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Design and Implementation of Underground Cable Fault Detector

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Abstract-A fault in electrical equipment can be defined as a defect in its electrical circuit due to which the current is diverted from the intended path. Faults are generally caused by mechanical failure, accidents, excessive internal, external stresses, and others. When a cable is faulty the resistance of such cable is affected. If left unrectified, it will totally hinder voltage from flowing through the cable. The challenge with the existing methods used for locating faults in underground cables is the inaccuracy in calculating the distance where the fault is located and the low durability of such equipment. To overcome these challenges, this paper presents a novel underground cable fault detector that has the capacity to measure the resistance of the cable, detect the type of fault in a cable, and also accurately compute the location of the fault using cheap materials. Several tests were conducted using the proposed device, and the results indicated that the proposed method produced satisfactory results in detecting both open circuit and short circuit problems in underground cables within a maximum distance of 2km.

Keywords- *Underground Cable, Fault Location, Fault Detection, Arduino Microcontroller, LCD*

I. INTRODUCTION

Underground cables have been extensively used for power distribution networks over the years [1]. 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 [1]. They are cheap, easy to maintain and environmental friendly [2]. 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 [9]-[13]. They ensure fewer transitory interruptions through tree falling on wires or electric poles falling down thereby improving public safety. Life-wire contact injuries is drastically reduced [14]-[19]. It leads to the elimination of unattractive poles and wires on the streets thereby enhancing the visual range of the drivers and pedestrians on the streets [2].

To lessen the threat posed by environmental impacts on the highly sensitive distribution networks, the underground high voltage cables are increasingly used [3]. Despite these advantages, locating faults in underground cables can be a very cumbersome task. It is therefore very necessary to develop very efficient technique for detecting faults in these cables. These papers is geared towards designing a system that can locate the faulty points in an underground cable in order is to facilitate quicker repair, improve the system reliability and reduced outage period to the barest minimum. The underground cable system is very useful for distribution mainly in metropolitan cities, airport and defense services [3], [20].

When faults occur, the power flow is redirected towards the fault and the supply to the neighborhood is impeded [16]. Voltages turn out to be destabilized. Timely detection of fault is highly essential in electrical cables. To achieve this, the microcontroller is used in this paper to quickly detect four main types of faults and give trip signal to relay. Our contribution in this paper is the design and implement underground cable fault distance locator device that can be used to detect faults in the line and isolate the connected system or instrument connected to it. The device has the capacity to detect the type of fault that has occurred in a faulty line. The Atmega328p microcontroller is used to detect the fault through the designed circuit and it also displays on the LCD screen. A relay circuit is also connected to the circuit to save the system from being damaged by disconnecting the faulty circuit from the healthy one. The proposed system works by first converting analog signals to digital signals. These signals are generated by the microcontroller, the microcontroller will compare the input digital signal of the ADC and will compare with the given set range of value, if the input is above or below the range of set value, the microcontroller will send a signal to the relay to trip the circuit and also send a parallel signal to the LCD to display the type of fault that has occurred. Thus, the tripping and display of the fault type are achieved in this paper.

II. REVIEW OF PREVIOUS WORK

Over the years, researchers have made several efforts to design and implement an electronic underground cable fault detector that will help to overcome the problems as well as challenges encountered in the use of underground cables and detection of faults that occurs in the underground cables but unfortunately, there were limitations to their designs.

Reference [4] proposed fault location model for underground power cable using microcontroller. The hardware model of Underground Cable Fault Locator is implemented and favorable results were brought forward. This hardware model can locate the exact fault location in an underground cable. There needs to further enhance the work so that it can also locate open circuited cable. [5] Developed a prototype that uses the idea of OHMs law to detect faults in cables. The proposed system uses a set of resistors representing cable distance in Kilo meters and fault detection is by a set of switches at every Kilometer (kms) to validation 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. [6] Presented a system that can detect the location of open circuit and short circuit fault in the underground cable from the base station in kms with the help of Atmega16 microcontroller. Only the simulation was done using PSIM simulator. Reference [7] proposed a microcontroller based underground cable fault distance locator. However, there was no evaluation to know the performance of their proposed system. [8] 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 work has one limitation or the other. For this reason, we designed and implemented a microcontroller based underground cable fault detector that is capable of running on dual power supply i.e. AC mains supply as well as a DC battery pack, and display results on an LCD module. This is an improvement on the previous work 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 when comparing to its Arduino based counterpart.

III. Materials and Methods

To achieve the implementation of the microcontroller based underground cable fault detector some approach was 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 to the project board (temporary board) and tested before transferring it 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. Figure 1 shows the power supply unit, probe terminal unit, microcontroller unit and LCD display unit.

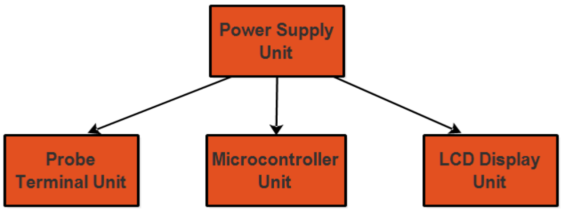

Figure 1. Block diagram of the microcontroller based underground cable fault Detector

A. Design of Power Supply Unit

The final output voltage model for the operation of this project is DC voltage. The power supply circuit is shown in figure 2.

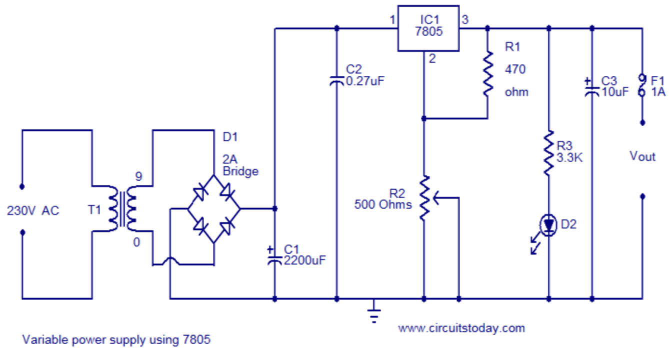

Figure 2. The power supply unit

For calculation the transformer rating of the power supply unit, we use the specifications of the transformer used. Transformer ratings:

Vrms = 12v

Irms = 500mA

$$V_{peak} = V_{rms} x \sqrt{2} \quad (1)$$

$$= 12 \text{ x } \sqrt{2}$$

$$V_{peak} = 16.97\text{v}$$

$$I_{peak} = I_{rms} x \sqrt{2} \quad (2)$$

$$= 500\text{mA x } \sqrt{2}$$

$$= 707\text{mA}$$

The load resistance of the entire circuit RL, is given by:

$$RL = \frac{V_{peak}}{I_{peak}} \quad (3)$$

$$RL = \frac{16.97}{707} = 23.9952$$

$$\text{RL} \cong 24\Omega$$

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Voltage after rectification V_{dc} is given by;

$$V_{dc} = \frac{2V_{peak} - 2V_d}{\pi} \quad (4)$$

where V_D is the voltage drop across the two diodes of the positive half cycle of the bridge rectifier circuit ($V_D = 0.7$)

$$V_{dc} = \frac{2 \ x \ 16.96 - (2x0.7)}{\pi}$$

$$V_{dc} = 10.8 - 1.4 = 9.4v$$

Current after rectification, Idc is given by:

$$I_{dc} = V_{dc} \quad (5)$$

$$RL = \frac{9.4}{24} = 0.392A$$

$$I_{dc} = 392mA$$

The filter capacitor (C1) is designed to hold the peak to ripple voltage at approximately 10% of the voltage. Therefore,

$$V_{ripple}(V_r) = 0.1 \ x \ V_{peak} \quad (6)$$

$$V_{ripple}(V_r) = 0.1 \ x \ 16.97 = 1.697v$$

To obtain the value of capacitor C1, we use the equation;

$$V_{ripple}(V_r) = \frac{2.4Idc}{C} \quad (7)$$

Where 2.4 is a constant value.

$$C1 = \frac{2.4Idc}{V_r} = \frac{2.4 \ x \ 0.392}{1.697}$$

= 0.554 farads, C1 = 554μf

But a standard value of 1000 μf was used for the construction of the paper. In order to supply the ATmega328p Microcontroller with the required + 5v, a LM7805 voltage regulator was used. The minimum input voltage required by the LM7805 voltage regulator is given by;

$V_{in} = V_{out} + 2$

$V_{in} = 5 + 2 = 7v$

This means that the minimum input required by the LM7805 to produce an output of 5v is 7v.

B. *Design of Probe Terminal Unit*

The design of the probe terminal unit is as shown below:

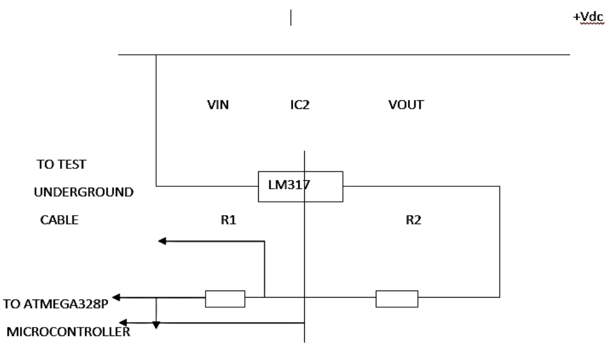

Figure 3. The probe terminal unit

The output voltage (Vout) of the variable voltage regulator (LM317) to the ATmega328p microcontroller is given by;

$$V_{out} = 1.25 \ x \ (1 + \frac{R_2}{R_1}) \quad (8)$$

Where 1.25 is a constant

But from the equation the value of R1 and R2 are unknown. The expected output voltage to the ATmega328p controller is 5v. The value of R2 is given by;

$$R_2 = \frac{V_{out}}{Idc}$$

If Vout = 5v and Idc = 392mA (from power supply unit).

Therefore,

$$R2 = \frac{5}{392mA} = \frac{5}{392x10^{-3}} = 12.755\Omega$$

The value of resistor R1 is then obtain from equation 1

$$V_{out} = 1.25 \ x \ (1 + \frac{R_2}{R_1})$$

$$5 = 1.25 \ x \ (\frac{1 + 12.755}{3})$$

$$R1 = \frac{12.755}{3}$$

R1= 4.25Ω

But the standard value of 4.2Ω is used for R1 and 12Ω was used R2 in the construction.

C. *Design of the Microcontroller Unit*

The microcontroller unit is made up of the ATmega328p microcontroller, a 16MH2 crystal oscillator, a pull-up resistor as shown in figure 4 below.

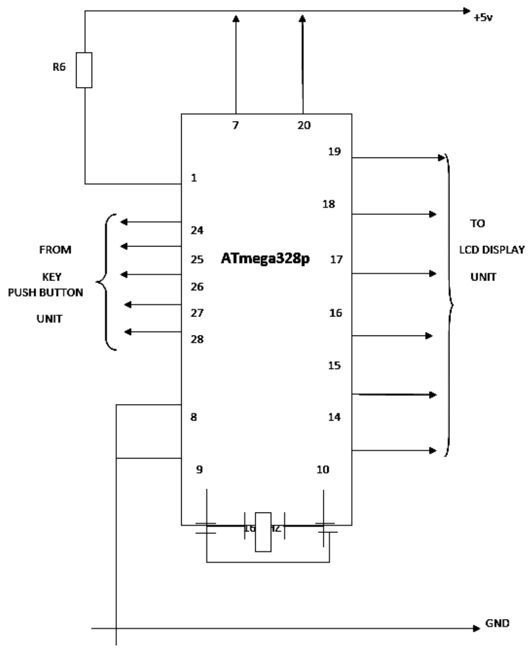

Figure 4. The Microcontroller unit

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

$$R3 = \frac{VCC}{I_{dc}} = \frac{V5CC}{392mA}$$

$$R3 = \frac{5}{392x10^{-3}} = 12.755\ \Omega$$

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 = 1/F (9)

But F = 16MHz

$$T = \frac{1}{16MHz} = \frac{1}{16\ x\ 10^{6}}$$

$T = 6.25x100^{-8}$

$T = 0.0625\mu s$

This is the time taken for the ATmega328p microcontroller to execute one command or instructions before the nest. The values of capacitors C2 and C3 were chosen to be 22pf, which are used to stabilize the frequency of 16MHz crystal oscillator from external interference machines such as sings, distortion.

D. Design of the LCD Display Unit

The LCD display unit is made up of a 16x2 LCD display and a 10kΩ variable resistor as shown in figure 5.

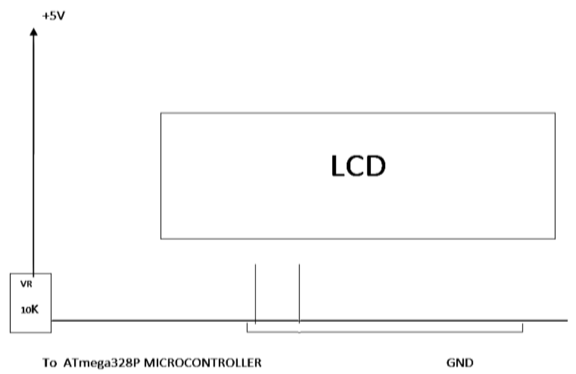

Figure 5. The LCD display unit

The 10kΩ variable resistor (VR) is used to set the contrast of the LCD display and this is set to $^{2}/_{3}$ of the supply voltage. That is given by;

VR = 10kΩ

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

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

$$ILCD = \frac{V}{R} = \frac{5}{6.67} = 0.749A$$

ILCD = 750mA

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

E. The ATmega328p Microcontroller

The ATmega328p microcontroller is a 28pin, 8-bit microcontroller with 32kb flash memory with read-while-write capabilities. The ATmega328p microcontroller is shown in fig 6.

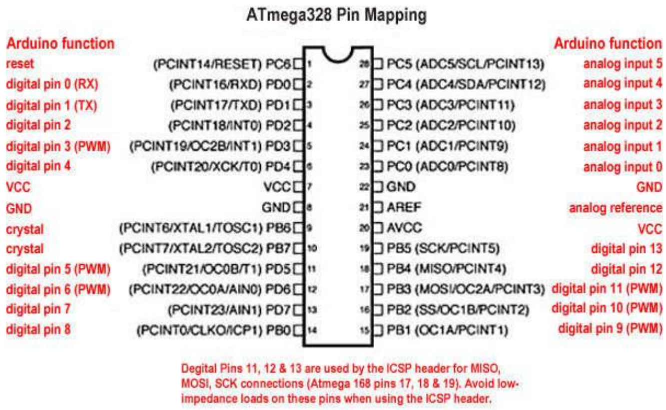

Figure 6. The ATmega328p microcontroller

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.

F. LM7805 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 output voltage. The 7805 has an output voltage of 5v, others like 7812 have output shown in figure 7 below.

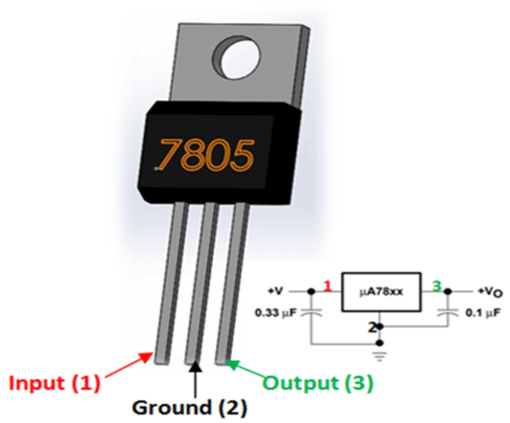

Figure 7. The LM7805 voltage Regulator

TABLE I. DESCRIPTION OF ATMEGA328P PINS

Pin Number	Description	Function
1	PC6	Reset
2	PDO	Digital pin (Rx)
3	PD1	Digital pin (Tx)
4	PD2	Digital pin
5	PD3	Digital pin (PWM)
6	PD4	Digital pin
7	VCC	Positive Voltage (Power)
8	GND	Ground
9	XTAL1	Crystal Oscillator
10	XTAL2	Crystal Oscillator
11	PD5	Digital pin
12	PD6	Digital pin
13	PD7	Digital pin
14	PB0	Digital pin
15	PB1	Digital pin (PWM)
16	PB2	Digital pin (PWM)
17	PB3	Digital pin (PWM)
18	PB4	Digital pin
19	PB5	Digital pin
20	AVCC	Positive voltage (ADC) power
21	AREF	Reference voltage
22	GND	Ground
23	PCO	Analog input
24	PC1	Analog input
25	PC2	Analog input
26	PC3	Analog input
27	PC4	Analog input
28	PC5	Analog input

The LM7805 is used to supply a regulated + 5v supply to the ATmega328p microcontroller.

G. Software Development

Our proposed system is controlled by a software computer program. The workings of the program are according to the flow chart shown in figure 8.

IV. RESULT AND DISCUSSION

The results and various tests carried out on the constructed work is discussed in this work.

A. Test on the Power Supply Unit

A power supply unit is a virtual unit of the project. It supplies power to the whole system. The work is designed to work on +5v de supply based on specifications of the other units, since the system works on de power supply. It cannot be directly operated with the mains supply (230vac). The mains supply must be converted to de for the system to operate. The coil windings of the step down transformer was tested using a digital Multimeter to ensure that there is no break in continuity of the coil windings (open circuit test) and there is no faulty contact of two separated wires (short circuit test) before connecting it to other components of the circuit. Other components of the power supply units such as the bridge rectifier chip (BDR1), filter capacitor (C1), was as well as the voltage regulator (LM7805) were also tested for open circuit and short circuit fault using the same process with the digital multimeter.

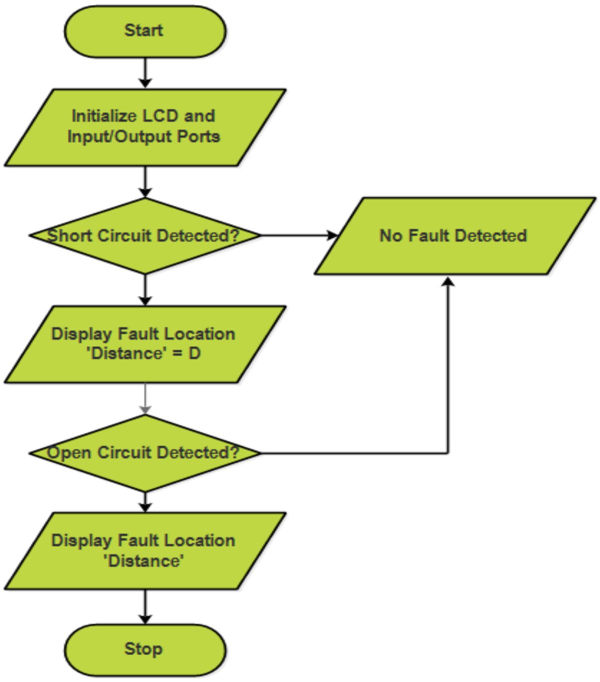

Figure 8. Flow chart of underground cable fault detector

B. Test on the Microcontroller Unit

All relevant information including the pin configuration of the microcontroller was elaborated in the previous chapter. The microcontroller is the heart of the system because it controls the activities of all other units of the paper. The microcontroller was tested using the digital multi-meter and all pins are tested to ensure that there is no break in continuity of the pins or a faulty contact between two or more pins of the microcontroller.

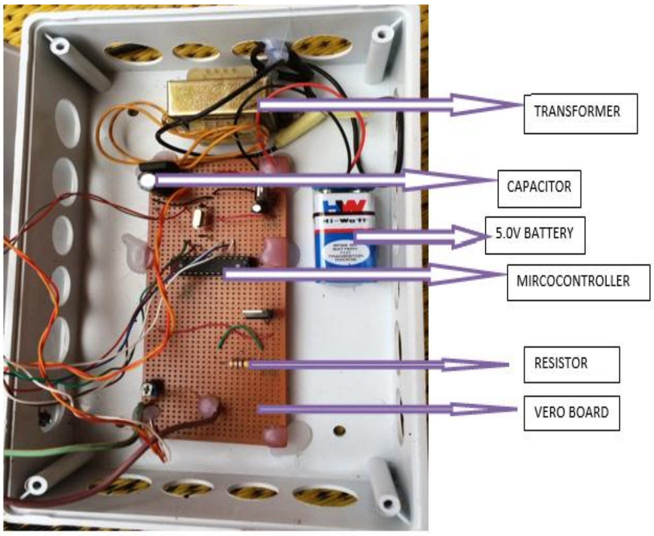

Figure 9. Internal View of underground cable distance fault locator.

C. Test on the LCD Display Unit

The LCD display unit consist of an LCD module which is also tested using the digital Multi-meter to ensure that there is no discontinuity in the internal circuitry of the LCD (open circuit test) and also to ensure that there is no faulty joint of the pins internally (short circuit test) before connecting it with the project circuit. This step is very important because the LCD is directly connected to the microcontroller if it is faulty or damage it could automatically damage the microcontroller too or make it to malfunction.

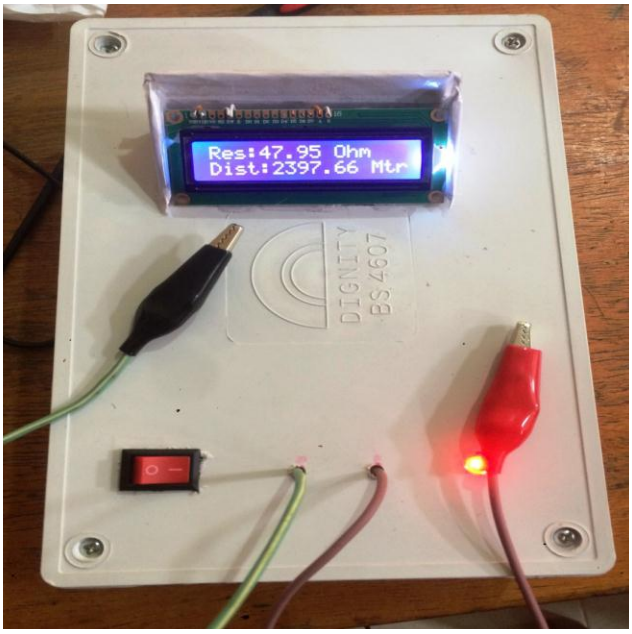

Figure 10. Test on the LCD display Unit.

D. Test On Open Circuit

Figure 11. Test on open circuit

E. Test On Short Circuit

Figure 12. Test on short circuit

F. Test On The Software Program

In an effort to achieve a successful operating hardware in a project that makes use of set of instructions, software design and development is very vital. The software design structure that allows right know-how of the system architecture, detailing more on which device plays as an input to the system and output from the system. Despite the fact that, systems hardware cannot function properly without software programmed installed in the memory. However, on this project software development and implementation, software programming is a specification employed to permit the microcontroller read inputs and decide output or logical action according to the instruction given.

G. Result Of Various Units

The result of the design carried out in the previous chapters and the test of the various units is shown in the table 2.

TABLE II. RESULT OF VARIOUS UNITS

S/N	Open Circuit Test	Short Circuit Test	Test Result
1	Power Supply Unit		
	OK	OK	OK
2	Microcontroller Unit		
	OK	OK	OK
3	LCD Display Unit		
	OK	OK	OK
4	Software Program		
	NILL	NILL	OK

The results of the tests performed above suggested that the system sub-units are effectively designed and regard to the system as a whole. After completing all the various units, the project was cased in a plastic casing for compact presentation. The project operates on mains power supply but also has an alternative source of power from a battery.

V. CONCLUSION

This paper designed, implemented a microcontroller based underground cable fault detector. We have successfully designed, implemented and tested a cheap underground cable fault detector. Our proposed method can detect both open and short circuit in underground cables with a maximum distance of 2km. In the future, effort will be concentrated to increase the maximum distance for fault detection to 3km or more, and a graphical display monitor to improve on its information of the underground cable fault could replace the LCD display.

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