On the way to compare the polarity reversal withstand capability of HVDC mass-impregnated and extruded cable systems

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ABSTRACT

This paper describes a broad test campaign for comparing the performances of extruded cable systems under polarity reversal with those of MIND cable systems. The campaign, based on a partnership between TERNA, CESI, and a few major cable manufacturers worldwide, is is being performed in the new HVDC test labs of CESI in Mannheim, Germany. The tests will include a mixed arrangement of both load cycles and voltage polarity reversals tests. The test protocol has been selected from TERNA's experience in testing MIND cables, and aging and life models for extruded cables developed together with the University of Bologna, Italy.

KEYWORDS

Current Source Converters; Extruded insulation; HVDC cables; Loading cycle tests; MIND insulation; Voltage polarity reversal

INTRODUCTION

The reversal of voltage polarity is essential in HVDC cable systems with Current Source Converters (CSC), since it enables to revert the direction of the power flow. Mass Impregnated Non-Draining (MIND) cables are known to be able to withstand the voltage polarity reversal without particular problems. Such ability is assessed by performing a dedicated polarity reversal loading cycle test with voltage polarity reversals every 4 hours, according to Electra 189, 2000 [1]. Moreover, since long ago TERNA, the Italian Transmission System Operator (TSO), has introduced in its test protocols for HVDC MIND-insulated cable systems the so-called "sustained polarity reversal loading cycle test". This test has proved to be very effective for a thorough assessment of the cable system performances in the presence of polarity reversal during cable tests of different HVDC interties: the Italy-Greece and SAPEI [2] and the up-coming Italy-Montenegro.

On the contrary, HVDC cables with extruded insulation are known to suffer voltage polarity reversal by much [3]. In fact, HVDC extruded cable systems have gained fast increasing shares in the HVDC cable system market during the last decade, with many land and especially submarine HVDC cable links of the extruded type commissioned worldwide; HVDC extruded cable systems with voltage and power ratings up to 320 kV and 1000 MW, respectively, are commercially available [4-6]. However, most if not all of these systems work with Voltage Source Converters (VSC) because of their unsatisfactory behavior in the presence of voltage polarity reversal. This behavior has hampered the development of HVDC extruded cable systems with Current Source Converters (CSC), with one single realization worldwide to date: the Hokkaido-Honshu intertie, a bipolar subsea cable link commissioned in Japan on December 2012. The Hokkaido-Honshu intertie features 600 MW transmission capacity and ±250 kV rated voltage; it is also the first HVDC extruded cable system in the world that can be used at 90°C under polarity reversal via Line Commutated Current Source (LCC) converters [7,8]. As discussed broadly in the literature, the problems for HVDC extruded cable systems under voltage polarity reversal arise from the space charge that is accumulated in the extruded insulation (see Chapter 4 of [3] for a wide review).

However, the latest R&D activities led some manufacturers to develop HVDC extruded cable systems that are claimed to be capable to withstand polarity reversal [9,10]. Since the experience is quite scarce, voltage polarity reversal loading cycle tests capable to compare the performances of extruded cables and accessories in the presence of polarity reversal with the known behavior of MIND cables and accessories are required.

For this reason, TERNA has decided to invest in a research activity based on the assessment of the behavior of DC extruded cables under polarity reversal stress. This paper describes the main features of a broad and thorough test campaign that aims at this goal. TERNA has involved CESI with its HVDC facilities and few major HVDC extruded cable world manufacturers. The tests, already ongoing, are performed in the new HVDC test labs of CESI in Mannheim, Germany. This test campaign has been mainly based on two main sections: the ageing section made of a mixed solution of both load cycles and voltage polarity reversals tests and a sustained voltage polarity reversals section. Voltage levels and duration of the various stages of the tests have been selected on the one hand from the experience gained by TERNA in testing MIND cables, and on the other hand on dedicated aging and life models developed for extruded cables in cooperation with the University of Bologna, Italy [11-13].

SPACE CHARGES VS. VOLTAGE POLARITY INVERSION

As hinted at in the Introduction, since the very early trials HVDC cables with extruded insulation were found to suffer under voltage polarity reversal by much, especially those cables where standard XLPE compounds for AC usage were employed [14-16]. This evidence, supported by plenty of more and less recent experimental data (see e.g. [17]), proved that voltage polarity reversal causes a reduction in the life of extruded insulation. It was then clear that remarkable R&D activities were needed in order