Twenty years of extruded HVDC cables from a material supplier's perspective

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ABSTRACT

Twenty years have passed since the world's first commercial extruded HVDC cable system was inaugurated in November 1999 on the island of Gotland, Sweden. More than thirty projects (> 10.000 km) of land and submarine HVDC extruded cable links have so far been installed on four continents. The technology has progressed further with qualification of a 640 kV cable system based on next generation HVDC XLPE insulation system.

The successful introduction and market adoption of extruded HVDC cable systems is the outcome of comprehensive and successful innovation programs. This paper will present a review of the work with emphasis on the development of the insulation system.

KEYWORDS

HVDC; Cable; XLPE; Space charge, Conductivity; Leakage current

INTRODUCTION

Extruded HVDC cables insulated with crosslinked polyethylene (XLPE) have recently been qualified up to 640 kV. This has been made possible by improvements in material and cable processing technology. The purpose with the present paper is to discuss the evolution of the insulating system from a material supplier's perspective from the beginning of extruded cables for DC towards the high stress and voltage levels of today.

Properties that have no or limited importance in AC cables must be addressed when designing materials for DC applications and vice versa. Where the development of the first generation XLPE materials needed to focus on minimising the space charge accumulation, the next generation could focus on the optimisation of the electric conduction properties of the insulating material without jeopardising the already achieved space charge performance.

FIRST DEVELOPMENT PHASE LEADING TO 320 KV PERFORMANCE (1990S)

Overview

In the 1990s lapped paper insulation system (fluid filled or mass impregnated) was the established technology for high voltage DC cables. It was recognised that a technology shift to a polymeric system would give several advantages as evidenced by polymeric cables replacing lapped cables for AC distribution and partly in AC transmission systems up to EHV levels at that time. These advantages include increased operating temperatures and simpler manufacturing process [1]. Initial tests with polymeric HVDC cables, however, had not been successful due to breakdowns linked to formation of space charges in the insulation [2]. The use of line-commutated converters (LCC), where polarity reversals are needed to change the direction of the power flow, made space charge accumulation, or rather the minimisation of it, into a highly critical issue.

The first non-destructive methods for determination of the space charge distribution were developed in the 1970s and the technique that later became the most widely used by researchers, pulsed electro-acoustic (PEA) was introduced in 1985 [3].

The need from the market for extruded DC solutions and the technical advances leading to the availability of space charge measurement methodology initiated an extensive material and cable development program leading to the world's first commercial polymeric HVDC cable system, inaugurated on the Swedish island of Gotland on 19th November 1999 [1]. Meanwhile, converter technology had evolved with the introduction of transistor based voltage source converters (VSC) in 1997. Polarity reversals are not needed for this converter type making the cable systems less sensitive to space charge accumulation.

The Gotland project comprised a bipolar land cable link rated at 80 kV, but the voltage level was subsequently increased reaching 150 kV in 2002 when the Cross Sound cable, the first polymeric subsea cable, and the Murray link cable were commissioned in USA and Australia, respectively.

Test methods

The focus during the development of the first generation of polymeric HVDC insulation system in the 1990s was to minimise space charge accumulation. The measurement tool used was a PEA system utilising both press moulded plaques and cables as test samples. The plaques consisted of 2 mm insulation with 0.5 mm semiconductive electrodes on both sides. The standard procedure for the plaque measurements was recording the charge distribution on non-degassed specimens after three hours at 40 kV and 50°C. The measurements were done both with applied voltage (voltage-on) and without voltage (voltage-off).

The impact from sample preparation and measurement parameters were thoroughly investigated. It was found that degassing will lead to reduction in space charge [4]. This observation together with numerous studies reported in the literature illustrate the importance of the peroxide decomposition products. As the relative amounts of the various decomposition products are influenced by the crosslinking temperature and time, measurements were performed on plaques prepared using different crosslinking conditions [5]. It was noted that the different crosslinking temperatures could have a substantial impact on the PEA results. In addition the effect from different poling times, voltage and measurement temperature was investigated [5].

Cable samples employed for investigation of space charge properties included model cables with insulation thickness between 1.5 mm and 5.5 mm, the latter equivalent to 20 kV