Aging Monitoring of I&C Cable in Nuclear Power Plant via Parameter Estimation of Time-Frequency Domain Reflectometry

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ABSTRACT

The failure of I&C cables in NPPs can lead to malfunctions in the connected devices, which can give rise to critical accidents. In order to assess the aging status of I&C cables, TFDR, a nondestructive diagnostic technique, is utilized in this paper. In addition to the conventional TFDR result, the attenuation constant and the signal energy are proposed to analyze the aging precisely. It is expected that the proposed TFDR parameters bring out more reliable management and operation of NPPs.

KEYWORDS

Accelerated Thermal Aging Test, Instrumentation and Control (I&C) Cable, Parameter Estimation, Time-Frequency Domain Reflectometry (TFDR).

1. INTRODUCTION

Instrumentation and control (I&C) cables in nuclear power plant (NPP) play important roles in the communication of control and monitoring signals of NPPs. However, the harsh environments of NPPs, such as high temperatures and radiation, can accelerate the aging process of the cables. Consequently, the failures can occur unexpectedly before the designed lifetime and can lead to breakdowns or malfunctions in NPPs which can result in massive damage and economic loss. Moreover, in NPP, access to the cables in harsh environments can be limited. Accordingly, a monitoring methodology, which can be applied without access to cables, is necessary for reliable and safe management.

Although the state-of-art diagnostic techniques for cables can be utilized in aging monitoring, their applications can be limited in NPP. Visual Inspection (VI) is a diagnostic method to detect cable faults [1]. However, the method is only feasible to detect the faults which are observable from the outer jacket of the cable; thereby identification of faults in the inner insulation is limited. The partial discharge (PD) test evaluates the electrical insulation state by measuring the charge from defects or imperfections [2]. Since access to cables is limited in harsh environments, the PD test, which is conducted near cables, is restrictively applicable. Elongation at break (EAB) and indenter modulus (IM) both measure the mechanical property of the insulation [3],[4], but these methods are destructive methods that are not suitable for monitoring cable aging. Fourier transform infrared (FTIR) spectroscopy, differential scanning calorimetry (DSC), and oxidation induction time (OIT) tests can be applied to cable insulation [5-7], however, applications to the cables are limited at present due to vulnerability to external environments.

Reflectometry, a nondestructive method, can diagnose cable faults and monitor the condition of cables without accessing the installation sites. The conventional reflectometry techniques can be classified into time domain reflectometry (TDR) and frequency domain reflectometry (FDR) [8] according to the type of domain analysis. However, each methodology has limited accuracy and resolution by the only use of time or frequency domain information. To integrate the advantages of TDR and FDR, time-frequency domain reflectometry (TFDR) is developed [9]. TFDR analyzes reflected signals in the time-frequency domain to calculate the time-frequency cross-correlation (TFCC) function by which high-resolution detection can be achieved. The high-resolution capability of TFDR, which is distinct from other reflectometry techniques, can be particularly effective for cable aging monitoring when accelerated aging occurs in the local section of a cable. Furthermore, the time-frequency analysis in TFDR can provide the diverse characteristics of a reflected signal which can be utilized to assess various changes in insulation conditions during aging. In this paper, the parameter estimation of TFDR is conducted to analyze the aging process more precisely. In addition to the TFCC, the attenuation constant and the signal energy are additionally extracted from the reflected signal.

To develop the aging monitoring technique, real-world aged cable samples should be prepared. Ideally, the analysis of the actual aging process can be conducted from the aged cables in the field. However, the preparation is limited by long-term aging periods. In this paper, the accelerated thermal aging test, a widely-used methodology for aging insulation [10], is employed as the aging method for the cables. This test can provide the cable samples of different aging levels, so that TFDR results can be presented as a function of time.

The rest of the paper is organized as follows: the theoretical background of TFDR and accelerated thermal aging test are described in Section 2. Next, Section 3 describes the experimental setup. Section 4 summarizes the experimental results and the related discussion. Finally, Section 5 concludes the paper.

2. THEORETICAL BACKGROUND

2.1 Time-Frequency Domain Reflectometry

Based on the transmission line theory, reflection occurs when a traveling wave encounters a discontinuity in the characteristic impedance of the line. Reflectometry analyzes the reflected signal to detect the impedance discontinuities such as defects and faults. Generally, the process of reflectometry consists of the injection of the reference signal and analysis of the resulting reflected signal. Distinctions between specific reflectometry techniques, such as TDR and FDR, arise from differences in the reference signal type and analysis methodology for the reflected signal.