Microcontroller-based Cable Fault and Insulation Flaw Detection in Low-Voltage Cables

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Abstract: ***The objective of the work presented here is to detect the exact location of fault or insulation flaw in electrical cables. As described in this report, the system uses two methods. The first one is the principle of a Varley loop to determine the exact distance of the fault in the underground cable up to the accuracy of a meter. When any fault like short circuit and earth fault occurs, the length of the fault of the cable can be determined from the fault resistance using the bridge in the Varley loop. The other method is based on electromagnetic sensing and finds the exact location of the fault. When the current flows through the cable, an electromagnetic field is induced, which is sensed by an inductive coil connected to the electronic amplifier circuit. The microcontroller is used to make the necessary calculations and display the fault distance after that. It also captures the signal from the amplifier and shows a fault or no-fault condition based on the program. This method is a cheaper and simpler alternative to existing ones for detecting cable insulation flaw.***

Keywords: Varley loop; Underground Cable Fault, Arduino; ADC Cable Insulation Flaw; Inductive Electromagnetic Radiation; Arduino.

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1. Introduction

For the low voltage and medium voltage distribution lines, underground cables have been used for many decades worldwide. To reduce the effect of distribution networks to environmental influences, underground high voltage cables are used more and more now. Underground cables have been widely used in power distribution networks due to the advantages of underground connection, involving more security than overhead lines in bad weather, less liable to damage by storms or lightning. It is less expensive for a shorter distance, eco- friendly and required less maintenance [1].

But, if any fault occurs in an underground cable, then it is difficult to locate the fault. So, this paper explains one such method developed to detect the location of the fault in a digital way. There is a great requirement of locating the fault point in an underground cable in order to facilitate quicker repair, improvement of the system reliability and reduced outage period [2].

From the literature reviewed, it is seen that different designs are proposed by different authors for using various methods to locate the faults in underground cables. Variety of methods such as the techniques using Megger, Optical sensing, Electromagnetic Field and Varley loop sensing are being used for fault detection and pin-pointing. The accuracy levels and complexity of the set-up used vary along with the cost of the equipment in various such methods. The earliest techniques recorded in the literature suggest the use of Megger based techniques for locating the fault. The use of optical and electromagnetic methods is relatively new, mainly developed during the last decade [3, 4].

The automatic underground fault locator systems have a higher level of acceptance as compared to manual ones [5]. The automatic fault locator has perceived benefits of protection against any underground faults, i.e., short circuit and open circuit faults. The present system as described in subsequent sections is therefore designed to give the exact distance reading from the feeder end to where the fault occurs in underground cable automatically. Also, it can be taken to any location for operation, whenever the fault occurs and is basically made to serve for the need for a simple and cheap cable fault locator.

A cable fault can be defined as any defect, inconsistency, weakness or non-homogeneity that affects the performance of the cable. All faults in underground cables are different and the success of a cable fault location technique depends to a great extent on practical aspects as well as the experience of the operator. A variety of methods of detecting and locating faults on power transmission cables lines exist using different techniques.[6] In general fault location techniques can be classified into two groups, mainly the tracer method and the terminal method. Most of these methods utilize the measurements from voltage and current transformers at substations or switching stations to perform their analyses. A study as in [7] examines the effectiveness of using magnetic field sensing coils as alternative measurement devices for the purpose of cable fault detection and location.

Faults in cables can be classified as Open circuit fault and Short circuit fault. Open circuit faults are better than short circuit faults, because when these faults occur current flowing through the cable becomes zero. This type of fault is caused by the breaks in conducting path. Such faults occur when one or more phase conductors break [8]. Quick fault detection can help protect equipment by allowing the disconnection of faulted lines before any significant damage is done. Accurate fault location can help utility personnel remove persistent faults and locate areas where faults regularly occur, thus reducing the frequency and length of power outages [9-11].

Due to the simple relationship between current and magnetic field intensity, it is understandable that magnetic field sensors have previously been used in fault detection and location schemes. These schemes often used magnetic field sensors in place of current transformers since magnetic field sensors can be installed independently from a substation or switching station with a minimum amount of additional equipment [12]. The measured magnetic field can be used similar to a current measurement for fault detection and location [13].

1.1 Historical Background

From the literature reviewed, it is seen that different designs are proposed by different authors for using various methods to locate the faults in underground cables. Variety of methods such as Megger technique, Optical sensing, Electromagnetic Field and Bridge methods are being used for fault detection. The accuracy levels and complexity of the set-up used vary along with the cost of the equipment. The earliest techniques recorded in the literature suggest the use of Megger based techniques for the purpose. The use of optical and electromagnetic methods is relatively new, mainly developed during the last decade.

The use of cable thumper is the most accurate method for testing open circuit fault in cable but it has its own drawbacks, as it is time-consuming in detecting longer cables since it requires time to walk through. Moreover, the high voltage surge in the cable may weaken or damage the insulation of the cable. To overcome this Time Domain Reflectometer method is used for detecting open circuit fault as it causes no degradation in the cable insulation. The Murray and Varley loop techniques are the most commonly used technique in testing the underground fault for different bridge methods.

Researchers are trying to develop a new method to detect and locate the fault in cable automatically. Few techniques such as the use of microcontroller and IOT are being implemented to give an accurate location of the fault occurrence in the cable. The use of microcontroller and IoT reduces the complexity in locating the fault and also reduces the time consumption in the operation.

1.2 Motivation

The underground cable fault location has a higher public acceptance and perceived benefits of protection against any underground faults i.e. short circuit and open circuit faults. The system is designed to give the exact distance from the feeder end to where the fault occurs in an underground cable. The main necessities for using automatic cable fault detection is its easy operation, cost-effective, easy to handle and is of low maintenance cost. It can be taken anywhere for operation whenever the fault occurs and is basically made to serve for the betterment of the society.

1.3 Literature Review

In Techniques of locating underground cable faults inside conduits, by Cheung, Gilbert, Y. Tian, and T. Neier [1], they discuss on an integrated cable condition diagnosis and fault localization system via sheath current monitoring and recent progress in the diagnosis of electric power Apparatus using Non-Conventional Partial Discharge Measurement. K. Padmanabhan, G.S Sharon, N. Sudharini, K. Vishnuvarthini in [2] mentioned that underground cables are preferred in many areas specially in urban places. When it is easy to detect and correct the faults in the over-head line by mere observation, it is not possible to do so in an underground cable. As they are buried deep in the soil it is not easy to detect the abnormalities in them. Even when a fault is found to be present, it is very difficult to detect the exact location of the fault. This leads to the digging of the entire area to detect and correct the fault which in turn causes wastage of money and man-power. So, it is necessary to know the exact location of faults in underground cables. Whatever the fault is, the voltage of the cable has the tendency to change abruptly whenever a fault occurs. We make use of this voltage change across the series resistors to detect the fault. The purpose of the paper [3] developed by A. Jagtap, J. Patil, B. Patil, D. Patil, A. A. H. Ansari, A. Barhate is to determine the distance from the base station's underground cable fault in kilometres. In this project, they used a simple concept of ohm’s low. When a fault occurs in the system the distance located on a liquid crystal display (LCD). Until the last decade, cables were designed to be placed above the head and, at present, there is no underground cable that is higher than the previous method. adverse weather conditions such as storms, snow, torrential rains and pollution do not affect underground lines but when a fault occurs in underground lines, it is difficult to locate the fault in an underground cable. They could find the exact location of the fault. Now the world has become digitized, so; this research is to detect the exact location of the fault in digital form. The underground cabling system is a more common practice in many urban areas. Although the fault occurs for some reason, at that time, the repair process for this particular cable is difficult because of not knowing the exact location of the cable breakdown. G. Ojha, A.G. Roy, R. Verma, V. Kumar developed a method to detect the fault and the distance at which the fault has occurred is calculated [4]. The fault location in the underground cable is a bit cumbersome process so to deal with such problem a method is given in this research. To determine the location of fault, a series resistor is used and the voltage across this resistor is measured and then is sent to the microprocessor to calculate the distance at which the fault has occurred. This is a safe and cheap method for obtaining the fault location in an underground cable. This method also does not have a high-power requirement and is portable too.

T. Nandini, Shalini, T. Sai Sangeetha, D. Gnanaprakasam developed a project to detect the location of the fault in underground cable lines from the base station to exact location in kilometres using an Arduino microcontroller kit [5]. In the urban areas, the electrical cable runs in undergrounds instead of overhead lines. Whenever the fault occurs in the underground cable, it is difficult to detect the exact location of the fault for the process of repairing that particular cable. The proposed system finds the exact location of the fault. This system uses an Arduino microcontroller kit and a rectified power supply. Here the current sensing circuits made with a combination of resistors are interfaced to Arduino microcontroller kit to help of the internal ADC device for providing digital data to the microcontroller representing the cable length in kilometres. The fault creation is made by the set of switches. The relays are controlled by the relay driver. A 16x2 LCD display connected to the microcontroller to display the information. In case of a short circuit, the voltage across series resistors changes accordingly, which is then fed to an ADC to develop precise digital data to a programmed Arduino microcontroller kit that further displays exact fault location from the base station in kilometres. Whenever a fault occurs in a cable, the buzzer produces the alarm to alert and to take immediate action by field workers. The Study of 3-Ph Underground Cable Fault Locator Using Acoustic Method as described in [6] by G.S. Darvhankar describes the technique for detecting faults in the underground distribution system is presented. An HV surge tester is used to generate a spark at fault position which produces noise and vibrations in the fault site. This noise is picked up with the help of sensitive ground microphone which is further amplified in surge wave receiver set and exact fault point is located by detecting the fault having maximum noise and vibrations. The result is found that the proposed technique provides satisfactory result and will be very useful in the development of power systems protection scheme.

Underground Cable Fault Distance Locator by A. Sharma [7] aimed to detect the location of the fault in underground cable lines. The proposed system finds the exact location of the open-circuit fault. This system uses an 16F887 microcontroller and a rectified dc supply. Here, the project uses a capacitance method. When the current is flowing through to the wire than the electromagnetic field is induced which is sensed by a Darlington pair i.e. it removes an unwanted noise than it will be filtered and then pass through a voltage regulator gives a constantly 5v supply and then embedded IC is used to represent a fault. The project is assembled with the capacitance method and representing fault in terms of yes or no. The fault occurring at a particular distance is displayed on a Liquid crystal display (LCD) interfaced to the microcontroller 16x2 LCD display connected to the microcontroller to display the information. This project deals with a microcontroller, buzzer and LCD. This proposes greatly reduces the time and operates effectively.

Fault Location for Power Transmission Systems Using Magnetic Field Sensing Coils by K. J. Ferreira [8] describes the various methods of detecting and locating faults on power transmission lines exist. Most of these methods utilize the measurements from voltage and current transformers at substations or switching stations to perform their analyses. This thesis examines the effectiveness of using magnetic field sensing coils as alternative measurement devices for the purpose of fault detection and location. Fault Location on a Transmission Line Using High Frequency Travelling Waves Measured at a Single Line End by M. Aurangzeb describes how travelling waves measured at one end of a transmission line can be used for fault location [9]. The algorithm indicates which phases are involved in the fault and uses auto-correlation on the recorded faulted phase to give an initial estimate of the fault position. A fault at this position and involving the indicated phases is then applied to an EMTP simulator that models the power network in the region around the fault locator. The transient components in the current signals generated by the simulator, and measured at the same location as the fault locator is then cross-correlated against the signals captured on the actual power network. Travelling Waves Based Earth Fault Location in 400kV Transmission Network Using Single End Measurement by A. Elhaffar in [10] investigates the problem of fault location based on transient signals obtained at single-end of the transmission line. Current travelling waves are utilized to locate faults on the transmission system. In this paper, a review of different travelling wave methods in fault location is presented. The wavelet transforms are used for analyzing power system fault transients to determine the fault location and to provide time resolution for the high-frequency components of the fault transients. These signals are decomposed into their modal components. Wavelet transform is found to be an excellent tool for identifying the travelling wave reflections from the fault. Validation of fault location is carried out by ATP/EMTP simulations for typical 400 kV power system faults. Fault location using Wavelets by F.H. Magnago [11] describes the use of wavelet transforms for analyzing power system fault transients in order to determine the fault location. Travelling wave theory is utilized in capturing the travel time of the transients along the monitored lines between the fault point and the relay. Time resolution for the high-frequency components of the fault transients, is provided by the wavelet transform. This information is related to the travel time of the signals which are already decomposed into their modal components. Fault Detector with Improved Response Time for Electrical Transmission System J. R. McBride, Mauldin, S.C [12] use electromagnetic sensing method for locating the fault. These schemes often used magnetic field sensors in place of current transformers since magnetic field sensors can be installed independently from a substation or switching station with a minimum amount of additional equipment. Fault Detection and Location System for Power Transmission and Distribution Lines by M. L. Kejariwal, B. Thapar discusses the method of finding the faults which occur in an electrical pole through the feeder in power system [13]. The fault detection apparatus includes detecting coils mounted on the static line on either side of each pole, and a third detecting coil positioned so as to detect an orthogonal magnetic flux due to a phase-to-phase fault. A microprocessor on each pole analyzes the type of fault from the output of the three coils, and transmits the identification of the pole and pertinent fault data, when appropriate, to a repeater system. Thus, fault information from an entire power system can be fed through the repeater system into a central location. General methods for cable fault location in underground cables published by the DneproEnergoTechnologiya Ltd describes in [14] that whenever a fault occurs in the system, one must determine the kind of fault and the exact location which it occurs. Determine the distance to a fault with the help of a low-voltage, or high-voltage time-domain reflectometer TDR. The cable line is traced with a sound frequency generator (GZCH-2500) and the induction receiver (POISK-2006M or P-806) (i.e, to determine the route of underground cable on the ground surface) and to limit fault area, i.e, the area within which it is located. IOT based underground cable fault detector by N. Sampathraja [15] proposed a system of detecting a short circuit fault of the underground cable by using a PIC16F877A controller. The fault distance, phase and time detected is displayed on the LCD 16X2 screen display. This system uses the basic Ohms law, when the fault occurs in the cable, the voltage varies and is used to calculate the fault distance. The system uses Wi-Fi module, microcontroller and Real-Time clock. The ADC of the microcontroller provides the magnitude of the voltage drop across the resistor based on this voltage the distance of the fault is located. Here, the real-time clock DS1307 is connected to the microcontroller to display the time at which the fault has occurred. The fault occurred will be sent to display in the webpage using Wi-Fi module. Underground cable fault detection using IOT by Henna Sam E.J. [16] shows that the various existing methods, such as the tracer method and the terminal method are used for cable fault detection. The tracer method is a way to locate the underground fault by walking through the cable circuits. This method includes tracing approach through acoustic, electromagnetic or current. The terminal method is a technique used for testing cable faults from the feeding end station without walking through the cable lines exhaustively. A bridge technique is the most approved methods that link with the resistor to determine the fault. The input and output ports of Microcontroller, LCD display, RTC and Wi-Fi module of the system are configured and initialized. When a fault occurs (switch is pressed), the fault distance, time and phase are displayed corresponding to that fault. The above fault information will be displayed in the webpage using Wi-Fi module. The prototype uses resistors to represent the cable length. The resistors RR1 to RR5 represents R-phase of the cable. Similarly, RY1 to RY5 and RB1 to RB5 represent

Y and B phase of the cable. RN1 to RN12 are used to represent the neutral lines. To represent the occurrence of fault in underground cables, switches are used. Each phase is connected with a relay, which in turn is connected to Port C of Microcontroller. When there is no fault, the LEDs connected to each relay glows. When a switch connected to a particular phase is closed, the LED connected to the particular phase alone glows. The resistance connected to that particular phase adds up and the voltage drop thus generated is given to Port A of the Microcontroller. The voltage drop is converted to distance and is displayed in the LCD. Additionally, the pin of Port C connected to that particular LED goes high and the name of the faulted phase is displayed in the LCD. The Real-Time Clock DS1307 is connected to Port C of the microcontroller to display the time at which fault has occurred. For every clock period, the time gets incremented. During a fault, SCL pin of RTC synchronizes the data and SDA pin transmits data to the Microcontroller, which is displayed in the LCD. The switch over connection is activated during fault period of the cable to transmit uninterrupted power supply. Analysis of fault and its location using microcontroller for underground cable by S. Sahana, H.K.P Kumar [17] describes the various elements and devices used in the system. This paper uses different sensor devices for detecting the various types of fault (open circuit fault under-voltage fault, over-voltage fault, short circuit fault) which may occur in the cable. The corresponding changes in the current and voltages help in determining the type of fault in the cable. The sensors will send the received signals to the controller via the Monostable Multivibrators and interfacing stage (the buffer, driver and the relay unit). The voltage drop will be fed at the microcontroller by the ADC unit and make a necessary calculation for locating the fault. GSM is an interface to the system for transmitting the data to the receiving station. Here, the data received at the receiving station are displayed using MATLAB coding. Underground cable fault detection using Robot are described in [18] by J. Althaf is based on how the Robot is designed to detect the fault using a signal injector, low-frequency signal to pass through the wire and the electromagnetic field developed is used to detect the fault. The basic principle used in this system is Faraday’s law. If a current is flowing inside the wire, there will be an EMF generated inside it. An inductor is used in this case for a voltage using the EMF. When there is a short circuit in the cable the EMF generated will be zero and the voltage developed will be negligible, the condition is provided where the voltage less than 20(binary values), the robot will stop and there is a point of discontinuity at that location and the alarm circuit will trigger. An accurate fault locator for underground distribution networks using modified apparent impedance calculation by T.A. Kawady [19] proposed a new fault algorithm for underground cable. The algorithm is able to calculate the fault distance, which depends on the basic impedances with the different characteristics of the cable segment. This system uses MATLAB-Simulink to compare the performances with the original apparent impedance approach. This proposed test method is able to detect a wide variety of fault resistance and loading circumstances. The test results confirm the efficiency of the proposed algorithm for locating fault in the underground system. Development of prototype underground cable fault detector by D. Dharani [20] describes the use of a prototype for detecting the fault distance in the cable. The prototype uses the simple Ohms law principle. The current varies depending on the length of the fault occur at the cable. A set of resistors are used representing the cable in Km distances. Manual switches are used to set the fault on the cable. A fault occurring at a distance with the phase of the cable is displayed at the LCD display, which is interfaced with the microcontroller. This paper also explains the different common fault occurring in the underground cable, such as the open-circuit fault, short circuit fault and earth fault. The Murray loop bridge is used in this prototype for calculating the resistance of the faulty cable and for finding out the distances. Underground Cable Fault Distance Detector using ATmega328 Microcontroller by T. Kedia, V. Sahare in [21] describes that short circuit fault in the form of a line to ground is detected. They have used the terminal method for finding out the distance of the faulty part of the cable, as in many cases developed by other microcontroller devices. Here, Time Domain Reflectometer (TDR) is also used for sending low energy signals through the cable. This paper explains how they have used the relay and the relay driver to drives the bulb load to indicate the fault, which occurs at any phase and trips the power supplies to the set of resistors of the corresponding phases. In the paper, it is shown that the test is performed under simulation form and they have found out the result of the fault location of the cable.

2. Cable fault detection using Varley Loop Method

2.1 Varley Loop Method

In the present work, Varley loop-based testing method is used for locating short-circuit and earth faults in underground cables. This test employs the principle of the Wheatstone bridge [8].

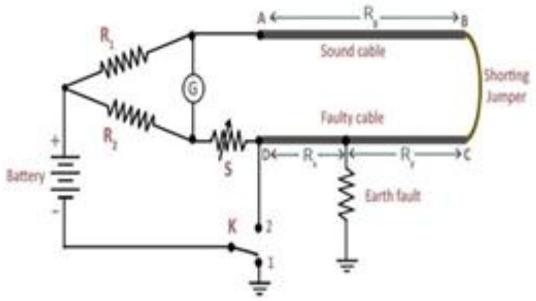

Figure 1: Varley loop method for earthed fault

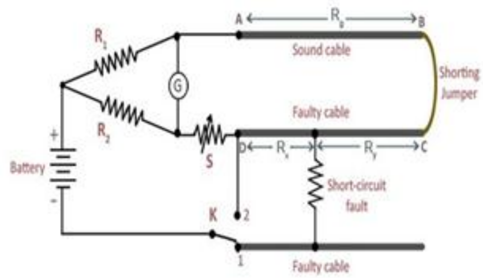

Figure 2: Varley loop method for short circuit fault

To locate fault using Varley loop, connections are done as shown in the circuit diagram of Figure 1 and 2. Resistors R1 and R2 are fixed and the resistor S is variable. A stepper motor is to be used to vary the resistance to bring the bridge to a balanced condition. The balanced resistance value will be given to the microcontroller for applying that value to the program to be developed. The program will automatically calculate the distance of fault, based on the algorithm to be developed during the experimentation.

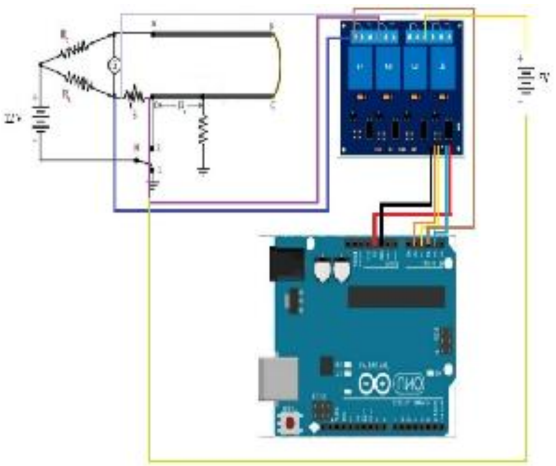

Figure 3: Circuit diagram of automatic cable fault distance locator

2.3 System Design of Varley Loop Method

In this research, we have used a Varley loop method for locating short circuit and earth fault faults in underground cables. This method employs the principle of Wheatstone's bridge. The resistances R1 and R2 are fixed, and a variable resistor S is inserted in the faulty leg. In this test, the switch K is first thrown to position 1. Then the variable resistor S is varied till the galvanometer shows zero value (i.e. the bridge is balanced).

Let's say, the bridge is balanced for the value of S equal to S1. Then,

$$\frac{R_1}{R_2} = \frac{R_g + R_y}{R_x + S_1}$$

Let, $R_g + R_y = R_3$

$$\frac{R_1 + R_2}{R_2} = \frac{R_3 + R_x + S_1}{R_x + S_1}$$

$$R_x + S_1 = \frac{R_2\,(R_3 + R_x + S_1\,)}{R_1 + R_2}$$

$$R_x = \frac{R_2\,(R_3 + R_x) - R_1 S_1}{R_1 + R_2} \qquad (1)$$

Now, the switch K is thrown to the position 2 and the bridge is balanced by varying the resistor S is equal to S2. Then,

$$\frac{R_1}{R_2} = \frac{R_3 + R_x}{S_2}$$

$$R_1\, S_2 = R_2\,(R_3 + R_x) \qquad (2)$$

Now, putting the result of eq. (2) in eq. (1),

$$R_x = \frac{R_1\,(S_2 - S_1)}{R_1 + R_2}$$

Since the values of R1, R2, S1 and S2 are known, R_x can be calculated. When R_x is known, the distance from the test end to the fault point L_x can be calculated as,

$$L_x = R_x/r$$

Where, r = resistance of the cable per meter.

Now, when the bridge is in a balanced condition, the relay module consisting of 3 relays will be interfacing with the Varley loop circuit. The relay 1 and relay 2, which is connected between the two ends of the terminal of variable resistor S trips, when the galvanometer reads zero value and therefore the relays 3 which is connected as shown in the figure 3 will then extract the balanced resistor which will then be fed to the Arduino for distance calculation from the equation $L_x = R_x/r$.

2.2 Block Diagram

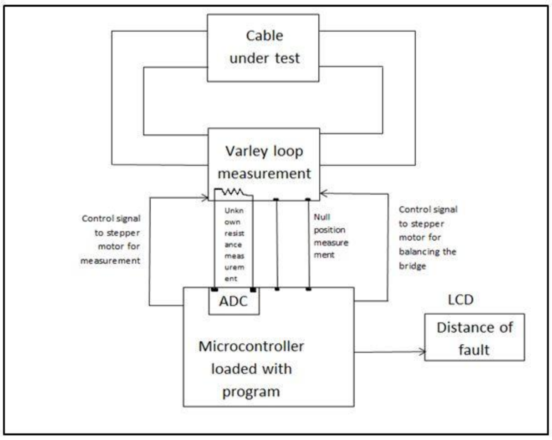

Figure 4: Block diagram of automatic cable fault distance locator

At first, the Varley loop bridge is brought into a balanced condition. The variable resistor is used to vary the resistance to bring the bridge to the balanced condition.

The relays are connected across the terminals of the variable resistor S. The relays will be operated (tripped) by a signal sent from the microcontroller when the bridge is in a balanced condition. The balanced resistance value will then be given to the microcontroller. The change in resistance will then be converted automatically to the faulty distance of the cable. The program has been developed for making the system automatic.

2.4 Microcontroller Based Automatic Cable Fault Distance Locator

Algorithm:

The microcontroller is interfaced with the relay module circuit. The analog pins of the microcontroller are connected with the input pins of the relay module, which consists of three relays to be operated. The Vcc pin of the relay module is supplied from the Arduino board. Accordingly, the contacts of the relays are connected as shown in the above circuit diagram. These contacts operate according to the program being fed from the Arduino microcontroller and therefore the required operation works satisfactorily.

The algorithm for the program is as the following:

Step 1: Start.
Step 2: Initialize the pin modes and variables (pot resistance), and flag variables.
Step 3: Voltage analog read by the ADC.
Step 4: Check for voltage value.
Step 5: When voltage = 0, set pin A1, A2, A3 high and low to pin A4 and read analog voltage across the resistance (pin A4).
Step 6: Converting voltage to resistance value.
Step 7: Print resistance value.
Step 8: Else if voltage > 0, set A1, A2, A3 low and make A4 high.
Step 9: Halt.

2.5 Components Used

Table 1: Components used in automatic cable fault distance locator using arduino

	NAME OF COMPONENTS	RATINGS	QUANTITY
1	Arduino Microcontroller	ATMEGA328P	1
2	Battery	12V	1
3	Liquid crystal display (LCD)	16*2	1
4	Resistors	470Ω, 100Ω, 220Ω, 47Ω	1(each)
5	Resistors	330Ω	1
6	Variable resistance	10Ω	1
7	Relay Table	5V	3

2.6 Implementation

This research can be implemented on underground cable. In the present work, only low voltage cables were tested with. However, a slight modification can lead to the implementation of the same technique for high voltage cable fault detection also.

2.7 Experimental Results and Analysis

The output results obtained from the microcontroller are shown in Figure 5, when the voltage across the galvanometer goes higher than zero value, which implies that it is in unbalanced condition.

The output result of the voltage when the bridge is in the balanced condition is shown in Figure 6. During a balanced condition, the voltage value is zero and therefore the Arduino reads the resistance value from the Varley loop circuit and displays in the serial monitor of the Arduino. Figure 5 and figure 6 shows the results after experimenting.

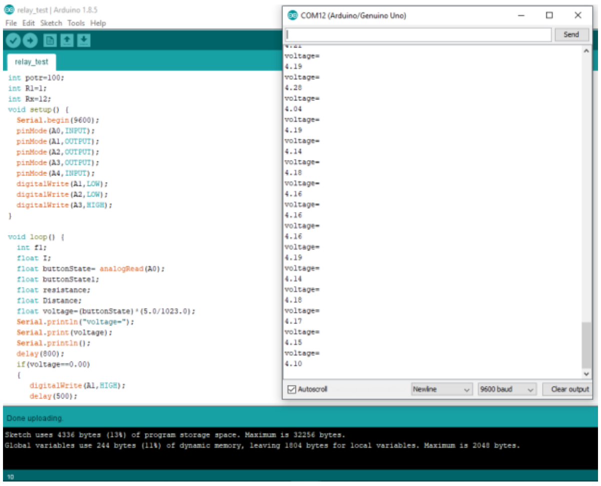

Figure 5: Output result during the unbalanced condition

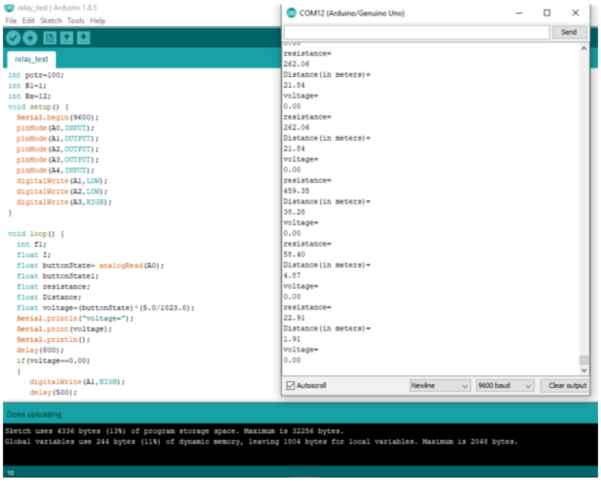

Figure 6: Output result during balanced condition

During the testing of the setup, it was found that if the unknown resistance value is very small, then it is difficult to bring the bridge to the balanced condition. The bridge is very sensitive and the voltage deflects randomly if the unknown resistance is very small. But through much continuous trial, the voltage could be made stable, by choosing proper ratings of standard arm resistances. After that, the bridge could be interfaced with the Arduino for making the system automatic.

The relay module is interfaced with the microcontroller and when the voltage across the galvanometer is higher than zero value, the relays do not trip. But as soon as the Arduino reads zero value it automatically sends signals for tripping the relays.

3. Cable fault detection using Electromagnetic Sensing

3.1 Electromagnetic sensing technique

The current methodology is based on the measurement of electromagnetic radiation of fault location. The fault may or may not lead to significant short circuit current flow from the fault location. The electromagnetic field created in the flaw in the insulation is detected using the inductive sensor. The detailed methodology is explained in the following section.

The present cable fault and insulation flaw detection technique is developed with the following objective:

i. To determine whether the cable has a flaw or not.
ii. To determine the location of the fault.
iii. To trace the cable line with an inductive sensing technique.
iv. To locate and pinpoint the fault point or flaw location within the area of the fault.

Induction method for cable fault location is based on the fact that during current flowing through a cable a magnetic field is created around the cable. The nature of the distribution of this field depends on many factors such as cable structure, the connection method of the generator, a type of fault, presence of a cable sheath contacts with ground, puncture in insulation, uneven insulation etc.

The induction sensor transforms the above-mentioned magnetic field into an electrical signal, which is then amplified, and converted into a voltage signal. Under certain conditions, the magnetic field around cable fault location increases sharply, which is an indication of the fault location during cable fault location process.

To find a route of a cable line and point of fault with the induction method, the receiver package includes a remote inductive sensor and the receiver having a resonant narrowband amplifier.

The inductive sensor consists of a cylindrical multi-turn coil, winded on either ferrite core or air core. It is important to understand that such sensor, with respect to the variable magnetic field, shows different sensitivities. The signal will be minimal or absent, if the magnetic field lines are weak due to insulation on the cable. At flaw or puncture locations, the magnetic field will be stronger and the same will be detected by the inductive sensor.

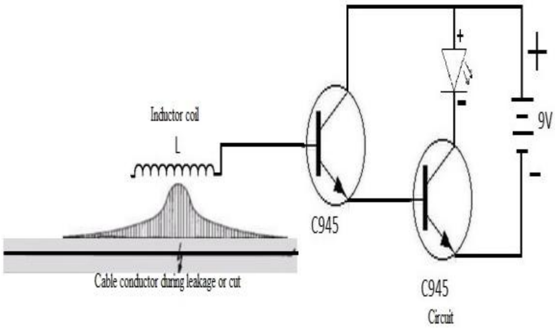

Figure 7: Cable fault detection technique

3.2 System design of electromagnetic sensing technique

Figure 8 shows the total experimental set-up for cable insulation flaw detection.

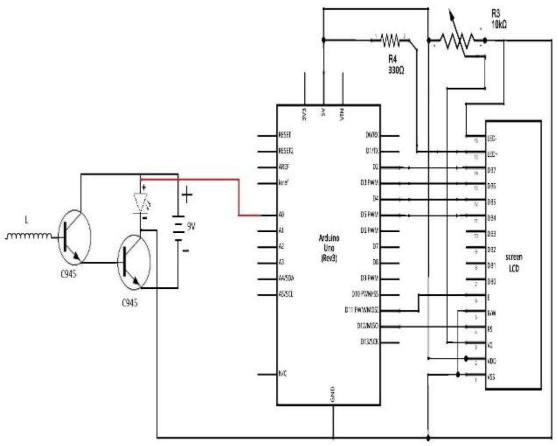

Figure 8: The circuit diagram of electromagnetic sensing technique.

The circuit uses direct current (DC) supply of 9-volt. When the inductor coil is placed near the test conductor, current flowing through the conductor will start inducing electromagnetic field in the inductor coil and this induced field produces an induced voltage in the coil. This voltage is then amplified using a Darlington pair. A LED attached to the circuit will glow according to the induced voltage. The amplified voltage is then fed to the analog input pin of the microcontroller. The microcontroller is programmed to send display command to the LCD based on the following algorithm:

If ($V_{in} \geq$ Threshold)
Send signal to LCD ("Fault")
Else
Send signal to LCD ("No Fault")

Table 2: Indication of fault by LCD

LED INDICATION	LCD INDICATION	INFERENCE
High Glow	Fault	Fault/ Flaw in insulation
No Glow	No fault	No Fault/ No Flaw in insulation

During the process of testing the cable, the inductor coil is run over the surface of the cable and when there is no leakage or cut on the conductor it indicates that the cable is working under normal condition. In this case, the LED will not glow.

While running the inductor coil over the surface of the conductor when there is any leakage or any cut on the cable the LED will glow instantaneously. Table 2 shows the indication by the LCD display, both during fault and no-fault.

3.3 Block diagram

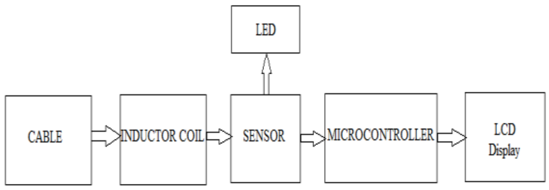

Figure 9: Block diagram cable fault detection using electromagnetic sensing.

The inductor coil is placed near the test conductor, the current flowing through the conductor will start inducing electromagnetic field in the inductor coil and this induced field produces an induced voltage in the coil.

This voltage is then amplified using a Darlington pair in the sensor circuit. A LED attached to the circuit will glow according to the induced voltage. The amplified voltage is then fed to the analog input pin of the microcontroller.
The microcontroller is programmed to send display command to the LCD.

3.4 Microcontroller based automatic cable fault distance locator

Algorithm:

The microcontroller is interfaced with amplifier circuit. The analog pins of the microcontroller are connected across the LED terminals. Accordingly, the terminals are connected as shown in the above circuit diagram and send the signal to the microcontroller to operate. The required operation works satisfactorily.

The algorithm for the program is as the following:

Step 1: Start.
Step 2: Initialize the pin modes, variables and number of rows and column displaying in the LCD
Step 3: Voltage analog read by the ADC.
Step 4: Check for voltage value.
Step 5: When voltage ≤ 1.49, print “No Fault” in the LCD screen.
Step 6: Else if 1.8≤voltage≤ 2, print “Fault” in the LCD screen.
Step 7: Halt

3.5 Components used

The components used for the work are shown in Table 3.

Table 3: Components used in electromagnetic sensing technique

Sl. No.	NAME OF COMPONE-NTS	RATINGS	QUANTI-TY
1	Microcontroller	ATMEGA 328P	1
2	Battery	9 V	1
3	LCD	16x2	1
4	Inductor coil	10mH	1
5	Variable Resistors	10 Ω	1
6	Transistor	C945	2
7	LED	9V	1

3.6 Experimental results and analysis

Below are the results of testing done on different conductor cables:

Table 4: Experimental results during testing of faults on the conductor cable

CABLE CONDITION	LED INDICATION	VOLTAGE MEASURED AT THE OUTPUT OF THE AMPLIFIER (mV)
Fault	High Glow	4-5
Healthy	No Glow	0-4

As we can see from Table 4, during experimenting on the conductor cable, the voltage has a different range as shown in the table when the LED glows and when the LED does not glow. So, using these types of microcontroller was programmed.

Table 5: Experimental results during testing of faults on a mobile charger cable

CABLE CONDITION	LED INDICATION	VOLTAGE MEASURED AT THE OUTPUT OF THE AMPLIFIER (mV)
Fault	High Glow	4.3-5
Healthy	No Glow	0-4

Similarly, during experimentation on a charger cable, the voltage ranges as shown in Table 5 were measured and accordingly the programming was done on the microcontroller to show the LCD display of Fault/ No fault.

Comparing the level of voltages as seen from the above two sample tables, it could be concluded that the range of voltages observed during no-fault and during fault are almost similar in different types of cables. Hence, the microcontroller can be configured to show fault/ no-fault locations using the voltage inputs.

Figure 10 and Figure 11 show the experimental set-up for the cable insulation flaw detection using electromagnetic radiation sensing technique. The display shows cable fault in case of a flaw in the insulation detected by the inductive sensor.

Figure 10: Depiction through photo of the experimental set-up during no-fault

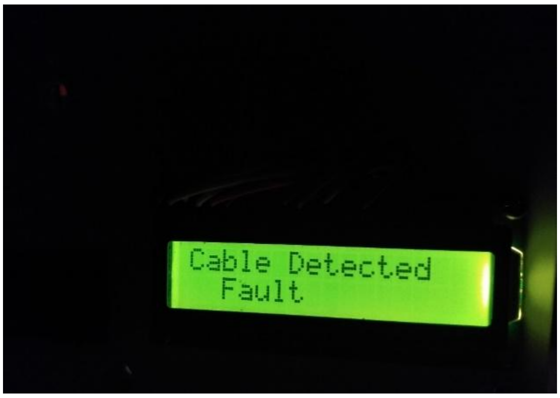

Figure 11: Detection of cable fault during experimentation

4. Conclusion and future work

In the present research work, it was intended to study the process of detection of the exact location of circuit fault in the underground cables from the feeder end in few meters by using an Arduino microcontroller. The Arduino microcontroller is used to detect the changes in output voltage of the bridge circuit. As soon as fault occurs in the cable, the bridge is balanced at some other resistance than the normal condition. That resistance is then used to produce the voltage across the analog input ports of the microcontroller and thus the fault location is determined using an algorithm.

The research work using Varley loop test is expected to detect the fault by detecting the resistance, which in turns can be translated in to distance using an algorithm. Then the microcontroller is used to display the fault distance from the source end in the LCD display. A novel technique of cable insulation flaw detection using microcontroller based on inductive sensing of electromagnetic radiation from faulty location. The device senses the electromagnetic field in the cable continuously. When the device is near the fault point it senses the high electromagnetic signal and tells us that there a fault in that location. Thus, this technique can be very effective in detecting the location of the cable insulation flaw in all types of cables. This is cheaper and simpler technique with high reliability.

This research work can be extended for the following purposes by doing further research.

i. Application of the developed methods for HV cable fault detection with some modifications in the circuits.
ii. Incorporating acoustic signal in fault detection for underground location of the fault point.
iii. The cable insulation flaw detection can be extended to advanced level by incorporating microwave-infrared based techniques.

References

[1] G. Cheung, Yuan Tian and T. Neier, "Technics of locating underground cable faults inside conduits," in *2016 IEEE International Conference on Condition Monitoring and Diagnosis (CMD 2016)*, Xi'an, China, 25-28 September 2016, pp. 619-622. doi: 10.1109/CMD.2016.7757954

[2] K. Padmanaban, G. S. Sharon, N. Sudharini and K. Vishnuvarthini, "Detection of Underground Cable Fault Using Arduino," *International Research Journal of Engineering and Technology (IRJET)*, vol. 4, no. 3, pp. 2451-2454, Mar 2017. Available: http://www.academia.edu/33479505/Detection_of_Underground_cable_fault_using_Arduino

[3] A. Jagtap, J. Patil, B. Patil, D. Patil, A. A. H. Ansari and A. Barhate, "Arduino based Underground Cable Fault Detector," *International Journal for Research in Engineering Application & Management (IJREAM)*, vol. 3, no. 4, pp. 88-92, May 2017. Available: http://www.academia.edu/33635671/Arduino_based_Underground_Cable_Fault_Detection

[4] G. Ojha, A. G. Roy, R. Verma and V. Kumar, "Underground Cable Fault Distance Locator," *International Journal of Advance Research, Ideas and Innovations in Technology (IJARIIT)*, vol. 3, no. 2, pp. 550-552, March 2017. Available: https://www.ijariit.com/manuscripts/v3i2/V3I2-1364.pdf

[5] T. Nandini, J. Shalini, T. S. Sangeetha and D. Gnanaprakasam, "Underground Cable Fault Detection using Arduino," *International Journal of Engineering Science and Computing (IJESC)*, vol. 7, no. 4, pp. 6460-6462, April 2017. Available: http://ijesc.org/upload/47eea5901e73e8ae6aca4d6319d89128.Underground%20Cable%20Fault%20Detection%20using%20Arduino.pdf

[6] G. S. Darvhankar, A. S. Gharpande, S. D. Bhope, A.S. Meshram and J.A. Bobade, "Study of 3-ph Underground Cable Fault Locator Using Acoustic Method," *International Journal of advance Engineering and Research Development*, vol. 2, no. 1, pp. 124-128, January 2015. Available: http://www.ijaerd.com/papers/finished_papers/STUDY%20OF%203-ph%20UNDERGROUND%20CABLE%20F

AULT%20LOCATOR%20USING%20ACOUSTIC%20METHOD-12509.pdf

[7] A. Sharma, A. Mathur, R. Gupta, R. Singh and M. Singh, "Underground Cable Fault Distance Locator," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 6, no. 4, pp. 2581-2585, April 2017. Available: https://www.ijareeie.com/upload/2017/april/69_UNDERGROUND.pdf

[8] K. J. Ferreira, "Fault Location for Power Transmission Systems Using Magnetic Field Sensing Coils," MS Thesis, Electrical and Computer Engineering, Worcester Polytechnic Institute, United States, April 2007. Available: https://web.wpi.edu/Pubs/ETD/Available/etd-050707-120755/unrestricted/kferreira.pdf

[9] M. Aurangzeb, P. A. Crossley and P. Gale, "Fault location on a transmission line using high frequency travelling waves measured at a single line end," *2000 IEEE Power Engineering Society Winter Meeting. Conference Proceedings (Cat. No.00CH37077)*, Singapore, 2000, pp. 2437-2442, vol.4. doi: 10.1109/PESW.2000.847191

[10] A. Elhaffar and M. Lehtonen, "Travelling waves based earth fault location in 400 kV transmission network using single end measurement," *2004 Large Engineering Systems Conference on Power Engineering (IEEE Cat. No.04EX819)*, Halifax, NS, Canada, 2004, pp. 53-56. doi: 10.1109/LESCPE.2004.1356266

[11] F. H. Magnago and A. Abur, "Fault location using wavelets," in IEEE Transactions on Power Delivery, vol. 13, no. 4, pp. 1475-1480, Oct. 1998. doi: 10.1109/61.714808

[12] Fault Detector with Improved Response Time for Electrical Transmission System, by J. R. McBride. (1983, Oct. 4). *US Patent, US4408155A*. Accessed on: Oct. 4 2019. [Online]. Available: https://patentimages.storage.googleapis.com/d9/a9/0c/716d6285b76a7a/US4408155.pdf

[13] Fault detection and location system for power transmission and distribution lines, by M. L. Kejariwal, B. Thapar, V. Gerez and D. March. (1994, Aug. 30), *US Patent, US5343155A*. Accessed on: Oct 4, 2019. [Online]. Available: https://patentimages.storage.googleapis.com/9e/dc/41/423d9a9d7c3eb9/US5343155.pdf

[14] Dnepro Energo Technologiya Ltd, "*General methods for cable fault location in underground cables*", Dnepro Energo Technologiya, Feb. 14, 2016. [Online]. Available: http://detec.com.ua/news/general_methods_fof_cable_fault_location_in_underground_cablec/. [Accessed: 2 Sept. 2019]

[15] N. Sampathraja, L. A. Kumar, V. Kirubalakshmi, C. Muthumaniyarasi and K. V. Murthy, "IOT Based Underground Cable Fault Detector," *International Journal of Mechanical Engineering and Technology*, vol. 8, no.8, pp. 1299-1309, August 2018. Available: https://iaeme.com/MasterAdmin/uploadfolder/IJMET_08_08_132/IJMET_08_08_132.pdf

[16] H. Sam E. J., Pavithra U. H., Ramakrishnan P. V., R. Basha S and T. M. S. kumar, "Underground Cable Fault Detection Using IOT," *Asian Journal of Applied Science and Technology (AJAST)*, vol. 5, no. 2, pp. 737-746, April-June 2018. Available: http://ajast.net/data/uploads/5003.pdf.

[17] S. Sahana, B. M. Harish, S. M. Annu, H. V. Vani, T. Sudha and H. K. P. Kumar, "Analysis of Fault Detection and Its Location Using Microcontroller for Underground Cables," *International Research Journal of Engineering and Technology (IRJET)*, vol. 4, no. 6, pp. 1873-1878, June 2018. Available: https://www.irjet.net/archives/V4/i6/IRJET-V4I6358.pdf

[18] J. Althaf, M. Imthiaz and R. Raj, "Underground Cable Fault Detection Using Robot," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 3, no. 2, pp. 145-151, April 2013. Available: https://www.iaescore.com/journals/index.php/IJECE/article/viewFile/5469/5008

[19] T. A. kawady, A. I. Taalab and M. El-Sad, "An accurate fault locator for underground distribution networks using modified apparent-impedance calculation," *10th IET International Conference on Developments in Power System Protection (DPSP 2010)*. Managing the Change, Manchester, 2010, pp. 1-5. doi: 10.1049/cp.2010.0302

[20] D. Dharani. A and Sowmya. T, "Development of a Prototype Underground

Cable Fault Detector," *International Journal of Electrical, Electronics and Computer System (IJEECS)*, vol. 2, no. 7, pp. 17-21, 2014. Available: http://www.irdindia.in/journal_ijeecs/pdf/vol2_iss7/4.pdf

[21] T. Kedia, V. Sahare, K. K. Bauri, R. K. Sahu, S. Kumar and A. Lal, "Underground Cable Fault Distance Detector Using ATmega328 Microcontroller," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE)*, vol. 6, no. 10, pp. 8018-8026, October 2017. Available: http://www.ijareeie.com/upload/2017/october/19_3_Final%20Research%20Report.pdf

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