A DETECTION OF POOR CONTACT FAULT LOCATION IN THE LOW-VOLTAGE POWER CABLE USING STDR/SSTDR

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Abstract- This poor contact fault location of low-voltage power cable was performed by using reflectometry for research. This paper describes a cable accidents and importance, and Chapter 2, inform the principles and characteristics of a typical reflectometry, Chapter 3, we describe the applied removal reference signal technique for the detection performance of sequence and reflected signal used in the reflectometry. And Chapter 4 describes the experimental conditions and the environment, the cable fault detection test was performed. Compare the result was confirmed by the measurement using the cable fault detection.

Index Terms- Cable accidents, cable fault detection, power cable, STDR, removal reference signal, reflection signal

I. INTRODUCTION

As people's living standards improve along with the growth and development of modern industry, power consumption by businesses and households has dramatically increased every year. At the same time, damage by electrical disasters such as electrical fire and electric shock has been on the rise annually. According to electrical disaster statistics released by the Korea Electrical Safety Cooperation, a total of 42,135 fire accidents occurred in the Republic of Korea in 2014. Among them, electrical fires accounted for 19.7% with 8,287 accidents. They caused 326 casualties (31: death, 295: injury) and KRW 70.6 billion of property damage. Among electrical fires, more than 25 percent is related with cables.[1]

These cable-related accidents are mostly caused by the following problems arising from wrong installation and diverse factors such as physical, electrical and environmental factors: insulation damage, open, short, poor contact fault and half disconnection. A cable fault can evolve into serious accidents including power failure and fire and cause diverse problems such as property damage, loss of information and setback in production. Therefore, the development of the technology needed to detect the cause and location of a cable fault and take a necessary action early is critical for preventing accidents and reducing possible damages.

In terms of a way to diagnose a problem in the electrical and communication cables and detect its location, reflectometry which measures signals reflected due to the mismatch of particular impedances at a fault location by applying a certain pulse such as radar to the cable is widely used. In this method, a cable fault location is estimated based on the occurrence of reference signals which are applied to the cable by the impedance bigger than certain impedance on the transmission line by applying a certain pulse to the cable and reflection signals on the same phase. Furthermore, the distance up to the fault location is calculated by measuring the time taken in detecting reflective waves.[2]-[3]

The time domain reflectometry (TDR) which analyzes the signals reflected using the reference signals applied to the cable as pulse in the time domain is mostly used. In this method, however, if fault distance is far, or the fault is minor, signal attenuation becomes large, making it hard to classify reflection signals. As a result, a fault discrimination error may occur, or a measurement error increases. To take care of these problems, recently, there have been a lot of studies which adopt the following approaches: Sequence time domain reflectometry (STDR) which spreads signal bands using pseudo noise (PN) sequence and spread spectrum time domain reflectometry (SSTDR) which modulates the sequence into sinusoidal sequence.[4]-[6]

Recently, there have been a lot of studies such as verification on the power quality of high-voltage direct current (HVDC) submarine cable using reflectometry, detection of the cause and location of high-voltage transmission cable fault using reflectometry and detection of the cause (open, short) and location of fault in the low-voltage cable. On the contrary, there has been no study on the detection of minor accidents such as poor cable contact and partial disconnection in the low-voltage cable.

In this study, therefore, there was an experiment with a goal of detecting poor cable contact using STDR/SSTDR which is the main cause of electrical accidents against the FR-CV cable which is widely used among low-power cables (600V or lower).

II. STDR/SSTDR AND REFERENCE SIGNAL REMOVAL TECHNIQUES

A. STDR/SSTDR

The signal measurement methods aimed to detect the type and location of a fault on the power line include TDR which uses correlations between pulse and time domain, time-frequency domain reflectometry (TFDR), STDR which spreads pulse using sequence and SSTDR which modulates the sequence into
sinusoidal sequence. In STDR and SSTDR approaches, signal spread and time-correlation analysis techniques were used to figure out the location of a cable fault. This STDR/SSTDR-based cable fault location detection mechanism is shown in Fig. 2.1 below:

The STDR is a technique to detect the location and type of a cable fault by measuring the arrival time and phase of the signal reflected from the fault spot after applying pseudo noise (PN) sequence with good auto-correlation property. In contrast, the SSTDR modulates the PN sequence with good auto-correlation property with sinusoidal sequence and applies the modulated signal to the cable.

As shown in Figure 2.1 above, the applied signal 's(t)' which uses the N-long sequence 'c = [c_0, c_1, ..., c_{N-1}], c_i \in \{-1,1\}' in the STDR and SSTDR can be stated as follows in Equation 2.1 below:

\[
s(t) = \sum_{n=0}^{N-1} c_n P_{c_n}(t - nT_c).
\]  \[2.1\]

In the STDR, the signals multiplied to the sequence are divided into '0' and '1' in Equation 2.2. In the SSTDR, they are sinusoidal signals as stated in Equation 2.3 below:

\[
P_{t_1}(t) = \begin{cases} 1 & 0 \leq t \leq T_c \\ 0, & \text{other wise} \end{cases}
\]  \[2.2\]

\[
P_{t_2}(t) = \begin{cases} \cos(2\pi f_c t), & 0 \leq t \leq T_c \\ 0, & \text{other wise} \end{cases}
\]  \[2.3\]

Here, 'T_c' refers to the chip duration of PN sequence with '1' or '-1' while 'f_c' represents carrier frequency. If the signal in Equation 2.1 is applied to the cable, reflection occurs after the elapse of a certain interval from the spot where the cable impedance changes. The reflected signal 'r(t)' usually includes noise according to the cable testing environment and can be stated in Equation 2.4 as follows:

\[
r(t) = \sum_{n=0}^{N-1} a_n s(t - \tau_k) + g(t)
\]  \[2.4\]

Here, 'a_n' refers to a size of the reflected signal 'a_ns(t - T_k)' while '\tau_k' represents the time delayed until the applied signal is reflected at the cable fault location. In addition, 'g(t)' is a noise signal. Then, as stated in Equation 2.5 below, the time & cross-correlation analysis with the reflection signal 'r(t)' is performed by moving the reference signal 's(t)' by '\tau' time. After that, the maximum value of the correlation coefficient is calculated.

After estimating the time taken for the signal applied by the difference among the maximum values of the correlation coefficient between the reference and reflection signals to be returned after being reflected from the fault location, the location of a cable fault is calculated based on Equation 2.6 below. Here, 'T' refers to the time slot (i.e. cycle) of the reference signal 's(t)'.

\[
C_r(\tau) = \frac{1}{T} \int_0^T s(t) r^*(t-\tau) d\tau
\]  \[2.5\]

\[
\tau = \frac{1}{V_p x (t_{f} - t_{i})}
\]  \[2.6\]

An important concept of reflectometry includes characteristic impedance and VOP. The former decides a type of reflection signal, and the latter refers to a speed of the signal transmitted in the cable. Therefore, the accuracy of measurement distance is dependent upon the accuracy of VOP.

**B. Reference signal removal for performance improvement**

If the attenuation is large because of remote cable fault location, or reflection signal is weak in a minor fault, performance significantly decreases. To improve fault and location detection performances under these circumstances, the maximum position ('\tau_{m}' ) of the correlation function \[C_{r,t} [k]\] of the measurement signal 'r(t)' and applied signal 's(t)' in each signal measurement method is estimated. Then, the applied signal 's(t)' is removed from the measurement signal 'r(t)' as stated in Equation 2.7 below:

\[
e(t) = r(t) - s(t - \tau_1)
\]  \[2.7\]
After estimating the maximum position \( (n_2) \) of the correlation function \( |C_{st}(K)| \) of \( e(n) \) and \( s(n) \), a \( n_2 - n_1 \) sample difference is calculated with.

### III. EXPERIMENTS

A poor cable contact can be divided into two categories: incomplete contact and intermittent poor contact. First, incomplete contact (low torque in the contact point) refers to a poor contact in the cable connections such as a circuit breaker and terminal block. It is also called ‘loose connection’ or ‘poor contact.’ Second, an intermittent poor contact (open/short) occurs when wire is connected partially or intermittently (wire connection partially weakens). In terms of the conditions of a cable contact fault, in this study, an incomplete contact (low torque in the contact point) fault test was performed. For a contact point, a molded case circuit breaker (MCCB) was used as shown in Fig. 3.1 below. According to torque (Nm) regulations in the Terminal Block KSC 2625, a test was conducted at 6Nm or below of reference torque as shown in Fig. 3.1(b):

**Fig. 3.1** (a) Access terminal (b) Poor contact

For a low-voltage cable, a FR-CV cable which is most widely used at 600V or below was chosen. In terms of its thickness and length, CV 2c6sq, 18[m], 60[m] and 120[m] cables were used as shown in Fig. 3.2 below:

**Fig. 3.2** Experiment cv 2c6sq cable for experiment.

For VOP, if a cable length is known, the time difference of the reflected waveform is measured by applying pulse to the cable as shown in Fig. 3.3 and calculated based on Equation 3.1. Then, the length of the cable is deducted.

\[
VOP = \frac{(\text{Cable} \times 2)}{(\text{Reflection time} - \text{reference time})} \quad [3.1]
\]

**Fig. 3.3** VOP measurement method of experimental Cable

For accurate VOP measurement, VOP measurements by pulse length were averaged and calculated by applying 10 [ns], 100 [ns], 200 [ns], 500 [ns] and 1000 [ns] to the cv 2c6sq cable. Then, for the VOP mean of the cv 2c6sq cable, \( 1.905 \times 10^3 \text{m/s} \) was estimated. The variables needed to detect a cable contact fault location using the STDR are stated in Table 3.1. In the STDR/SSTDR, 7 (m=3)-long ‘m’ sequence was used. For sampling rates, 125 [MS/s] was chosen. After setting a sample length per chip to 10, 50 [ns] was estimated.

**Table 3.1** VOP and Conditions of cv 2c6sq cable

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOP</td>
<td>( 1.905 \times 10^3 \text{m/s} )</td>
<td></td>
</tr>
<tr>
<td>Sampling Rate</td>
<td>125 M s/s</td>
<td></td>
</tr>
<tr>
<td>Sample Interval</td>
<td>5 ns</td>
<td>1/frequency</td>
</tr>
<tr>
<td>Sequence Type</td>
<td>m sequence</td>
<td></td>
</tr>
<tr>
<td>Sequence Length</td>
<td>L=7 (m=3)</td>
<td></td>
</tr>
<tr>
<td>Sample Length/chip</td>
<td>10 sample</td>
<td></td>
</tr>
<tr>
<td>Voltage (V)</td>
<td>1 V</td>
<td></td>
</tr>
</tbody>
</table>

### IV. RESULTS

**C. CV 2c6sq 60[m] + 120[m] poor contact fault**

In an off-line state, the cv 2c6sq 60 [m] cable was connected to the front and 120[m] cable to the back as shown in Fig. 4.1 below. Then, a poor contact fault detection test was performed at a 60 [m] spot on the 180 [m]-long cable.

**Fig. 4.1** Configuration of Poor contact fault

A fault location was calculated using Equation 4.1 below, and an error rate was calculated using with Equation 4.2:
A Detection Of Poor Contact Fault Location In The Low-Voltage Power Cable Using STDR/SSTDR

\[ D = \frac{V_p \times (t_s - t_t)}{2} \] [4.1]

\[ \text{Error} = \frac{\text{Actual Cable Length} - \text{Measurement}}{\text{Actual Cable Length}} \times 100 \] [4.2]

The graphs on the Fig 4.2(b) and 4.3(b) were created using the signal removal technique, and the waveforms in red represent the reflected signals from which reference signals were removed. According to the measurement using the STDR in Fig. 4.2, a poor contact fault was found at 60 [m] while ‘open’ was detected at 177.55 [m]. In the SSTDR-based measurement in Fig. 4.3, in contrast, a poor contact fault was observed at 58.67 [m] while ‘open’ was detected at 176.31 [m]. Using the reference signal removal technique proposed in this study, it was able to detect a poor contact fault and ‘open’ in the cable end, which were not found with the conventional STDR and SSTDR.

CONCLUSION

This study attempted to prevent a poor cable contact fault which is the second-most leading cause of cable-related electrical fires, following ‘short’. In terms of a diagnosis method aimed to prevent a poor contact fault in the cable connections such as an indoor low-voltage distribution box and street light/traffic light/lighting distribution box which are installed in places where user contact is frequent, the commonly used FR-CV cable among the daily-life, low-voltage cables (600V or lower) was targeted to detect a poor contact fault, a leading cause of electrical accidents in daily lives.

As a result, using the reference signal removal technique-based reflectometry, this study was able to locate a fault which could not be detected with the conventional method and identify more than two different types of fault. In addition, it was lower than the conventional reflectometry in terms of an error rate in locating remote fault and minor fault (poor contact). Therefore, it would be possible to locate a fault more accurately if a reference signal removal technique proposed according to the cable distance and signal measurement method is used. However, there should be further studies on the detection of a fault location in
on-line state in diverse fault conditions through the development of signal measurement algorithm.

ACKNOWLEDGEMENT

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