A Reflectometer for Cable Fault Location with Multiple 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 multiple pulse reflection method and the fault on the results of the measurement have been examined. A pulse generator with amplitude of 12 V and pulse width from 20 ns to 2 us has been designed as a multiple pulse reflection meter. The velocity of reflection pulse is calibrated in embedded system. The SOPC system detects the reflection pulse and measures the time of N times reflection pulses, then judge the fault type and compute the fault distance with corrected speed of pulse developed for measurement of pulse reflection by means of pulse velocity correction and have been examined here. Copyright © 2014 IFSA Publishing, S. L.

Keywords: Fault detection, Cable fault location, Pulse multiple reflection, embedded system, SOPC.

1. Introduction

Cable as an important transmission media, widely used in the important field of instrument and meter, electric power, communication, exploration etc. Cable fault occurs, not only affect the daily life but also the production. The importance of aging electrical wiring and associated faults of cable has been highlighted in [1] to [5].

The studies of finding the fault location on cables got started with the method of bridge suggested by Murray [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 during the measurement decreases the accuracy of the measurement of pulse reflection especially with long lines [6]. 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 [7].

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 cable. The pulses applied at the beginning of the cable and that are reflected from the point of fault have been captured and counter for SOPC system to estimate the fault type and locate the failure point distance screening on the LCD screen 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):

\[
L = V \times t / (2N),
\]

(1)

where \( L \) is the distance of the faulty point from the terminal of the cable, \( V \) is the velocity of the propagation of the pulse; \( t \) is the time of the pulse \( N \) times reflection, \( N \) is the reflected times.

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:

\[
V = V_s / \sqrt{\varepsilon_r},
\]

(2)

where \( V \) is the velocity of propagation of the pulse, \( V_s \) is the velocity of propagation of the light in space, \( \varepsilon_r \) is the 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 Fig. 1.

![Fig. 1. The diagram of Cable lumped parameter circuit.](image)

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 \( (Z_c) \) of the cable and it is written as below:

\[
Z_c = \frac{u}{i} = \sqrt{\frac{R + j\omega L}{G + j\omega C}}
\]

(3)

Generally, \( Z_c \) is complex, not only the amplitude, and phase changes. Phase variation reflects the cable characteristic impedance of the inductive or capacitive properties.

As the launch a high frequency signal, \( R<<j\omega L \), \( G<<j\omega C \), the cable characteristic impedance will be as flow:

\[
Z_c = \sqrt{\frac{L}{C}},
\]

(4)

where \( Z_c \) is the surge impedance, \( L \) is the inductance, \( C \) is the capacitance.

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

2.1.1. Reflection and Transmission Coefficient

As the transmission line considered as uniform distributed parameter elements, the impedance of cable is same when a wave propagates along the wire, but the wave impedance will change and voltage current traveling along the wire mismatch the transmission condition, when the waves propagate into the end of the line or arbitrary impedance mismatch point. As an example of open circuit, the electromagnetic wave to the terminal, which can’t continue to spread, and no load acceptance of energy, so the electromagnetic wave only by the line terminal to the starting end echo, echo phenomenon caused by the transmission line impedance mismatch is the reflection.

2.1.2. Breaker / open Circuit Fault

The occasion when the cable is completely broken is seen in Fig. 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 impedance of fault point \( Z \) is infinite, so reflection coefficient as flow:

\[
\rho_r = U_r / U_f = 1
\]

\[
I_f = L + I_f = 0
\]

\[
\Rightarrow \rho_r = L / I_f = -1
\]

\[
U_r = -Z_c \times I_f
\]

\[
U_f = U_r + U_f = Z_c \times (I_f - I_f) = 2U_f
\]

\[
\Rightarrow U_f = U_f
\]

\[
\rho_r = U_f / U_f = 1
\]
Therefore, when the cable is open fault, the reflected voltage and launch signal have same polarity; reflection signal current is opposite to emission signal.

2.1.3. Short Circuit Fault

When the transmission cable short circuit fault occurs, the fault point impedance $Z_0$ is 0, so the fault point voltage $U$ is 0 too, namely $U_r=-U_f$. Voltage reflection coefficient: $\rho_v$ is -1. so reflection coefficient as flow:

$$U=U_r+U_f=0$$
$$\Rightarrow \rho_v = \frac{U_r}{U_f} = -1$$
$$I_r = -\frac{U_r}{Z_c}$$
$$I=I_f+I_r = \frac{(U_f-U_r)}{Z_c} = 2I_f$$
$$\Rightarrow \rho_i = \frac{U_r}{U_f} = 1$$

Means when the cable is short fault, the reflected voltage and launch signal have opposite polarity; reflection signal current is same to emission signal. Show in Fig. 3.

2.2. Pulse Multiple Reflection

Multiple reflection method is the reflection principle of time domain reflection (TDR) on the basis of single echo detection method, aiming at the shortcomings and defects of. According to the principle of pulse emission, electromagnetic pulse signals occur multiple reflections in the fault, generating multiple echo effect, and the reflection coefficient of the same type of fault point are the same, just because the cable distribution resistance, capacitance of the pulse amplitude decreases gradually, as shown in Fig. 2 and Fig. 3. Therefore multiple pulses can be collected on the fault cable transmitter. Due to the propagation speed pulse signal in the cable is very fast, this caused the interval pulse time between two reflection pulses is so short. If a single echo detection method to achieve high test accuracy, the system needs to improve the sampling frequency (above 500 MHz). It puts forward a very high request to the hardware system, multiple reflection detection method is the echo acquisition and analysis, thus extending the system response to the echo time, reduces system acquisition speed requirements in the same test accuracy. Multiple echo detection method can effectively improve the resolution and accuracy of test system, and reduce the hardware overhead.

Multiple echo detection method is mainly used to detect and locate the fault type. Follow the principles in the process of testing: First, transmits a narrow pulse signal to the cable, and detects the multiple reflected pulses; second, amplifies, shapes and samples to multiple echo signal and send the captured signal to processor; third, the processor timing the interval time of N multiple reflection pulse with system clock, then send and latch the counter to calculate the distance of fault point; finally, determine the fault type with comparing whether negative voltage pulse. As shown in Fig. 4, open circuit detection, since the reflection coefficient is 1, reflected pulse polarity is the same to launched pulse, just as show in Fig. 3, the negative voltage comparative shaping circuit without pulse signal, then determines the fault type for circuit breaker or open.

Short circuit fault testing principle and process is same to open circuit. Due to short circuit fault point the reflection coefficients is -1, the reflected pulse and emission pulse is opposite polarity, so the echo
waveforms showing positive and negative pulse alternatively, just as Fig. 4. Specified number of interval echoes is counted, then locate the failure point, because the negative comparative shaping circuit get pulse signals, determine the fault type for short circuit, as shown in Fig. 5.

Fig. 5. Multiple echo detected short-cable.

Using multiple reflection method to fault detection, fault location calculation formula as flow:

\[ L = \frac{V \times M}{2Nf} \]

where \( L \) is the distance of the faulty point from the terminal of the cable, \( V \) is the velocity of the propagation of the pulse, \( f \) is the frequency of counter clk, \( N \) is the reflected times, \( M_1, M_2 \) are the value of counter for \( L_1, L_2 \).

3. Embedded System

Within the framework of the experimental study, a multiple 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. The general image of the pulse reflection meter is shown in Fig. 6. The experimental circuit is composed of three different sub-systems. These systems include FPGA, pulse generator and data sample.

Fig. 6. The embedded system scheme.

The pulse generator produces square wave signals from 20 ns to 2 us with amplitude of 12 V and 100 Hz to be sent to the cable by the pulse reflection meter by ADG201. The pulse generator to be used in the experimental study has been controlled by FPGA owned by the company of ALTERA. As the processor, the fast processor of EP3C16Q240C8 has been used.

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, three cables of 428xl type, twisted-pair and coaxial cable with lengths of 27.3 m 10 m and 101.3 m have been used to test the open-circuit and short-circuit.

Fig. 7 is the detected open circuit 6 times reflection in Oscilloscope.

For this purpose, pulses with changing between 80 ns with a frequency of 100 Hz and amplitude of 12 V have been applied to three of the cables. The results obtained at the end of these measurements are stated in Table 1.
Table 1. The measurements of three cable for different fault.

<table>
<thead>
<tr>
<th>Cable</th>
<th>Fault</th>
<th>Velocity (mm/ns)</th>
<th>Actule Len (m)</th>
<th>Detect Len (m)</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>428xl</td>
<td>open</td>
<td>19.8</td>
<td>27.3</td>
<td>27.1</td>
<td>-0.73</td>
</tr>
<tr>
<td></td>
<td>short</td>
<td></td>
<td></td>
<td>28.2</td>
<td>3.3</td>
</tr>
<tr>
<td>twist-pair</td>
<td>open</td>
<td>14.7</td>
<td>10</td>
<td>9.9</td>
<td>-1.0</td>
</tr>
<tr>
<td></td>
<td>short</td>
<td></td>
<td></td>
<td>10.5</td>
<td>5.0</td>
</tr>
<tr>
<td>Coaxial cable</td>
<td>open</td>
<td>22.0</td>
<td>101.3</td>
<td>103.9</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>short</td>
<td></td>
<td></td>
<td>105.4</td>
<td>4.1</td>
</tr>
</tbody>
</table>

5. Conclusions

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 embedded system for multiple pulse reflection measurement. The point of fault could be found easily in a short time by calibrated the velocity of pulse to improve the accuracy of test system.

The multiple pulse reflection method gives the most efficient and the fastest results with low-resistance short circuit faults and high-resistance open-circuit faults. 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. Pulse width is smaller and the measure blind length is shorter, but the reflection attenuation is more serious, so the width of the pulse and reflection pulse times N to be applied to the cable should be selected in proportion with the length of the cable.

References


