Detection of Vibration Faults of I&C Cables via Time-Frequency Domain Reflectometry

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ABSTRACT

This paper presents a method to detect local faults caused by vibrational stress using time-frequency domain reflectometry (TFDR) technique. The cable under test is I&C cable which is used in nuclear power plants (NPPs). The experiments simulate the coupling between the cable and terminal block during earthquake accident and continuous vibration in operation. Vibration faults are generated by the electrodynamic shaker, which is referred IEEE Std. 382 and 344. The TFDR result is compared with conventional method. The TFDR is expected to contribute to the safe operation of NPP by detecting vibration faults.

KEYWORDS

I&C Cable, Time-frequency cross-correlation, Time-frequency domain reflectometry, Vibrational Stress, Vibration test,

1. INTRODUCTION

The instrumentational & control (I&C) cables in NPPs are crucial in transmitting electrical signals and controlling internal components. However, because of harsh environment of the I&C cables in NPPs such as high temperature, radiation emitted by the reactor, and vibration caused by the generator, the cables are constantly exposed to the hazards of failures. Research on the factors which affect the condition of the cable is underway. The accelerated aging test [1] has been studied in consideration of the thermal and radiation factors. Also, the water tree test [2], is carried out to consider the effect of humidity from cooling water in the NPP. However, research on the vibrational stress on the connection of the cable has not been carefully studied yet. For example, IEEE Std. 383 [3] provides a standard test for the cables used in NPPs. However, it only provides test methods for thermal and radiation exposure and aging of cables, and cannot be used for vibration tests such as accident or continuous vibrational stress since vibration is one of the major causes of failures [4], [5]. The physical contact between the cable and the terminal block due to vibration causes stress at the cable junction point. The higher the vibration frequency and the longer the vibration time, the greater vibrational stress applied to the cable junction point. As a result, the cable junction points under high vibrational stress cause functional failure with an open fault and can lead to serious accident, such as the shutdown of the generator or reactor. Therefore, it is important to diagnose the vibration faults and to prevent the faults through maintenance.

Enhanced standards and regulations are in place to ensure the safe operation of nuclear power plants. Cables are also managed through regular inspections. Although multiple diagnostic techniques, such as the diagnostic partial discharge (PD) [6], dissipation factor (Tan δ) [7], and elongation at break (EAB) [8], [9], are implemented to diagnose the condition of the power cable, the I&C cable mainly diagnosed by the Megger test and the time domain reflectometry (TDR) [10]. The Megger test can diagnose the condition of cable, but it cannot detect the fault location. The TDR diagnostic method is used to determine the location of fault in the cable. Cables can be damaged by thermal, electrical and radiation, and in this case, the insulation of conductors can be deteriorated. The deterioration causes an impedance discontinuity at the fault location. The way TDR detects the location of the fault is to use the magnitude of the reflected signal at the impedance discontinuity point. The magnitude of the reflected signal is determined by the reflection coefficient, and a reflected signal is measured at hard faults or the cable end where the large reflection coefficient exists. The hard faults can be diagnosed by the TDR. But, when the magnitude of reflected signal is small, due to small reflection coefficient, the reflected signal is prone to be affected by noise complicating the diagnosis through the TDR. Also, the judgment of fault in TDR may vary depending on the expertise opinion. Despite the importance of the I&C cables, the conventional cable diagnostic techniques used for NPPs are not suitable for determining cable faults. Therefore, NPPs require more objective and accurate fault diagnosis techniques.

The TFDR, the proposed method in this paper, is improved reflectometry which can resolve the limitations of the TDR and Megger test by using time and frequency localized reference signal and cross-correlation. Since the TFDR calculated the similarity between the reference and reflected signal, the TFDR has better accuracy to diagnose the location of fault. The TFDR can be used to estimate the location of the fault using the time-frequency cross-correlation at the point where the reflection coefficient is small, so the fault location that cannot be diagnosed by the TDR can be diagnosed. Since the impedance of the fault location continues to change, faults due to vibration will be measured with smaller reflected signals than in the case of hard faults. Therefore, the TFDR is expected to diagnose vibration faults by identifying the vibration position on the cable connection. In the paper, we present an analysis of a vibration fault based on the TFDR.

The paper presents a method to detect local faults caused by vibration using the TFDR technique. Experiments are conducted under the assumption that faults may occur due to incomplete connection, resulted from vibration of generator, or seismic causes. The experiment to verify proposed method is implemented as follows: emulation of the cable section in the NPP, simulation of the vibration fault, and detection of the vibration fault by the TFDR method. In order to assume the interior of the NPP, the cable sections containing two terminal panels in the NPP is simulated. The cable under test is a class 1E multi-core I&C cable which is generally used in NPPs for control operations. Class 1E is the safety classification of the electric equipment and systems which designed to support functional features in design basis events [11]. The vibration input is applied to the cable junction point according to the IEEE Std. 344 and the TFDR is