



AUTOMATIC FAULT DETECTION AND LOCATION IN POWER TRANSMISSION LINES USING GSM TECHNOLOGY

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ABSTRACT

Many electricity transmission companies across the world and Ghana in particular are continuously looking for ways to utilise modern technologies, in order to improve reliability of power supply to consumers. These transmission companies mainly relies on circuit indicators (FCIs) to assist in locating specific spots within their transmission lines where power fault had occurred.

In this paper, a smart GSM based fault detection and location system was used to adequately and accurately indicate and locate the exact spot where fault had occurred. This will ensure a shorter response time for technical crew to rectify these faults and thus help save transformers from damage and disasters. The system uses a current transformer, a voltage transformer, PIC 16F877 Microcontroller, RS-232 connector, and a GSM modem. The system automatically detects faults, analyses and classifies these faults and then, calculates the fault distance from the control room using an impedance-based algorithm method. Finally the fault information is transmitted to the control room. In conclusion, the time required to locate a fault is drastically reduced, as the system automatically and accurately provides accurate fault location information.

Keywords: GSM modem, impedance-based algorithm, Microcontroller, RS-232 Connector, Voltage Transformer

I. INTRODUCTION

Many electric power transmission companies such as Ghana Grid Company limited (GRIDco) in Ghana, have primarily relied on circuit indicators to detect faulty sections of their transmission lines. However there are still challenges in detecting the exact location of these faults. Although fault indicator technology has provided a reliable means to locate permanent faults, the technical crew and patrol teams still has to physically patrol and inspect the devices for longer hours to detect faulty sections of their transmission lines.

1.1 Problem Statement

To reduce the duration of outages and minimise response time to major faults, and to optimise reliability of supply, it is inevitable for power transmission companies such as GRIDco to search for a low-cost communicating device with low power consumption that will relay accurate fault information at real-time back to the control centre.

This research work seeks to design an automatic and efficient fault detection and location system for both overhead and underground power transmission network system using both existing fault indicator technology and commercially proven communication technology to quickly and accurately pin point faulted sections of a transmission system.

1.2 Research Objectives

- To design an efficient impedance-based and robust automatic fault detection and location system for overhead and underground power transmission lines in Ghana.
- To reduce response time needed to rectify and save expensive transformers from damage or theft which usually occurs during longer power outages.
- To increase productivity of technical crews since the time needed to locate faults will be minimised.
- To ensure stability and reliability of the power supply system in the country to boost economic growth.

1.3 Scope of Work

This work is limited to the design of an efficient system that will detect and locate line to line and line to ground faults in overhead and underground transmission lines which will automatically indicate to the control room the exact spot of the transmission line where a fault had occurred.

II. BACKGROUND STUDY

Globally, there are three phases in electric power supply system. These encompass the generation phase, the transmission phase and the distribution phase. Each of these phases involves certain distinct production processes, work activities and hazards.

2.1 The Generation Phase

The generating phase begins at the base station where stored energy of gas, oil, coal, nuclear fuel, or falling water is converted to electrical energy. In Ghana the generating power voltage from these stations, controlled by Volta River Authority (VRA) is usually from 13.2 kV to 24 kV [1]. This is further stepped up by transformers to higher voltages prior to transmission by GRIDco systems.

2.2 Transmission Phase

After generation, transformers at the generation substation then boost up the voltage to high voltages that ranges between 69KV to 330 kV [2] before it is transmitted over great distances across the country by GRIDco using transmission lines (cables). These transmission lines are constructed between transmission substations that are located at the generating stations and distribution substations. The Transmission lines are mainly supported overhead on towers.

At the receiving end of the transmission lines substations, these voltages are stepped down to between 34.5 to 138 kV. This power is then transferred to the distribution substation controlled by ECG and NEDco both in the southern and northern part of the country respectively.

2.3 Distribution Phase

As stated above, the distribution phase (controlled by ECG and NEDco) connects the transmission system of GRIDco to the customer’s equipment. The distribution substation reduces the transmitted electrical voltage from 161KV, to 24 kV. A distribution transformer further reduces the voltage to 240V, which is the standard voltage recommended in Ghana.

Transmission and distribution substations are installations where the voltage, phase or other characteristics of the electrical energy are changed as part of the final distribution process [3].

Fig 1 depicts the stages and the stakeholders responsible for power generation, transmission and to distribution for consumers in Ghana.

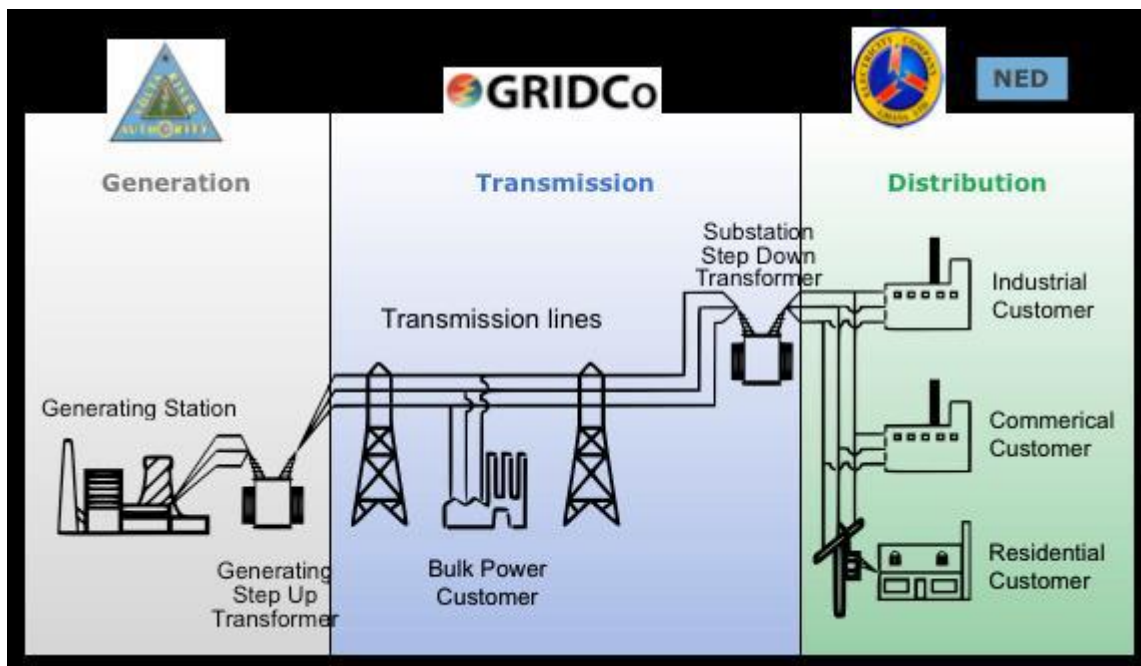


Figure 1: Generation, Transmission and Distribution of Power (Source: Ghana power reliability report 2010)

2.4 Ghana Transmission Grid

Ghana electrical transmission system is very complex and dynamic than other utility systems, such as water.

Energy produced from the generating stations in Ghana is transmitted to GRIDco power sale customers through an interconnected transmission network at 69, 161, 225kV and 330KV voltage levels [4].

The existing transmission network comprises of: [5]

A 161kV closed loop grid serving the concentrated load centres of the southern part of Ghana and a long 161kV direct line from Kumasi to the relatively lightly loaded northern parts of Ghana where electricity penetration is low. Also a 161kV radial line from Techiman to Sawla in the north-western part of the country, extends to Wa, in the Upper West Region at 34.5kV. A single circuit 225kV 220km transmission line between Prestea substation in the Western part of Ghana and Abobo substation, located near Abidjan in Cote d'Ivoire.

A double circuit 161kV line connecting the Akosombo Generating Plant in Ghana to Lome substation in Togo, to supply power to both Togo and Benin

In all there are 66 substations that either serve as switching stations with no power transformers (Volta), step-up stations for the generation plants and/or step-down stations that step down the high voltages to various medium voltages (34.5kV, 11.5kV, 6.6kV) with total installed transformer capacity of 2,630MVA, meant for the distribution system.

The Ghana power network is also interconnected with the power grids of neighbouring Cote d'Ivoire (CIE), Togo and Benin (CEB). A Map of the transmission grid is shown below in fig. 2. Below.



Figure 2: National transmission system of Ghana [http://www.gridcogh.com/en/national-grid.php].

2.5 Architecture of the GSM Network

Global System for Mobile Communications (GSM) is a digital wireless network standard designed by standardization committees from major European telecommunications operators and manufacturers. The GSM standard provides a common set of compatible services and capabilities to all mobile users across Europe and several million customers worldwide

2.6 Common Courses Of Transmmission Line Faults.

There are many courses of faults in power transmission leading to power outages if not properly managed.

Notable among them includes:

- Faults at the power generation station
- Damage to power transmission lines (tree falling on lines)
- Faults at the substations or parts of distribution subsystem
- Lightening

2.7 Types of transmission line faults

Power system's faults may be categorized as shunt faults or series faults. The most common type of shunt faults is **Single Line-to-ground faults (SLG)**. This type of fault occurs when one conductor falls to the ground or gets into contacts with the neutral wire. It could also be the result of falling trees in a rainy storm. This type could be represented as shown in Fig 3. below.

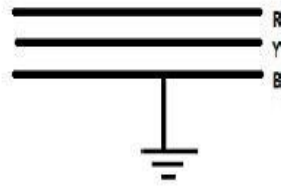


Figure 3: Single Line to ground fault

The second most occurring type of shunt faults is the Line-to-Line fault (LL). This is said to occur when two transmission lines are short-circuited. As in the case of a large bird standing on one transmission line and touching the other, or if a tree branch happens to fall on top of two power transmission lines. This type could be represented as shown in the Fig. 4 below.

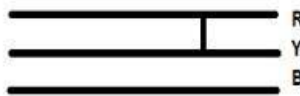


Figure 4: Two line to line faults

The third type of shunt fault is the Double Line-to-Ground fault (DLG) in fig. 5 below. This can be a result of a tree falling on two of the power lines, or other causes.

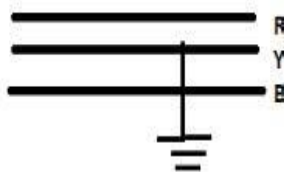


Figure 5: double line-to-ground fault

The fourth and the real type of fault is the balanced three phase (Fig. 6), which can occur by a contact between the three power lines in many different forms.



Figure 6: Balanced Three Phase Fault

III. RESEARCH METHODS

The methods deployed in this study critically examined the various technologies and methods used globally in the transmission of power over great distances and terrains with a sharp focus on current methods used in Ghana (GRIDco) for detecting faults in transmission lines.

Primary data was gathered through interviews and questionnaire with technical crews of the major stakeholders in the power transmission sector. This activity primarily aims to ascertain the current methods used by GRIDco

who is solely responsible for bulk transmission of power throughout Ghana and beyond, for detecting faults in their transmission lines.

Secondary data was also acquired from official websites of GRIDco, Volta River Authority (VRA) and Electricity Company of Ghana (ECG).

3.1 Stakeholders Analysis:

In all three (3) main stakeholders were identified and contacted for information on how transmission faults are detected and fixed. These companies include

- i) Volta River Authority (VRA), (Solely responsible for the generation of power in Ghana using thermal, hydro, Solar and other renewable materials for power generation).
- ii) Ghana Grid Company Limited (GRIDco), (solely responsible for the transmission of electrical power from the generation station to the various distribution substations across the length and breadth of the country and even beyond the borders of Ghana to the neighboring countries). This includes Cote d'Ivoire on the west, Togo on the eastern corridor, through to Benin and to the western parts of Nigeria.
- iii) Electricity Company of Ghana (ECG) and Northern Electricity Distribution Company (NEDco) (responsible for bulk distribution of power to commercial and domestic consumers at the southern and northern part of the country respectively..)

The major stakeholder and the main focus for data acquisition in this study was GRIDco, because they are the sole unbundled bulk power transmission supplier in Ghana and hence received a bulk of the questionnaires and interviews

A total of 30 questionnaires were distributed to different groups of workers within the major stakeholder (GRIDco) as mentioned above. However out of a total of 30 questionnaires distributed, 26 were returned due to follow-ups from the researcher. These figures constituted 86.6% response rate.

Again interviews were also granted to three (3) local operational managers of GRIDco (Systems operations manager, network operations manager and local supervisor for operations).

The questionnaires and interviews seek to enquire among other things but not limited to the following questions:

- i. The major causes of transmission line faults in all GRIDco's network
- ii. How these faults are detected and located.
- iii. The socio-economic effects of these transmission outages

Results from the questionnaires analysis indicated that even though the system used by GRIDco to detect faults on its transmission lines is equipped with an automatic fault detection system, this can only detect line to earth faults. After detection, the system automatically cuts off supply to the faulted line and indicate to the control room that a fault had occurred. But however the system lacks the ability to automatically detect the exact spot that the fault had occurred along the transmission line

The usual practice after a fault had been detected is to manually inspect the entire suspected faulted line by response crew until the fault is located. This takes the team a considerable amount of time especially when the line traverses through forested regions and rough terrains. Again due to the ongoing rural electrification projects embarked upon by the government of Ghana, most of these transmission lines run through forested and inaccessible terrains that makes it very difficult for the technical crew to locate and reach the faulted spot. This



lines are more often isolated from inspection crew who constantly patrols the poles in the rural areas. From the responses, bush fires forms 65% of damaged poles leading to power outages.

This difficulties to detect and spontaneously locate the exact spots of transmission line faults has lead to wide power outages that has resulted to lost of life and property in certain cumunities across the country.

To adequately address these problems to ensure constant supply of electricity to consumers where they needs it most, and to boost socio- economic growth, it means that an efficient authomatic line fault detection using GSM technology will be most appropriate for GRIDco transmission lines.

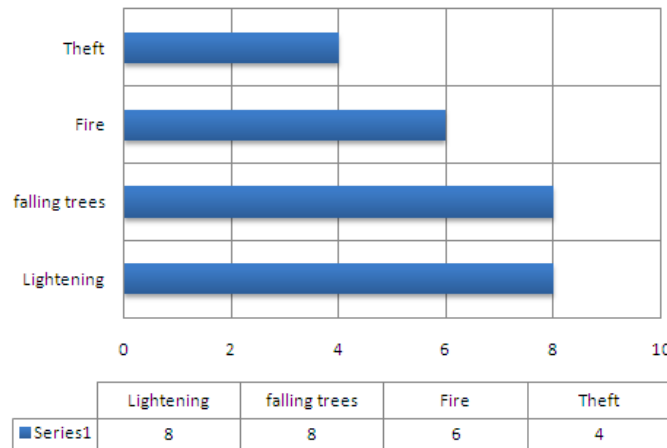


Figure 7: Common Causes of line faults

IV. TYPES OF FAULT LOCATION METHODS

Considerable research has been carried out in the area of fault diagnosis methods, particularly to radial distribution systems. These methods uses various algorithmic approaches, where the fault location is iteratively calculated by updating the fault current. A brief overview of the algorithmic approaches has been presented in the following section:

4.1 Impedance And Other Fundamental Frequency Component Based Methods For Detecting Faults On Transmission Lines

The distance of fault from the primary distribution bus is estimated by impedance based method. Voltage and current values measured at one end or both ends of the line are required in this method. The method uses mathematical equations to estimate the fault location [7].

[8] suggested a technique that used the fundamental frequency voltages and currents measured at a line terminal before and during the fault. The fault location technique was described by considering a single-phase-to-ground fault on a radial system. Nevertheless, they still considered the line to be fully transposed, and was only good for line-to-ground faults.

[17] proposed a method that was based on measurements provided by Intelligent Electronic Devices (IEDs) with built-in oscillography function. This is installed only at the substation level and on a database that stores information about the network topology and its electrical parameters. In particular on 11kV networks,

application of the method was a problem. It was difficult to obtain reliable statistical estimates, and also time consuming due to iterative process and need to know the fault type before specific equation could be applied.

4.2 High Frequency Components and Travelling Wave Based Methods

This method was generally based on the reflection and transmission of the fault generated by travelling waves on the faulted power network. Although in this technique fault can be located with high accuracy, the implementation is complex and more expensive than the implementation of impedance based techniques. This is because it needs too many added equipment such as the GPS system, fault transient detectors and diagnostic software. Furthermore, due to the complex configurations of distribution systems, the configuration or the sites to install the fault transient detectors become very difficult.

4.3 Knowledge-Based Method

The third category is knowledge-based method. This method can be divided into three groups:

- a. Artificial intelligence and statistical analysis based methods
- b. Distributed device based methods
- c. Hybrid methods

4.4 Artificial Intelligence (AI) and Statistical Analysis Based Methods

There are several artificial intelligent methods such as Artificial Neural network (ANN), Fuzzy Logic (FL), Expert System (ES) and Genetic Algorithm (GA). These methods can help operators or engineers to do much laborious work. By using these methods, the time factor is substantially reduced and human mistakes are avoided. Therefore, many researchers used AI based methods in transmission system fault locations.

[9] developed a fault location method for multi-ring distribution systems using neural network. They used the feeder fault voltage, circuit breaker status, real power of feeders during the normal condition, and real power of feeders during short circuit, etc, to train the neural network.

4.5 Distributed Device Based Methods

Another type of knowledge-based technique is distributed device based methods for locating fault. [10] presented a mathematical approach that located faults based on installed voltage sensors' information and the network's topological structure. The relation of the voltage sensors with sections was formulated as a matrix. The other matrix was constructed based on the topological relation between sections and nodes in an electric network. Through some matrix operations, all faulted sections could be found.

4.6 Hybrid Methods

Almost all of the above methods locate faults based on one algorithm, such as the fault distance calculation or operated protective device's status analysis. Some have investigated the use of hybrid methods that locate faults based on more than one algorithm to achieve a more accurate estimation of the faulted section.

[11] proposed a hybrid method that computed the fault distance using measurements available at the substation. They used post-fault values of current or voltage to reduce the multiple estimation problems induced by the existence of multiple fault points in the network. To identify the actual fault location, a fault diagnosis procedure was applied to rank the list of multiple potential fault locations. By doing a circuit simulation, the operation of a



particular combination of protective devices and the load change pattern during different fault scenarios could be obtained. Then by matching the fault situation to these scenarios, the actual faulted section could be determined.

V. COMPONENTS FOR THE PROPOSED (New) SYSTEM

This section highlights the state-of-the-art devices that will be needed to implement the system. These devices will provide the much needed attributes for the new system: robustness, low cost, efficiency, accuracy and low power.

5.1 Microcontroller

A microcontroller (MCU) is a small computer on a single integrated circuit (IC) containing a processor core, memory, and programmable input/output peripherals. Program memory is also often included on the chip, as well as a typically small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications.

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, and power tools [12].

5.2 The PIC16F877 Microcontroller

Programmable Intelligent Computer (PIC) is a family of Harvard architecture microcontrollers made by Microchip Technology, derived from the PIC1640 originally developed by General Instrument's Microelectronics Division.

The PIC16F877 falls in the mid-range of the PIC family of microcontrollers and finds use in a wide range of applications in diverse fields due to the fact that it is readily available. It also has a large number of pins (40 pins) with a maximum of three functions per pin which makes it much easier to use as compared to others with limited pins and a high number of functions per pin. It also has an optimal cost-to-performance ratio.

The above mentioned desirable characteristic of the PIC16F877 microcontroller coupled with the fact that it has an in-built Analog to Digital Converter and sufficient program memory to store the control algorithm, have largely affected its choice for the design of the automatic fault detection and location system discussed in this work.

5.2.1 PIC16F877 Microcontroller Architecture

The key features of the PIC16F877 microcontroller are summarily presented with the block diagram in Fig. 8 below.

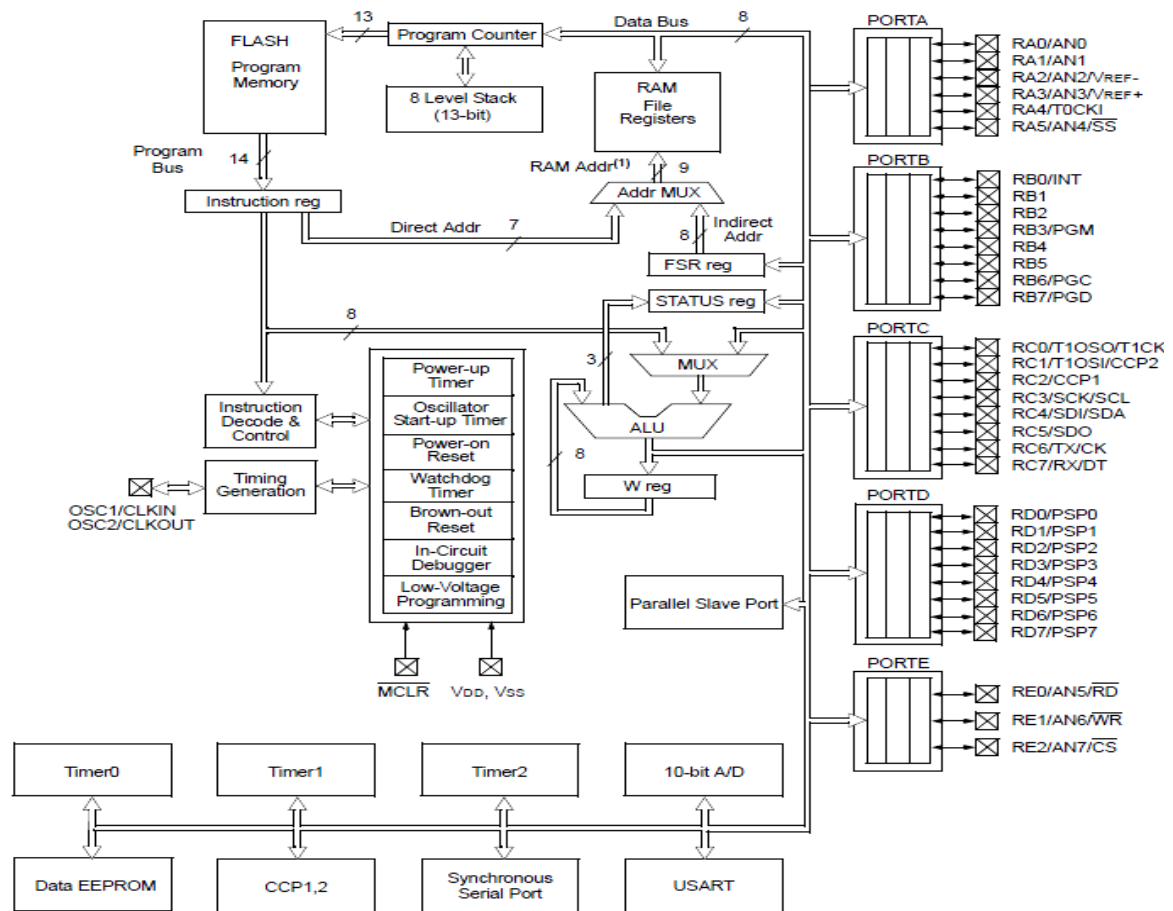


Figure 8 : Block Diagram Of The Pic16f877 Microcontroller [14].

5.3 The GSM Modem

A modem (modulator-demodulator) is a device that modulates an analog carrier signal to encode digital information, and also demodulates such a carrier signal to decode the transmitted information. The goal is to produce a signal that can be transmitted easily and decoded to reproduce the original digital data.

The GSM Modem comes with a serial interface through which the modem can be controlled using attention (AT) command interface. An antenna and a power adapter are provided.

The basic segregation or working of the modem is as follows: [15]

- Voice calls
- Short Message Service (SMS)
- GSM Data calls
- General Packet Radio Services (GPRS)

VI. THE PROPOSED SYSTEM

The proposed system is intended to automatically detect faults when they occur, analyse the fault to determine the type and then send information based on the fault type and fault location to the control room via GSM. The

device location is determined by the SIM card in the modem, each SIM card having a unique identification and hence is used as the device's address.

The system senses, analyses and transmits. It does this with the microcontroller which analyses, interprets and sends digital signals to the I/O devices for the system to operate. By programming, the microcontroller is made to perform these functions.

6.1 System Hardware

The automatic fault detection and location system comprises of a current transformer, a voltage transformer, a microcontroller, an RS-232 connector and a GSM modem as shown in the block diagram in Fig. 9.

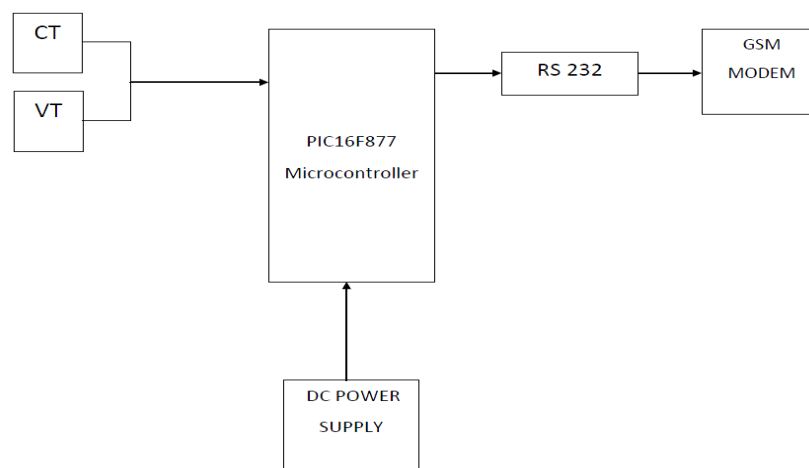


Figure 9: Block Diagram of Proposed Fault Detection and Location System

6.2 Mode of Operation

The set up or field device consists of 3 major components, instrument transformer (CT and VT), GSM modem and microcontroller. The primaries of the CT and VT which are connected to the line sense the corresponding current and voltage values of the system and feed the output to the ADC of the microcontroller which converts the signal to a digital form in order to be processed by the CPU of the microcontroller.

The microcontroller serves as the central point of the set up. It contains a set of programming codes which have been stored in the EEPROM which enables it to classify the fault type based on the voltage and current values. Based on the program, the microcontroller compares these values to see whether they are within the range required. If the voltage and current values are out of range as compared to the reference, it gives an indication of a fault.

The microcontroller also calculates the fault distance, relative to the device based on an impedance-based algorithm and then relays this information to the modem for transmission. In summary, the microcontroller classifies, calculates the fault distance and relays the information to the modem for transmission via the serial communication interface (SCI) which serves as an interface between the microcontroller and the modem. The RS-232 serves as the connector between the microcontroller's serial communication port and the modem.

The device is placed in the boundary of the sectionalised regions in the transmission system and the location of the fault is calculated relative to the position of the device. The unique identity of the SIM card in the GSM



modem is used as an address for the device (for instance 0267006700 could be saved as Tarkwa Section-3 at the control room). The flow chart of the operation of the microcontroller is shown in Fig. 10

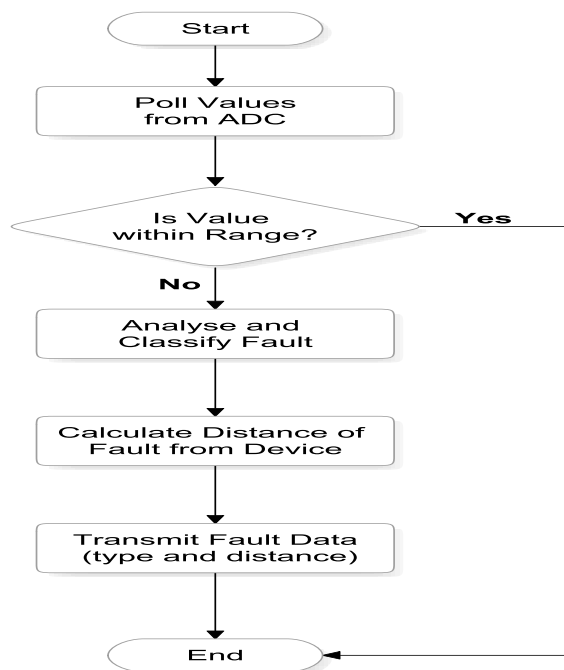


Figure 10: Flow Chart of Field Device

6.3 Communication Process

Data from the field device is communicated firstly to the Base Transceiver Station (BTS) which serves as an access point for all the field devices. The BTSs are mounted on strategic locations on the field to achieve a nationwide coverage.

They are placed at strategic locations so that they can cover a particular span or region since their network coverage is limited. They are placed in conjunction with other BTSs to help overlapping of their coverage area in order to cover a large portion than they would if they were placed in isolation.

Next the data moves on to the Base Station Controller (BSC) which manages the radio resources of one or more BTSs. It serves as a gateway or link between the BTS and the switching system. The data signal then moves to the switching system which directs the data signal to its right destination and that is the control room.

Finally, the data signal arrives at the control room where another modem will receive the information, loads it to a local server and displays it on a screen, so that the operator can take the appropriate action. Fig. 11 shows the communication process from field device to control room.

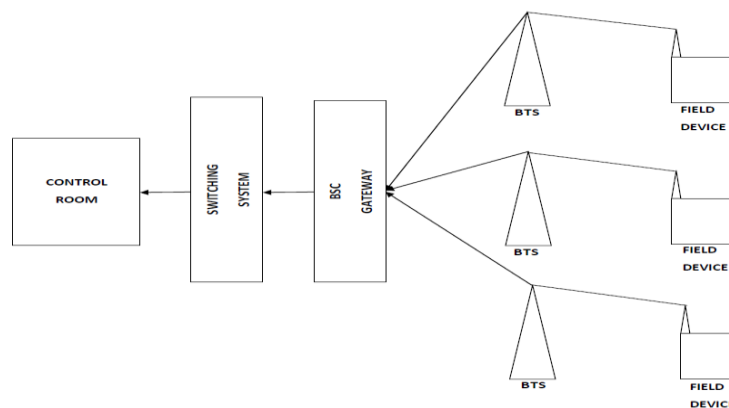


Figure 11: Communication Process from Field Device to Control Room

6.4 Impedance-Based Fault Location Algorithm

Impedance-based methods require the following approach:

- Measure the voltage and current phasors.
- Extract the fundamental components.
- Determine the phasors and fault type.
- Apply impedance algorithm.

VII. CONCLUSION

In conclusion the proposed system will provide a reduction in the time required to locate a fault by automatically providing accurate fault location information especially in the radial 161Kv radial lines from Kumasi to the northern part of Ghana, Sawla.

The system will also be usefull in the double circuit 161kV line connecting the Akosombo Generating Plant in Ghana to Lome substation in Togo, to supply power to both Togo and Benin

It will also allow operators such as GRIDco to correctly detect and locate faulted segments on their transmission lines and, therefore, minimise power disruptions to distribution substations and help save expensive transformers.

7.1 Recommendations

It is recommended that:

- Any interested researcher should take up the programming and simulation of the fault detection and location system presented in this work to realise the expected results for further detailed analysis.
- Any interested researcher should take up a project on the optimal placement of the fault detection and location device in transmission systems.
- Any interested researcher should take up a similar project for distribution systems.



LIST OF ABBREVIATIONS

Abbreviation	Meaning
AI	Artificial Intelligence
ANN	Artificial Neural network
AT	Attention
BSC	Base Station Controller
BTS	Base Transceiver Station
CPU	Central Processing unit
ECG	Electricity Company of Ghana
ES	Expert System
EEPROM	Electrically Erasable Programmable Read Only memory
FL	Fuzzy Logic
GA	Genetic Algorithm
GPRS	General Packet Radio Services
GRIDco	Ghana Grid Company limited
GSM	Global System for Mobile Communications
IC	Integrated Circuit
MCU	Microcontroller
NEDco	Northern Electricity Distribution Company
PIC	Programmable Intelligent Computer
SCI	Serial Communication Interface
SMS	Short Message Service
VRA	Volta River Authority
VT	Voltage Transformer

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