Stories From China

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The World's First 500-kV, Three-Core, Cross-Linked-Polyethylene-Insulated AC Submarine Cable

Under the trend of large-scale development of offshore wind farms in China, the installed capacity of individual wind farms continues to increase from 500 to 1,000 MW or even higher. However, the cost of using the sea is increasing correspondingly because of the scarcity of offshore wind farm resources. The traditional 220-kV three-core submarine cable can no longer satisfy the engineering requirements of transmission capacity and economy. On August 17, 2023, the world's first 500-kV, three-core, cross-linked-polyethylene (XLPE)-insulated AC submarine cable was put into use. The submarine cable is applied to the Guangdong Yangjiang Qingzhou Offshore Wind Power Project (Phase I and II) with an installed capacity of 1,000 MW and two 60-km circuits. Compared with the single-core 500-kV submarine cables, the three-core 500-kV submarine cables integrate the three-phase core and the optical cable into one. This integration has lots of advantages in area saving and cost reduction, but it also brings many technical problems due to the structural changes and the increase in conveying distance.

The Yuedian Yangjiang Qingzhou offshore wind farm I is located in the adjacent sea area near Shaba town in Yangxi, Yangjiang, Guangdong, China (Figure 1). The wind farm has a sea area of approximately 64 km2, a water depth of 35 to 38 m, and an offshore distance from the center of approximately 50 km. The Yuedian Yangjiang Qingzhou offshore wind farm II is also located in the adjacent sea area near Shaba town in Yangxi, Yangjiang, Guangdong, China. The wind farm has a sea area of approximately 96 km2, a water depth of 37 to 43 m, and an offshore distance of approximately 55 km. The electricity generated by the wind turbine is connected to the offshore substation through 16 circuits of 66-kV integrated submarine cables, which is then connected to the onshore control center through 2 circuits of 500-kV three-core AC submarine cables. The onshore centralized control center plans to build a new 500-kV line to connect to the 500-kV Yuexi Switching Station. A new 500-kV line is proposed to be built in the onshore centralized control center to connect to the 500-kV Yuexi Switching Station.

The rated voltage of the cable system is 500 kV, with a maximum operating voltage of 550 kV and a maximum transmission capacity of 1,000 MW. The neutral point grounding scheme is adopted in the system. The rated lightning impulse withstand voltage is 1,550 kV, and the three-phase short-circuit current is 63 kA. The designed service life of the 60-km cable is 40 years.

The sectional phase diagram of the 500-kV three-core AC submarine cable is as shown in Figure 2. The main structural layers include water-blocking conductor, conductor shielding layer, insulation layer, insulation shielding layer, water blocking buffer layer, lead sheath, non-metallic protective layer, cable filling, winding layer, inner liner and composite OPGW, armor layer, and outer sheath.

The conductor adopts the TR type round copper wire, which is a kind of tightly pressed twisting round copper single wire. The conductor has a longitudinal waterproof sealing structure, using appropriate waterproof materials to prevent seawater from entering the conductor after cable damage. The conductor shielding layer is composed of a semi-conducting wrapping tape and an extruded semi-conducting compound layer. The semi-conducting material adopts a super smooth cross-linked semi-conducting material, and it is compatible with the insulation layer. The main insulation is made of super-clean cross-linked polyethylene, with the eccentricity of the insulation controlled under 5% range. The minimum average breakdown field strength at power frequency of the main insulation is not less than 30 kV/mm, and the minimum impulse average breakdown field strength is not less than 60 kV/mm. The insulation shielding layer is an extruded semi-conducting layer, which is co-extruded with the conductor shielding layer and the insulation layer.

A longitudinal water-blocking layer is fixed outside the insulation shielding layer, which is wrapped with the semi-conducting water-blocking expansion bands. The water-blocking expansion bands are wrapped tightly, with the expandable surface faced with the metal shielding layer. The water-blocking layer makes the insulating semi-conducting shielding layer evenly contact the metal shielding layer, resulting in good conductivity. The metal sheath adopts lead alloy, which can withstand certain radial pressure and is with little change of deformation. At the same time, it also acts as a radial water-resistant layer for the cable. The lead sheath is a seamless lead alloy with appropriate elasticity for continuous extrusion.

The armor layer of the cable sheath adopts galvanized low-carbon round steel wire, fully considering the requirements of armor strength mechanically. The nominal diameter of the single wire in the armor layer is not less than 6 mm, with the metal armor applied on the outer side of the filling layer and the protective layer. The asphalt is adopted on the armor layer to

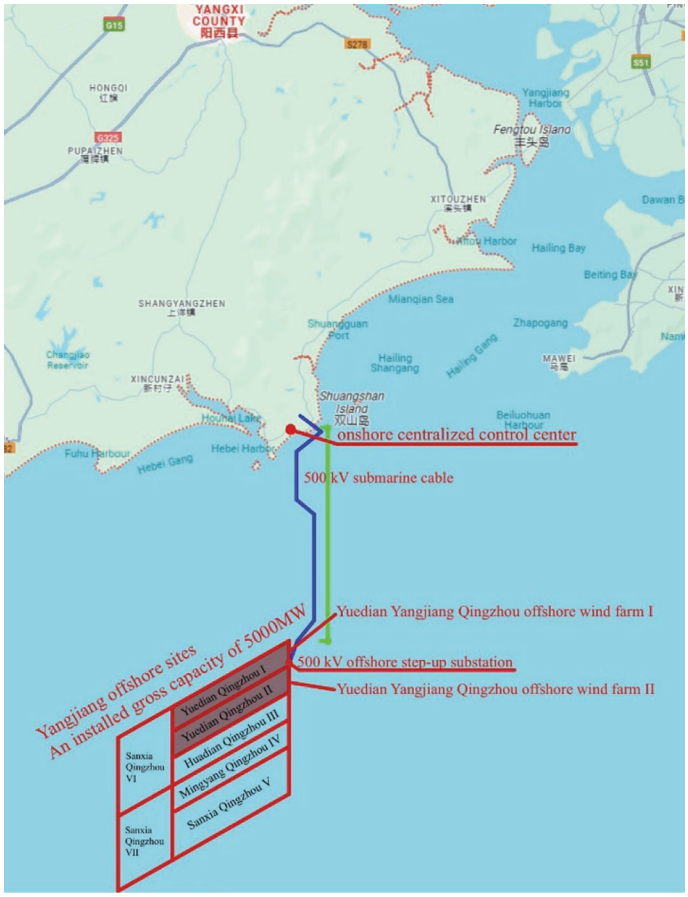

Figure 1. Road map of the submarine cable.

provide further corrosion protection and adhere all the protective layers. The outer sheath of the cable uses fiber materials and is also uniformly coated with asphalt as an anti-corrosion layer. The thickness of the fiber outer sheath is about 4.8 mm.

The 500-kV three-core AC submarine cable adopts factory joints and uses similar materials and structures as the cable body to connect the submarine cable. The cable joints are processed in the factory. The mechanical and electrical properties of the joints are close to the performance of the cable body, including the outer diameter. The processing is carried out between the pressure lead process and the armor process. The performance of the factory joint is basically the same with the submarine cable for the processed final product. So, there is no special consideration in the laying process.

The 500-kV three-core AC submarine power cable was continuous extruded for 20 km in length. On March 10, 2023, the first 500-kV submarine cable of Yuedian Yangjiang Qingzhou Offshore Wind Farm Project (Phase I and II) completed the

Figure 2. Sectional phase diagram of the 500-kV three-core AC submarine cable.

withstand voltage test and the partial discharge test for the entire 60-km cable for the first time worldwide. Each phase of the conductor continuously withstands voltage for one hour under the condition of 2 U0. Dongfang Cable has obtained the type test report and the prequalification test report of the 500-kV submarine cable with a single core of 1,800 mm2 (including factory joints) in 2018. The performance of the cable has been verified in the subsequent construction of the State Grid Ningbo Zhenhai-Zhoushan Interconnected 500 kV Submarine Power Transmission Engineering. In 2023 the 500-kV three-core 1,800-mm2 submarine cable (including factory joints) produced by Dongfang Cable's "Future Factory" obtained a type test report, laying a great foundation for ensuring the smooth operation of this project. Up to now, the cable has been running well.

The Yuedian Yangjiang Qingzhou Offshore Wind Farm Project (Phase I and II) is the first application of the high-capacity 500-kV three-core AC submarine cables in the whole world, which is of great significance. After the completion of the construction, it can provide 3.6 billion kilowatt hours of clean electricity to the power grid every year. Compared with coal-fired power plants of the same scale, it can save about 1.05 million tons of standard coal consumption and reduce carbon dioxide emissions by about 2.78 million tons per year.