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A Novel Reflectometer for Cable Fault Analysis with Pulse Reflection Method

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Abstract

In this paper, the studies of finding the failure location on a sample cable by using the pulse reflection method and the effects of parameters resulting from the fault on the results of the measurement have been examined. A pulse generator with amplitude of 5 V and pulse width between 40 ns and 2000 ns has been designed as a novel pulse reflection meter. The images of reflection seen on the oscilloscope screen have been transferred to software of ANALYSIS, developed for measurement of pulse reflection by means of serial communication and have been examined here.

1. Introduction

The studies of finding the fault location on cables got started with the method of bridge suggested by Murray [1]. This method is based on the principal which prescribes that while a resistance bridge having a galvanometer in the midst of it is in the position of balance, the resistances found on its cross arms are equal to each other [1]. In this method, the resistances of the junction points and the sensitivities of galvanometers affect the accuracy of the measurement. HDW Electronics suggested secondary impulse method which is based upon investigating the traveling waves. In this method, the short circuit occurring at the point of failure as soon as there, occur an arc here can be found with a low voltage pulse reflection signal sent to the cable. However, the fact that the arc lasts for a short time (100 μs) during the measurement decreases the accuracy of the measurement of pulse reflection especially with long lines [2]. Li and Gong have studied on extending the period of arc in order to solve this problem. P. F. Gale has suggested impulse current method based upon investigating traveling current waves [1]. This method suggests that the reflections of arc established by a pulse generator at the point of fault are examined through an inductive coupling element and thus the point of fault is found. This method has made it possible to find out the fault location with a high rate of accuracy independently of the parameters related to the fault [3]. However, in this method, the accurate analysis of the reflected waves mostly necessitates the experience of the operator.

In this study, a low voltage pulse reflectometer has been developed in order to find the fault location according to the pulse reflection method with the cables and the experiments based upon finding the points of failure have been carried out on a sample cable. The pulses applied at the beginning of the cable and that are reflected from the point of fault have been gathered on the screen of an oscilloscope and the data on the screen have been transferred to a software developed for this study and the results have been examined here.

2. Pulse Reflection Method

Pulse reflection method is an efficient method that eliminates the needs such as extra junctions, a healthy core, or complicated calculations arising in the classical preliminary position finding methods that are carried out with bridge circuits. In this method, a pulse is sent from one end of the faulty cable. This pulse reflects completely or partially from any impedance change occurring on the cable. Distance of the point where the impedance changes, is guessed considering the period that lasts between the exit of the pulse from the source to the return of pulse to the source and the propagation velocity of the pulse [1]. The point of failure is calculated as in Eq. (1).

$$l = v.\frac{t}{2} \tag{1}$$

l: Distance of the faulty point from the terminal of the cable [m],
t: Time of the pulse going and coming back [μs],
v: The velocity of the propagation of the pulse [m/μs].

The propagation velocity can be defined as the speed of propagation of energy in a certain environment. Each cable has its own speed of propagation changing according to the qualities of the material. The propagation velocity is calculated with the equation stated below:

$$v = \frac{v_s}{\sqrt{\varepsilon_r}} \tag{2}$$

v: The velocity of propagation of the pulse [m/μs],
v_s: The velocity of propagation of the light in space [m/μs],
ε_r: Relative dielectric constant of the cable insulator.

2.1 Investigating the Characteristics of the Fault

The cables are generally modeled with an R resistance, L inductance, C capacitance between the conductors or conductor-shield and G conductance [4]. In a circuit which is modeled in this way, inductance and resistance are in series connection while capacitance and conductance are in parallel connection. Equivalent circuit diagram for a cable is shown in Figure 1.

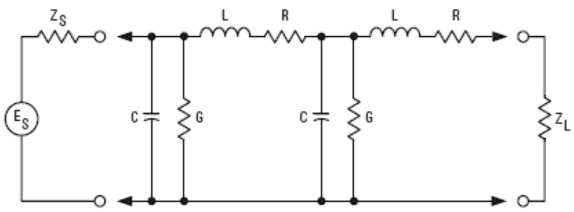

Fig. 1. Equivalent circuit model for cables

The ratio of the voltage *e,* induced by the pulse applied to the cable while it is running on the cable to the current *i* which is induced is called as the characteristic impedance (Z_0) of the cable and it is written as below:

$$Z_0 = \frac{e}{i} = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \qquad (3)$$

As R = G = 0 when the line is accepted to be lossless, the characteristic impedance will be as below:

$$Z_0 = \sqrt{\frac{L}{C}} \qquad (4)$$

Z_0: Surge impedance (Ω)
L: Inductance (H/m)
C: Capacitance (F/m)

The characteristic impedance is not based upon the length of line as it can be seen at the Equation (4).

2.1.1 Reflection and Transmission Coefficient

If a transmission line having a Z_0 characteristic impedance of finite length is terminated with load impedance equal to the characteristic impedance, all the energy sent from the source is transferred to the load. But, if there is a difference between the characteristic impedance and the load impedance, this difference comes out as a wave reflecting from the load to the source. In fact, this wave is the energy that is not transferred to the load [4]. When a pulse is applied to a cable with Z_0 characteristic impedance, the pulse reflects back if there is a fault with the cable. The amplitude and polarity of the reflecting wave is established according to the ρ which is the reflection coefficient. The reflection coefficient can be defined as below:

$$\rho = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad (5)$$

2.1.2 Examining Series Faults

The reflection coefficient of the series fault is as defined in the Equation (6).

$$\rho = \frac{Z_S}{Z_S + 2.Z_0} \qquad (6)$$

The occasion when the cable is completely broken is seen in Figure 2. In this case, all the energy of the pulse reflects back to the source as the impedance of the point of failure will be infinite. With a cable which has an open-circuit at the end of the cable, the reflection coefficient is ρ = 1 as Z_s will be infinite [5].

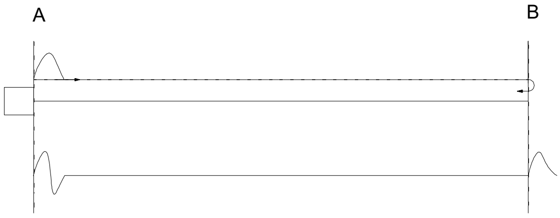

Fig. 2. The pulse reflecting from open-circuit.

2.1.3 Examining Shunt Faults

The reflection coefficient for a shunt fault is as defined in Equation (7):

$$\rho = \frac{-Z_0}{2.Z_E + Z_0} \qquad (7)$$

The fault impedance Z_E is zero with the faults where the end of the cable is short-circuited. Because of this reason, the reflection coefficient is ρ = -1 with such faults.

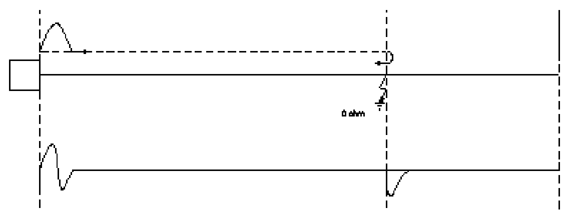

Fig. 3. The pulse reflecting from short-circuit.

A shunt fault can be seen in Figure 3. As the fault is completely short-circuited here, the pulse completely reflects back to the source, however, its pole has changed [6, 7].

3. Application Design

Within the framework of the experimental study, a pulse reflectometer has been designed and measurements have been carried out on the cables for various occasions of faults. The results of the measurements have been examined on computer software which has been developed dedicatedly for pulse generator. The general image of the pulse reflection meter is shown in Figure 4. The experimental circuit is composed of three different sub-systems. These systems include pulse generator, oscilloscope and interface software.

The pulse generator produces square wave signals to be sent to the cable by the pulse reflection meter. The pulse generator to be used in the experimental study has been established on the development card of dsPICDEM1.1 owned by the company of MICROCHIP. As the processor, the fast processor of Microchip dsPIC30F6014 has been used.

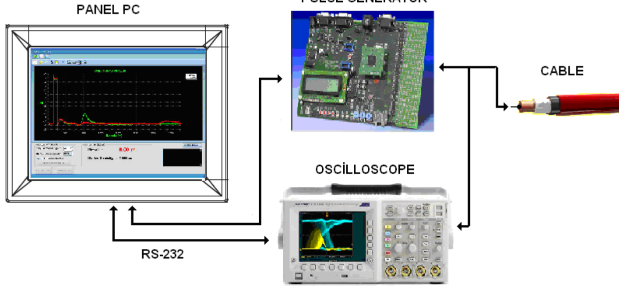

Fig. 4. The general setup of pulse reflectometer

The pulse generator has been designed to produce pulses with wave width changing between 30-2000 ns. Square wave signals have been produced through using PWM module of the processor. The system basically changes the amplitude of the reflecting signal by means of changing the wave width of PWM signals according to the instructions coming from ANALYSIS software. An oscilloscope with a trademark of Textronix TDS 3034 which has a real-time sampling speed of 2.5 GS/s has been used within the experiment circuit in order to screen the waves sent and reflected in the pulse reflection measurement.

3.1 Embedded System Software

Pulse generator is controlled by the embedded software of "ANALYSIS". The flow diagram of the software is shown in Figure 5.

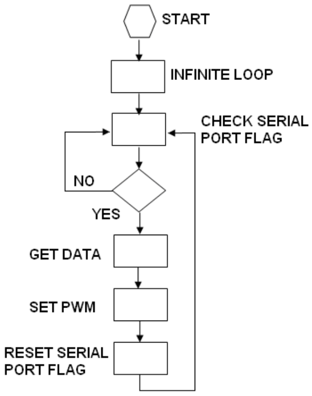

Fig. 5. Flow diagram of the embedded software

Within this software, a PWM pulse width has been defined for each value coming from the computer. The processor adjusts the PWM pulse width after receiving the instruction and making a decision.

3.2 Analysis Software User Interface

The user interface of pulse reflectometer is ANALYSIS software. This software has been developed within the environment of Borland C++ 6.0 with C++ base. The main screen of the software is as shown in Figure 6.

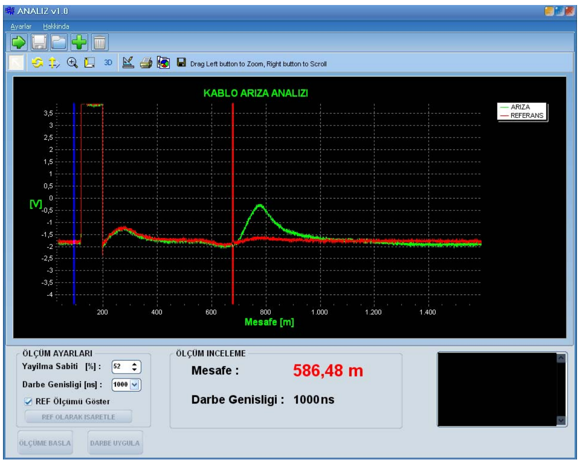

Fig. 6. ANALYSIS software main interface

ANALYSIS software receives the image of fault captured on the oscilloscope screen through the serial port into the computer and processes the image according the parameters defined by the user and calculates the approximate fault distance. The software can perform both classical and comparative pulse reflection measurements.

4. Experimental Study

In the experimental studies, the faults established artificially on a point on the cable have been examined by means of using pulse reflection measurements. For this purpose, two TTR cables of FSS-4 type and 4 x 1 mm^2 and with a length of 1617 m and 565 m have been used. At the 565th meter which is the point where the two cables join, a fault whose resistance can be adjusted by the help of a potentiometer with a 1 kOhm resistance. The resistance of the fault has been changed with the help of potentiometer located at the point of the fault and the reflection images of series and shunt faults having different resistance values have been examined. The photograph of the experimental setup has been shown in Figure 7.

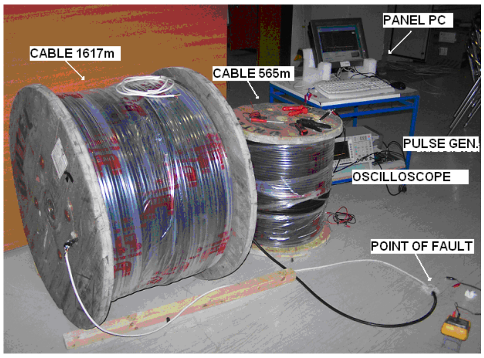

Fig. 7. The test arrangement

4.1 Determining Cable Parameters

First of all, the necessary studies in order to find the propagation constant of a cable with a length of 2182 m and the pulse width of the signal to be applied to a cable with that length have been carried out. The results of the measurements carried out with different propagation constants are stated in Table 1.

Table 1. The measurements carried out with different propagation constants for the cable FSS-4

Fault Distance [m]	Error [%]	Propagation Constant
2132	-2.51	50%
2173	-0.64	51%
2195	0.37	52%
2248	2.79	53%
2289	4.66	54%
2331	6.58	55%
2367	8.23	56%
2413	10.33	57%
2455	12.25	58%
2498	14.22	59%
2540	16.14	60%
2755	25.97	65%
2964	35.53	70%

The same experiment has been carried out again with a different type of cable in order to compare the results obtained at the end of this experiment. A HO5VV 3 x 2.5 NYAF cable with a length of 34.5 m has been used in this experiment. The cable has been experimented through pulses with a width of 100 ns, with amplitude of 5 V and frequency of 1 kHz. The propagation constant has been selected to be %70 at first. The results obtained at the end of this measurement are stated in Table 2.

Table 2. The measurements carried out with different propagation constants for HO5VV 3 x 2.5 NYAF cable

Fault Distance [m]	Error [%]	Propagation Constant
33.4	-3.19	55%
34.02	-1.39	56%
34.24	-0.75	57%
35.01	1.48	58%
35.78	3.71	59%
36.35	5.36	60%
37.05	7.39	61%
37.69	9.25	62%
38.31	11.04	63%
38.89	12.72	64%
39.53	14.58	65%
42.46	23.07	70%

After determining the propagation constant, the width of the pulse to be applied to the cable for has been determined. For this purpose, pulses with changing between 40 ns and 2000 ns, with a frequency of 1 kHz and amplitude of 5 V have been applied to both of the cables. The results obtained at the end of these measurements are stated in Table 3 and Table 4.

Table 3. The measurements carried out with pulses having different width for FSS-4 cable

Wave Width [ns]	Fault Type	Fault Distance [m]	Error [%]
40	Open-Circuit	Cannot be measured.	
100	Open-Circuit		
200	Open-Circuit		
250	Open-Circuit	2236	2.24
300	Open-Circuit	2245	2.65
320	Open-Circuit	2257	3.2
350	Open-Circuit	2246	2.7
400	Open-Circuit	2278	4.16
420	Open-Circuit	2259	3.29
450	Open-Circuit	2249	2.83
500	Open-Circuit	2274	3.98
520	Open-Circuit	2214	1.23
550	Open-Circuit	2211	1.1
1000	Open-Circuit	2179	-0.37
2000	Open-Circuit	2196	0.41

Table 4. The measurements carried out with pulses having different width for HO5VV 3 x 2.5 mm^2 NYAF cable

Wave Width [ns]	Fault Type	Fault Distance [m]	Error [%]
40	Open-Circuit	34.6	0.29
80	Open-Circuit	34.57	0.2
100	Open-Circuit	34.39	-0.32
150	Open-Circuit	34.36	-0.41
200	Open-Circuit	34.51	0.03
220	Open-Circuit	34.8	0.87
250	Open-Circuit	34.26	-0.7
300	Open-Circuit	34.64	0.41
320	Open-Circuit	33.78	-2.09
350	Open-Circuit	35.2	2.03
400	Open-Circuit	Cannot be measured.	
500	Open-Circuit		
1000	Open-Circuit		
2000	Open-Circuit		

4.2 Experiment 1 – Series Fault

A potentiometer of 1 kOhm has been connected with a series connection at the joint point of two cables with a length of 1617 m and 565 m used in the experiment. The results of the measurements obtained at the end of this experiment are stated in Table 5.

Table 5. The results for series fault

Fault Resistance [Ω]	Reflection Amplitude [V]	Fault Distance [m]	Error [%]
0	0	0	-100
20	0.49	594.69	5.25
40	0.62	589.66	4.36
60	0.73	586.25	3.76
80	0.81	585.73	3.67
100	0.95	576.5	2.04
300	1.33	576.43	2.02
500	1.5	571.11	1.08
1000	1.65	568.12	0.55

4.3 Experiment 2 – Shunt Fault

The potentiometer located at the joint point between the cable pulleys has been connected parallel between the two cores of the cable and a short-circuit fault has been established between the two cores. The results of the measurements obtained at the end of this experiment are stated in Table 6.

Table 6. The results for shunt fault

Fault Resistance [Ω]	Reflection Amplitude [V]	Fault Distance [m]	Error [%]
0	-1.8	567.55	0.45
20	-1.3	575.43	1.85
40	-0.93	574.4	1.66
60	-0.77	574.84	1.74
80	-0.65	577.05	2.13
90	-0.57	574.74	1.72
100	-0.56	574.51	1.68
150	-0.37	577.66	2.24
200	-0.33	583.64	3.3
250	-0.29	586.92	3.88
500	-0.21	592.57	4.88
1000	-0.05	601.86	6.52

5. Discussion

It is apparent in the tables obtained at the end of the measurements that the propagation constant for the long cable should be 52% while it should be 57% for the short cable. The measuring error can be minimized to a great extent when the correct propagation constant is chosen. As it is clear by means of the data stated in Table 3, the end of the cable can be just seen through a pulse with a width of 250 ns when the FSS-4 cable with a length of 2182 m is in question while the end of the cable cannot be seen when the values of pulse width are lower than this value. This fact is shown in Figure 9 by adding the results of the measurements on each other. The case with the short cable is just on the contrary of this. As is seen in Figure 8, interference has occurred between the beginning pulse and reflection pulse after a limit value and the beginning and end of the cable cannot be distinguished since then.

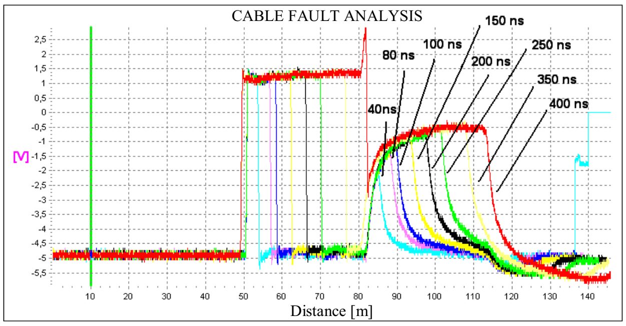

Fig. 8. The reflection images obtained at different pulse width with the short cable

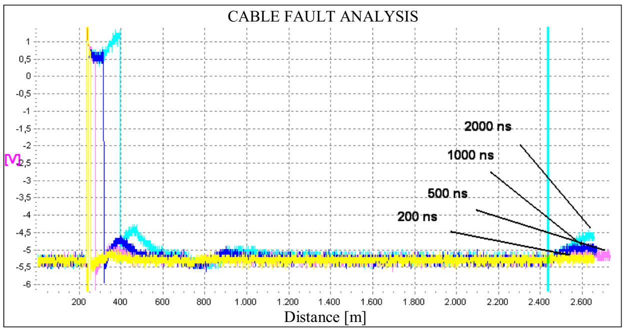

Fig. 9. The reflection images obtained at different pulse width with the long cable

The results of the measurement obtained with the series fault are shown in Figure 10. It can be seen that the lower the fault resistance gets, the lower the amplitude of the reflecting wave gets. It has turned out to be more difficult to find the point of failure as the amplitude of the reflecting wave gets lower and accordingly the accuracy of the measurement decreases, too.

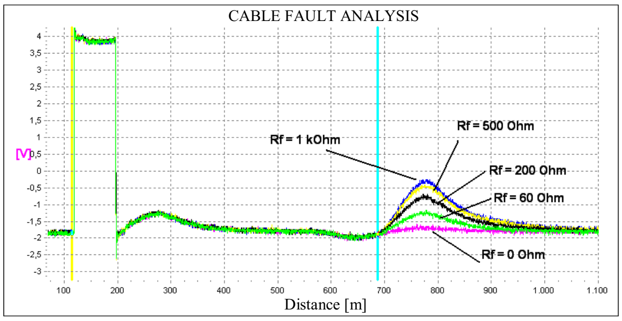

Fig. 10. The results of the measurements belonging to the experiment of series fault

The results of the measurement belonging to the experiment of shunt fault are shown in Figure 11. It is apparent from the results of the measurement that the higher the fault resistance gets, the lower the amplitude of the reflecting wave gets. It is quite difficult to find the fault since the pulse reflection value is too low when the fault resistance goes higher than 200 Ohm. On the other hand, the point of failure cannot be seen when the fault resistance is 1 kOhm.

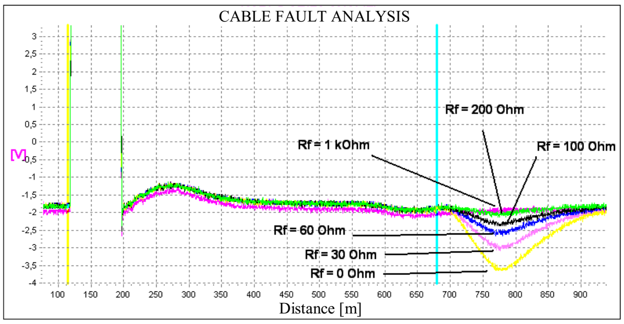

Fig. 11. The results of the measurements belonging to the experiment of shunt fault

6. Conclusion

In this study, a pulse generator that can produce pulses with a constant amplitude but adjustable pulse width has been designed. The measurements carried out for this study have been examined comparatively through the software developed for pulse reflection measurement. The propagation constant has been changed on the software and its effects on the results of the measurements have been examined. The point of failure could be found easily in a short time by means of the capability and quality of the software to compare the real trace with the reference trace.

The pulse reflection method gives the most efficient and the fastest results with low-resistance short circuit faults and high-resistance open-circuit faults. However, pulse reflection method has been found to be insufficient if short-circuit faults, where fault resistance is bigger than ten times of cable characteristic impedance, are in question. For the pulse reflection measurement to be efficient and accurate, the energy of the pulse should be higher than the loss taking place on the cable in order for the pulse reflecting from the failure location to reach the source. Because of this reason, the width of the pulse to be applied to the cable should be selected in proportion with the length of the cable.

7. References

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