Recent Advances in Low Voltage Cables Condition Monitoring

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ABSTRACT

Understanding the condition of low voltage cables is becoming increasingly important to asset managers in aging nuclear plants. Previous research has indicated the sensitivity of advanced electrical testing techniques to non-destructively assess thermal aging in these cables; However clear guidance for performing and interpreting these test techniques was still required. This paper presents the results of additional research designed to expand the understanding of these test techniques as applied to additional cable insulations commonly found in North American nuclear plants, as well as additional stressors beyond thermal aging. From these results, provisional guidance for the interpretation and assessment of these test results is proposed.

KEYWORDS

Low Voltage Cables; Instrumentation and Control; Condition Assessment; Dielectric Spectroscopy; Insulation Resistance.

INTRODUCTION

Background

A large proportion of nuclear power plants around the world are entering a period of extended operations beyond their original design life of 35 to 40 years (depending on the type of reactor). While several large components in these plants can be refurbished or replaced to support this life extension process, most original electrical cables remain in place due to the quantity, complexity, and cost of replacing them. As a result, there has been an increased interest in the nuclear industry for improved techniques to assess the condition of cables, specifically low voltage (LV) cables which represent the bulk of cables found in these plants.

Initial Electrical Power Research Institute (EPRI) led research demonstrated the potential and applicability of Low Frequency Dielectric Spectroscopy (LFDS) and Polarization / Depolarization Current (PDC) methods to identify and quantify the level of degradation of thermally aged LV cables [1]. Key results from this research indicated that LFDS and PDC test methods can be applied to various insulation types and track thermally induced insulation degradation. It was found that preliminary metrics, such as C' at 1mHz or the Isothermal Relaxation Current at 100s, trended well with the level of degradation and with traditional material-based techniques such as Indenter Modulus (IM) or tensile elongation at break (EaB). Furthermore, the research showed the crucial importance of carefully considering experimental parameters and cable test configurations in unshielded or multi-conductor shielded arrangements to achieve optimal results in diagnostic electrical tests. These initial results were presented at the 2019 Jicable conference [2][3].

In recent years other research groups have also explored the use of comparable electrical techniques to assess the impact of environmental aging on LV nuclear power cables. Dielectric spectroscopy in the 20Hz - 500kHz range was found to be sensitive to thermal degradation for an crosslinked polyethylene (XLPE) insulated cable and to correlate well with material testing results such as EaB [4]. Similar results were reported for an Ethylene Propylene Rubber (EPR) insulated cable with good agreement between tan delta at 1kHz and EaB over the thermal aging period [5].

Research from Suraci et. al. also investigated the impact of thermal and radiation aging on cable samples, using physical, mechanical, and dielectric spectroscopy-based testing to monitor the impact of radio-thermal aging on both coaxial and twisted-pair XLPE insulation. Results indicated good correlation between electrical permittivity responses measured through high frequency dielectric spectroscopy (up to 1 MHz) with changes in mechanical and physio-chemical responses [6][7].

Other recent work began exploring more fundamental impacts of thermal, radio-thermal, and different insulation construction types on material and electrical test results. In particular, these investigations have shown the influence of small changes in additive concentration present in XLPE insulation on the dielectric responses [8][9].

Following the promises of its initial project and the increased interest of the industry for LFDS and PDC methods, EPRI initiated a Phase II research project to address remaining gaps in knowledge. This paper presents the key findings from this work completed in 2021 [10].

Objectives

The intent of the Phase II EPRI research summarized in this paper was to further investigate the applicability of LFDS and PDC based techniques to assess the condition of typical LV cables used in and obtained from nuclear power plants. More specifically the objectives of this research were to:

1. Expand the application of LFDS and PDC based techniques to additional types of XLPE and EPR insulated LV cables found in North American Nuclear Power Plants and subjected to global thermal aging.
2. Explore the influence of water exposure on the dielectric response of LV cables tested with LFDS and PDC based techniques and, if possible, discriminate those responses from the effects of thermal aging.
3. Explore the influence of external environmental parameters, such as relative humidity and ambient temperature variance, on the dielectric response of LV cables tested with LFDS and PDC based techniques.
4. Develop condition assessment methodology for thermally aged LV cables based on diagnostic metrics extracted from the dielectric response.