THE EFFECT OF BENDING FATIGUE ON THE BREAKDOWN STRENGTH OF POLYMER-INSULATED CONDUCTORS

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ABSTRACT

ROV cables are subjected to various mechanical stresses. This paper investigates the effect of bending fatigue on the dielectric strength of XLPE and polypropylene cable. Single conductors were aged on a bend-over-sheave setup for 5000 and 10000 cycles, and short breakdown tests were performed. Partial discharge (PD) analysis was also done to study the degradation mechanisms underlying the breakdown results. XLPE showed significant degradation with bending fatigue, while polypropylene showed the opposite effect. PD analysis showed that PD magnitude increased with ageing for XLPE and decreased for polypropylene.

KEYWORDS

Dynamic cables, mechanical ageing, bending fatigue, electrical breakdown, breakdown testing.

INTRODUCTION

In recent years, there has been a sharp increase in interest in underwater and offshore sectors due to offshore wind farms, deep-sea mining ROVs, etc. [1]. Subsea power transmissions require dynamic export cables known as umbilical cables. These are remarkably different from static cables in terms of their electro-mechanical design. The non-polymeric components, like the armour, are expected to fail mechanically before the polymeric components, like the insulation [2]. In addition, the cable may include multiple sets of single- and three-phase systems, signal conductors, and optical fibres.

ROV Umbilical Cables

Remotely operated vehicles (ROV) are unmanned vehicles used for deep sea operations [3]. The ROV umbilical cables are responsible for functions like power transmission, vertical deployment, recovery, and data exchange (e.g., through signal conductors or optical fibres) [4]. These dynamic cables are typically designed for a limited lifetime of approx. 10000h and, consequently, have thin electrical insulation. A small outer diameter also reduces the drag force on the cable [5].

Unlike static power cables, the power conductors lack individual grounded sheaths, as shown in Fig. 1. Since these cables are designed for mechanical loads and electrical stress, there is a need to understand how much bending stress can degrade the dielectric.

Cross-linked polyethylene (XLPE) is one of the standard insulation materials used in these kinds of cables [6]. However, polypropylene is gaining popularity due to its recyclability and zero-degassing properties compared to other insulation materials [7]. Hence, in this paper, both materials are explored.

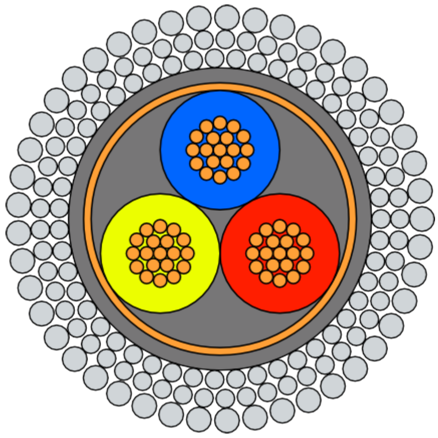

Fig. 1: Cross-section of a generic three-phase umbilical cable showing the three insulated conductors with a shared copper shield. The three-layer steel armour takes most of the mechanical stress.

Ageing Mechanisms

Such an ROV system can be divided into two parts, which undergo different ageing mechanisms.

The part of the cable under water undergoes mechanical forces like tensile stress, compressive stress, and drag force [8]. Regarding electrical ageing, water treeing was the main focus of the literature [8,9]. However, water treeing has not been observed in normal operation due to (i) long growth time and (ii) the low chances of water entering the insulation [10]. Coupled with the fact that the part under water is subject to annual cutting, water treeing is not the main lifetime-limiting factor of ROV cables.

The more interesting part is the part on the winch, which undergoes bending stress coupled with thermal stress (higher temperature and thermal cycling) due to layers on the winch. Hence this paper will focus on the effect of bending on the dielectric strength of the insulation.

Outline

The following steps were taken to test single conductors (insulated with XLPE and polypropylene) aged through cyclic bending. The cable used for the experiments has a nominal insulation thickness of 0.88mm and is rated for 2.6kV.
First, the mechanical ageing and electrical breakdown testing setups were designed. A bushing had to be designed to apply the test voltage to the conductor and reliably cause breakdown of the insulation. Breakdown results of unaged and mechanically aged cable pieces are presented and compared to see the effect of bending stress on the degradation of the dielectric. Partial discharge analysis is performed on different cable samples to understand the breakdown results better. In the partial