Research Gap in Management of Insulation Aging of Medium Voltage Cables in Nuclear Power Plants

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ABSTRACT

Condition monitoring and aging management equipment and techniques have been developed and implemented for safety-related instrumentation and control cables in nuclear power plants. This paper describes the need for a research and development effort that should be initiated to adapt these techniques to other safety-related cables in support of light water reactor sustainability. In particular, the research should focus on adaptation of existing reflectometry methods to locate problems such as high resistance shunts, electrical trees, water trees, and voids in the insulation of medium voltage cables.

INTRODUCTION

Nuclear power plant cables are typically categorized in terms of their rating as low voltage (≤ 1 kV), medium voltage (between 1kV and 100 kV), and high voltage (>100 kV) cables [1]. Low voltage cables encompass an important subcategory called instrumentation and control (I&C) cables which typically carry less than 125 volts. This subcategory constitutes a majority of safety-related cables in nuclear power plants whose aging has been the subject of substantial research and development (R&D) projects in the nuclear industry, national and international laboratories, universities, and vendor organizations [2]. As a result, a variety of techniques have been developed and implemented in nuclear power plants to test the integrity of polymers that are used for insulation material of I&C cables. These techniques include electrical, mechanical, and chemical tests with the electrical measurements providing the only nondestructive means to perform in-situ testing of I&C cables in nuclear power plants. The same techniques may also serve to uncover degradation and flaws in medium voltage (MV) cables but research is needed to investigate this claim. In particular, the nuclear industry is eager for an in-situ technique to locate degradation in MV cables. Table I provides a listing of the electrical, mechanical, and chemical techniques and the corresponding measurements related to each technique.

The main problems with the insulation layer in MV cables are referred to as “water trees” and “electrical trees”. These are tree-like voids (Fig. 1) in the insulation material that can get filled with moisture (water tree) creating conductive pathways or can become charged (electrical tree) creating regions of electrical stress leading to cable degradation and failure. Moisture can also corrode the shield layers making it difficult to test the cable using tan delta, partial discharge, or other electrical techniques. Underground MV cables are particularly vulnerable to the issues just mentioned and locating faults in underground MV cables is currently of great interest to the nuclear industry.

BACKGROUND

A majority of nuclear power plants in the U.S. have applied for license renewals to operate for 60 years and almost all have been granted regulatory approval. The approvals have in most cases been predicated upon plants implementing equipment condition monitoring measures as necessary to ensure that aging will not lead to failure of critical components and structures including cables. In response, test equipment and techniques have been developed for testing I&C cables and research is now needed to validate these techniques for MV cables or develop new techniques as necessary to locate degradation in the insulation of MV cables. This will help the nuclear industry determine if and when MV cables must be repaired, replaced, or rejuvenated and will save substantial costs in unnecessary replacement of MV cables.

Cable replacements in the nuclear industry can have a significant financial impact on utilities. In fact, estimates have shown that for every dollar that is spent to install MV cables, it will cost 10 dollars to replace the cable [3]. Typical nuclear power plant MV cables can be thousands of feet long with some portions underground or inaccessible making replacement even more expensive.

RESEARCH GAP

The interest in condition monitoring and aging management of reactor components began in the mid 1980’s when NRC initiated the Nuclear Plant Aging Research (NPAR) program [4]. This interest intensified in the 1990’s when the first few nuclear power plants applied for license renewal to operate for an additional 20 years beyond the first 40 years for which they were originally designed and licensed. Today, with a few U.S. plants initiating the process to apply for a second license renewal to operate for 80 or more years, the interest in new methods for condition monitoring of safety-related components have peaked and both the nuclear industry and NRC are seeking information and data to help formulate requirements and guidelines to allow plants to operate beyond 60 years. New research yet to be done will provide this information and data, and as importantly, will lead to new condition monitoring techniques for MV cables.

TABLE I. Cable Testing Techniques

Technique	Measurement
Electrical Measurements	IR, LCR, TDR, RTDR, FDR
Mechanical Measurements	EAB, IM
Chemical Measurements	FTIR, SEM, EDS, DSC

DSC: Differential Scanning Calorimeter
EAB: Elongation at Break
EDS: Energy Dispersion X-Ray Spectroscopy
FDR: Frequency Domain Reflectometry
FTIR: Fourier Transform Infrared Spectroscopy
IM: Indenter Modules
IR: Insulation Resistance
LCR: Induction, Capacitance, Resistance
RTDR: Reverse Time Domain Reflectometry
SEM: Scanning Electron Microscope
TDR: Time Domain Reflectometry

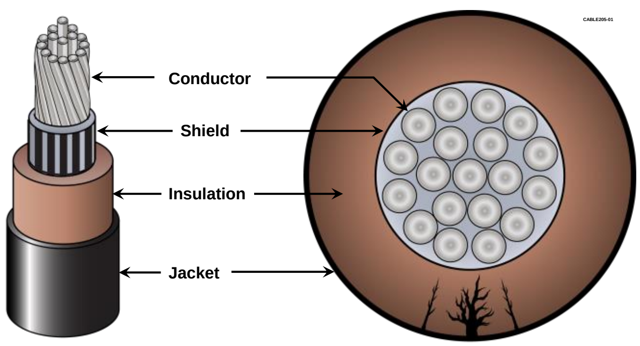

Fig. 1. Water trees in medium voltage cable insulation.

The results will help the regulators to determine if new stipulations are warranted to allow the plants to operate with existing MV cables for up to 80 or more years and to establish objective cable testing frequencies, replacement schedules, and condition monitoring methods for long-term operation.

To provide the nuclear industry and regulators with what is needed to manage MV cable aging, a hands-on R&D project must be undertaken to: 1) determine the extent to which the existing array of electrical, mechanical, and chemical testing techniques that have been developed and implemented for I&C cables will work for MV cables, 2) design an integrated test system to provide the nuclear industry with a tool for management of aging of MV cables, and 3) generate objective information and data through laboratory tests on aging characteristics of MV cables to help the industry and regulators formulate testing and replacement schedules for MV cables.

The focus of the research should be on adaptation of reflectometry techniques for locating faults in the insulation material of MV cables. This is needed because the existing MV cable testing methods such as Partial Discharge (PD), Tan Delta (TD), and AC withstand provide the bulk properties of MV cables but cannot always identify localized degradation. Localized degradations are a significant problem in wetted cable insulation because they disturb the potential gradient within the insulation and increase the potential across the remaining good insulation.

REFERENCES

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