Arduino - Based Faulty Pilot Cable Detector and Digital Sampling Oscilloscope

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***Abstract*- This paper shows another way of developing faulty pilot cable detector based on time-domain reflection (TDR). The faulty pilot cable detector is implemented on Arduino microcontroller. Since it is digital based, it is easily programmed and the circuitry is not as bulky as analogue type. Using the Arduino-based microcontroller, the faulty at the pilot cable can be detected by injecting the TDR pulse signal into the inspection cable or wire. The edge and reflected signals from the inspection cable are captured and measured by the Digital Sampling Oscilloscope. Then, the pattern of healthy or faulty cable with its location can be determined by analyzing the reflected pulse signal (step waveform). This system has been successfully tested on 30m cable with shorted and opened conditions. The whole system to detect faulty in the pilot cable are coded using C language.**

***Keywords*- Pilot Cable, Time Domain Reflection (TDR), Arduino Based Microcontroller, Arduino Pulse Signal Generator, Arduino Based DSO and Digital Sampling Oscilloscope .**

I. INTRODUCTION

The term of pilot cable is applied to conductors that transfer voltage or current signals from one point to another for comparison with other voltage or current signals as part of a protection scheme. Pilot cable is a special control cable laid in parallel with a power cable and intended for transmitting signal related to the operation of the cable. Pilot cables are also used to transfer switching signals from one point to another such as controlling signal in communication, cable protection and signaling, speech and data transmission [1].

Pilot cable have a bundle of wire that enclosed in wire amour or single core round hard drawn aluminum wire applied helically (spiral-shaped) over them and single core wire covered by dual insulation with an inner core of cellular polyethylene and outer skin of solid polyethylene [2] as shown in Fig. 1.

Fig. 1. Pilot cable structure and actual testing cable

In Malaysia, Tenaga Nasional Berhad, which is Malaysia Utility Company complying this pilot cable to provide the channel between the supply substation for communication and for protective relaying of high voltage undergoes and overhead [3].

However, when there is an over voltage in the pilot cable cores, it may cause severe damage to the power system and the problem also occurs when the pilot cable along the transmission line enters swampy area as water might seep into it and damage the pilot cable. Thus, this requires immediate actions and the persons in charge would like to know the location of the faulty cable so that they can amend the cable. This can be done if a pilot cable detector able to determine the healthy or faulty cable inside the pilot cable.

Thus, Analogue systems with TDR technique were developed by [4-5] to monitor and detect the faulty cables but unfortunately the systems are not only bulky and complex but they also need more power to operate the system.

Hence, an Arduino-based faulty pilot cable detector integrated with impulse generator and display is proposed here to overcome these problems. By using the Arduno-based microcontroller the TDR pulse signal generator and Arduino Digital Sampling Oscilloscope are implemented in this paper to detect pilot cable condition. Experimental results show and verify that the model is capable to detect fault in the cable.

II. TIME DOMAIN REFLECTION (TDR) SYSTEM OPERATION

The method to determine and analyze the faulty in the pilot cable by using the Arduino-based microcontroller is based on Time Domain Reflection (TDR) system. TDR is a technique for measuring and evaluating the impedance quality of the cable or wire in the transmission line system and/or components. Basically, TDR circuit is closed to RADAR circuit [6].

The principle of the TDR is based on two metal conductors to form an impedance and any changing in the impedance will cause the partial energy from the incident pulse signal will be reflected back [7]. Since the reflected voltage is in step function, the length cable can be calculated from the time delay between the incident and reflected voltage and the velocity of propagation (VOP) of the cable.

In this project, TDR pulse signal system sends a low-voltage with high frequency digital signal to the pilot cable and the injected digital signal travels to the end of the pilot cable and then it reflects back. The digital sampling oscilloscope is supposed to capture the injected and reflected signal. The delay between the incident and reflected signal and reflection coefficient, ρ seen from the waveform determines the type of fault and location of the fault. Fig. 2 shows the main block diagram TDR test set.

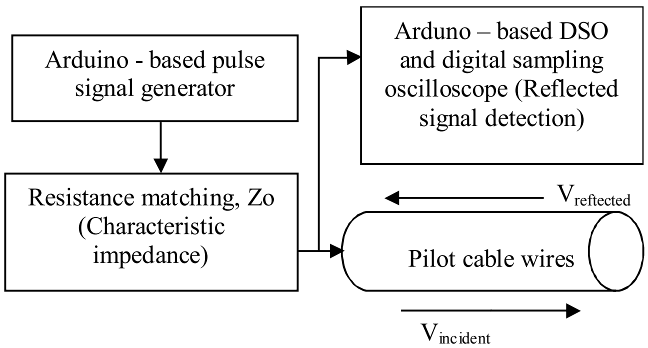

Fig. 2. Time domain reflection (TDR) system operation

The objective of this project is to build a system using Arduino-based microcontroller to test the faulty pilot cable using TDR technique. There are 3 main parts which are Arduino Pulse Signal Generator, Pilot cable and Arduino Digital Sampling Oscilloscope as shown in Fig. 3 and the functions of each part are described in Table 1 All of the parts except pilot cable wires are developed using C language and implemented on Arduino-based microcontroller.

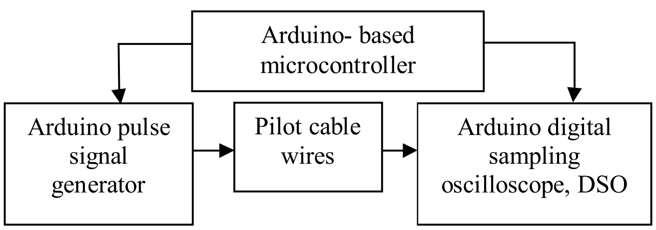

Fig. 3. Main part of Arduino-based faulty pilot cable detector

TABLE 1. FUNCTION OF MAIN PART ARDUINO-BASED FAULTY PILOT CABLE DETECTOR

Main Parts	Function
Arduino Pulse Signal generator	To generate digital signal with high frequency pulse width and delay between each pulse.
Tested Pilot cable	The pulse generator signal will be injected to this pilot cable to check the condition either the cable healthy or not.
Arduino DSO and Digital Sampling Oscilloscope	Used to display the reflected signal from the pilot cable and measure the delay in determining the fault's location.

A. *Arduino Pulse Signal Generator*

Pulse generator is a pulse repetition rate (Frequency), pulse signal width, and delay with respect to an internal or external trigger and high and low voltage between to pulse signal [8]. By using the Arduino Mega 2560, there are three different pulse signals with different pulse width developed to check three different length of pilot cable sample. From the datasheet of Arduino Mega 2560, the clock speed for this board is 16MHz.

$$time\ clock, T = \frac{1}{Clock\ Speed, f} \tag{1}$$

For Arduino mega, the clock time is 62.5ns. Time to execute one instruction program can't be less than this clock time.

$$time\ clock, T = \frac{1}{16M} = 62.5nS$$

In this work, the Arduino Pulse Signal Generator is generated by using port register in the Arduino port manipulation. Port registers allow for lower-level and faster manipulation of the input and output pins of the microcontroller on an Arduino board [9]. For Arduino Mega 2560, the microcontroller is using the Atmel Atmega 2560 microprocessor and PORTA register is used to generate the 3 different pulse width signals. The speed to set the PORTA High and Low is determined by the clock from the crystal oscillator which is 62.5ns.

- PORTA (HIGH or LOW) = 1 x 62.5ns = 62.ns.
- DDRA - The Port A Data Direction Register (read/write) used to declare the port used either input or output.
- PORTA - The Port A Data Register (read/write) used to set condition of port either HIGH or LOW.

For this project, there are three generated pulse signals with different positive pulse width which are 125ns, 250ns and 375ns with 2750 delay for all negative pulse width. The calculations for the Arduino pulse signal generator are shown as follows:

1) *125ns pulse generator width (for sample 10 meter):*
   Positive Pulse Width = 2 x 62.5ns = 125ns (2)
2) *250ns pulse generator width (for sample 20 meter):*
   Positive Pulse Width = 4 x 62.5ns = 250ns (3)
3) *375ns pulse generator width (for sample 30 meter):*
   Positive Pulse Width = 6 x 62.5ns = 375ns (4)
4) *Delay between pulse signal:*
   Delay between pulse = 44 x 62.5 = 2750ns (5)

Fig. 4 shows the result of Arduino pulse signal generator width 125ns (Yellow), 250ns (Purple) and 375ns (Blue) with the 2750ns delay between pulse and Fig. 5 shows the flowchart for the TDR Pulse Signal generator.

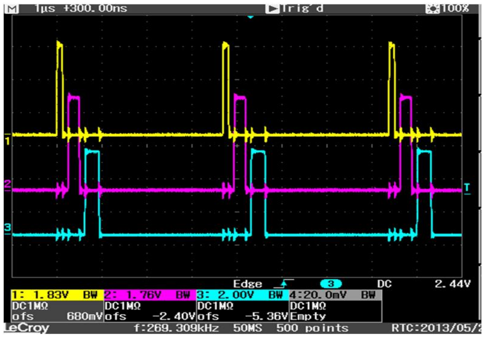

Fig. 4. Show the result of Arduino pulse signal generator

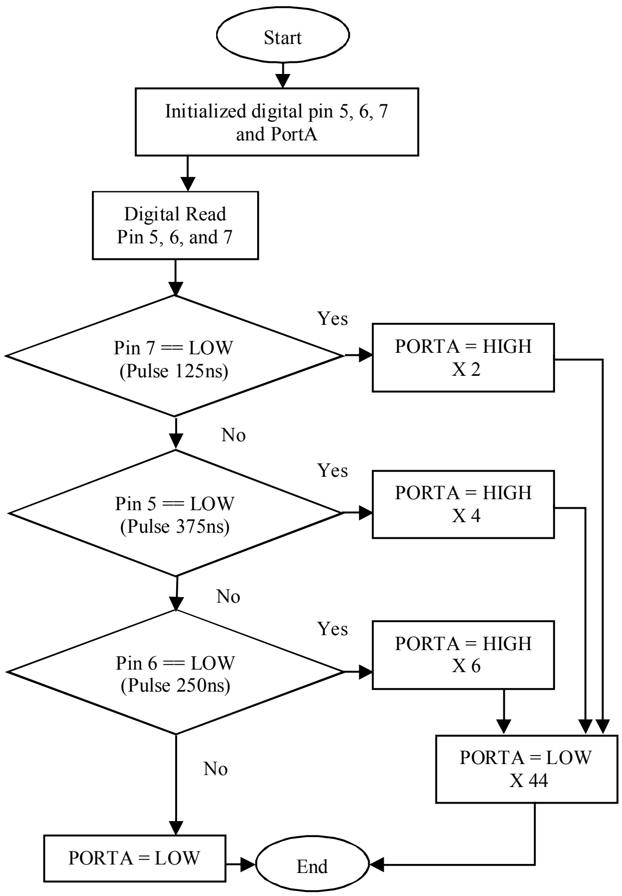

Fig. 5. Flowchart of TDR pulse signal generator

B. Type of cable fault

Some problems such as broken in the cable, loose connector and overvoltage may cause the fault in the pilot cable. There are three main type of cable fault such as Open circuit fault, short circuit fault and high impedance fault [8].

- Open Circuit Fault: This occurs when the conductor cable at the location fault is completely broken. This cause the high resistance shunted fault (connected to ground) between both side faulted cables.
- Short Circuit Fault: This occurs when the resistance from the conductor to ground is lower than characteristic impedance of the cable. It is categorized by a low resistance continuity path.
- High Impedance Fault: This fault demonstrates non-linear resistive characteristic which allowed to apparent resistance to vary with the applied voltage and current. It occurs when the resistance path that connected to the ground is higher than characteristic impedance.

C. Testing Method

There are three different lengths or sample of the pilot cable to be tested in this project. Different length of pilot cable needs different Arduino pulse signal from Pulse generator. Hence, choosing the appropriate pulse signal width is very critical so that the pattern of the reflected signal can display clearly in the DSO and easily to analyze the condition of the pilot cable. For this project, the length of the pilot cable to be tested is 10 meters, 20 meters and 30 meters. Table 2 shows the suitable signal pulse width for each of pilot cable length.

TABLE 2. PILOT CABLE LENGTH AND SIGNAL PULSE WIDTH

Length, m	Pulse signal width, ns
10	125
20	250
30	375

Velocity of propagation is one of criteria that can cause error in measurement. Hence, the correct VOP of the cable under test is needed to minimize the error [8]. The VOP must be determined by length of tested cable divided by time since different cables have different VOP.

$$Velocity\ of\ Propagation, VOP = \frac{Length\ (m)}{Time\ (s)} \quad (6)$$

- The value for the VOP has been determined from the healthy for cable 10m, 20m and 30m length of pilot cable. The VOP for the cable is 0.1m/ns.

For this project, the pattern of the reflected pulse signal is displayed on the oscilloscope and the pattern is analyzed to determine the transit time from monitoring point measured on the oscilloscope [10]. Hence, from the time transit delay of the reflected signal and velocity of propagation (VOP), the distance, where the faults occur, can be determined.

$$D = t \times Vp \quad (7)$$

Where, D = Distance of faulty of healthy cable
t = transit time from monitoring point measured on the oscilloscope.
Vp = Velocity of Propagation or VOP

D. Testing Criteria

In normal operation, the load impedance of the pilot cable is not equal to the characteristic impedance, Zo. If the load impedance is matched with the load impedance, all the reflected energy is absorbed by the source impedance. Hence, there is no reflection signal. But when the load impedance is mismatched with the cable impedance, some of the signal power is reflected back because it is unable to absorb the entire injected power.

The reflection coefficient, ρ is determined by the incident voltage divided by the voltage reflection.

$$reflection\ coefficient, \rho = \frac{Voltage\ Reflect, V_{ref}}{Voltage\ incident, V_{inc}} \quad (8)$$

For this project, the different lengths of sample pilot cable are tested by using the appropriate TDR pulse signal. To determine the healthy and faulty of the tested cable, there are two different tests, open circuit test and short circuit test.

- Open circuit test: used to check either the end of the cable is fully broken or not. When the cable is broken of open end, no current can flow between the cables. These mean that the incident current will be reflected back at the open circuit. The total current at the open circuit is the sum of incident and reflected current and the voltage become twice from the incident voltage. Hence the reflection coefficient, ρ for open circuit test is 1.

- Short circuit test: when the end of cable is connected to the load impedance that matching the characteristic impedance or ending cable connected to ground. All the reflected energy will be absorbed by the load impedance. Hence there is no reflection signal from the end of cable. The reflection coefficient, ρ for short circuit test is -1.

Fig. 6 shows the basic concept result for the Time Domain Reflection, TDR measurement.

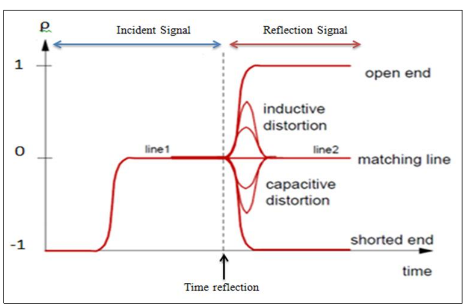

Fig. 6. Basic concept for TDR measurement result.

E. *Arduino Based Digital Sampling Oscilloscope (DSO)*

Oscilloscope is a type of electronic test measurement that uses to do observation of constant varying signal voltage. Usually oscilloscope has two-dimensional graph which are y-axis use for electrical potential different such as voltage, current and x-axis use as a time function's is a type of oscilloscope that used to measure the high-frequency signal. DSO accurately capturing signals whose frequency are much higher than the oscilloscope sample rate.

This work implement the Arduino based DSO and use Digital sampling oscilloscope, DSO to display the reflected pulse signal from the pilot cable. Hence, by see the pattern from the DSO, the faulty in the pilot cable can be detected.

Arduino based DSO is built using the Arduino Due microcontroller and Arduino processing software. The Arduino microcontroller receives the reflected signal from the pilot cable as an analog input to the microcontroller. This data is processed through the serial communication and the graph is generated and plotted on the oscilloscope. Fig. 7 shows the flowchart to display the pattern of Reflected signal from the tested pilot cable.

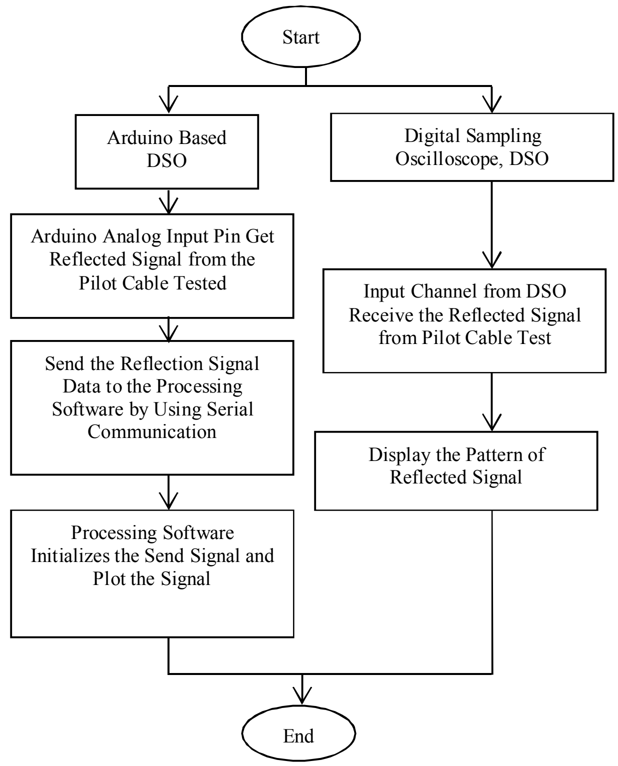

Fig. 7. Flowchart of displayed the pattern of reflected signal from pilot cable tested

III. Result and Discussion

A. *Arduino Pulse Signal Generator*

This work uses an Arduino mega 2560 microcontroller to produce pulse signal. From the calculations (2) – (5), there are three different pulse signals which are 125ns, 250ns, and 375ns. The delay between pulse signals is 2750ns. Fig. 8a-d shows the result for the pulse signal that produced from Arduino mega 2560.

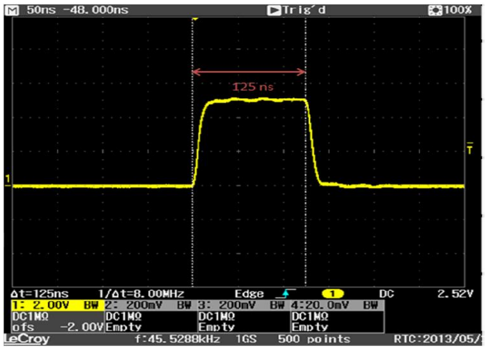

Fig. 8a. Result of 125ns pulse signal

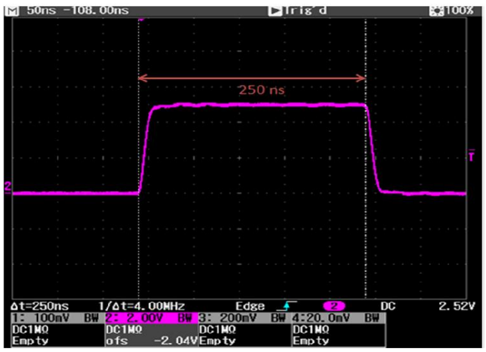

Fig. 8b. Result of 250ns pulse signal

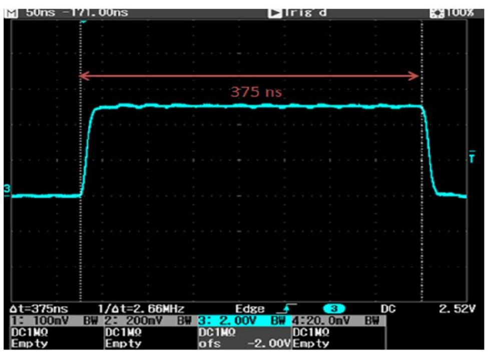

Fig. 8c. Result of 375ns pulse signal

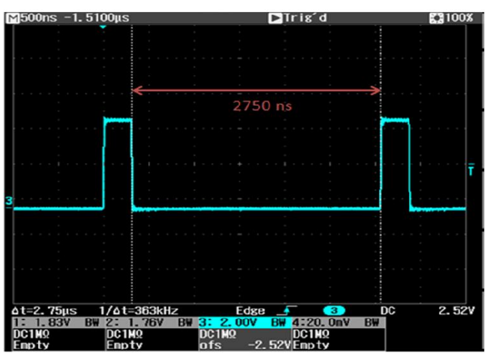

Fig. 8d. Result of 2750ns delay between pulse signals

B. Pattern for 10, 20 and 30 Meter Pilot Cable

By using the 125ns pulse signal generator, the 10 meter pilot cable is tested to determine the condition of the cable. Two testing methods have been conducted which are open circuit test and short circuit test to determine the condition of the pilot cable and the pattern of TDR pulse signal. Similar tests are applied to 20m and 30m cable too. However, different time of pulses has to be applied to the respective cable such as for the 20m cable, 250ns pulse signal is used to examine the pattern for 20meter pilot cable and for the 30m cable, 375ns pulse is applied to the testing cable.

1) Pattern for heatly pilot cable:

For healty 10, 20 and 30 meter pilot cable, the transmit time, t for the signal should be 100ns, 200ns and 300ns based on the equation (7). Thus, there should no reflection pulse signal during the transit time for the healty cable. Fig. 9 - 11 show the pattern for healthy cable and the TDR measured result.

From the result, there is no reflection signal for the healthy cable. Hence the reflection coefficient is 0 by using equation (8) and transit time is 100ns, 200ns and 300ns for 10 meter, 20 meter and 30 meter can be determined by equation (7).

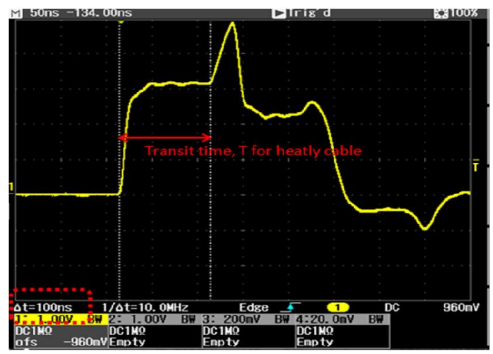

Fig. 9. The pattern for healthy cable of 10 meter (100ns)

Fig. 10. The pattern for healthy cable of 20 meter (200ns)

Fig. 11. The pattern for healthy cable of 30 meter (300ns)

2) *Pattern for faulty pilot cable:*

For this project, there are two type of cable fault which are open cable fault and short cable fault.

a) Open Cable fault 1: The pattern of open cable fault has been determined. From Fig. 12, it clearly dislays the waveform pattern for open cable fault.

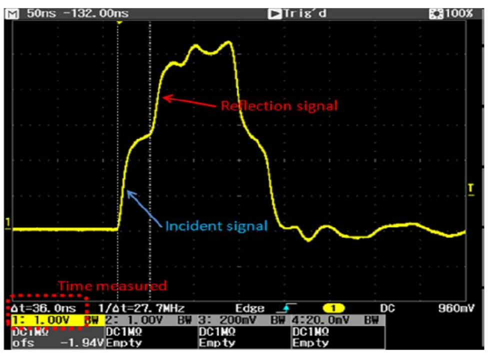

Fig. 12. Pattern of open cable fault 1

From Fig. 12 shows that the measurement of time reflection and the distance of the fault is calculated using eq. (7). The time reflection is 36.0ns, thus the open cable fault occurs at distance, D = 3.6 meter. The result also shows that the reflection signal is doubled from the incident signal. Thus, the reflection coefficient, ρ can be calculated using eq. (8) the calculated value of ρ is 0.77. Hence, from the time reflection and reflection coefficient, there is open cable fault at 3.6 meter for cable 1.

b) Open Cable fault 2: The pattern of open cable fault 2 has been determined. Fig. 13 clearly dislays the waveform pattern for open cable fault.

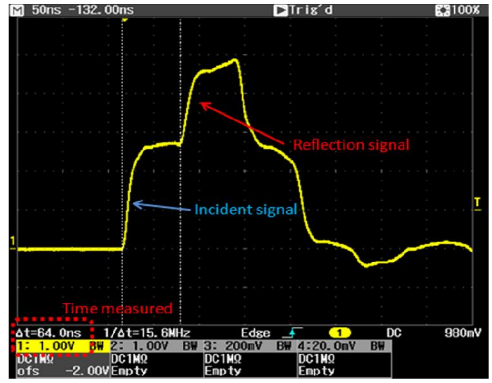

Fig. 13. Pattern of open cable fault 2

The time reflection is 64.0ns, thus the open cable fault occur at distance, D = 6.4 meter. The reflection coefficient, ρ is 0.8. Result also shows that the reflection signal is doubled from the incident signal. Hence, from the time reflection and reflection coefficient, there is open cable fault at 3.6 meter for cable 2.

c) Open Cable fault 3 : for 20 meter pilot cable, the pattern of open cable fault has been determined. Fig. 14 shows the waveform pattern for open cable fault for 20 meter cable.

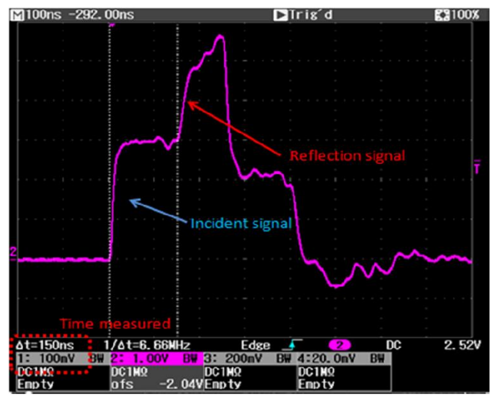

Fig. 14. Pattern of open cable fault 3

Fig. 14 shows that the time reflection for open cable fault is 150.0ns, hence the distance, D is 15.0 meter. The result also shows that the reflection signal is doubled up from the incident signal. The reflection coefficient for 15.0 meter open cable fault is 0.84.

d) Open Cable fault 4 : Fig. 15 displays the waveform pattern for open cable fault for 30 meter cable.

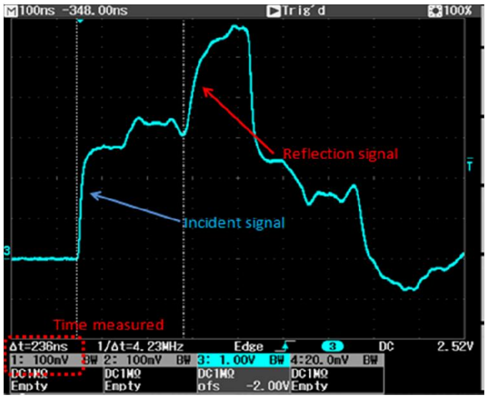

Fig. 15. Pattern of open cable fault 4

Result shows that the reflection signal is also doubled up from the incident signal. The reflection coefficient is 0.85 and The time reflection is measured for open cable fault is 236.0ns. Hence, the distance where the open cable fault occurred is 23.6 meter.

e) Short Cable fault 1: By using the short circuit test the pattern of short cable fault 1 has been determined. Fig. 16 shows the waveform pattern for short cable fault.

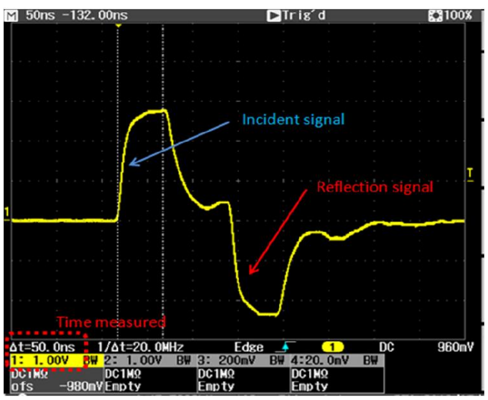

Fig. 16. Pattern of short cable fault 1

From the figure, the time reflection is 50.0ns, thus the short cable fault occurs at distance, D = 5.0 meter. For short cable fault, the reflection signal will be inverted from the incident signal, thus, The reflection coefficient, ρ is -0.84 (approximate to Short end cable, ρ = -1). Hence, from the time reflection and reflection coefficient, there is short cable fault at 5.0 meter for cable.

f) Short Cable fault 2: Short cable faulty in 20 meter pilot cable is determined by using the short circuit test. Fig. 17 shows the waveform pattern for short cable fault.

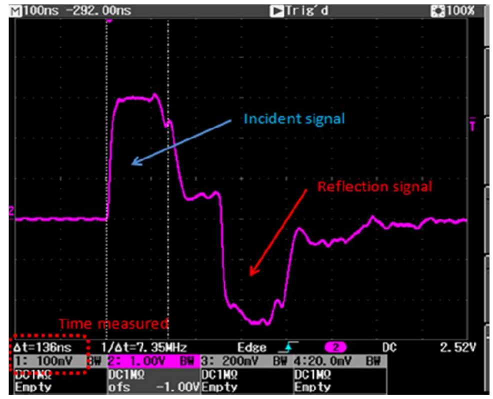

Fig. 17. Pattern of short cable fault 2

Fig. 17 also shows the reflection signal for short cable is upside-down from the incident signal. Thus, the reflection coefficient, ρ is -0.85 and the time reflection is 136.0ns. From that result, the faulty 20 meter cable occurs at 13.6 meter.

g) Short Cable fault 3: Short cable faulty in 30 meter pilot cable is determined by using the short circuit test. Fig. 18 shows the waveform pattern for short cable fault. the time reflection is measured for this short cable fault is 264.0ns, hence the distance, D is where the fault occur is 26.4 meter. Result also shows that the reflection signal for short cable will reflect down from the incident signal and the reflection coefficient, ρ is -0.94.

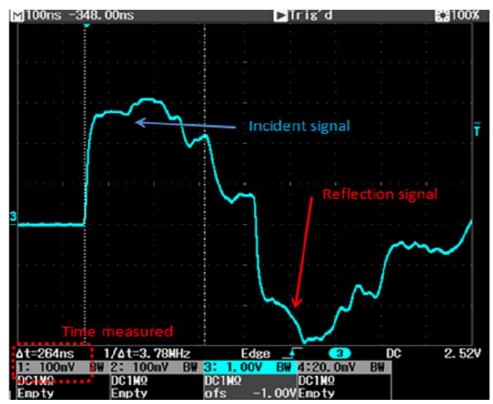

Fig. 18. Pattern of short cable fault 3

C. Arduino – Based Digital Sampling Oscilloscope, DSO

In this work, several pulse signals with different frequency and voltage are applied to the Arduino based DSO in order to test its performance.

a) 0.5Hz Pulse Signal

A 5V pulse signal with 0.5Hz frequency has been applied as the input to the Arduino based DSO. Fig. 19 shows the Arduino based DSO managed to display the waveform of the signal.

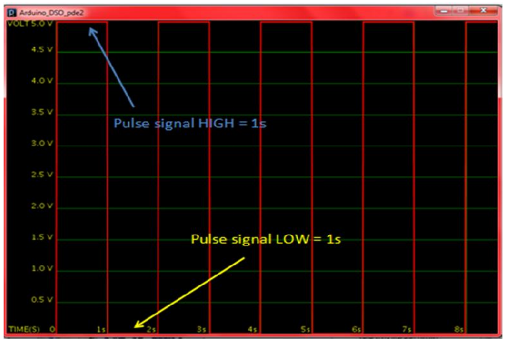

Fig. 19. Result for 0.5Hz pulse signal

b) Pulse Width Modulation Signal

Fig. 20 shows the result for pulse width modulation signal. It shows that the voltage pulse signal is 5 V, Pulse High 10ms and Pulse low 90ms.

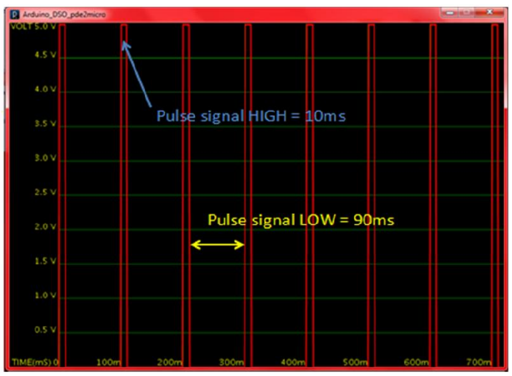

Fig. 20. Pulse width modulation signal.

c) 1M Hz Pulse Signal Generator.

Fig. 21 shows the result of Arduino-Based DSO for pulse signal with frequency 1 MHz. and the voltage for the pulse signal is 5V.

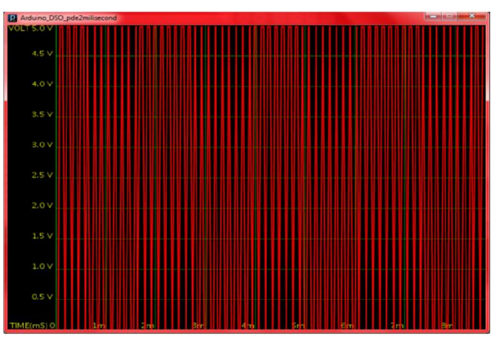

Fig. 21. Result for 1 MHz pulse signal generator.

This figure shows that the maximum sampling rate for the Arduino is at 1MHz pulse. Thus, this Arduino-based DSO is not able to display clearly the pulse signal that has frequency higher than 1 MHz. Hence, the Arduino – based DSO cannot display the pattern of reflected pulse signal from the pilot cable tested since it needs frequency greater than 1 MHz.

IV. Conclusion

In this paper, the objective of developing another method in detecting faulty in the pilot cable based on Arduino Microcontroller and using the concept time domain reflection, TDR technique is proven to be efficient and accurate. Since the system using the digital design and C programming, this TDR system can be used to detect any variation of pilot cable length. From the two tests which are open and short cable test, the system design is able to detect the healthy and determine the location of faulty cable. Besides that, it is also able to determine the type of fault. This will rectify the fault without requiring high maintenance because without knowing the fault, the whole pilot cable has to be removed or changed. From the results, the open cable fault occurs when the reflected pulse signal is reflected the same polarity with the injected pulse signal. For short cable fault, the reflected pulse signal is in opposite polarity with the injected pulse signal. The Arduino Mega 2560 generates the pulse signal with the amplitude 5V voltage. In real condition, the length of pilot cable to be tested is more than 1km. Hence the voltage of pulse signal must be higher to prevent losses voltage in the long pilot cable. This is the recommendation for future development if the testing will be carried out in real situation.

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