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ARDUINO MICROCONTROLLER BASED UNDERGROUND CABLE FAULT DISTANCE LOCATOR

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ABSTRACT

The growing concern for safety and infrastructural proliferations in the densely populated urban and suburban areas as well as the quest to preserve the aesthetic values in many modern localities have necessitated the need for underground installations. The underground cabling installations are devoid of faults common to the overhead transmission lines but are associated with certain kinds of faults such as short circuit and open circuit faults. Locating the exact position of any of these kinds of faults is very exhausting, costly and time-consuming because its power distribution system is invisible. Hence, a microcontroller based underground cable fault distance locator powered by Arduino is designed to detect and pinpoint location of faults in underground cable lines. A basic ohm's law is employed to achieve the variation of current with respect to resistance that determines the position of the fault. This device has a power supply unit, cable unit, control unit, tripping unit and display unit. The power supply unit provides power to the other components. The cable unit consists of a three-phase cabling system with switches between each phase to activate faults. The control unit takes in signals from the cable unit to cause control of tripping unit and display unit. The tripping unit then detects the phase which encounters the fault and the display unit shows the fault characteristics on the LCD. The distance to the fault is displayed, alongside the phase which encounters the fault for easy clearance.

Keywords: Underground cabling, faults, ohm's law, power distribution system, microcontroller.

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1. INTRODUCTION

During the early years, long transmission lines and overhead lines were an “indissoluble binomial” for the AC Power Systems [1]. Faults are considered as the total breakdown or loss of synchronism of power system network which does not exclude the environmental hazards such as electrocution and a devastating fire outbreak [2]. This means that the general belief as at the time was purely of the reliance on overhead lines for transmission of signals. This left the use of High Voltage (HV) and Extra High Voltage (EHV) insulated cables to be dedicated to DC submarine links. Faults are however meant to be located and cleared as fast as possible to forestall further loss of revenue and discomfort from the customer end [3]. The underground cable system was first considered in Northern Germany as early as 1870 and was implemented on the telegraph system [4]. This was generally as a result of a heightened regard for environmental conditions, the increasing hindrances encountered on the overhead lines, and increased reliability on the high-quality extruded insulations among other reasons.

The replacement of these overhead cables and lines by underground ones or inculcating a hybrid system (i.e. merging of the overhead lines and the underground cables) has been considered by power systems operators in the power sectors in various countries.

The underground cable system installations are mostly carried out for economic reasons amongst others. Some of the advantages of its installation are highlighted below.

1. A greatly reduced probability of damage from weather conditions e.g. lightning, winds, freezing, among others.
2. Underground cable system provides a reduced range of Electromagnetic Fields (EMF) emission [4].
3. Less components are installed alongside the underground cables. This is the opposite in the use of overhead lines as more components are installed alongside for safety, maintenance or repair.
4. Underground cable system reduces the probable hazard that could have been imposed on flying aircraft and wildlife.
5. There are reduced chances of conductor theft, sabotage and illegal connections [5].
6. In environmental conscious countries, underground cable system provides spaces for large trees to be planted and grow freely.

The advantages of underground system process can, in some cases, outweigh its disadvantages generally. One of the most observed and more practical disadvantage of underground system process is the fault location difficulty whenever it occurs.

2. LITERATURE REVIEW

Unlike the overhead cables, the underground cables are made to curb electromagnetic induction and to withstand various soil conditions. In order to serve its purpose, the underground cables are manufactured in thick protective layers, and with varying diameters depending on the depth of earth it is buried, and its volts-amp rating. Generally, underground cables for transmission are of less diameter than those for distribution. The anatomy of underground cables is shown below in fig. 1

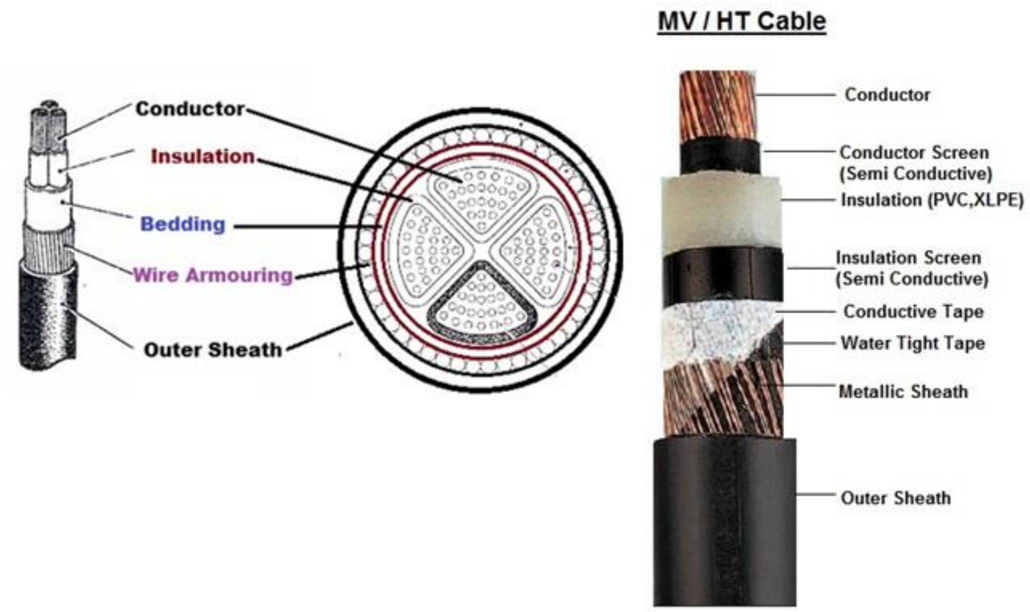

Figure 1 Parts of an underground power cable

The main part of the underground cable is the core conductor, which transmits the electrical energy from the source point to the load. Underground cables have now been made for different applications and at different voltage levels and are still under research and development. The selection of conductor is relative, depending on manufacturer's discretion. It could either be aluminum or copper in solid or stranded form. Also, its application could influence the choice of conductor, based on its flexibility, economics, physical property, shape, voltage, ampacity and other factors [6]. Conductors are made to carry current under various conditions and withstand pulling stresses during cable laying [7].

In order to prevent electrical field concentration, a semiconductor interface is provided between the conductor and the insulation. This is usually black in color. This is the conductor screen (or shield). It works synergistically with the insulation shield to make for a uniform cylindrical surface for even distribution of electrical stress [8].

There are different types of insulations for underground power cables, such as Ethylene Propylene Rubber (EPR), Cross-Linked Polyethene (XLPE), paper insulated and Tree-Retardant Polyethylene (TRPE) compounds. The insulation is used to insulate a high voltage working conductor from the shield, when working at earth potential [7]. The insulation has to be able to insulate electrical field under rated voltages, and during overvoltage. This therefore implies that the size of insulator varies directly as voltage rating.

The insulation screen is also a semiconductor. Apart from aiding of even distribution of electrical stress, the insulator screen borders electric field within the cable, reduce dangers arising from shocks, curb radio interference and protect voltage induced by cable when connected to overhead lines [9]. The outer part of the shield is usually connected to ground at one point. It is either metallic or non-metallic; drain wires or concentric neutral wires. The metallic sheath (or concentric neutral conductors) is the metallic part of the insulation screen and serves as a conduction path for neutral return current [10].

The conductive tape and water tight tape work simultaneously to ensure an improvement in electrostatic shield and serves as a moisture barrier. The outermost layer and the first point of protection for the cable is the cable jacket. It provides thermal, mechanical, environmental and chemical protection. The outer jacket could be made of different compounds like polyethene, nylon, and a number of other plastics. Some cable manufacturers prefer the use of sheath or armor instead of a jacket, as this provides better protection than a jacket.

2.1. Ageing phenomenon of underground cables

As cable ages, deterioration is inevitable. Most utility components, especially underground cables, have higher failure rates as time passes [11]. This deterioration is caused by thermal, mechanical, electrical and environmental factors or combination of any of these factors [12]. The underground cable eventually fails due to persistence of the acting factor.

The activation of any of these factors could cause either an intrinsic aging, or an extrinsic aging. Intrinsic aging occurs when the aging mechanism changes the bulk properties of the material used for insulation. On the other hand, extrinsic aging occurs when the aging mechanism causes degradation of the cable [8]. This degradation comes about by the persistent presence of defects, contaminants, protrusions or voids and their intercourse with any of the aging mechanisms [13].

Electrical stresses tend to be the most dominant ageing factor. Consequently, this stress causes the underground cable to fail via partial discharge or water treeing mechanism (that is, heightened by the presence of moisture) [8]. Water treeing activities is the major and the worst cause of cable failures in organic extruded dielectric and cross-linked polyethene, in particular. The cable encounters damages in its insulation in which the path of deterioration resembles a tree. In dry insulators, the main cause of treeing is the presence of partial discharge under high electric stress and water (or moisture) at low electrical stresses. In laminated cables, treeing is caused by drying of oil and burning of the insulating papers, leaving carbon deposits (carbon treeing). This forms a conductive path through the dielectric material leading to cable failure. Generally, they are formed by the presence of moisture, impurities, contamination and electric field over time [14]. Treeing occurs in two forms: -

1. Bow-tie treeing
2. Vented treeing.

Bow-tie trees grow from the insulation outwards towards the surface; the growth is in the direction of the electric field and in the both directions towards the two electrodes. They exhibit faster initial growth rate, but don’t grow so large enough to cause failure in insulation. Vented trees grow from the surface of the polymer inwards towards the dielectric system. They also grow in the direction of the electric field. However, they exhibit lower initial growth rate and can grow right through the entire dielectric thickness. This type of trees tends to cause more damage and, if not checked, lead to cable failure.

Nevertheless, reoccurring cable failures are caused by thermally aged insulation breakdown. This is mostly observed in the paper insulated cables. Insulation losses are increased by presence of moisture. This causes heat localization which gradually degrades the paper insulation [10].

2.2. Underground cable faults

Faults, if not attended to, tend to cause adverse or drastic effects on the workings of power systems in a number of ways. They cause an abnormal increase in voltage or current levels at specific points of the system, and this rise shortens the life span of the equipment. Faults also cause instability of the power system, causing three-phase equipment to operate abnormally. Faults are also liable to cause dangers to personnel and could also start a fire [15]. Therefore, it is expedient that a fault be disconnected or cleared as soon as it occurs, in order to maintain normal working conditions of the rest of the system.

As earlier seen, lengthy transmission lines are victims of environmental topography, giving it an increased fault probability. These faults are broadly classified to shunt and series faults. Shunt faults, however, have higher chances of occurrence (e.g. single line-to-ground fault). These faults can be caused by lightning, trees growing on lines, among others [14].

Generally, faults in power systems can be broadly categorized into two, which are symmetrical faults and unsymmetrical faults. Symmetrical faults are faults that occur in a power system without causing an imbalance of the system (i.e. the phases still maintain phase angles of 120° between the phases). This type of faults rarely occurs and exhibits a large amount of current flow. An example of symmetrical fault is when the three phases are short circuited to earth [16].

Unsymmetrical faults occur on one phase or two phases. An unsymmetrical fault causes an imbalance in the power system (i.e. the phases are no longer separated by a phase angle of 120°). They occur between phases or between phase (or phases) and ground [17].

Faults, whether symmetrical or unsymmetrical, are unsafe to the power system and personnel alike. They are usually caused by persisting ageing mechanisms and other factors. Some of these factors are: -

1. poor workmanship.
2. Inherent defects during manufacture.
3. Damage by improper handling.
4. National Electric Energy Testing, Research & Applications Center (NEETRAC) by Georgia Institute of Technology estimated 42.7% of outages to faulty splices and terminations [17].

2.3. Types of underground faults

2.3.1. Short Circuit and Earth Faults

Short circuit faults decrease impedances but increase phase angle. This, however, depends on the distance of the fault from the source [18]. Short circuit faults closer to source reduces impedance dramatically and increases fault current, therefore making it hazardous in nature [19,20]. They could be as a result of a damage in the cable insulation and causes overheating of conductors. Usually, arcing occurs at the point of fault or an area close the fault location [13]. Earth faults, on the other hand, are the most common faults in power system. This type of fault occurs when a current carrying conductor comes in contact with the lead (or metallic) sheath, which transfers current to the earth [21]. These faults manifest themselves in several ways.

2.3.1.1. Three Phase-to-Ground

This occurs when all three phases are in contact with each other. It is exhibited by large amount of current flow and a drastic voltage drop across the phases (very close to zero), while the system remains balanced, as shown in fig. 2.

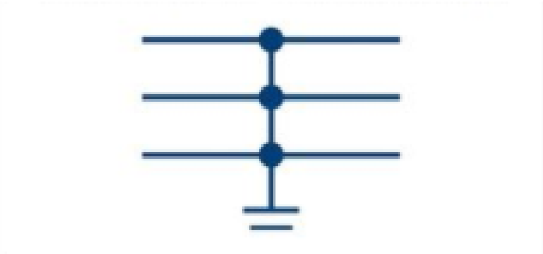

Figure 2 Three Phase-to-Ground fault

2.3.1.2. Three Phase short circuit fault

All the three phases are connected together at the fault location as shown in fig. 3, and there is heavy current flow through conductors to the ground. The system remains balanced.

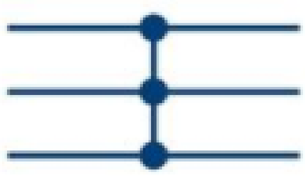

Figure 3 Three Phase short circuit fault

2.3.1.3. Line-to-Line fault

A short circuit occurs between two phases as shown in fig.4. It is exhibited by heavy current through the two phases, while the third still supplies its load. The system gets unbalanced due to these types of faults.

Figure 4 Line-to-Line short circuit fault

2.3.1.4. Line-to-Line-to-Ground

Fault current flows through the shorted phases and to the ground as shown in fig. 5.

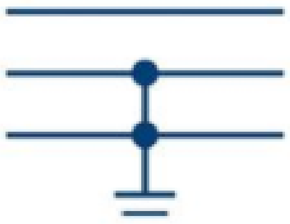

Figure 5 Double Line-to-Ground short circuit fault

2.3.1.5. Single Line-to-Ground

This type of fault accounts for 95 percent of faults in power systems [18]. The load is supplied by all three phases, but there will be a heavy flow of current to ground from the failed phase. This fault current circulates back, returns to the neutral and then to the generator. Fig. 8 shows the fault described.

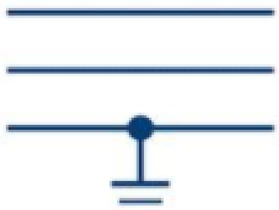

Figure 8 Single Lint-to-Ground short circuit fault

2.4. Open Circuit Faults

These types of faults are also called ferro-resonance [18]. This ferro-resonance causes very high voltage level across transformer windings and from line to ground. The voltage level is so high, it could damage the insulators and windings of the transformer. However, no current flows through the open circuit, making it less hazardous to personnel. An example of this is a loose joint connection or a broken conductor, usually caused when cable has been stretched beyond its limit [21]. It can also be caused by a malfunction of a protective device (e.g. circuit breaker, fuses, etc.). Open circuit faults isolate the load side from the generation or supply side and could cause an imbalance in the system [19].

2.5. Fault detection techniques

Faults have negative effects on power system as a whole. They constitute a major fraction of losses in the power system [22], and also pose a hazard to instrument and personnel. Therefore, it is necessary to locate and rectify a fault as soon as it is detected. Apart from reduced reliability, cable faults tend to be costly. Detection of these faults quickly would, not only save working time, but also play a part in loss of revenue for the power company [6]. Structural changes and reviewed policies have put the power sector in a position where they give customers quality and reliable supply of electrical power at reduced costs. This place power companies in positions where they can condone only a very small amount of losses and also, to optimize their maintenance culture as much as possible.

There have been permanent and fully functional methods for locating faults on overhead distribution lines. On the contrary, this is not the case for underground distribution lines, as methods required to perform the fault location are still in development and implementation stages. This doesn’t stand to meant that there are no functional means by which underground distribution cable faults could be located in the power sectors. However, researches are being conducted to discover a means in which these faults can be located easily, in no time and with little side effects on the service old cables [6].

Protective equipment is installed in power stations in order to clear faults or to isolate vital equipment from adverse effects due to the fault. In the event where actions protective equipment is unable to rectify a fault, it is necessary for skilled personnel to locate and clear the fault manually. Basically, three steps are involved when clearing a fault;

1. Fault localization.
2. Fault detection.
3. Fault clearing.

Fault localization is the process of fault location where the entire cable is examined and a hypothesis is made for the faulty region. Sectionalizing is a widely used method of fault location, in which the cable is cut and spliced physically into smaller lengths in order to identify the faulty area [19]. Fault detection aims at confirming a fault is present, meanwhile, fault location aims at discovering the exact physical location of the fault [6].

When clearing a fault, it is of utmost importance that the exact location of the fault be found. There are mainly two means of fault location;

1. Online method and
2. Offline method.

The online method employs the voltage and current levels which have been sampled, to determine the exact location of the fault [23]. This method has its applications mainly in underground cables as compared to overhead lines [24].

Offline method is performed with the aid of some dedicated instruments. These instruments are used to test for the service of the cable [20]. There are two major methods used based on offline location method.

A. Tracer method.

B. Terminal method.

Tracer method- This is the most widely used method by power stations generally. It involves walking along the cable route. Here, fault location is identified from acoustic or electromagnetic signals. It indicates the exact location of the fault [23,20]. Application of this method can be seen in Tracing coil method and Sheath coil method [23].

Terminal method- it involves the identification of a range for the fault location from one or both ends of the cable. The objective of the terminal method is to identify a general area of the fault so as to quicken tracing process [20]. Applications of the terminal method can be seen in Murray Bridge loop method and Impulse current method [23].

2.6. Murray Bridge Loop Method

This is one of the oldest method of underground and submarine cables localization. An end of the defective cable is connected through a resistor pair to a voltage source. A balance galvanometer (zero detector) is connected and the other cable end is short circuited. The galvanometer bridge is kept balanced by adjusting P and Q [21]. An example of Murray Loop Testing is shown in fig. 9 below.

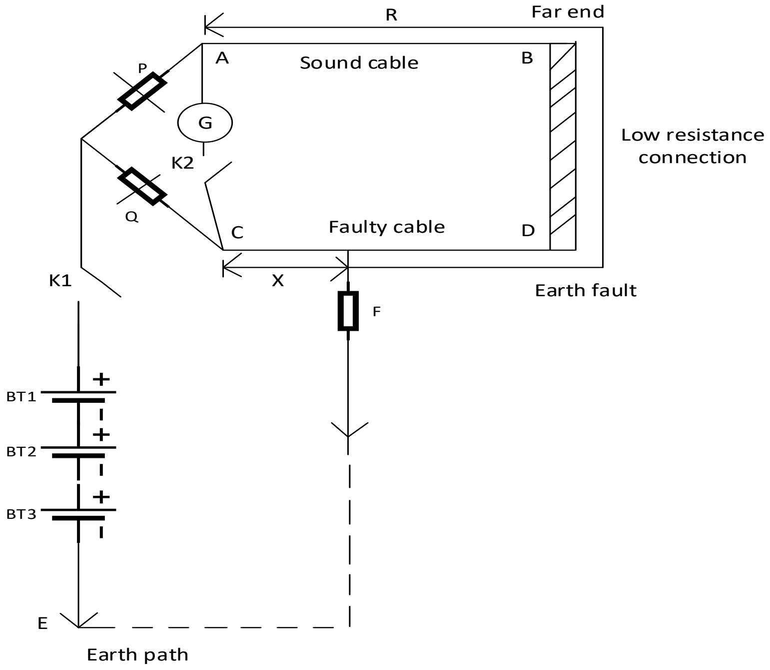

Figure 9 Murray Bridge Loop.

Where; l = line segment of wire,

x = length of faulty cable,

R_C = resistance of sound cable length,

R_D = resistance of faulty cable length,

R = ratio P/Q.

R_C is proportional to (l + (l – x)) = (2l – x) and R_D is proportional to x. Also,

$$P/Q = R_C / R_D$$

$$R = (2l-x)/x$$

$$X = 2l/(R+1)$$

However, the Murray Bridge Loop method is of the assumption that only a single fault exists along the cable length, cable resistance per unit length is uniform through the whole cable and has lower resistance as against the high resistance of the cable [22].

3. METHODOLOGY AND SYSTEM DESIGN

The whole system can be divided into 4 basic sections: -

1. DC power supply section,
2. Cable section,
3. Controlling section and
4. The display section [20].

The mode of operation can be seen in Fig. 10 below.

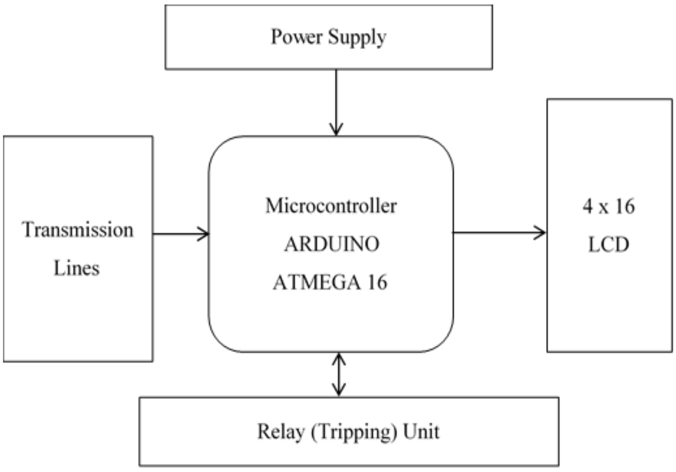

Figure 10 Block diagram of the proposed system.

THE DC SUPPLY SECTION: - This is the heart of the system. It embodies the rectification phase. 220V AC from a power supply is stepped down to 12V AC by a step-down transformer, and this stepped down voltage is rectified by a full bridge rectifier, to convert the AC voltage to an equivalent DC voltage value. The voltage output from this section is 15V and 5V, which are used to power other sections.

CABLE SECTION: - The cable section requires 5V DC from the rectification circuit. It comprises of resistors to indicate cables, and push button switches to activate the short circuit fault between the phases. The cables are represented by 4 1kΩ resistors in series for each phase (Red, Yellow and Blue phases). Each resistor represents 1km length span. Another set of 4 1kΩ resistors are used to cause voltage division at every 1km.

CONTROL SECTION: - The control section comprises two parts; the microcontroller part and the relay control (tripping unit). The Arduino receives 5V DC from the supply. The source code is used to control the activities of the relay unit is tripping off faulty lines and the display at the LCD. The Arduino digital output pins are connected to the relay driver and LCD. The relay driver is used to control each of the relays to cause tripping in each of the lines when a fault has been activated. The Arduino operation used to control the system is based on the following algorithm:-

i. Declare ports, initialize timer, ADC and LCD functions.
ii. Start an infinite loop; make pin 0.0 high, turning on relay 1.
iii. Display "R" (for Red phase) on first line of LCD.
iv. Call ADC function. The fault position is displayed based on ADC output.
v. Call delay.
vi. Iterate steps (iii) to (v) for the remaining phases.

This is represented as shown in the flowchart in fig. 11 below.

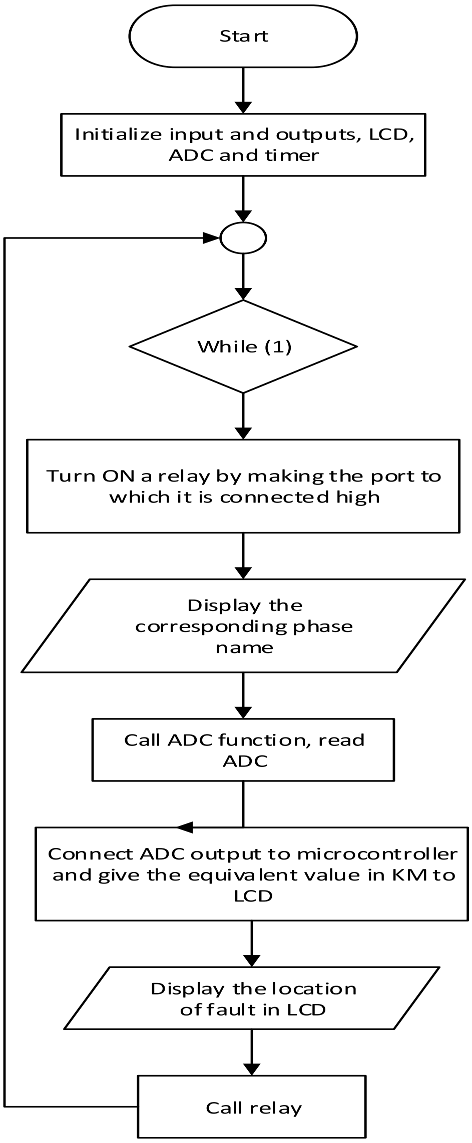

Figure 11 Flowchart of Arduino algorithm.

DISPLAY SECTION: - This section displays output of the control section. The LCD is the primary display device used. It gives the status of each cable and the distance to the fault when a fault has been activated, with the respective phase.

Cables have resistances, and therefore can be represented by a set of resistors in series. Cables also have resistance per kilometer ratings. These become very useful when measuring for fault distances in the cable. Any deviations in resistance for a particular length indicates the presence of a fault in the cable [23]. The series 1kΩ resistors for voltage drop divides the three cables into four sections, each represented as 1km. This voltage drop is used to pinpoint the location of the fault when activated by sensing current changes [20]. This voltage drop sends a signal to the Analog-to-Digital Converter (ADC) in the microprocessor, to develop accurate and corresponding digital data based on calculations programmed in the source code. The relay driver causes a trip on the affected phase, when the fault has been activated. This sends a signal in order to determine the phase in which the fault occurred on [25]. These data are then displayed on the LCD screen. For software simulation, a closed switch activates the short circuit fault between two lines. The voltage drop at that point causes a change in current, and this change sends a signal to the microprocessor for digital data analysis. The system is fully digital, although real life applications would contain analog data and readings also.

5. RESULTS AND DISCUSSION

Table 4-1 Voltage Drop Values used by microprocessor.

S/No.	Distance of fault occurrence (km)	Voltage across resistor (V)	ADC Output (*1000)
1	1km	3.35	670
2	2km	4.00	800
3	3km	4.30	860
4	4km	4.45	890

The results of the fault locations as detected by the device are shown in the table above. The ADC output is displayed on the LCD with respect to each varying distances of the fault locations. The power circuit is shown below;

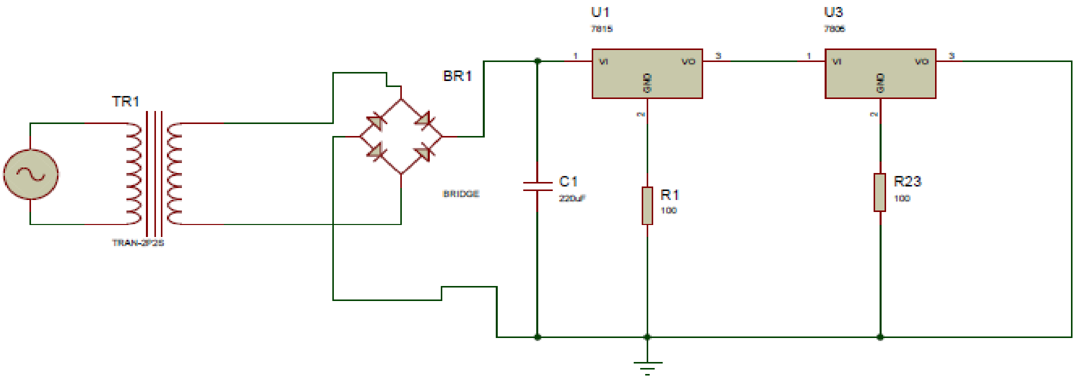

Figure 12 The Power Circuit

The schematic diagram of the system as a whole is shown below in Figure 12.

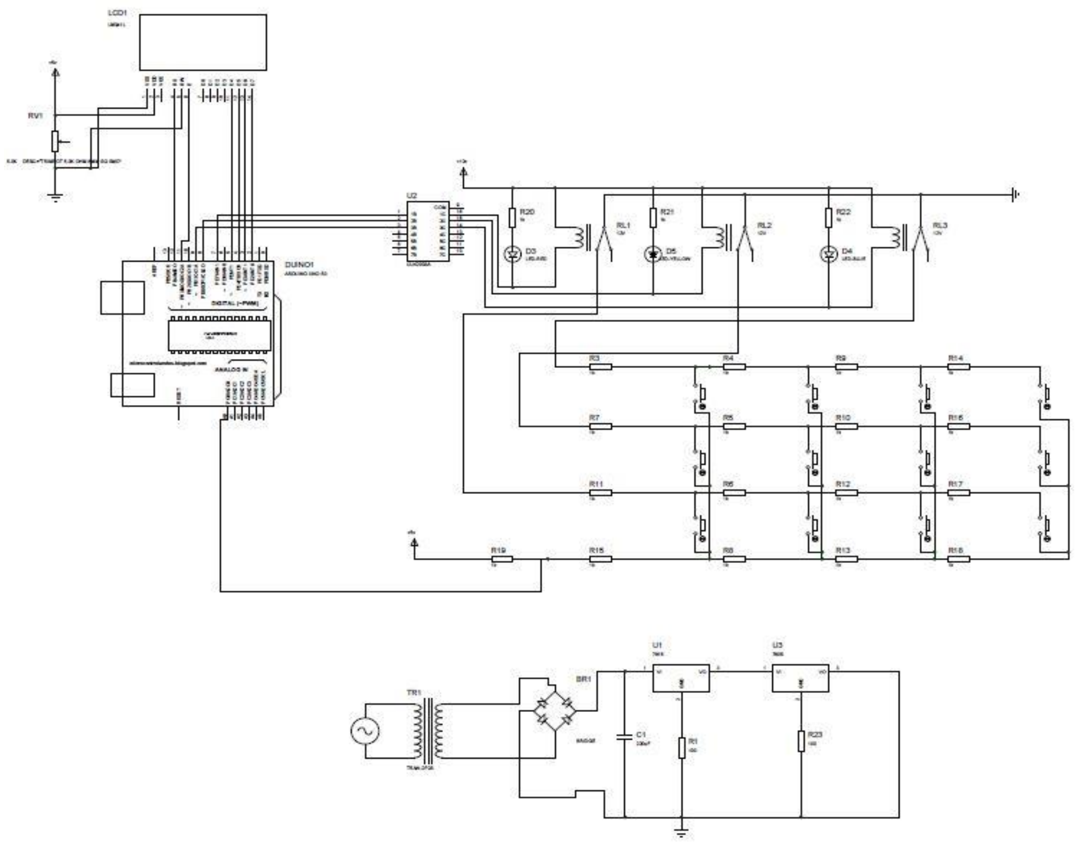

Figure 13 Schematic Diagram of the Proposed System.

5. CONCLUSION

Considerable efforts have been put into the issue of fault location in an underground cable power infrastructure as exemplified in the covenant university, ota, ogun state, Nigeria. However, a simple ohm's law-based technology has been developed to easily locate faults in an underground power cable layout and invariably helps to easily clear the faults, preserve aesthetics, reduce time duration, drudgery, and optimize cost.

The progress made in the underground cable detector design can induce high penetration of the underground cable technologies into the major cities of the developing countries to minimize environmental disasters associated with overhead transmission lines.

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