Development and Application of 400 kV XLPE DC Submarine Cable for Jiangsu Rudong Offshore Wind Farm in China

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ABSTRACT

Based on the grid connection requirements of the planned Jiangsu Rudong 1100 MW offshore wind farm, a cross-linked polyethylene-insulated high-voltage DC (HVDC, 400 kV) submarine cable was developed. To complete mass production and delivery of the 400 kV DC submarine cable, first, rheological properties of the target insulating material (LS4258DCE) were investigated under different temperatures. Moreover, the scorching resistance of LS4258DCE was analyzed based on the trend of extruder torque under high temperature and shear stress as a function of time. Using the insulation melt extrusion simulation model and the optimized process parameters, 153.5 t of the target insulating material was extruded in one operation cycle. After load cycle tests under 740 kV at the type test stage, a switching impulse withstand test at 1235 kV was conducted on one submarine cable loop. A 2 h DC test under 800 kV was executed on a submarine cable loop, factory joint, and intermediate joint. A repeated superposition test of lighting impulse up to 1800 kV was also executed. In particular, considering -800 kV as the initial voltage, and with increments of 80 kV, 10 cycles of lighting impulse were conducted under each voltage. Product delivery and acceptance of a long, HVDC submarine cable were accompanied by increased voltage during the DC test and decreased voltage and discharge after the test. After the 400 kV DC submarine cable was installed, the influence of rate of increase of voltage on the transient-state electric field was analyzed. The findings of this study demonstrated that during pressurization and with lower voltage increasing rate, the electric field of the insulation approached the electric field distribution at a steady state. The optimal voltage increasing rate was 1 kV/s. Based on the combined discharge technology, the discharge time of the HVDC submarine cable after the DC test decreased by 77.8%. In this project, all windmills were connected to the grid in December 2021, and the developed 400 kV DC submarine cable passed all pre-qualification tests in March 2022.

KEYWORDS

400 kV DC submarine cable; type test; pre-qualification test; electrical margin test; insulation extrusion technology; discharge technology

0 INTRODUCTION

Long and ultrahigh-voltage cross-linked polyethylene (XLPE) insulated submarine cables have been widely applied in high-capacity power transmission between mainlands and islands and the onshore transmission of offshore wind energy[1]. Compared with AC submarine cables, ultrahigh-voltage DC (HVDC) submarine cables have the advantages of large transmission capacity, long transmission distance, low line loss, low route occupancy, and low cost[2-4]. Typically, for energy transmission between islands and deep seas with an offshore distance of >100 km, AC transmission suffers from high power loss and thus is not economical; in case of DC transmission, however, the cable length is unlimited by the charging current, does not require a reactive power compensation device, and has a large transmission capacity, and thus, it has good market prospects. The world's first 400 kV extruded insulated DC submarine cable was installed in the "NEMO-Link" project connecting the UK and Belgium[5]. Thereafter, China installed the DC connection project for 400 kV offshore wind power transmission in Jiangsu Rudong, which is the first such project in China. Positive and negative poles of XLPE insulating DC cable loops were constructed, with 99 km of 400 kV XLPE DC submarine cables for each pole and 9 km of 400 kV XLPE DC land cables connecting the two converter stations at two terminals. Designed with a transmission capacity of 1100 MW, the cable used in the project is the DC transmission submarine cable with the highest voltage level, longest transmission distance, and largest transmission capacity in China at present[6]. The design of DC cable route sections is presented in Fig. 1.

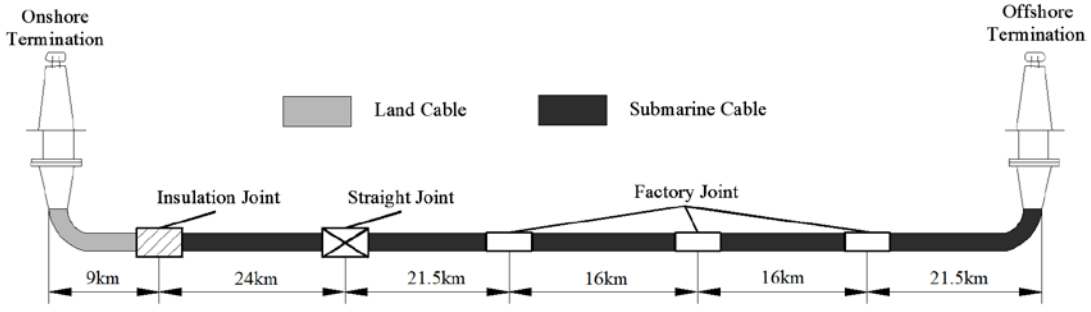

Fig. 1: Cable route of the Jiangsu Rudong 400 kV offshore wind farm DC connection project

Unlike AC submarine cables, in the insulation of DC submarine cables, electric field distribution is closely influenced by the electrical conductivity of the insulating material, which is a function of electric field intensity and