Aging Index of C&I Cable via Time-Frequency Domain Reflectometry with Optimized Reference Signal

Hobin **LIM**, Geon Seok **LEE**, Su Sik **BANG,** Gu-Young **KWON,** Yeong Ho **LEE,** Gyeong Hwan **JI,** Yong-June **SHIN;**
Yonsei University, Seoul, Republic of Korea, hobinlim1995@gmail.com, seok@yonsei.ac.kr, bang@yonsei.ac.kr, kgy926@yonsei.ac.kr, lyh9029@yonsei.ac.kr, wsn3333@gmail.com, yongjune@yonsei.ac.kr.

ABSTRACT

Time-frequency domain reflectometry (TFDR) is a non-destructive cable diagnosis technique, which has high accuracy in the localization of faults. Conventionally, a peak value of time-frequency cross-correlation function and an energy of reflected signals are used as the aging index of control and instrumentation (C&I) cables via TFDR. In this paper, we propose a new reference signal which can monitor the degree of aging of C&I cables more sensitive than conventional reference signal. Furthermore, the efficacy of the new reference signal is verified by performing the emulated aging test on two types of C&I cables.

KEYWORDS

Aging index, Cable diagnostics, Control and Instrumentation (C&I) cable, Exponentially modified Gaussian, Reflectometry

1. INTRODUCTION

In recent years, reliable operation of nuclear power plants has become significant as occurrence of serious failures such as loss of coolant accident (LOCA) and steam leakage accident [1]. Control and instrumentation (C&I) cable is one of the key elements for the safe operation of the nuclear power plants because its main role is interconnection of electrical systems with control, protection, instrumentation, and communication within the nuclear power plants [2]. Occasionally, due to heat and radiation of the nuclear power plants, performance of insulation properties of C&I cables gradually degrades, which can cause serious failures [3]. Thus, the health management of C&I cables is crucial for reliable operation of the nuclear power plants [4]-[6].

Fault diagnostics of C&I cables has been studied actively for stable operation of the nuclear power plants. Reflectometry, an electrical condition monitoring technique, is based on the signal transmission and reflection along a cable under test [2]. The application of the reflectometry is diverse, owing to its non-destructive characteristics and simple test equipment requirements. In the case of cable diagnostics, conventional reflectometry methods can be categorized into time domain reflectometry (TDR) and frequency domain reflectometry (FDR) [7]. The TDR is used to determine the characteristics of the cable by observing reflected signals in the time domain while the FDR is analyzed in the frequency domain [8]. These methodologies have been investigated for diagnosing the aging of C&I cables caused by heat and radiation of the nuclear power plants. However, the conventional methods have limitations; the resolution and accuracy of both TDR and FDR are limited by the rise/fall time and frequency sweep bandwidth, respectively [9].

In this paper, time-frequency domain reflectometry (TFDR), which can resolve the disadvantage of the conventional technologies and integrate their advantages, is used to estimate failure of C&I cables with improved both accuracy and resolution. The TFDR analyzes the reference signal and reflected signals in the joint time-frequency domain by using Wigner-Ville distribution. The result of TFDR is normalized with time-frequency cross-correlation which indicates the similarity between the reference signal and reflected signals. By analyzing time-frequency cross-correlation function obtained from the TFDR, the fault location of C&I cables can be detected accurately [9]. Also, from a peak value of the result of time-frequency cross-correlation function, a criterion for defining aging index has been proposed which can indicate the degree of aging of C&I cables in quantitative manner [10].

However, reliability issues arise in the conventional aging index. Since TFDR is based on the similarity analysis between the reference signal and reflected signals, the method is not useful when estimating the degree of failure [7]. In fact, as the degree of fault increases, the change of aging index is not always proportional to the effect of aging. In addition, there are cases where the aging index is inconsistent depending on the environment of the experiment, the type of cable, and even the influence of the noise of the equipment receiving the signal. To resolve this limitation, aging index of C&I cables has been proposed based on the energy of the reflected signal identified from the fault location [7].

The index has a property that changes according to reference signal of TFDR because the aging index is defined as energy amount of the reflected signal. When the aging index provided from an arbitrary reference signal does not respond sensitively, the reliability of the degree of aging degrades. Therefore, it is important to design an optimal reference signal of TFDR to make the aging index sensitive. The widely used reference signal in TFDR is a linearly modulated chirp signal with a Gaussian envelope [7]-[10]. This signal has a simple and intuitive advantage in determining the center frequency and the bandwidth of the signal compared to other signals [9], [11]. However, this signal has a limitation that signal designer cannot flexibly adjust the center frequency under the fixed bandwidth. In fact, a signal with high frequency is more affected by attenuation due to skin effect during propagation in cable than a signal with relatively low frequency [9]. Thus, we design a new reference signal that avoids attenuation in high frequency bandwidth and emphasizes low frequency bandwidth to make the aging index more sensitive. Furthermore, this paper proposes an algorithm for designing the new optimal reference signal of TFDR based on exponentially modified Gaussian (exGaussian) to make aging index more sensitive than the conventional reference signal, Gaussian-enveloped linear chirp.