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Time Domain Reflectometry Concept for Underground Cable Fault Detection using CST Simulation Software

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Abstract: In order to help reduce the ratio of fatal accidents involving cable maintenance and highway users, the implementation of the time domain concept for underground cable fault detection using Computer Simulation Technology (CST) Cable Studio software was used. This system was designed to improve the detection of faults in underground cables by focusing the time domain reflectometry (TDR) signal reflect in normal and fault condition. This approach is one of the safety procedures used by workers and highway users to avoid accidents and damage. There are several adjustments that need to be made in order to make the problem described appropriate for the working environment and to obtain a better underground fault detector. To obtain the analysis findings of the strength and integrity design, this project was evaluated using CST cable simulation. The properties of cable in normal and fault conditions for street lighting must be focused on to achieve and analyse the results obtained in order to complete this project. The result obtained for each condition ideal, short, open, and short and open circuit will be analysed to see the different of Time Domain signal that will produce.

Keywords: Time Domain Reflectometry, Underground Cable, Fault

1. Introduction

Underground cable can be considered as the most critical aspect in the street lighting installation system. To guarantee that the street lighting works well, we must first ensure the cables are in good working order before installing them in the street lighting. The condition of underground cable, particularly near the highway, is less of a concern in this case. If there is a problem with the cable, it is difficult to identify. To detect the fault, a specialized detector is required.

Before installing the cable, it is important to perform an insulation and continuity tests on the cable to ensure that it is free of damage and in good working order. However, after the cable is installed, there

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is a possibility that the underground cable will be damaged. The defect can occur for a variety of reasons, including moisture entering the insulation, mechanical harm during transport, the laying procedure, or various forces faced by the cable during its installation and operation. The lead sheath is regularly destroyed, mainly because of the acts of environmental pollutants, soil, and water, or mechanical damage and crystallized of lead caused by vibration [1].

Insufficient of detector leads to delay on some project that a company handle. This is because cable may face several of problems. Next, the problem occurs when underground cable faced faulty is to determine which part of the cable had the problem after it has been installed for long period. The fault of the cable in mostly happen when there is moisture entering the insulation, mechanical damage during transportation, the laying method, or various pressure encountered by the cable during installation and operation are all possible causes of the problem. The lead sheath is regularly degraded, mostly as a result of pollution, soil, and water, as well as mechanical damage and lead crystallized produced by vibration [1].

Therefore, in order to improve an easier way to detect faulty, the time domain reflectometer (TDR) concept can be used. The time it takes for the signal to reflect back from the point of impedance change is measured by a TDR (or the point of fault). A TDR sends a short-duration low energy signal (of about 50 V) at a high repetition rate into the cable. This signal reflects back from the point of change in impedance in the cable (such as a fault) [2]. The use of Computer Simulation Technology can generate a TDR signal output for normal and fault condition for the 3-phase connection system and single-phase connection system.

2. Materials and Methods

This study is to develop a simulation that can detect a fault in underground cable and reflect the time domain reflectometry (TDR) signal by using computer simulation technology (CST) Cable Studio software. The TDR pulse was utilized to partly troubleshoot any cable faulty by sending a signal through the cable and reading the reflected signal. The flowchart for the entire project planning process is shown in Figure 1. The starting element in this study is data collection on underground cable characteristics. The first step in constructing the system is determining the node, segment, and cable type using the CST software simulation. To begin the simulation, it is needed to complete the design schematic for a 3-phase connection in both normal and fault conditions. Next, set the frequency and impedance, and run the design simulation. If TDR signal is not visible keep designing the schematic until TDR signal is reflected. After the simulation for the three-phase connection is complete, use the same steps to develop the design schematic for the single-phase connection in both normal and fault conditions.

The 16mm² PVC/SWA/PVC was chosen in this project to simulate the underground cable fault detection. This type of cable is commonly used in street lighting installation in highway. Table 1 shows that the specification of underground cable that used in this simulation.

Table 1: The specification of underground cable

Cross Sectional Area of Conductor (mm^2)	Shape of Conductor	Nominal Insulation Thickness (mm)	Nominal diameter of steel wire (mm)	Nominal Sheath Thickness (mm)	Approx. Overall Diameter (mm)	Approx. Cable Weight (Kg/Km)
16	CC	1.00	1.60	1.80	26.3	1648

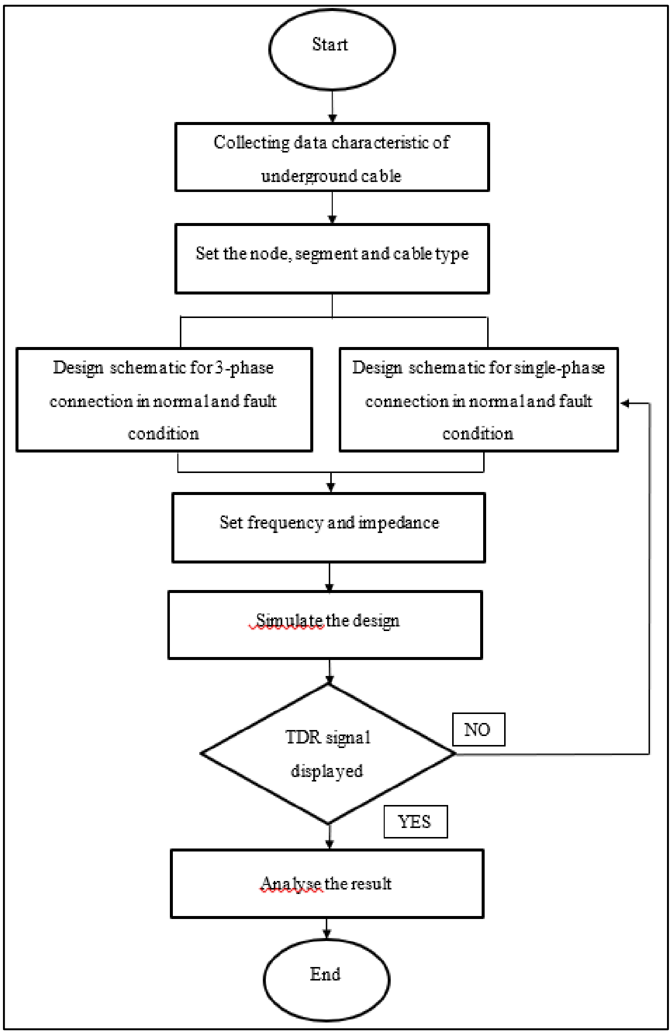


Figure 1: Flowchart for this project

By constructing twisted pair PVC cable, the simulation results from CST Suite Studio were collected. This software includes precise calculations and design cable solutions. Additionally, it provides the ability to construct a suitable electromagnetic three-dimensional simulation based on the techniques given, and it will enhance efficiency throughout a wide frequency range. The simulations were performed considering 3 street light pole with distance 40m each pole as shown in Figure 2. There are two conditions to investigate the fault in underground cable which is the underground cable that terminate at junction box streetlight and the cable at output junction box to lantern lamp. The cable that has been applied is 6 AWG where the material of conductor is copper with diameter 1.6mm and the material for insulator is PVC with thickness is 1.0mm.

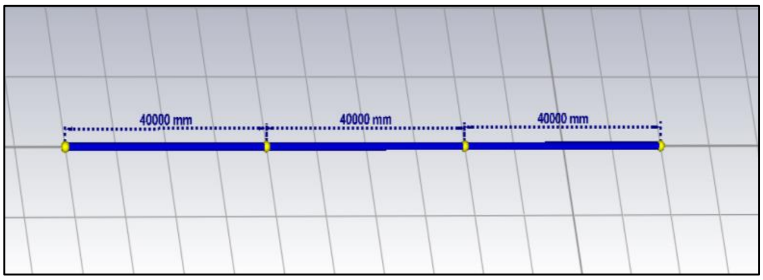
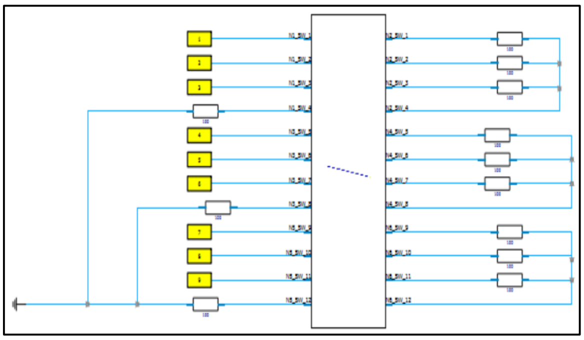


Figure 2: CST design for the system

Figure 3(a) shows the cable termination at box junction for each street light pole with the 3-phase connection at ideal condition. The port for 1, 2, and 3 is for the street light 1, port 4, 5, and 6 for the street light 2 and port 7, 8, and 9 for the street light 3. In Figure 3(b) shows the connection of open circuit at port 2 for the first street light, port 4 for the second street light and port 9 for the third street light pole. Figure 3(c) shows the short circuit connection at port 1 to the neutral point for street light 1, meanwhile port 5 is connected to the neutral point for street light 2 and port 9 to neutral point for the street light pole 3. The open and short circuit connection for the street light 1 where port 1 and neutral is a short circuit while port 3 is an open circuit. Whereas, for the street light 2 is in normal condition without any fault. Meanwhile, the street light 3, port 7 is an open circuit while port 9 and neutral is a short circuit is shown in Figure 3(d). For the parameter list was set for the frequency is 50Mhz and excitation was set to Gaussian signal with the impedance of 100ohm.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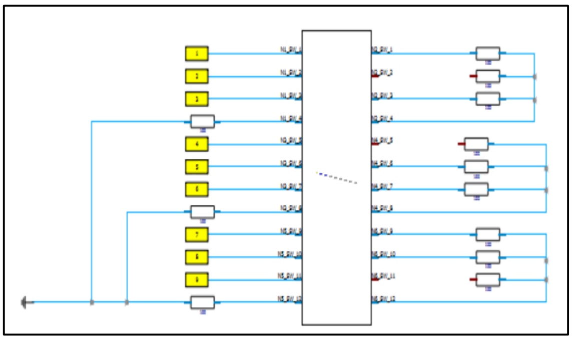
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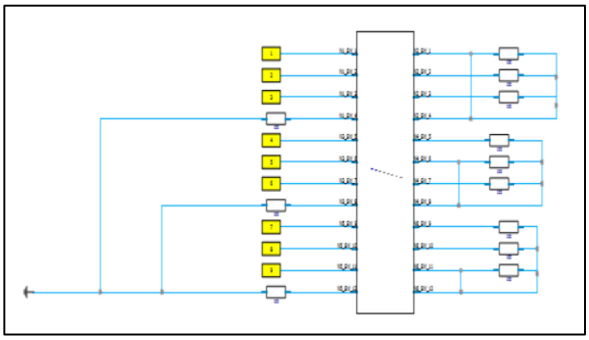
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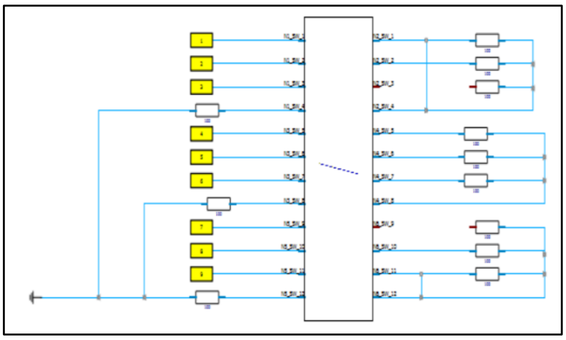

(d)

Figure 3: The schematic design for (a) an ideal condition; (b) open circuit condition; (c) short circuit condition; and (d) an open and short circuit condition

Figure 4(a) shows the cable termination from output box junction to input lantern lamp for each street light pole with the single-phase connection at ideal condition. The port for 1 is for the streetlight 1, port 2 for the street light 2 and port 3 for the street light 3. Figure 4(b) shows the schematic design for short circuit condition. It is noticed that the streetlight 1 is in open condition, street light 2 is in normal condition and street light 3 is in an open circuit. Figure 4(c) shows the schematic design for short circuit condition. Referring to Figure 4(c), the streetlight 1 is in normal condition, whereas for the street light 2, the yellow wire short with neutral meanwhile for street light 3, blue wire was short with neutral. Figure 4(d) shows the schematic design for open and short circuit condition. It is observed that the streetlight 1 is in open condition, street light 2 is in normal condition and street light 3 which is blue wire short with neutral. For the parameter list was set for the frequency is 50Mhz and excitation was set to Gaussian signal with the impedance of 100ohm.

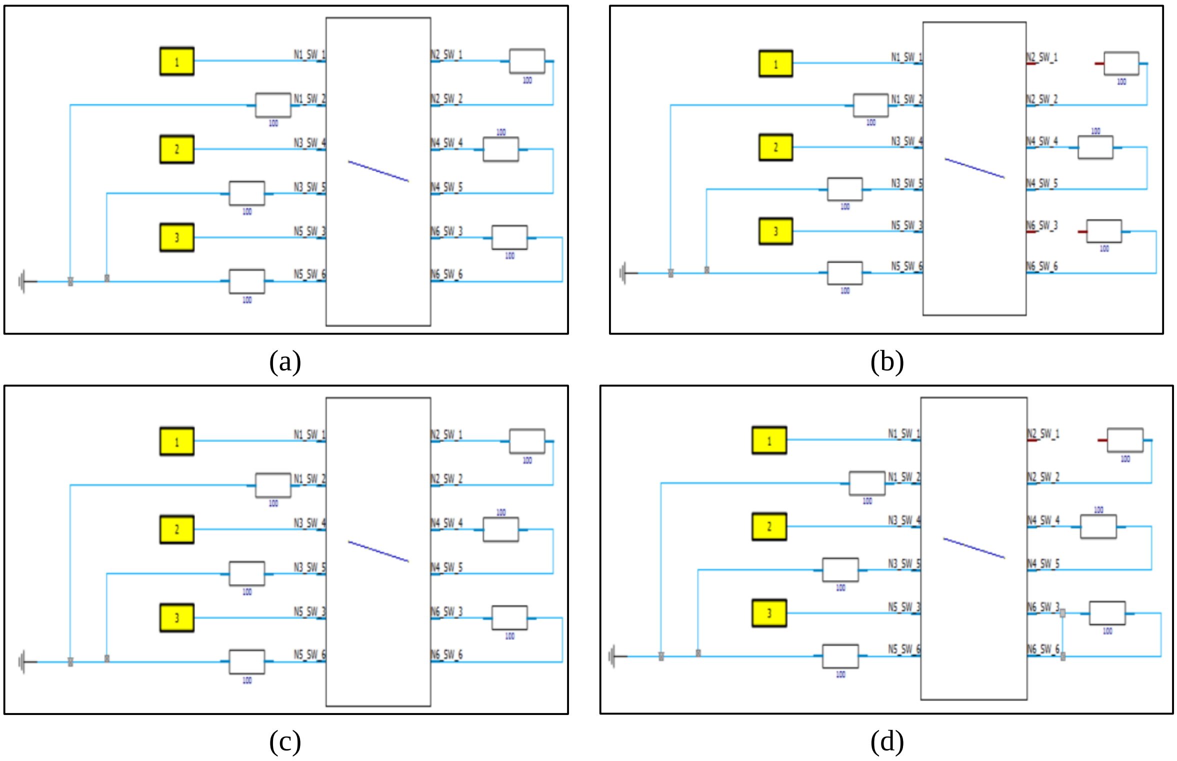


Figure 4: The schematic design for (a) an ideal condition; (b) open circuit condition; (c) short circuit condition; and (d) an open and short circuit condition

3. Results and Discussion

This section discusses on the result obtained from the simulation that has been done using CST simulation software. The analysis of the result covered from the 3-phase connection of underground cable terminated to input junction box and the result for single-phase connection of the output junction box to input lantern lamp streetlight.

3.1 Results

The results for 3-phase connection of underground cable terminated to input junction box is shown in this section. Figure 5 shows the Time Domain (TD) signal of ideal condition. The connection is in normal condition, so the TD signal does not display any errors. Because the cable between each street light pole is the same length (40m), the reflected signal seems to overlap with one another. Figure 6 shows the TD signal reflected for open circuit condition, short circuit condition and also TD signal that reflected for open and short circuit condition for 3-phase connection. The summary of the peak amplitude value is tabulated in Table 1.

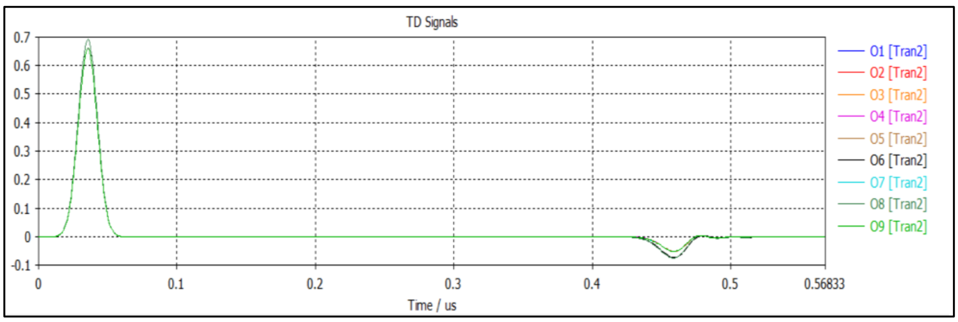


Figure 5: TD signal for ideal condition for 3-phase connection

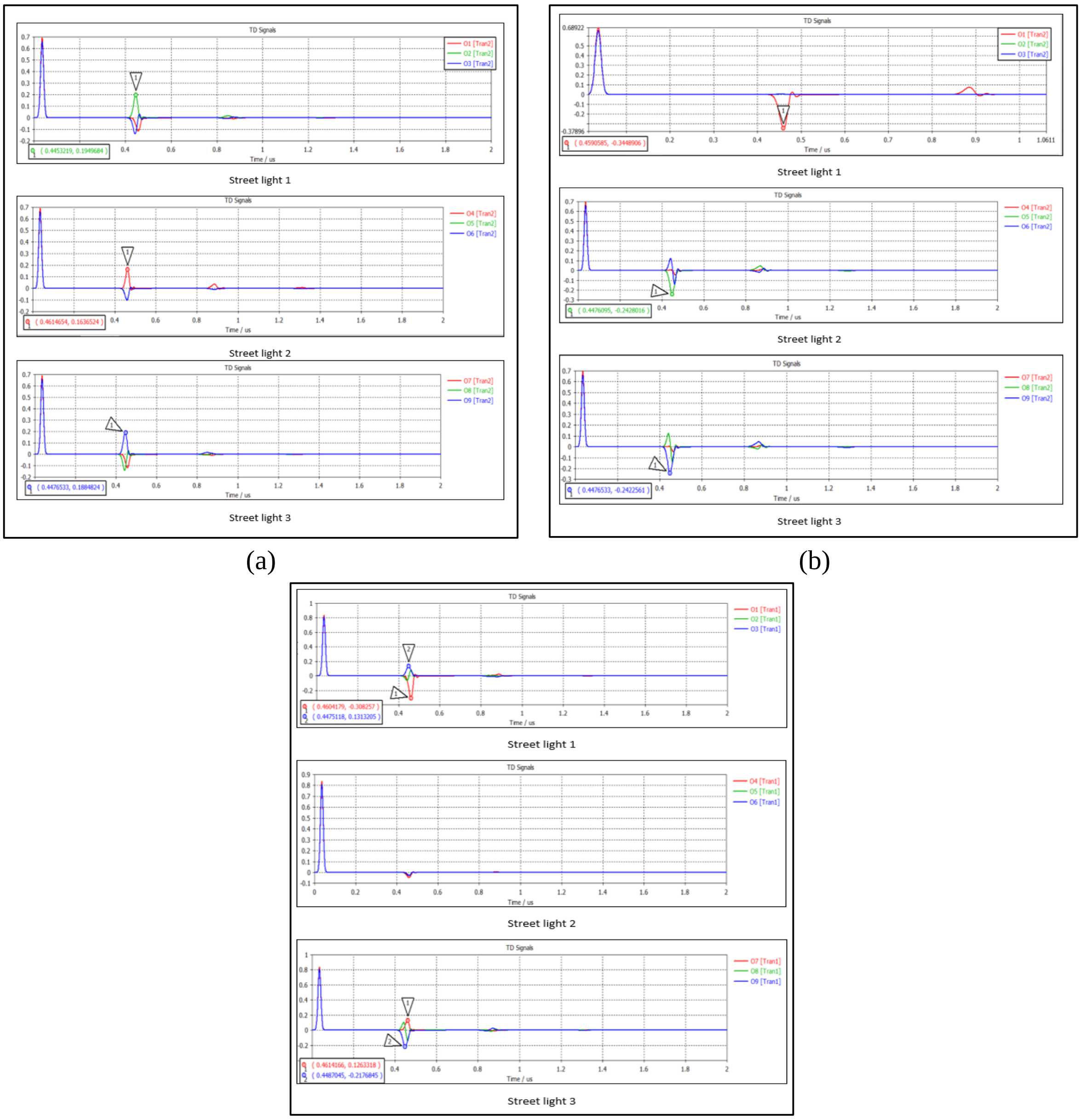


Figure 6: TD signal for (a) open circuit condition; (b) short circuit condition; and (c) that reflected for open and short circuit condition

Table 1: Result obtain from the 3-phase connection of underground cable terminated to input junction box

Cable Fault	Street light 1		Street light 2		Street light 3	
	Time µs	Peak Amplitude	Time µs	Peak Amplitude	Time µs	Peak Amplitude
Open circuit	0.4453219µs	0.1949684	0.4614654µs	0.1636524	0.4476533µs	0.1884824
Short circuit	0.4590585µs	-0.3448906	0.4476095µs	-0.2428016	0.4476533µs	-0.2422561
Open and short circuit	0.4475118µs	0.1313205 (Open circuit)	No fault applied at the connection		0.4614166µs	0.1263318 (Open circuit)
	0.4604179µs	-0.308257 (Short circuit)			0.4487045µs	-0.2176845 (Short circuit)

The result for single-phase connection of cable that terminated at output junction box to input lantern lamp street light is shown in this section. This simulation was performed to investigate the fault occur on underground cable from output junction box to input lantern lamp. Figure 7 show the TD signal for ideal condition. The connection is in normal condition, so the TD signal does not display any errors. Because the cable between each street light pole is the same length (40m), the reflected signal seems to overlap with one another. Figure 8 shows the TD signal reflected for open circuit condition, short circuit condition and also TD signal that reflected for open and short circuit condition for single phase connection. The summary of the peak amplitude value is tabulated in Table 2.

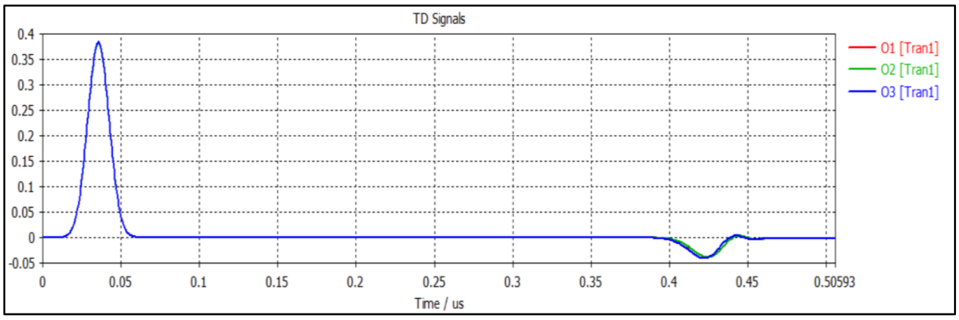
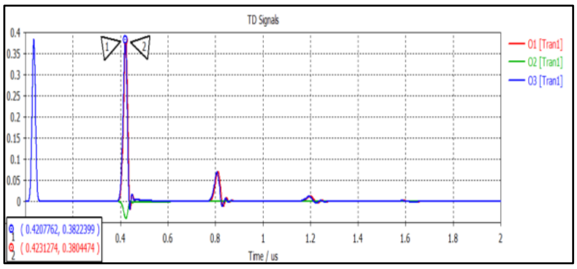
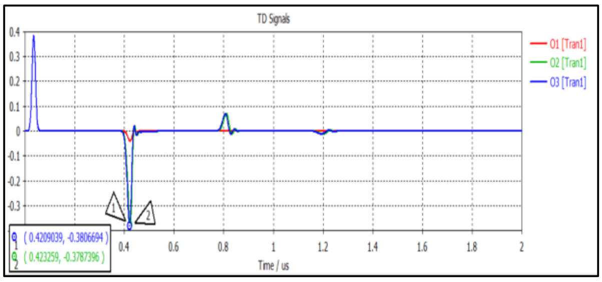


Figure 7: TD signal reflected for ideal condition for single-phase connection.



(a)



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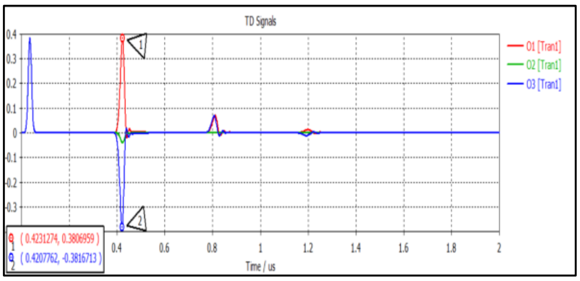

(c)

Figure 8: TD signal reflected for (a) the open circuit condition; (b) for short circuit condition; and (c) for open and short circuit condition

Table 2: Result obtain from the cable termination from output box junction to input lantern lamp for each street light pole with the single-phase connection

Cable Fault	Street light 1		Street light 2		Street light 3	
	Time μs	Peak Amplitude	Time μs	Peak Amplitude	Time μs	Peak Amplitude
Open circuit	0.4207762μs	0.3804474	No fault applied at connection		0.4231274μs	0.3822399
Short circuit	No fault applied at connection		0.4209039μs	-0.3787396	0.423259μs	-0.3806694
Open and short circuit	0.4231274μs Open circuit	0.3806959	No fault applied at connection		0.4207762μs Short circuit	-0.3816713

3.2 Discussions

To analyse the underground cable on street lighting, two simulations have been performed. In order to investigate the condition of the underground cable terminated at the street light input box junction in normal, open, and short circuit, the first simulation was carried out by constructing a 3-phase connection. The following simulation uses a single-phase connection design to connect the cable from output junction box to input lantern lamp. This simulation's objective is to analyse the reflected time domain reflectometry signals in normal and fault condition of underground cable that terminated at input junction box streetlight and the cable terminated from output junction box street light to input lantern lamp. For ideal condition, the TD signals for single-phase and three-phase connections are almost same in time, meaning that there is no difference in terms of peak output TD signals due to the same cable length which is 40m [3]. Besides, both signals have the same peak amplitude, which is located at negative region Y-axis. The peak amplitude may be same as short condition, just the peak amplitude differs the ideal condition and the short condition where the ideal condition has a smaller peak amplitude than the short condition [4].

For open condition, the TD signals for single-phase and three-phase connection are almost same in time of peak output TD signals because the length of cable effect the time of peak output TD signals [3]. Meanwhile, the peak amplitude for three-phase connection is reduced by half than the peak amplitude for open condition in single-phase. As for the shape of waveform, the signal reflected for open condition is in positive region [5].

For short condition, the time of peak output TD signals and the peak amplitude is almost same for both simulations where the signal reflected is in negative region [5]. Additionally, there are splice reflection where the peak amplitude is moving from positive to negative but the cable splicing does not lead to changes in voltage because cables that are joined together have the same AWG size [6].

Lastly, the simulation for open and short condition has been done to analyse the TD signals that reflected when multiple faults occur at a time in the system. The result that obtained show that the signal for open and short condition is reflected as similar to how the signal reflect when fault occur.

4. Conclusion

In conclusion, with the help of simulation using CST simulation software, the reflected time domain reflectometry signals in normal and fault condition of underground cable that terminated at input junction box streetlight can be obtained. Normally fault can be occurred in underground and at the junction box. This simulation was done by constructing 3-phase connection of PVC cable to investigate and analyse the time domain signal at ideal, open, and short circuit. The simulation was done successfully when the output time domain signals reflected is same as theory of time domain reflectometry. The reflected TDR signals in normal and fault condition of cable terminated from output junction box streetlight to input lantern lamp street light also has been successfully simulated. This simulation was done by constructing single-phase connection of PVC cable where only one single live wire and neutral that terminated to input lantern lamp in order to investigate and analyse the time domain signal at ideal, open and short circuit. The simulation was done successfully when the output time domain signals reflected is same as theory.

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