

Design and Manufacturing of ±200kV HVDC Submarine Power Cable in Zhoushan Flexible DC Transmission Project

Ming **Hu**, Zhongtian Technology Submarine Cable Co., Ltd, Nantong(China), hum@chinaztt.com

Shuhong **Xie**, Zhongtian Technology Group Co., Ltd, Nantong(China), xiesh@chinaztt.com

Jianmin **zhang**, Zhongtian Technology Submarine Cable Co., Ltd, Nantong(China), zhangjm@chinaztt.com

Hongliang **Zhang**, Zhongtian Technology Submarine Cable Co., Ltd, Nantong(China), zhanghongliang@chinaztt.com

Xiaolong **Zhang**, Zhongtian Technology Group Co., Ltd, Nantong(China), kris.zhang@zttcable.com

ABSTRACT

Zhoushan multi-terminal flexible DC transmission project in Zhejiang province, China is the world's first five-terminal DC transmission project, in which 103km ±200kV submarine fiber optic composite power cable linking Dinghai and Daishan is supplied by ZTT transmitting capacity of 400MVA with conductor cross section of 1000mm². This paper demonstrates the simulation verification design of the insulation thickness and electric stress of the ±200kV HVDC cables for this project and proves that the electric stress at any point of insulation complies with the performance of insulation material. Manufacturing process of cable and factory splice is also introduced together with the relevant tests carried on the submarine composite cable including DC voltage test according to CIGRE TB 496 and mechanical test that verifies the reliability of the power cable factory splice and optical fibers.

KEY WORD

Zhoushan flexible DC Project; ±200kV; DC Cable; Electrical stress;

0 PREFACE

Zhoushan multi-terminal flexible DC transmission project is the first five-terminal flexible DC transmission project in the world located in the north area of zhoushan isles of Zhejiang province, which adopts ±200kV DC submarine power cable and land cable to connect up main land's converter station (Dinghai), Daishan land's converter station, Hengshan island's converter station, Yangshan island's converter station and Sijiao island's converter station. The project has come into operation since June, 2014. It reinforces the electric connection between isles, develops the technological level, builds solid foundations for wind energy and solar energy and improves the international competition in DC current transmission.

The cable between Dinghai island and Daishan island is main circuit. It contains conductors which cross section is 1000mm², optic fiber cable of 24 cores. Load of the cable is 400MW. The length of DC submarine cable offered by ZTT is 103km. Each submarine cable has two sets of factory joints. The length is ground cables is 9.2km which has 12 sets of factory joints. It is the first application of ±200kV XLPE DC cables in china which has the highest voltage, biggest cross section and longest length. Construction of the cable in main circuit is XLPE insulation, lead sheath, thick round galvanized steel armor, PP outer serving and optic fiber cable. The production model type: DC-HYJQ41-F-200kV 1x1000+2x10B1+2x2B4, the construction is shown in Fig.1.

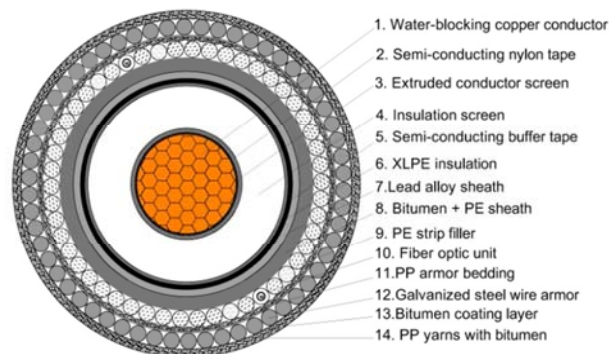


Fig.1 Construction of DC submarine cable

1 INSULATION THICKNESS DESIGN OF HVDC SUBMARINE CABLE

Design for insulation thickness uses finite elements doing iteration calculation. Electric field in insulation depends on the environment temperature, while temperature in insulation depends on the thickness. To make sure the long operation of cable, electric field in insulation during operation shall not higher than designed value. Construction of submarine cable is shown in Tab. 1

Tab. 1 Dimension of 1000mm² HVDC submarine cable

1. Conductor	Compacted round water blocking conductor	8. Bitumen+PE sheath	Nominal thickness: 0.5+4.0mm
	Nominal dia.: 38.2mm		Nominal dia.: 93.4mm
2. Semi-conducting nylon tape	Nominal thickness: 2x0.12mm	9. PE strip filler	Nominal thickness: 6.0mm
	Dia.: 38.6mm		Nominal dia.: 105.4mm
3. Extruded conductor screen	Nominal thickness: 1.2mm	10. Optic fiber cable	Numberxtype: 2x12B1
	Nominal dia.: 41.0mm		Nominal dia.: 5.0mm
4. XLPE insulation	Nominal thickness: 16.0mm	11. PP yarns bedding	Nominal thickness: 2.0mm
	Nominal dia.: 73.0mm		Nominal dia.: 109.4mm
5. Insulation shield	Nominal thickness: 1.0mm	12. Steel wire armor	Nominal thickness: 5.0mm

	Nominal dia.: 75.0mm		Nominal dia.: 119.4mm
6. Semi-conducting water blocking tape	Nominal thickness: 2x0.5mm	13.Bitumen	Nominal thickness: 0.2mm
	Nominal Dia.: 78.0mm		Nominal dia.: 119.8mm
7.Lead alloy sheath	Nominal thickness: 3.2mm	14. PP yarns with bitumen	Nominal thickness: 4.0mm
	Nominal Dia.: 84.4mm		Nominal dia.: 127.8mm

Condition: Soil thermal resistivity 1.5K·m/W, temperature 35°C, buried depth in ground 700mm. Max temperature of conductor is 70°C.

200kV DC submarine cable's cross section is 1000mm², and its rated current is 1000A. Finite element analysis demonstrates that rated current 1000A and no-load 0 A, temperature of conductor, temperature of insulation, electric field, temperature field of HVDC submarine cable, as shown below:

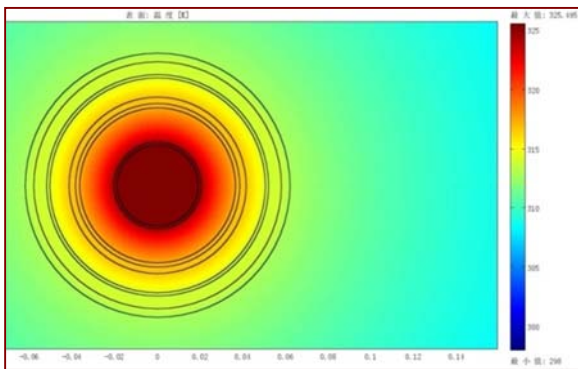


Fig. 2 Temperature field at rated load

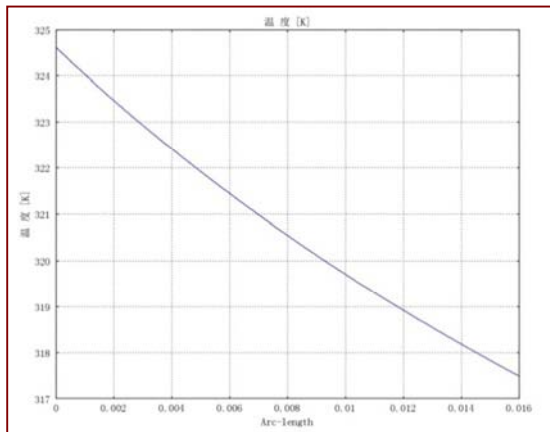


Fig.3 Curve of temperature field at rated load

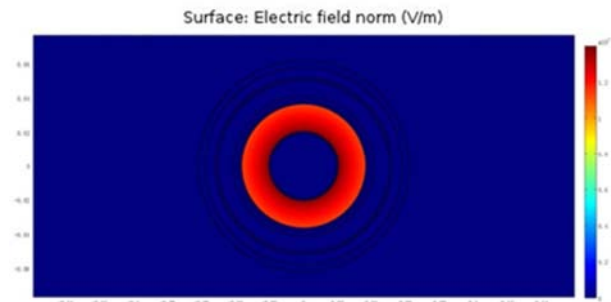


Fig.4 Electric field in insulation at rated load

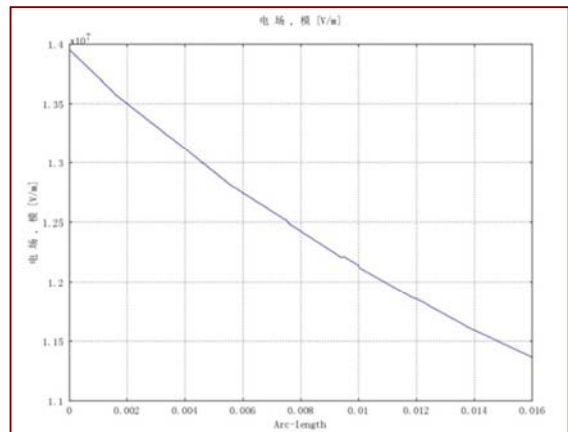


Fig.5 Curve of electric field in insulation at rated load

When rated current is 1000A, max electric filed in conductor shield is 13.9kV/mm, min electrical filed in insulation shield is 11.3V/mm.

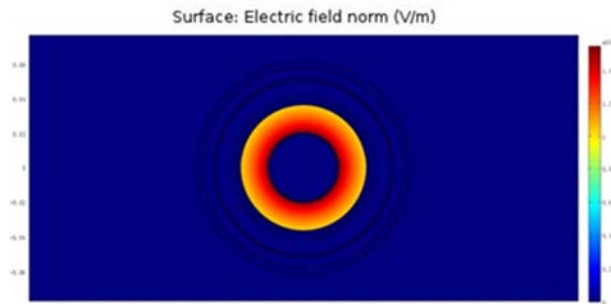


Fig. 6 Electrical field in insulation at empty load

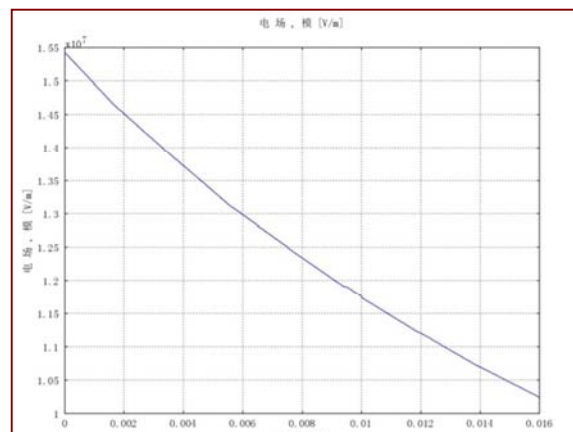


Fig. 7Curve of electrical field in insulation at empty load

At empty load, the current is 0A and max electric field in

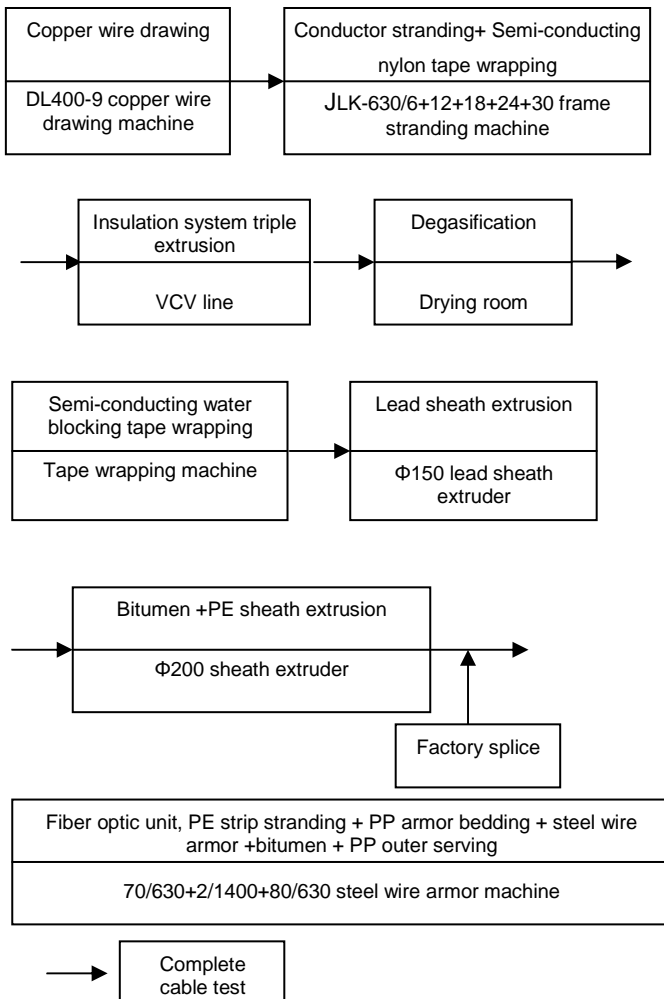
conductor shield is 15.4kV/mm, min electric field in insulation shield is 10.3kV/mm.

At full load and no load, insulation thickness of 200kV cable with 1000mm² is 16.0mm. During operation, electric field in insulation is less than permitted value 20kV/mm. Safety margin of insulation meet the requirement.

2 PRODUCTION PROCESS

DC submarine power cable is composed of insulated cores, fiber optic unit and outer protective layer. During the manufacturing of insulated cores, imported cross-linking semi-conducting screen material and dielectric insulation material dedicated for DC cable is used and processed by VCV dry-curing triple extrusion followed by degasification in drying room. The cores are designed with performance of radial and longitudinal water tightness and corrosion resistance. For the fiber optic unit, stainless steel tube is taken to protect the fibers and the unit is integrated in the composite cable together with a PE strip buffer layer under the steel wire armor .The fiber performance can be monitored online in the production. All the electrical, optical and mechanical performance tests of the cable in each manufacturing phase shall be carried out to ensure the cable performance can comply with the requirements.

The flow chart is shown as below:



Factory splice is mainly applied in the long submarine power cable exceeding the maximum continuous

manufacturing length for the connection of pieces of insulated cores before armoring is applied. Also it is used in the transition joint for the land cable. The mechanical and electrical performance of factory splice shall be identical to or close to that of the original cable. The size of each component of factory splice (Fig.8) shall be the same with that of the main cable or a bit larger by a couple of millimeters. The splice is required to undertake the mechanical force encountered during the production, transfer and installation of cable and also to meet all the electrical requirements as the original cable.

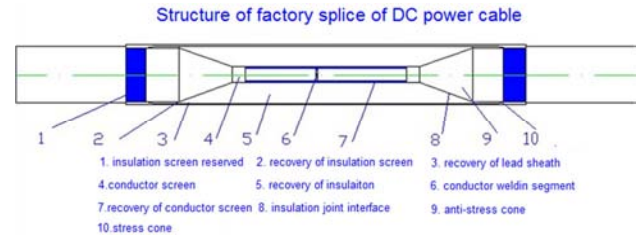


Fig. 8 Sketch of the factory splice of DC power cable

3 VERIFICATION TEST

3.1 Routine voltage test

The DC submarine cable length (factory splice included) from Dinghai-Daishan island in Zhoushan is 51km, voltage test for which shall use negative DC voltage of 370kV (1.85U₀) applied between the conductor and metallic screen for 60min and no break down in insulation shall occur. The maximum test voltage of the equipment is ±1000kV and maximum charging current reaches 60mA. The high voltage sections of the test equipment are all installed outdoor and take composite insulating pillar structure for the voltage test of complete DC submarine cable. The test equipment is show as Fig.9.



Fig.9 DC voltage test equipment

To guarantee the test safety and facilitate the observation of the change of the tested submarine cable, test equipment and system charging current, the test voltage shall be raised gradually, slowly and uniformly and then held at -370kV for 60min. In this process, the charging period shall be controlled no more than 20min to avoid the adverse effect on the insulation caused by the too long charging period. The voltage raising process is shown as Fig.5. The power cable is equivalent to a big capacitor that will be injected with substantial electric charges during the DC voltage test process and after the voltage test the charges shall be released through discharge treatment. The grounding resistance of the potentiometer in the test equipment and the test terminal discharge at the same time, which form the discharge circuit in the first phase. In the second phase, the discharge is realized by controlling the high-power absorbing grounding resistance

and then discharged quickly by arc discharge of electric steel tape. In the third phase, line resistance discharge rod is used to decrease the system voltage to zero. After the test, discharge in the fourth phase shall be performed to ensure the safety of cable and personnel by making the DC equipment and cable conductor grounded through an Preface wire and after 5min of discharge, the high-voltage wire is removed. However, the residual space charge still remain in the insulation after the test, so the conductor, lead screen and wire armor need to be linked and grounded.

3.2 Mechanical test

In the type test process, coiling test and tensile bending test are carried out to verify the stability of fiber optic unit and if it can withstand the great mechanical force. The test is described as below.

Coiling test: Simulate the coil and torsion condition of the submarine cable in the manufacturing and installation. Verify the structure stability of the cable. The length of submarine cable shall ensure a complete eight turns of winding (Fig.10). In the coiling process, the cable will withstand torsion, so before coiling, a parallel line shall be marked to aid in the test of the uniformity of torsion. The cable ends shall be fixed to prevent from turning. The coiling shall be repeated for 3 times in the opposite direction which complies with the expected frequency of cable manufacturing, transportation and installation. The uniformity of torsion is measured visually by the torsion of marking line on the cable surface. The absolute value of change of fiber attenuation after test shall no more than 0.03dB.



Fig.10 Coiling test site picture

Bending tensile test: the test is for the design of the force withstood by cable in the cable installation and recovery. Recovery is the case that the cable or covering laid on the seabed is no more than the diameter of cable^[8]. The treatment of submarine cable end shall ensure the ultimate tension applied on the different cable components away from the cable end is equivalent to the distribution proportion of tension in the installation.

The tension test device is shown as Fig.11. The submarine cable sample shall be winched to the drum wheel and go through coiling, straight and then coiling for 3times with no change of bending direction. The test tension is 80kN. Take two optic fibers from each units and total four optic fibers are linked with each other and one end is connected to the optical transmitter and receiver CD400. In the tension applying process and bending test,

make an observation of the change of fiber performance.



Fig.11 Bending tensile test site picture

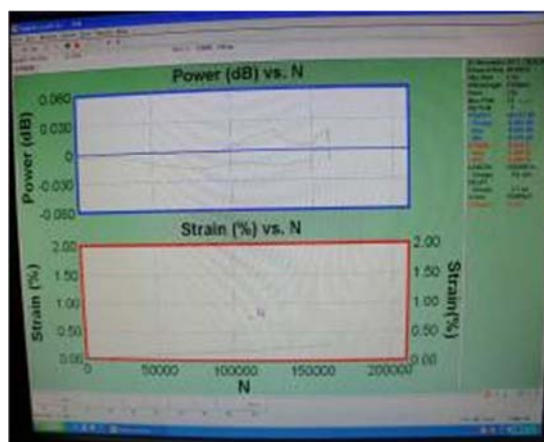


Fig.12 Bending tensile test result picture

After the coiling test, the maximum additional fiber attenuation is 0.026dB. After the tensile bending test, the maximum additional fiber attenuation is 0.021dB.

The tests above demonstrate that the fiber optic unit and its surrounding structure are stable, have great tension and compression resisting ability and are confirmed to be reasonable and applicable. Subsequently, the submarine cable with factory splice shall undergo the all performance type test according to CIGRE 496 and the prequalification test shall also be carried out in the Zhoushan marine transmission research center. Currently, the prequalification test has already been performed for eight months. The prequalification test system of Zhoushan ± 200 kV flexible DC cable includes DC submarine power cable, transition joint, DC land power cable, land cable straight joint and outdoor termination.

4 CONCLUSION

This paper uses the method of FEA to simulate and analyze the electric stress of DC cable for Zhoushan multi-terminal flexible DC transmission project. In the case of both empty and full load, the electric stress at any point of the insulation is lower than the permissible operation stress of insulation material and large insulation safety margin is considered. ± 200 kV XLPE insulated DC submarine fiber optic composite power cable and DC land power cables designed and produced by ZTT have passed all performance test and are under prequalification test. Zhoushan multi-terminal HVDC transmission demonstration project has started successfully, which indicates that the domestic developed DC cable system

has been officially put into operation and will face the test of the long-term operation. Also in the laboratory, prequalification test intended for the DC cable system has been carried out by simulating the operating environment. At present, both the actual operation and simulation test prove that all the products used in this project have a stable performance and meet the relevant standards and engineering requirements. With the technical progress and mature of DC cable system, Chinese flexible DC transmission and distribution engineering development and application can be promoted better.

BIBLIOGRAPHY

- [1] Liming Yang, Material and structure design of flexible DC cable insulation cable, Automation of electric power systems [M], 1913-08
- [2] Bing Zhang, Design of DC cable insulation, High Voltage Technology, 2004-08.
- [3] CIGRE TB 496 Recommendations for Testing of DC Extruded Cable Systems for Power Transmission at a Rated Voltage up to 500kV, 2012.
- [4] Zhaoying He, Voltage Test Research of XLPE Insulated Power Cable.[Gegree thesis] 2005 South China University of Technology: Electrical Engineering