzzy Logic Method involves the use of linguistic rules to classify and determine the type of fault [15]. Matching Approach makes use of multiple data for the identification and location of faults by comparing measured and simulated data [16]. Most of these methods have been used for fault detection in Ghana.

In [17], GSM technology and microcontrollers were used to determine faults with the help of the impedance-based method. This system focused on transmission line fault which is managed by the Ghana Grid Company (GRIDCo). Currently, GRIDCo has sophisticated automatic fault detection systems that determine faults and their location. The only shortcoming of GRIDCo's system is the inadequate ability to accurately determine line to earth faults. This design solely focused on finding the line to earth fault on GRIDCo's transmission lines.

Machine learning algorithms were employed in [18] for fault detection and location within the network of ECG. This design was based on current and voltage signals from sensors. A machine learning decision tree was used to extract the fault and fault location from the current and voltage signal. This system was generally expensive and did not consider fault locations for earth faults. The expensive nature also makes it difficult for ECG to implement at every distribution centre.

In [7], an impedance-based algorithm method with microcontroller and GSM was used to determine faults on ECG's distribution system. This system uses a PIC 16F877 microcontroller to successfully determine faults and their location on the distribution system. However, the focus of this fault location system was primarily for the power system elements like transformers and switch gears and did not consider distribution lines into details.

Internet of Things was used in [19] to determine fault conditions on a transmission line. The system monitors the individual phase of the transmission line by using relays. A Wi-Fi system is integrated into the microcontroller along with the GSM model for remote control and monitoring purposes. This design makes it applicable in urban areas. Most rural areas in Ghana lack access to the internet which makes it difficult to be implemented in rural areas.

A fault detection and condition monitoring for distribution systems was proposed in [20]. The system used an impedance-based method and GSM technology to monitor the health of selected power system equipment on the distribution line. The focus of this research was on condition monitoring of transformers and parameters associated with the efficient operation of the transformer.

In all previously published work involving fault detection and location on distribution lines in Ghana, only power system equipment's, symmetrical faults and components of unsymmetrical faults have been considered. To the best of the author's knowledge, no impedance-based method using GSM and ATmega 328P microcontroller have been used to identify and locate unsymmetrical faults on ECG distribution lines.

FAULTS IN DISTRIBUTION SYSTEMS

There are generally two types of faults that can occur on a distribution system. The series fault, which is also called the open-circuit faults and the shunt fault, which is also called short circuit faults.

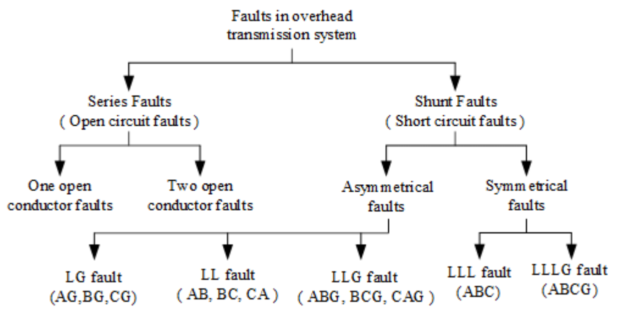

Figure 4. Classification of Faults [21]

Series Faults

These types of faults usually occur when the line has an unbalanced impedance. They usually happen in series with the line which is why it is commonly referred to as series faults. They usually occur when there are breaks in the conductor or the circuit breaker in one or more of the phases begin to malfunction. At the occurrence of a series fault, the loading in the alternator reduces which creates speed a little above the synchronous speed. This results in overvoltage in the system [22]. These types of faults are however tolerable at a much higher level as compared to shunt faults.

Shunt Fault

These faults occur when conductors from the respective phases of the distribution lines come into contact with each other or any power system equipment. This results in a substantial amount of current flow in any of the affected phases. This type of fault is dangerous and are relatively common in distribution systems. There are generally two types of shunt faults, the symmetric type of shunt faults and the asymmetric type of shunt fault. In symmetrical faults, the three-phase system can be considered as a single-phase system under normal operating conditions. This type of fault affects all three phases of the distribution line equally [23].

The symmetrical faults are usually caused by the system energization with maintenance clamps attached to it. Only a few faults recorded by ECG in their day-to-day activities are symmetrical [24]. Most faults recorded by ECG are due to unsymmetrical faults which would be the focus of this paper. Unlike symmetrical faults, unsymmetrical faults do not affect all the phases equally. The major causes are insulation breakdown, over-voltage and lightning discharge and mechanical damage to the distribution line. The most common types of unsymmetrical faults are listed below.

The line-to-line (LL) Fault

The line-to-line fault occurs when two energized conductors are short-circuited because of high winds, rainy storms etc. They can occur in both overhead lines and underground systems. During this fault, there is usually an increase in current in the faulted phase and a 180-degree phase shift between the faulted phase current. Figure 5 shows an illustration of a line-line fault.

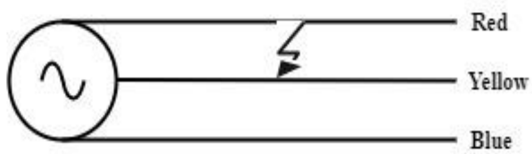

Figure 5. Line-Line Fault

Single-Line-Ground (SLG) Fault

This type of fault is usually called the phase to earth fault or the short circuit fault. It occurs when one phase of the distribution line contacts the ground or a distribution line. These are usually caused by wind, trees falling on the wire. Figure 6 shows an illustration of a line-line fault.

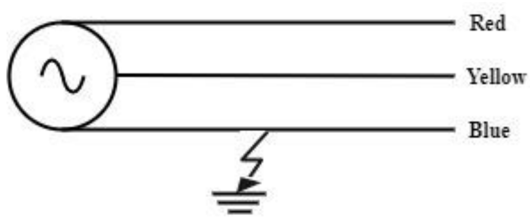

Figure 6. Single-Line-Ground Fault

Line-Line-Ground (LLG) Fault

This fault is also commonly called the double line to ground fault and occurs because of two energized phases connecting to the ground. These faults are very severe due to zero impedance and a

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high flow of fault current to the ground. This produces a substantial asymmetry and could result in a three-phase fault if not cleared early. Figure 7 shows an illustration of a line-line fault.

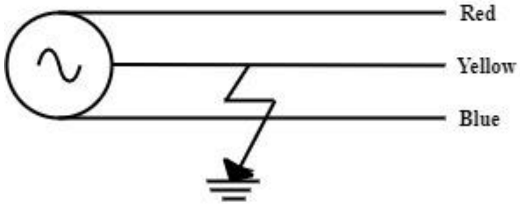

Figure 7. Line-Line-Ground Fault

Line-Line-Line Ground (LLLG) Faults

These types of faults are commonly called balanced three-phase faults and are very rare. It occurs as a result of contact between all three energised phases in any way or form. Some contributing factors to these faults are equipment failure, falling tower or line connecting the remaining phases. It is the most dangerous fault and least likely to occur. Figure 8 shows an illustration of a line-line-line fault.

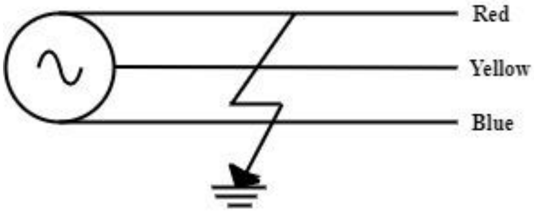

Figure 8. Line-Line-Line-Ground Fault

The percentage occurrence of each fault type and its severity, as well as fault occurrences due to each power system element, are shown in Table I and Table II [25].

Table 1. Fault Type and Severity

Type of Fault	Percentage of Occurrence (%)	Severity
SLG	70	Less Severe
LL	15	Less Severe
LLG	10	Less Severe
LLLG	5	More Severe

Table 2. Power System Element and Occurrence of Fault

Power System Element	Percentage of Fault Occurrence (%)
Transformers	10
Overhead Lines	50
Underground Cables	9
Switch Gear	12
CT, PT Relays, Control Equipment	12

Causes of Fault in Distribution System

The various contributing factors that cause failure in the distribution system can be classified into three main categories:

Intrinsic factors

These are internal factors by the equipment itself such as the age of equipment, manufacturing defects in the equipment.

Extrinsic factors

These are also factors which occur outside the distribution system such as falling trees, bird or animal disturbances, wind ice lightning, etc.

Human error

These are also factors caused by either the negligence or mistake of human beings. Examples are vehicular accidents, accidents by contractors or work crew.

Global System for Mobile Communication

Global System for Mobile Communication is used to establish efficient linkage between a computer and a GSM-Global Packet Radio Service (GPRS) system. The GPRS is an extension of GSM that ensures a high rate of data transmission [26]. This GSM/GPRS module is made up of a GSM/GPRS modem put together with power supply circuit and communication interfaces (like RS-232) for the computer. These GSM modules are effective at fault communication [27].

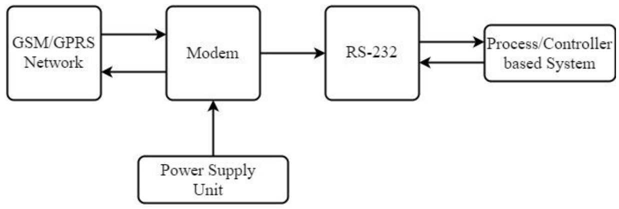

Figure 9. Block Diagram of a GSM Module

METHODOLOGY

The design of this system relies on the use of a potential transformer, microcontrollers, and the GSM module. The system can detect all the different types of asymmetrical faults at the occurrence of faults on the three-phase overhead lines. When the system detects a fault, it classifies according to the characteristic condition of the voltage and current and the location of the fault. The signal received is transferred to the microcontroller for detection and classification. The GSM module sends a message in the form of a short message service (SMS) to the ECG official on duty. The ECG official on duty would act based on the location and severity of the fault.

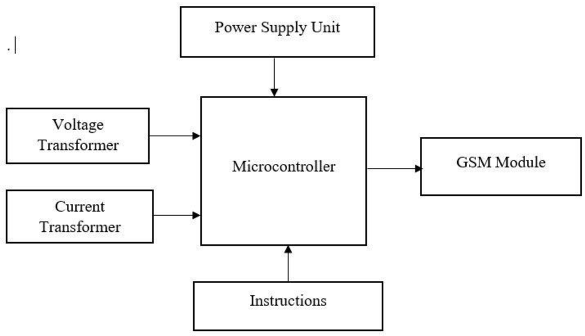

Figure 10. Block Diagram of Proposed Design

Working Principle

The block diagram in Figure 10 shows the proposed system which is made up of the power supply unit, instrument transformer, microcontroller, and a GSM module. The instrument transformer will have its primaries connected to the distribution lines to continue the sensitivity of the power flow. Once a fault occurs, current and voltage values would deviate from the nominal ranges which are detected by the instrument transformer. Signals are given to the microcontroller (ATmega 328P QFP) which acts based on a set of instructions stored on its erasable programmable read-only memory (EPROM). The microcontroller which is powered by the power supply unit has devices like capacitors and diodes that helps with rectification, filtering, and voltage regulation process.

The voltage provided is regulated to between 5 V-10 V for the effective operation of the microcontroller. The microcontroller is programmed with reference values depicting ranges of each fault, type, and fault of location. At the occurrence of a fault, voltage and current faults are given to the microcontroller which compares with the reference data to give the type of fault. The microcontroller also calculates the fault distance relative to the device based on the impedance-based algorithm and then relays the information through the GSM module which acts as a communication medium. Figure 11 shows the flow chart for the operation of the system.

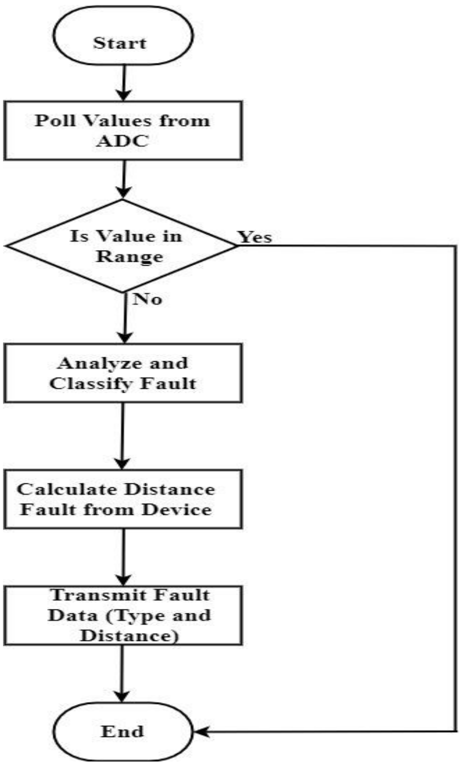

Figure 11. Block Diagram of Proposed Design

The Functionality of the Flowchart

When the system starts, poll values are obtained from the ADC by the microcontroller. These values go through the decision stage where questions are asked, as to whether values received are in range or not. When values or signals are in range the process ends but if the values fall out of range the process continues to analyze and classify fault. The next stage is to calculate the distance of fault from the device, which eventually gives the location of the fault using the impedance-based algorithm. There are respective relays controlling each line in the setup. Therefore, at the occurrence of fault relays device opens to break the circuit and then finally, information about the fault, is transmitted to a mobile phone by a GSM module and the process ends.

Design Criteria

The design of the proposed system would satisfy the following criteria:

Provide Enhanced Security
It should provide maximum safety for both the electrical and users of electricity being the customers

Accurate
It should have the ability to perform or work without mistakes or very limited mistakes for easy location and detection of faults.

Fast Time of Response
It should have a fast time of response to rectify the fault within the shortest possible time.

Relatively easy to understand
The system should be user friendly, that is it should not be complex and difficult to understand. Individuals using the system should be able to navigate easily with the information given.

Uses relatively cheaper components
The system should be cost-effective; implementation of the system should be possible with relatively cheaper components.

Selection of Hardware Component

Component's selection is very important in the designing and implementation of a cost-effective system. Careful selection of components helps in more robust prototypes and saves design and implementation errors.

Microcontroller
In the selection of the microcontroller for this project, considerations were given to the required speed of processing, ability to handle multiple tasks efficiently, the total number of input and output usable pins, availability of programming software and power requirements of the microcontroller. The Atmega328P QFP microcontroller was selected for the implementation of the project because of its high level of integration due to the availability of compiler resources and low power consumption within the limits of 1.8–5.5 volts [28]. Its unique combination of performance and design flexibility provides 32 KB.

Power Supply
The power supply unit selected for the project consisted of a 12 V center-tap transformer, a 7805-voltage regulator, 2 diodes, 2 capacitors, red light emitting diode (LED) and a resistor. The LM 7805 regulates the voltage from 12 V to 5 V suitable for the system. The capacitors used were for smoothing the rectified DC. The red LED gives an indication that the required voltage of 5 V is delivered to the system. The power supply circuit is presented in figure 12.

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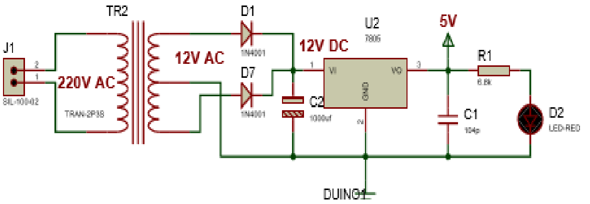

Figure 12. Circuit Diagram of Power Supply Circuit for the Microcontroller

The power supply would deliver a voltage of constant value 5V to power the Atmega328P QFP microcontroller. The power from the main power supply cannot be fed directly to the LM 7805 voltage regulator because it takes voltages between the values of 7 V to 25 V mixed with ripples. A smoothing capacitor, C_2 is employed to filter out the rectified voltage before it is fed to the voltage regulator.

Capacitors

A capacitor is a passive two-terminal electrical component that stores electrical energy. Two capacitors C_1 and C_2 would be used in the power supply circuit for filtering of the rippled rectified DC. The peak value of the transformed voltage is calculated using equation (1).

$$V_{peak} = V_{peak} - 2V_{diode} - V_{min} \quad (1)$$

The required capacitance and the period for a full-wave rectification of the capacitor is calculated using equation (4) and equation (5) respectively.

$$Q = CV \quad (2)$$

$$V = IR \quad (3)$$

$$C = \frac{It}{V} \quad (4)$$

$$T = \frac{1}{f} \quad (5)$$

Diode

The 1N4001 diode was selected for the rectifier circuit because of its ability to handle the peak inverse voltage during the negative half cycle of the rectification process. From the datasheet of the 1N4001 diode, the maximum DC blocking voltage of the diode is 50 V [29]. The peak inverse voltage is calculated using equation (4)

$$V_{peak} = \sqrt{2} \times V_2 \times 2 \quad (6)$$

Table 3. Functions of the Hardware Component

Unit	Component	Function
Power Supply Unit	Rectifier	Converts the bi-directional AC waveform from the transformer into unidirectional pulses
	Voltage Regulator	Maintains the output value at a constant value of 5 V required by the microcontroller
Control Unit	Microcontroller	Controls and coordinates the input and output devices based on set of embedded instructions
Sensing Unit	Potential Transformer	Senses and Steps down voltage/current for accurate and precise measurement
Communication Unit	GSM Module	Creates message using microcontroller which records the fault and location of feeder and sends the information to the officer on duty
Instructions	EPROM	Responsible for storing the instructions or programs used by the controller

SYSTEM TESTING

Successful testing of the designed system confirms the success of the design. The sub-blocks consisting of the power supply unit, the instrument transformer, the microcontroller, and the GSM module are all tested to confirm their satisfactory functionality.

Power Supply

To be sure that the output of the power supply unit is delivering the expected output voltage of 5 V to the microcontroller, an LED is connected across the output of the voltage regulator to measure its regulated voltage. The LED operates with a voltage of + 5.01 V ≈ + 5.00 V. From the test results the voltage at the output of the LM 7805 voltage regulator is suitable for the microcontroller. An LED is placed in series for the purposes of debugging.

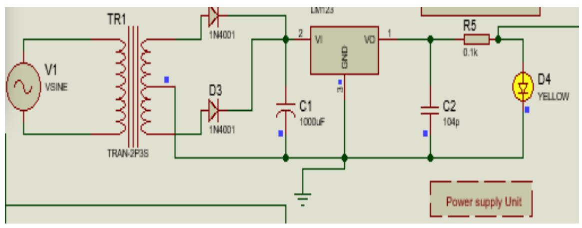

Figure 13. Circuit Diagram of Test Simulation of the Power Supply Unit

GSM Module

To test for the functionality and compatibility of the GSM module with the microcontroller, it was connected to a virtual terminal. The successful communication between the virtual terminal and the microcontroller means the GSM module will be compatible with the microcontroller since both the GSM module and the virtual terminal use the same serial mode of communication. Figure 14 shows the circuit diagram of the serial communication link in conjunction with the virtual terminal which communicates with the microcontroller to display "It's a line-line problem AT AT+CMGF +233435345435 message sent successfully".

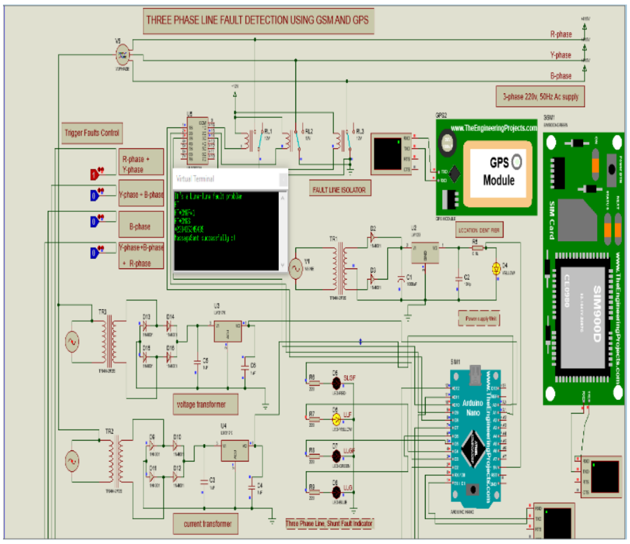

Figure 14. Circuit Diagram of Test Simulation of the Power Supply Unit

Circuit Implementation

This shows the entire circuit diagram of the system design in the Arduino software package. This circuit diagram has the fault line isolator, which is used for creating the type of fault, the line shunt fault indicator to show the type of faults, the potential transformer (voltage and current transformer) to measure voltage and current value and the power supply unit.

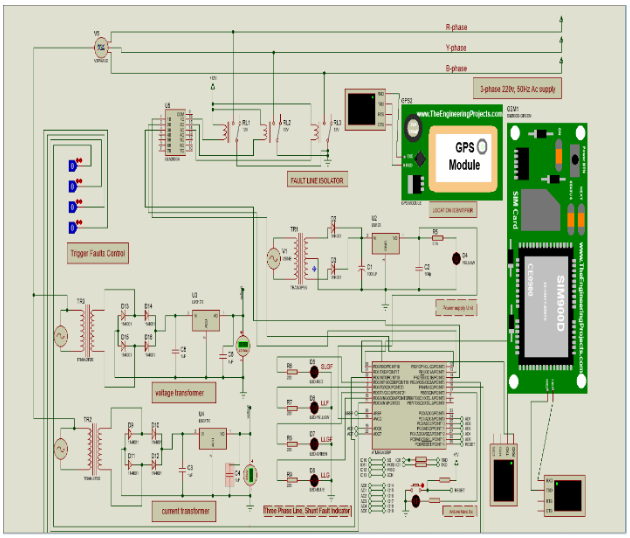

Figure 15. Circuit Diagram of System Design

RESULTS AND DISCUSSION

The results and discussions are based on simulations test for the different fault scenarios that was investigated for this project.

Line-Line Fault

A line-line fault was injected into the system by triggering the R-phase and Y-phase of fault control which opens the corresponding relay(s) of the line on which this fault is located. In this case, RL1 on the fault line isolator was open. The opening of the relay sends a signal to the microcontroller and a corresponding LED which switches to display the type of fault.

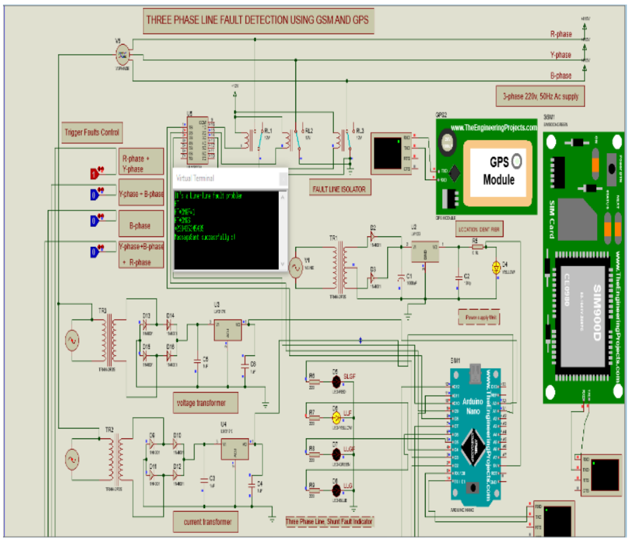

Figure 16. Result of Line-Line Fault

Single-Line-Ground Fault

A single line-ground fault is also ingested into the system to determine the response time and communication display. This was also done by triggering the B-phase and the ground fault control which opens the corresponding relay RL3 of the line to the ground on which this fault is located. The opening of the relay sends an immediate signal to the microcontroller and a corresponding LED which lights up to display the type of fault. The microcontroller then communicates to the GSM module, which displays the said fault and location on a display screen.

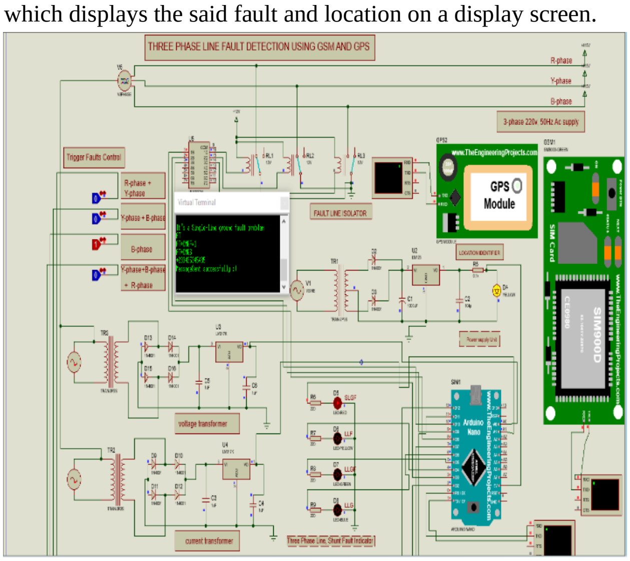

Figure 17. Test Result of Line-Ground Fault

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Line-Line-Ground Fault

In scenario 3, the line-line-ground fault was introduced into the system to check whether the design will as well be able to display and communicate the fault as expected. This was also done by triggering two phases and the ground trigger fault control which opens the corresponding relay(s) of the lines on which this fault is located. The opening of the relay sends a signal to the microcontroller and a corresponding LED which switches to display the type of fault. The microcontroller communicates to the GSM module which displays the said fault and location on a display screen with help of a virtual terminal.

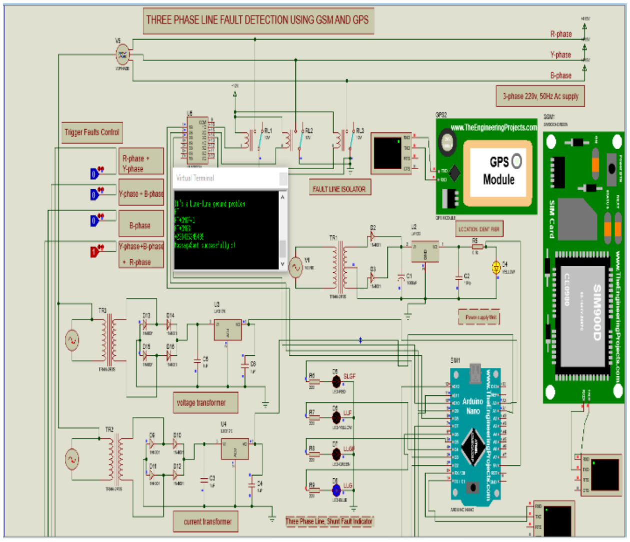

Figure 18. Test Result of Line-Line-Ground Fault

Line-Line-Line-Ground

In scenario 4, a line-line-line-ground fault was introduced into the system to see if the design will be able to display and communicate the fault as expected. This was also done by triggering all three phases of the line and the ground fault control which opens the corresponding relay(s) of the lines on which this fault is located as shown in figure 19.

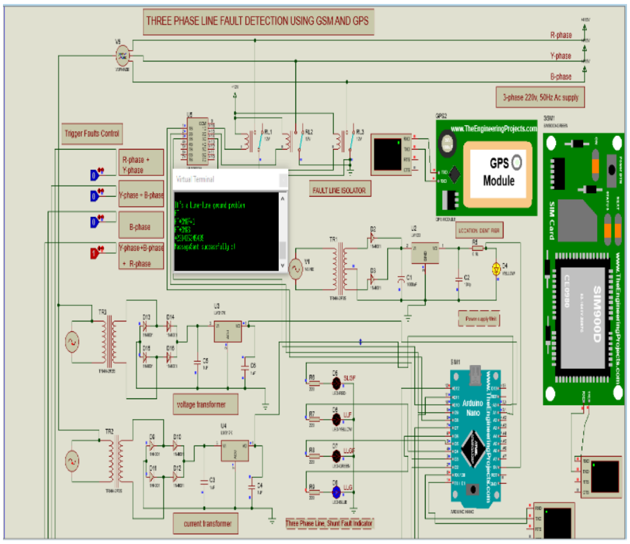

Figure 19. Test Result of Line-Line-Line-Ground Fault

The opening of the relay sends a signal to the microcontroller and a corresponding LED which switches to display the type of fault. It can be seen from Figure 14 that all the relays are opened since all the phases were affected. The microcontroller then communicated to the GSM module which displayed the said fault and location on a display screen with the help of a virtual terminal.

No Fault Condition

Under no fault conditions, no systems are triggered, and the corresponding relays all stay connected. The virtual terminal which displays the fault conditions also remains blank as shown in figure 20. The system remains in this mode until a fault is triggered or detected

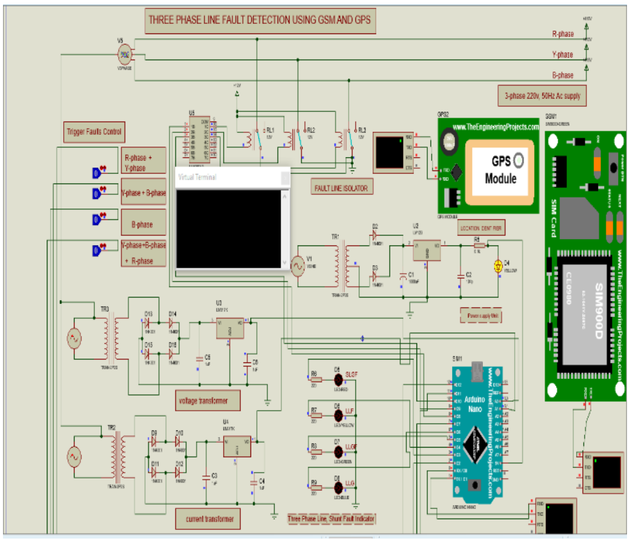

Figure 20. Test Result of No-Fault Condition

CONCLUSION

In conclusion, improving electricity accessibility and reliability remains one the biggest objective of ECG. Reducing the time spent on locating faults and determining the type of faults would ensure that this objective is met. The implementation of this GSM module to improve this electricity reliability focuses mainly on the early fault detection on distribution lines. It ensures that fault is easily detected to ensure customer satisfaction and quick response to faults. This system can monitor distribution system conditions in real time which also helps with system monitoring and control. The ability to detect fault location and type of fault helps to save time and resources. The implementation of this system would ensure electricity wastage and reduce the losses incurred by the Electricity Company of Ghana.

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NOMENCLATURE

A	Ampere
R	Resistance
V_{peak}	Peak Voltage
V_{diode}	Voltage of the diode
V_{min}	Minimum Voltage
C	Capacitance of the Capacitor in rectifier circuit
I	Current
V	Volt
f	frequency of rectified voltage in hertz
T	Period
Q	Charge across capacitor in rectifier circuit
t	time
Hz	Hertz
GWh	Gigawatts hour
kWh	Kilowatts hour

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AC Alternating Current
DC Direct Current
KB Kilobyte

APPENDICES

Table 1 Specifications of Atmega 328p

Parameter	Value
CPU type	8 – bit AVR
Performance	20 MIPS at 20 MHZ
Flash Memory	32 KB
SRAM	2 KB
EEPROM	1 KB
Pin count	28 – pin PDIP, MLF
Maximum operating frequency	20 MHz
Number of touch channels	16
Maximum I/O pins	26
USB Speed	No