International Journal of Innovative Scientific & Engineering Technologies Research 12(3):81--91, July-Sept, 2024

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Design And Construction Of Microcontroller Base Electrical Underground Cable Fault Detection

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ABSTRACT

Underground cable fault detection is a critical aspect of maintaining and ensuring the reliability of electrical power distribution networks. This study presents a microcontroller-based system for detecting and locating faults in underground cables. The system utilizes a microcontroller unit to monitor and analyse the electrical parameters of the cables. Upon detecting an anomaly indicative of a fault, the system accurately determines the fault's distance from the monitoring station. Key components of the system include voltage and current sensors, an analog-to-digital converter (ADC), and an efficient fault detection algorithm implemented in the microcontroller's firmware. The proposed solution offers a cost-effective, reliable, and real-time approach to fault detection, minimizing downtime and maintenance costs in power distribution networks. The effectiveness of the system is validated through experimental setups and field trials, demonstrating its potential for widespread deployment in modern power systems.

Keywords: Underground Cable, Fault Detection, Microcontroller and Real-time Monitoring

1.0 INTRODUCTION

Underground cables have been extensively used for power distribution networks over the years. This is because of their suitability for underground connections, better security from activities of vandals and thieves, and resistance to hazardous climatic conditions such as thunderstorms and whirlwind. They are easy to maintain and environmentally friendly. They have reduced maintenance and operating costs such as lower storm restoration cost. Also, underground cables eliminate the menace of wind-related storm damage. They are not subjected to destruction caused by flooding which usually spoil and interrupt electric service. When there is an occurrence of fault, to locate the type of fault and the point of the fault becomes very laborious and tedious and, in most cases, due to the process of tracing the point of fault occurrence, the strength and the quality of such cable is reduced. This drawback alone is one of the factors that have made the use of underground cable inadequate in most places. With the trend of this present digitized era, this project will be focusing on fault location in an underground cable. Fault occurrence in electrical cable is very common for either overhead or underground cable. Locating a point of fault in long distance underground cable and identifying the types of faults (open - circuit and short - circuit fault) are tedious tasks. The most common types of faults that occur in underground cables are open-circuit, short-circuit and earth faults. The faults are described in the following section.

i. Open- circuit fault

This is due to a break in the conductor of a cable and can be caused when a conductor is pulled out of joint. The open-circuit fault can be checked by a megger. For this purpose, the three conductors of the core cable at far end are shorted and earthed. Then resistance between each conductor and earth is measured by a megger. The megger will indicate zero resistance in the circuit of the conductor that is not broken. However, if a conductor is broken, the megger will indicate an infinite resistance. Most at times, the test for continuity is used to indicate an open-circuit in a cable.

ii. Short-Circuit Fault

When two conductors of a multi core cable come in electrical contact with each other due to insulation failure, it is called short-circuit fault. Megger can also be used to check this fault. For this, the two terminals of a megger are connected to any two conductors. If the megger gives a zero reading it indicates short-circuit fault between these conductors.

1.1 Problem Statement

Despite the numerous advantages of underground cable over the overhead counterpart, the problem of locating the point of fault and the locate type of fault in 2.5 kilometres (km) distance becomes an issue. Therefore, this project," design and construction of microcontroller based underground cable fault detection can be used to a point of open circuit and short-circuit fault in 2.5 km underground cable from the base station. This problem is solved using ohm's law which is based on the voltage drop caused by the impedance of the conductor when a current is passed through it.

1.2 Aim and Objectives

The aim of the project is to design and construct a microcontroller based underground cable fault detector that can detect a fault within 2.5 km faulty cable. The aim can be achieved by the following objectives.

1. To design and construct the major components of the project.
2. To layout, implement and test the project.
3. Aaccurate **Fault Detection and Location**
4. Real**-Time Monitoring and Reporting**
5. **Cost-Effective and Scalable Solution**

2.0 Review of Similar Works

Over the years, researchers have made several efforts to design and implement an electrical underground cable fault detector that will help to overcome the problems as well as challenges encountered in underground cable fault detection.

This prototype uses the simple concept of ohms law. The current would vary depending on the distance of fault in the cable. This is done by assembling a set of resistors to represent the cable length in kilometre (Km) and fault creation is made by a set of switches at every one km to cross-check the accuracy of the fault. The fault distance and the phase are displayed on the LCD display of the system. The software program is burned into ROM of the microcontroller. The power supply consists of a step down transformer (230/12V), which steps down the voltage to 12V AC. This is converted to DC using a bridge rectifier. The ripples are removed using a capacitive filter and it is then regulated to +5V using a voltage regulator LM7805 which is required for the operation of the microcontroller and other components.

A. Gupta, V. Kumar, R. Sharma, R. Meena, R. Choudhary and R. Kumar, in their paper titled "distance calculation for underground cable fault" [1] proposes fault location model for underground power cable using microcontroller. The aim of this project is to determine the distance of underground cable fault from base station in kilometres. This project uses the simple concept of ohm's law. When any fault like short circuit occurs, voltage drop will vary depending on the length of fault in the cable, since the current varies. A set of resistors are therefore used to represent the cable and a DC voltage is fed at one end. The fault is detected by detecting the change in voltage using analogue to digital converter and a microcontroller is used to make the necessary calculations so that the fault distance is displayed on the LCD display. The basic principle behind the system is ohms law. When fault occurs in the cable, the voltage varies which is used to calculate the fault distance. The system consists of Wi-fi module, microcontroller, and real-time clock.

R. Ali and M. A. Jamal, in their paper titled "a new approach to fault location in three-phase underground distribution system using combination of wavelet analysis with ann and fls" [2] aim to determine the underground cable fault. B. Bhuvneshwari, A. Jenifer, J. John Jenifer, S. Durga Devi and G. Shanthi in their paper titled "underground cable fault locator" [3] proposed fault location model for underground power cable using microcontroller. The hardware model of underground cable fault locator is implemented and favourable results were brought forward. This hardware model can locate the exact fault location in an underground cable. There are needs to further enhance the work so that it can also locate open-circuit cable. A. D. Dhivya and T. Sowmya in their design and construction paper titled “developement of a prototype underground cable fault detector” [4] developed a prototype that uses the idea of ohm’s law to detect faults in cables. The proposed system uses a set of resistors representing cable distance in kilometres and fault detection is by a set of switches at every Km to validate the accuracy of the detection. The type of fault at any particular distance is displayed on the LCD interfaced with the microcontroller. Their work is only simulation as no design and construction work is involved. J. P. Singh, N. S. Pal and S. Singh in their paper titled “underground cable fault distance locator” [5] present a system that can detect the location of open circuit and short circuit fault in the underground cable from the base station in km with the help of ATmega16 microcontroller. Only the simulation was done using psim simulator. S. Seshma, G. Monika, P. Ashwini, T. Saurabhi and S. S. Chaudhari, in their paper titled “underground cable fault distance locator by using microcontroller” [6] proposed a microcontroller based underground cable fault distance locator. However, there was no evaluation to know the performance of their proposed system. S. Shari, S. Tariq, A. Bangi and K. Khot, in their work titled “underground cable fault detector using GSM” [7] introduced a smart GSM based fault detection and location system that can be used to accurately locate the specific place where fault had occurred.

All the above works have one limitation or the other. For this reason, the design and implementation of a microcontroller based underground cable fault detector capable of running on dual power supply (i.e. AC mains supply as well as a DC battery pack) and display of results on an LCD module is proposed. This is an improvement on the previous works available in literature. This design also runs on computer software program because it uses an ATmega328P microcontroller that also requires “sketch” or “source code.” Another advantage of this proposed system is that it is cheaper the its arduino based counterpart. Underground cables have been extensively used for power distribution networks over the years. This is because of their suitability for underground connections, better security from activities of vandals and thieves, and resistance to hazardous climatic conditions such as thunderstorms and whirlwind. They are easy to maintain and environmentally friendly. They have reduced maintenance and operating costs such as lower storm restoration cost. Also, underground cables eliminate the menace of wind-related storm damage.

3.0 METHODOLOGY

To achieve the implementation of the microcontroller based underground cable fault detector, some approaches were taken. First is designing the circuit on a computer system, collection of the electronic components and other materials required for the project, after which the programming of the ATmega328p microcontroller using programmer kit was done. The components were assembled on the project board (temporary board) and tested before transferring them to the vero board (permanent board). Finally, the entire system was tested and the casing was done. In this section, the design, analysis, specification as well as method or steps taken to realize the implementation of the microcontroller based underground cable fault detector was described. The design of the system is made up of several units: the power supply unit, probe terminal unit, microcontroller unit and LCD display unit as shown in figure 3.1 below.

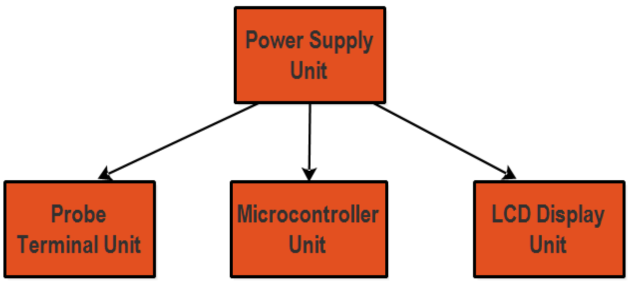


Figure3.1 Block diagram of the microcontroller based underground cable fault detector.

3.2 System Description

The underground cable fault locator has various units or sections. Each of the units perform a specific function in *the* system. The following units or sections are discussed.

i. Power supply

The power suppy used is 9V D.C battery to power the whole circuit.

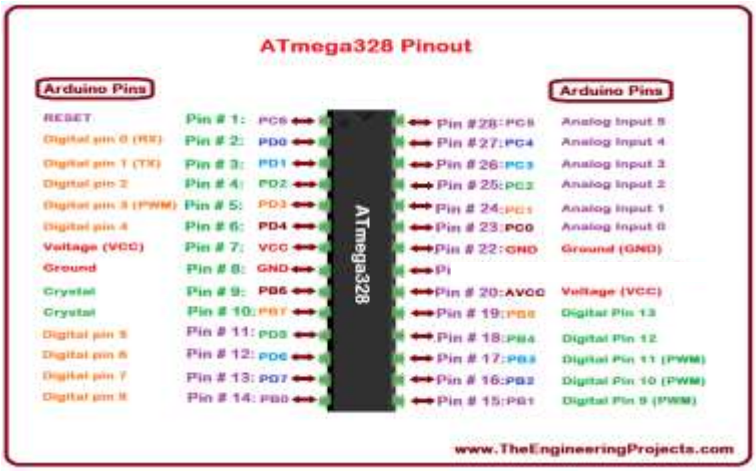
ii. Regulated DC Power Supply

This gives the necessary electrical power requirement for every other component in the system,i.e. the microcontroller unit, the USB to serial converter and the LCD operating on 5V.

iii. Microcontroller Unit

The microcontroller unit is made up of the ATmega328p microcontroller, a 16MHz crystal oscillator and a pull-up resistor as shown in below.

Figure 3.2 Microcontroller



A microcontroller is a self-contained system with peripherals, memory and a processor that is designed to govern the operation of embedded systems. In this project it receives, processes and controls the operation of all other functional units beside the power supply.

iv. Liquid Crystal Display Module

A liquid crystal display (LCD), is an electronically modulated optical device that uses the light-modulating properties of liquid crystals together with some reflectors to form a character. A 20x4 character backlit LCD is used as the output device for the user.

The HD44780 dot-matrix liquid crystal display controller displays alphanumeric and Japanese characters and symbols. It can be configured to drive a dot-matrix liquid crystal display under the control of a 4-bit or 8-bit microprocessor. Since all the functions such as display RAM, character generator, and liquid crystal driver, required for driving a dot-matrix liquid crystal display are internally provided on one chip, a minimal system can be interfaced with this controller/driver.

v. Potentiometer

Potentiometer in the circuit is used to set the reference resistance per kilometre. The reference value of resistance in the potentiometer which the analogue and digital converter (ADC) converts to voltage is used by the microcontroller to compare the measured value of the length of a conductor.

vi. Scaling Unit

Scaling unit in this circuit is a voltage divider circuit which interprets the resistance value of the short-circuited conductor to the ADC of the microcontroller. This resistance which is proportional to length of the cable is then being compared to reference value in the potentiometer and the final value is given in terms of length in kilometres.

vii. Conductors

These are short/open circuited conductors whose point of short/open circuit is to be determined based on some factors, such as material, resistivity voltage and the gauge of the conductor.

3.3 Hardware Design And Construction

The circuit diagram used in this project is shown in figure 3.3 as captured from proteus schematic editor. The hardware design involves the design of the circuitry in each of functional blocks. The following sections detailed the design of each of the blocks as shown in the figure 3.3 below.

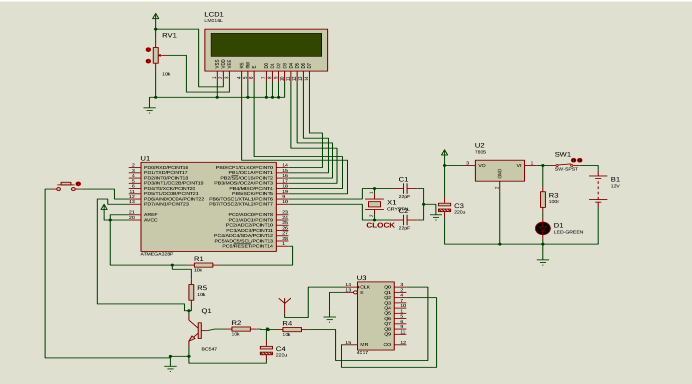


Figure 3.3 Circuit diagram of underground cable fault distance locator

The Designed System Operates as follows:

- When the system is energized, the microcontroller initializes the LCD.
- A welcome message comes up on the LCD and ADC.
- With the probe being open circuited, the LCD displays open circuit detected. The reference resistance of the cable to be measured per kilometres is set using potentiometer.
- Then when the cable connected between the two terminals is short circuited the resistance of the cable is measured and then compared with the reference. The final value is then converted to length by the microcontroller.
- The value of the length in kilometre is divided into two which gives an approximate point of short circuit in the cable.
- The value obtained is displayed on the LCD in kilometres.

The design of the system is carried out in the different sectional blocks as follows.

3.4 Voltage Regulator

The LM7805 voltage regulator is a fixed linear voltage regulator integrated circuit (IC). It belongs to the family of the 78xx. The xx is the output voltage. The 7805 has an output voltage of 5V, while others like 7812 has an output voltage of 12V.

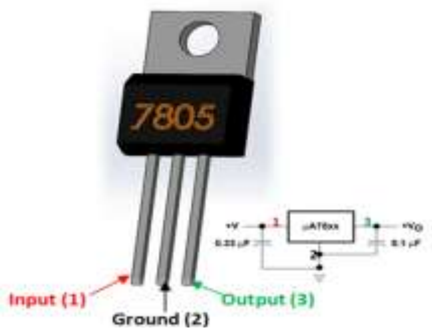


Figure 3.4 Voltage regulator.

3.5 Design of the Microcontroller Unit

The microcontroller unit is made up of the ATmega328p microcontroller, and is designed based on the circuit connection as shown in the figure 3.5 below.

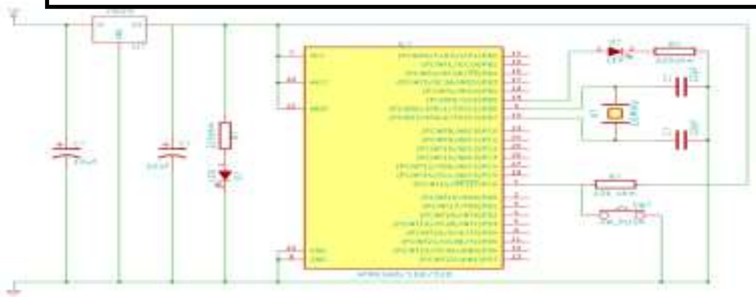


Figure 3.5 Controller circuit connection

The value of the pull-up resistor R3 is obtained by using simple ohms law equation

$R_3 = \frac{V_{cc}}{I_{dc}}$ - - - - - - - (1)

$= \frac{5v}{I392mA}$

$R_3 = \frac{5}{I392mA}$

R_3 =12.755Ω

However, a standard available value of 12Ω was used for the project construction. The time of program execution by the ATmega328p microcontroller is given by

Clock cycle time $t = \frac{1}{F}$ - - - - - - (2)

but f = 16MHz

$t = \frac{1}{16MHZ}$

t = 0.062µs

This is the time taken for the ATmega328p microcontroller to execute one command or instructions before the next. The value of capacitor C2 and C3 were chosen to be 22PF which are used to stabilize the frequency of 16MHz crystal oscillator from external interference machine such as sings, distortion. The external oscillator (16 MHz) with two (2) 22PF capacitors. To know the actual value of the crystal oscillator we have to look into some calculation. using the relation below:

$f_{int} = \frac{f_{quartz}}{4}$ - - - - - - (3)

Where:

f_{int} = is the internal frequency of microcontroller

f_{quartz} = is the frequency of crystal oscillator

From the data sheet of atmega 328p f_{int} = 4MHz (i.e. the internal frequency of the microcontroller).

$f_{quartz} = f_{int} \times 4$

$f_{quartz} = (4 \times 10^6) \times 4$

$f_{quartz} = 16 \times 10^6 H_Z$

=16MHz

The capacitor used with the oscillator is 22PF (from data sheet of 16 MHz crystal).

3.6 Design of the LCD Display Unit

The LCD display unit is made up of a 16×2 LCD display and a 10KΩ variable resistor as shown in figure 3.6 below.

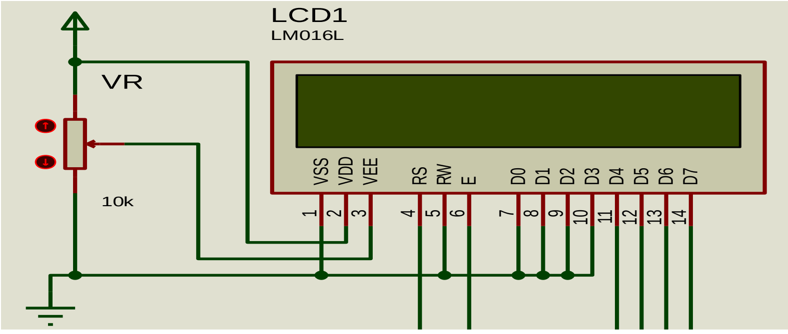


Figure 3.6 LCD display unit

The 10KΩ variable resistor is used to set the contrast of the LCD display and this is $^2/_3$ of the supply voltage that is given by;

Vr = 10kΩ

Set resistance =10$\times\frac{2}{3}$=6.67kΩ

The current required for the brightness of the LCD is given by

$I_{lcd}=\frac{V}{R}$ - - - - - - - - (4)

$I_{lcd}=\frac{5}{6.67}$

= 0.750A

I_{lcd} =750mA

This is the current required to set the brightness or contrast of the LCD to display information without getting overheated or damaged.

3.7 The Atmega328p Microcontroller

The ATtmage328p is a 28 pins 8-bit microcontroller with 32kb flash memory with read-while-write capacities. The ATmega328p is shown in figure 3.7 below.

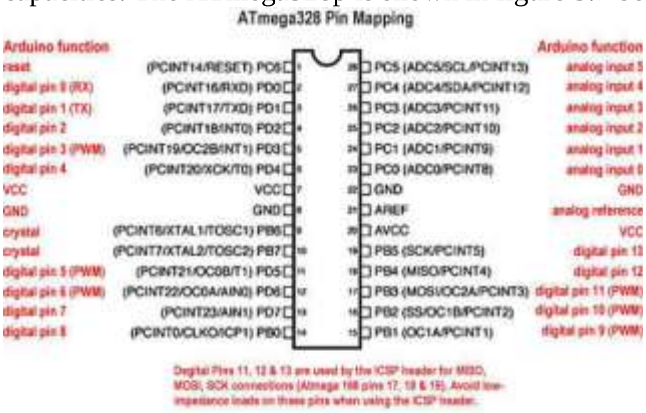


Figure 3.7: ATmega328pin mapping

The ATmega328p microcontroller has an endurance of 1000 write/erase cycle which means that it can be erased and programmed to a maximum of 1000 times without being damage or destroyed. The ATmega328p microcontroller is sometimes referred to as the arduino based microcontroller because of its popularity on the arduino board.

3.8 Voltage Divider Circuit

This circuit determines the unknown resistance of the unknown cable length per kilometre and then sends it to the ADC of the microcontroller through the current limiting resistor. the current limiting resistor is to make sure that current more than 40mA does not enter the MCU for this is capable of destroying it especially when the resistance of the unknown cable is negligible. The ADC of the MUC then converts it to machine language before the MCU can now converts it to length when it compares its value to the reference resistance. The diagram of the voltage divider circuit is as shown in figure 3.8 below:

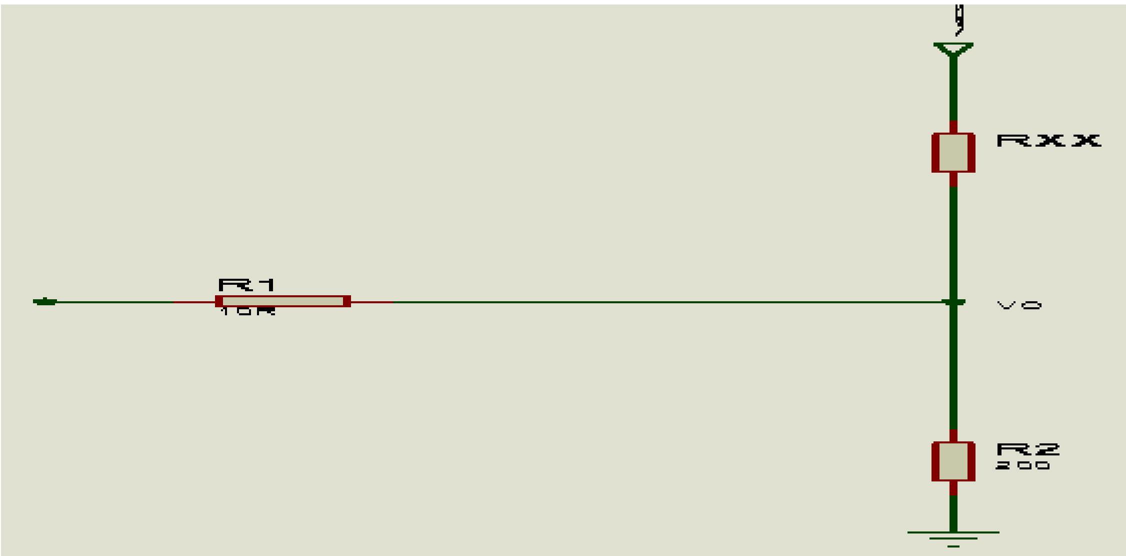


Figure 3.8: Voltage divider circuits

The mathematical calculation is expressed as follows:

$$v_{out} = \frac{V_{cc} \times R_{xx}}{R_{xx}+R} \times R_{xx} \quad (5)$$

$$v_{out} = \frac{V_{out} \times R}{V_{cc} - V_{out}}$$

Where

$V_{out} =$ Voltage drop across the 200Ω fixed resistor.

$V_{cc} =$ Supply voltage which is equal to 5V

$R_{xx} =$ Resistance of the short circuit fault cable to be measured.

R = The resistance of the fixed resistor in the voltage divider (200Ω).

The value from the formula shown above is what the microcontroller uses to determine the length of the short circuit cable.

This section details the stages involved in the construction, including vero board project assembling and packaging.

3.9 Component Soldering

Soldering was done using soldering work station and soldering lead. This process involved appropriate mounting of various components on the vero board with reference to components' layout as shown in plate 3.1 below.

Plate 3.1 Component side of the finished circuit board

Plate 3.2 Project casing

4.1 Performance Evaluations

This chapter is mainly concerned with the testing and assembling of the components on the vero board according to the designed circuit. Testing of individual components, blocks and the entire system was carried out before assembling. The system was initially implemented on a matrix board. When the system worked, it was then transferred on the vero board where the components were properly soldered.

Microcontroller (ATmega 328-Pu), microcontroller socket, voltage divider circuit were soldered on the circuit board, the LCD was pinned to the upper surface of the circuit, while the potentiometer, variable resistor, switch, and the socket for the probe were also placed on and by the side of the plastic casing of the project. Then the whole components and blocks were connected together using wire connectors. The entire circuit can be divided into five units which are;

i. Power supply unit
ii. Microcontroller unit
iii. Analogue digital converter (ADC) unit
vi. Voltage divider unit
v. Potentiometer.

4.2 Testing

A lot of tests were carried out especially before and after the assembling of components. The digital millimetre was of a great use during this process. It was employed in checking for the current and voltage rating at every point in the circuit. It was also employed to determine the resistance value of most components especially resistors. The continuity and short circuit was also tested using millimetre. The test carried out during and after the whole project includes the following.

I. Continuity test
II. Components test
III. Wiring test
IV. Short circuit test
V. Open circuit test
VI. Entire unit test.

4.3 AT mega 328-Pu (Microcontroller)

The two major ports used in the MCU unit are the port B and port D. The port B and port D were responsible for mathematical analysis which is mostly conversion of resistance value to length and also comparing the measured value with the reference value set by the potentiometer and then displays the value in kilometres which tallies with the point of short circuit.

4.4 Analog and Digital Converter

This particular unit converts the analogue (high level language) values to machine language. ADC helps to interpret what happens on the external environment to the microcontroller for mathematical analysis. This includes the reference value set at the potentiometer and resistance value of the short circuit cable, the current and voltage values of the circuit.

4.5 Potentiometer

This is the component or the unit used to set the reference for the wire gauge to be measured in ohm per kilometre. This reference value is what the MCU uses to compare the measured value in order to determine the exact location of the short circuit in kilometres.

4.6 Circuit Operation

the system is energized by means of a switch, the MCU, LCD and entire system get energized. The LCD first boot and then displays the current state of the system either short circuit test or open circuit. Then the reference resistance per kilometre of the wire gauge to be measured is set on the potentiometer. The two terminals of the short-circuited cable are then connected to the probe of the meter and the point of the short circuit is displayed on the LCD in kilometres. When the two terminals of the short-circuited cable were then connected to the probe of the meter the point of the short circuit was displayed on the LCD in kilometres. The results obtained from difference faults and wire gauge were tabulated as shown in tables 4.1 and 4.2 below.

Table 4.1 results obtained from different faults

s/n	Open Circuit	Short Circuit	Faults Location in KM	Remarks
1	Fault occurred	-	1.2	Red and blue phase
2	-	Fault occurred	1.5	Yellow and red phase
3	Fault occurred	-	1.7	Yellow phase
4	-	Fault occurred	2.0	Yellow, blue and red phase
5	-	-	2.5	No fault found

Table 4.2: Copper Wire gauge and Result obtained

Wire gauge measured (mm)	Resistance/kilometres Ω/KM	Distance in (Km)
25	0.672 ohms/km	500 meters
50	0.386 ohms/km	800 meters
70	0.268 ohms/km	1-1.5 km
95	0.193 ohms/km	2-3 km
120	0.153 ohms/km	3-3.5km
150	0.124 ohms/km	1-4 km
185	0.0991 ohms/km	1-5 km
240	0.0754 ohms/km	4-6 km

Table 3 Aluminum wire gauge and Results Obtained

Wire gauge measured (mm)	Resistance /kilometers	Distance in kilometers
50	0.641 ohms/km	600 meters
70	0.443 ohms/km	900 meters
95	0.320 ohms/km	1-2.5 km
150	0.206 ohms/km	2-3 km
185	0.164 ohms/km	3-4 km

5.0 CONCLUSIONS

The system has been experimentally proven to work satisfactorily by connecting two cables of the system to the underground faulted cable from the main source (generating power) which is being detected by the system. The microcontroller ATmege 328p application was successfully tested on different faults locations, thus proving its portability and wide compatibility. The major aim of this project which is locating short circuit, open circuit, and Earth fault in the underground cable without going through the huddles of excavation has been realized. The constructed system could detect flexible faults within the range of 0 to 2.5km of cable length. Any test conducted beyond 2.5km distance could not yielded results.

ACKNOWLEDGEMENT

The researcher which to acknowledge the Tertiary Education Trust Fund (TetFund) for sponsoring this research through the Institutional Based Research (IBR) grant to Federal Polytechnic of Oil and Gas, Bonny

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