Development of fault distance locator for underground cable detection

FH Md Arifin¹, MZ Hasan¹, IS A Mahyudin¹, SNM Arshad²

¹Faculty of Engineering Technology, Universiti Malaysia Perlis (UniMAP), Malaysia
²School of Electrical Engineering, Universiti Malaysia Perlis (UniMAP), Malaysia

Email: fatinhasirahmdarifin@gmail.com

This project proposes fault distance locator model for underground power cable using an Arduino uno. The use of underground cables arise a problem of identifying the fault location and the distance of cable fault as it is not open to view as in case of overhead cable. Thus, the underground cable fault distance locator is develop to detect the exact fault location and the distance of underground cable fault from based station in kilometers as the system will detect the faulted cable on underground and will send the information to the control room by using a relay. An underground cable system is a common practice followed in major urban area. The concepts of Ohm’s law are used in this project and are placed underground with short circuit type fault condition. If any fault occurs, the voltage drop will vary depending on the length of fault in cable since the current varies. Tracer method is used to detect faulted by walk through the cable lines. Fault point is traced by the audible signal or electromagnetic signal. These projects are equipped with a set of resistors, power supply, a set of switches, Arduino Uno and LCD. The prototype of an underground cable fault distance locator is designed with the performance of Tracer method.

1. Introduction

Till last decades, a million miles of cables are strung in the air across the country. But currently it is laid in the underground, which is larger to an earlier method. Underground cables are not affected by any adverse weather condition like pollution, heavy rainfall, snow and storm. To reduce the sensitivity of distribution networks to environmental influences underground high voltage cables are used more and more. 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 shorter distance, eco-friendly and low maintenance.
Underground cable system is a common practice followed in many urban areas. However, when any problem occurs in cable, it is very difficult to find the exact location of the fault due to not knowing the exact location of the cable. So, this project is used to detect the location of fault in digital way. The requirement of locating the faulty point in an underground cable in order is to facilitate quicker repair, improve the system reliability and reduced outage period. The underground cable system is very useful for distribution mainly in metropolitan cities, airport and defense services.

Day by day, the world is becoming digitized so the project is proposed to find the location of fault in digital way. When the fault occurs, the process of repairing related to that particular cable is very difficult. The fault of the cable mainly occurs due to many reasons. They are inconsistent, any defect, weakness of the cable, insulation failure and breaking of the conductor. To overcome this problem, the development of fault distance locator for underground cable detection used to find the location of the fault for underground cable [1-5].

2. Methodology

Figure 1 is shows the block diagram of an underground cable fault distance locator system. This project is assemble with a set of resistors that represents the cable length in kilometers and fault creation consists of a set of switches on every kilometer is known to cross check the accuracy of the same. This is the model for the proposed underground cable fault locator distance using the Arduino Uno. It is divided into four parts, the DC power supply part, cable part, controlling part and display part. The DC power supply consists of AC supply, transformer, rectifier and voltage regulator. AC supply of 230 V in step-down by transformer, bridge rectifier converts the AC signal to a DC signal while the regulator is used to generate a constant DC voltage.

The cable is represented by a set of resistors with switches. The current sensing part on the cable represented as a set of resistors and switches used as fault creator to specify a fault at each location.
Next is the controlling part that comprising an Analog to Digital Converter (ADC) that receives input from the current sensing circuit. ADC converts this voltage to a digital signal and feeds the Arduino with the signal. The display part consists of the LCD display interfaced to the Arduino which shows the status of the cable of each phase and the distance of the cable at the particular phase, in case of any fault [6-10].

Figure 2. Flowchart of project coding.

Figure 2 is shows the flowchart of project coding. The system will initially be displaying no fault [ ] on the LCD screen in every phase represented by R (red), Y (yellow), and B (blue). Theoretically, the switch represents the creator of the fault must be pressed to find fault in the LCD display.

Figure 3. Simulation circuit
From above Figure 3, the Proteus simulation software is used to illustrate the full circuit diagram of the project. The Arduino Uno is the main peripheral of the circuit as it controls the entire working part that are DC power supply part, cable part and controlling part. All this part is combined to produce an underground cable fault distance locator.

**Calculation of fault**

Fault is calculated theoretically using Ohm's law. Input voltage is 9.71V and the values of resistance are 1000 Ω for every fault created. The calculation method for each fault is the same, which distinguishes only the fault distance from the power supply. Calculation below shows the project is implementing the Ohm’s law.

a) Transformer

\[
\text{Current ratio in transformer} = 1 : 16.37 \\
W_{\text{primary}} = V_{\text{primary}} \times I \\
W_{\text{secondary}} = V_{\text{secondary}} \times I
\]

\[
\begin{align*}
12 \text{ VA} &= 240 \text{ V} \times I \\
I &= 0.05 \text{ A} \\
W_{\text{primary}} &= 12 \times 0.05 = 0.6 \text{ W} \\
W_{\text{secondary}} &= 12 \times 16.37 \times 0.05 = 11.999 \text{ W}
\end{align*}
\]

b) Buck converter:

*Bridge diode* = 4 x 0.7 \(V_{\text{drop}}\)

\[
\begin{align*}
V_p &= (V_{\text{secondary, rms}} \times 1.414) - V_{\text{drop}} \\
&= 17.93 \text{ V} \\
V_{\text{dc(avg)}} &= \frac{2V_p}{\pi} \\
&= 11.41 \text{ V} \\
V_{\text{ac}} &= V_{\text{dc}} \times 1.41 \\
&= 16.09 \text{ V}
\end{align*}
\]

c) Signal injector:

\[
\text{NE555} \ V_{\text{drop}} = 1.7\text{V}
\]

Signal injector, \(V_{\text{output}} = V_{\text{dc}} - \text{NE555} \ V_{\text{drop}}\)
= 9.71 V

**Schematic of Signal Injector**

Based on Figure 4, 555 multi vibrator circuits are used to generate low frequency voltage (3 KHz). Two capacitors are placed in series to power supply. The center-tapped between the capacitors are connected to signal generator while pin 3 of 555 multi vibrator are connected to oscilloscope. The voltage will be Vcc/2 between the series capacitors. Signal generator is set up with input square waveform and 3 KHz of frequency. Pin 3 of 555 multiibrator is the output pin which generates frequency. This circuit is powered by either 9v battery or 9v dc power supply with 0.3A input current. The output of this circuit diagram is the generation of 3 KHz voltage frequency with square waveform. Pin 3 of 555 multiibrator and the capacitor midpoint are then connected to the cable. The output is done alternately among the four steps.

![Figure 4. Circuit Diagram of Signal Injector](image)

**Calculation on short-circuits current**

a) Single phase fault by ohmic reactance method:

\[
I_{F,\text{transformer}} = \frac{\text{KVA} \times 1000}{E_{L-L}} \quad (8)
\]

\[
= 0.05 \text{A}
\]

\[
M_{\text{transformer}} = \frac{100}{\%Z_{\text{transformer}}} \quad (9)
\]

\[
= 138.89
\]

\[
I_{\text{sc,secondary}} = I_{F,\text{transformer}} \times M_{\text{transformer}} \quad (10)
\]

\[
= 6.9445 \text{A}
\]
\[ I_{sc,secondary} = \frac{V_{primary}}{V_{secondary}} \times M_{\text{transformer}} \times I_{sc,primary} \quad (11) \]

\[ I_{sc,primary} = 0.00305 \, \text{A} \]

\[ \text{Source } Z_0 = \frac{HV}{\sqrt{3} \times \text{HV fault current}} \quad (12) \]

\[ = 45430.84 \, \Omega \]

\[ Z_{\text{transformer}} = \frac{Z \times (HV)^2}{100 \times \text{VA}} \quad (13) \]

\[ = 34.56 \, \Omega \]

\[ Z_{\text{iterm} \text{total}} = Z_{\text{iterm} \text{source}} + Z_{\text{iterm} \text{transformer}} \quad (14) \]

\[ = 45465.4 \, \Omega \]

\[ Z_{\text{LV}} = \frac{\text{total } Z_0 \times (LV)^2}{(HV)^2} \quad (15) \]

\[ = 169.64 \, \Omega \]

\[ I_{f,LV} = \frac{LV}{\sqrt{3} \times Z_{\text{LV}}} \quad (16) \]

\[ = 0.05 \, \text{A} \]

b) Three phase fault by ohmic reactance method:

\[ I_{F,\text{transformer}} = \frac{\text{KVA} \times 1000}{E_{L-L} \times 1.732} \quad (17) \]

\[ = 0.02887 \, \text{A} \]

Inserting the answer on equation (17) to equation (9), to (16) becomes,
\[ M_{\text{transformer}} = 138.89 \]
\[ I_{sc,secondary} = 4.0095 \, \text{A} \]
\[ I_{sc,primary} = 0.00176 \, \text{A} \]
\[ \text{Source } Z_{\theta} = 78579.39 \, \Omega \]
\[ Z_{\text{transformer}} = 34.56 \, \Omega \]
Z_{total} = 78613.95 \, \Omega,
Z_{LV} = 293.32 \, \Omega,
I_{f,LV} = 0.289 \, A

3. Results and Discussion

The effect of fault occurred to the ADC output and voltage across series resistor. The ADC output and voltage across series resistor are recorded in Table 1 when the condition of switches is applied in the system. The output waveform of each condition of switches is generated if the condition is fulfilled.

| No. | Switch closed | Voltage across series resistor (V) | Distance at which fault occurred (KM) | ADC output |
|-----|---------------|------------------------------------|--------------------------------------|------------|
| 1   | SW1           | 3.33                               | 1 KM of first cable                  | 170        |
| 2   | SW6           | 4.00                               | 2KM of second cable                 | 204        |
| 3   | SW11          | 4.29                               | 3KM of third cable                  | 219        |
| 4   | SW2 and SW7   | 3.5                                | Between 1KM to 2KM of first and second cable | 197        |
| 5   | SW6 and SW12  | 4.2                                | Between 2KM to 4KM of second cable and third cable | 210        |
| 6   | SW4, SW8 and SW12 | 4.44 | 4KM of first, second and third cable | 227 |

Analysis on fault condition on underground cable

1 KM Blue LED on

Based on Figure 5, the waveform obtained is a straight line with maximum voltage of 2.15V. Fault occurs in the first condition when SW4 is pressed and blue cable has fault at 1 KM. The maximum voltage is lower than the voltage supply due to the fault in the 1KM cable single phase only. The incoming frequency is around 3 KHz after being injected by the signal injector circuit. Theoretically, the waveform for all fault voltages is a straight line only that distinguishes it in terms of distance and fault cable type. The current reading at 1 KM fault cable which is 0.072A. This reading is obtained higher than value of current without fault cable. In terms of distance, the current value obtained in condition 1 is higher compared with other single phase fault.
4 KM Blue LED on

Based on Figure 6, maximum voltage obtained is 4V at 4KM fault cable which indicate that single phase fault occur. This is due to the value of voltage obtained is higher at 4KM. The cable involved is blue when SW12 is pressed. The voltage reading at 4KM fault cable on load with 0.154V. The load is connected to the blue cable to emit the waveform, the voltage value and also the current flow value. The current reading at 4KM fault cable with 0.068A.

1 KM Red and yellow LED on

Based on the figure 7, the maximum voltage for this condition is 5V from 12 V supply when SW2 and SW13 are pressed. This is due to the fault occurs on red and yellow cables that represent 1 KM up to 3 KM. This condition generates a low voltage on the fault cable than the second conditions due to the fault distance that goes along 3KM even the fault occur at line-to-line.
Figure 7. Waveform of fault cable at 1 KM to 3 KM (R and Y)

The voltage reading in fault condition at load is 0.187V. The reading at voltage is higher than the second condition because it only involves two cables which are yellow (1KM) and red (3KM) that fault occur compared with the three cables that occur fault in the second condition. The result voltage at the load section shows that the fault at 3KM distance has a higher voltage to load because fault occurs only in phase-to-phase fault state. The current reading measured are 0.283A which is higher than condition 1 and 2. This is due to the double-line fault that involves red and yellow cable at distance 1KM to 3KM.

4KM Yellow and blue LED on

Figure 8, shows the maximum voltage at fault is 3V from the 12V supply, indicating it is a double-line fault occurs at 4KM. The cable involved is yellow and blue when SW7 and SW8 are pressed. It is the lowest voltage on the cable fault in this experiment because fault occurs at maximum distance on two cables.

Figure 8. Waveform of fault cable at 4 KM (Y and B)

The reading on the voltage at the 4KM load section is 0.569 V. Voltage on load when fault cable occurs is 0.569V where the reading is higher than the reading voltage at third condition. This is due to the third condition involves two cable at kilometer 1 and 3 while the fourth condition involves two cables at the same distance at 4KM.
1 KM Red, yellow and blue LED on

Based on Figure 9, the waveform fault on the cable is red (straight line) while the waveform of injected cable is yellow (sine wave). Injected cable turns the waveform of half-square wave to sine wave indicates the occurrence of damage to the cable. The maximum voltage at fault is 9.0V from the 12V supply, indicating it is a three phase fault occurs at 1KM distance from the power distribution board. The cable involved is red, yellow and blue when SW1, SW13 and SW14 are pressed.

![Waveform of fault cable at 1 KM (R, Y, and B)](image)

Figure 9. Waveform of fault cable at 1 KM (R, Y, and B)

The voltage reading at fault on load for the fourth condition is 0.195 V. The reading is higher from the previous condition due to three-phase fault that involve three fault cables in different kilometers. The current reading for fault at 1KM, 2KM and 3KM is 0.331A. This value is higher than the current value at fifth condition because fault occurs at different distances.

1 KM to 3 KM Red, yellow and blue LED on

Based on the waveform, the maximum voltage at fault is 5V from the 12V supplies which indicate it is a three phase fault occurs at 1KM to 3KM. The cable involved is red (3KM), yellow (2KM) and blue (1KM) when SW2, SW5 and SW14 are pressed. It gives the same maximum voltage as the third condition because the fault occurs within 3 KM distance. The difference between the third and fourth conditions is the location of the fault on the cable, where the fourth condition fault occurs on the three cables while the third condition, the fault occurs only on two cables which are yellow and red. Therefore, the voltage that reaches the load is less than the voltage that reaches the load at the third condition with 0.195V and 0.187V respectively as shown in figure 10.
Table 2 is the comparison between the reading of voltage and current in theoretical and practical. Current reading in theoretical are the same along the kilometers which is 0.05 A and 0.289 A due to the range of the particular phases. For line-to-line fault and three-phase fault obtained the same reading in theoretical due to the same source of fault. So, it is consider the same cause of the range of fault current. Practically, for the condition while pressing SW2, SW5 and SW14, the voltage and current reading are increasing. This is due to the three-phase fault occurred at 1 KM to 3 KM that far away from the source which makes the current increase.

Table 2. Comparison reading of fault current and voltage between theoretically and practically

| Faulted cable            | Theoretically | Practically |
|--------------------------|---------------|-------------|
|                          | Voltage (V)   | Current (A) | Voltage (V) | Current (A) |
| Press SW4                | 2.0           | 0.05        | 2.15        | 0.072       |
| Press SW11               | 4.0           | 0.05        | 4.0         | 0.068       |
| Press SW2 and SW13       | 5.1           | 0.289       | 5.0         | 0.283       |
| Press SW7 and SW8        | 3.2           | 0.289       | 3.0         | 0.256       |
| Press SW1, SW13 and SW14 | 8.2           | 0.289       | 9.0         | 0.283       |
| Press SW2, SW5 and SW14  | 4.6           | 0.289       | 5.0         | 0.331       |

4. Conclusion

As a conclusion, the objectives of this project are achieved. The first objective is to develop a portable detector for exact fault location and distance fault. The system is battery operated and pinpoint fault accurately in the system. Secondly, to develop prototype underground cable for a development of underground cable fault distance locator. The locator is represented by a line robot which sense the electromagnetic field produced in a fault cable. Next, to construct the performance prototype that used in measures the fault distance by using Tracer method. The final prototype able to perform with the desired way on how this system operates in real life.
References

[1] D. D. A. S. T, “Development of A Prototype Underground Cable Fault Detector,” pp. 1–6, 2014.
[2] R. Priyanka and B. Priya, “Underground Cable Fault Detection,” vol. 3, no. 3, pp. 235–237, 2016
[3] J. P. Singh, N. S. Pal, S. Singh, T. Singh, and C. Engineering, “U c f d l,” vol. 3, no. 1, pp. 21–26.
[4] J. Althaf, M. Imthiaz, and R. Raj, “Underground Cable Fault Detection using Robot,” vol. 3, no. 2, 2013.
[5] K. P. Kumar, K. D. S. Prasad, and K. Sravanthi, “Wavelet-Based Fault Location and Distance Protection Method for Transmission Lines,” vol. 4, no. 7, pp. 5–16, 2014.
[6] M. B. Eteiba, W. I. Wahba, and S. Barakat, “ANFIS Approach for Locating Faults in Underground,” vol. 8, no. 6, 2014
[7] A. Sharma, A. Mathur, R. Gupta, R. Singh, and E. M. Singh, “Underground Cable Fault Distance Locator,” pp. 2581–2585, 2017.
[8] E. Engineering, “Arduino Based Underground Cable Fault Detector,” pp. 17–21, 2016.
[9] I. Journal, O. F. Engineering, U. Cable, F. Distance, and L. By, “International journal of engineering sciences & research technology underground cable fault distance locator by using microcontroller,” vol. 9655, pp. 26–29, 2016.
[10] Q. Shi, O. Kanoun, and S. Member, “Wire Fault Diagnosis in the Frequency Domain by Wire Fault Diagnosis in the Frequency Domain by Impedance Spectroscopy,” no. March, 2015.